Arab Republic of Egypt

Ministry of Housing, Utilities and Urban Development

Housing & Building National Research Center

Egyptian Code
Concerning Design Criteria and Rules
Of
Potable Water and Sanitary Drainage Treatment Plants and Pumping Stations
ECP 101 – 1997

Part1: 101/1
Sanitary Drainage Pumping Stations

Standing Committee for the preparation of
Egyptian Code
Concerning Design Criteria and Rules
Of
Potable Water and Sanitary Drainage Treatment Plants and Pumping Stations

Edition 2008

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Ministry of Housing, Utilities and Urban Development

Minister Office

Ministerial Decree
No. 168/1997

Concerning the Egyptian Code of Sanitary Drainage pumping Stations

Minister of Housing, Utilities and Urban Communities

- After perusal of Law No 6/1964 regarding design criteria and rules of construction and building works
- And, Presidential Decree No. 46/1977 regarding Public Authority for Housing, Building and Urban Planning Research Center
- And, Ministerial Decree No. 79/1991 and Ministerial Decree No. 318/1992 on formation of the standing committee for the preparation of Egyptian Code Concerning Design Criteria and Rules of Potable Water and Sanitary Drainage Treatment Plants and Pumping Stations.
- And, Ministerial Decree No. 492/1996 on formation of the main committee on design criteria and rules of construction and building works.
- And, the note presented from chairman of standing committee for Design Criteria and Rules of Potable Water and Sanitary Drainage Treatment Plants dated 05/06/1997.

Decided the following:

Article (1): Part (1) of Egyptian Code Concerning Design Criteria and Rules of Sanitary Drainage Pumping Stations shall be applied.

Article (2): Concerned bodies as mentioned in Law No. 6/1964 shall adhere to implement provisions of this code.

Article (3): Housing & Building Research Center shall publish, define and train on provisions of this code.

Article (4): This decree shall be published in the Egyptian Gazette and shall enter into effect after six months of its publication.

Minister of Housing, Utilities and Urban Communities

Prof. Dr. Eng. Mohamed Ibrahim Sulayman

Introduction

Due to the huge investments in the filed of infra structural of water supply and sanitary drainage projects, as these projects represent the urgent priorities in development programs, and due to the change of urban styles in our community, so it is necessary to chose systems and methods suitable for sanitary drainage treatment.

As sanitary drainage projects are carried out according to special conditions and specifications followed by each administrative entity in cooperation with the authorities and bodies implementing these works, this has led to a multiplicity of jurisprudence in the preparation of design criteria and rules for the sanitary drainage works (pumping stations and treatment plants) due the multiplicity of agencies working in this area, which led to differences in the criteria and rules to be followed for the same type of works.

Therefore, it was issued decree of Minister of Construction, New Urban Communities, Housing and Utilities No. 79/1991 and No. 318/1992 on formation of the of the standing committee for the preparation of Egyptian Code Concerning Design Criteria and Rules of Potable Water and Sanitary Drainage Treatment Plants and Pumping Stations under Law No. 6/1964.

The committee prepared the code draft for sanitary drainage pumping stations and distributed it to the concerned bodies, such as general authorities, universities, consultation offices, research centers and institutes, armed forces, contracting companies and others, to give their opinion, and then a public symposium was held to discuss the various opinions. Based on these discussions, this code was prepared in its final form.

This code has been issued by the Ministerial Decree No. 168/1997. Housing & Building Research Center shall publish, identify and train on this code for the development of sanitation works in the Republic.

With God's Blessings

Minister of Housing, Utilities and Urban Communities

Prof. Dr. Eng. Mohamed Ibrahim Sulayman

Preface

Due to the successive development and steady expansion in the filed of constriction, building and reconstruction at a national scale, it was issued Law No. 6/1964 regarding design criteria and rules of construction and building works (Article 1), where Ministry of Housing, Utilities and Urban Communities is responsible to implement this work.

From this standpoint, Housing & Building National Research Center in accordance with the Presidential Decree No. 63/2005, shall publish, update and train on the code, work items specifications and technical specifications of construction materials in order to comply with the international trends and meet the local conditions so that the codes work as a guide in the field of construction and building works and also to guide the engineers and the workers in the construction filed.

To ensure achieving the desired objectives of these codes, the main committee formed from representatives of the Ministry of Housing, Utilities and Urban Communities and the ministries concerned with construction and building works, as well as university professors, experts and consultants in this field, shall develop the general approach in all areas related to construction and building works also sets the general policy and planning for method of work on a permanent basis, form the standing committees and specialized subcommittees of professors, consultants and senior engineers in the fields of application related to construction and building works whom have long recognized experience in this field from outside and inside the center.

The Centre benefited from all the expertise available at home and outside in the preparation of codes in order to support and increase the effectiveness of the preparation of codes. The various committees were the melting pot of all knowledge and expertise, and a model for the close link between the Centre, Universities, production sectors and services, and in furtherance of national participation and contribution in this national work that contributes to increase the effectiveness of the development of scientific planning.

Perhaps the most important controls to measure the volume of work in the codes, is to record what is being achieved to be untroubled of the effort done and know our location on the road through what has been prepared and issued from codes and specifications contained in the attached tables, note that the codes have being updated at a continuous basis according to the new scientific, technological developments and in accordance with the experiences gained from conditions of application.

God is the source of our strength in this regard,,

Chairman
Housing & Building National Research Center
Prof. Dr. Eng. Omima Ahmed Salah Eldin

List of Construction and Building Codes issued from the Center

No	Code Name	Code No
1	Design Criteria and Rules of Potable Water and Sanitary Drainage Treatment Plants and Pumping Stations:	101
	Volume 1: Sanitary Drainage Pumping Stations	101/1
	Volume 2: Sanitary Drainage Treatment Works	101/2
	Volume 3: Potable Water Purification Plants	101/3
	Volume 4: Potable Water Pumping Stations.	101/4
2	Design and Execution of Pipelines for Potable Water and Sanitary Drainage Networks	102
3	Urban and Rural Roads Works:	104
	Part (1): Preliminary Studies for the Roads	104/1

	Part (2): Traffic Studies	104/2
	Part (3): Engineering Design	104/3
	Part (4): Roads Materials and their Test	104/4
	Part (5): Bridges Design and Construction	104/5
	Part (6): Constructional Design of Roads	104/6
	Part (7): Surface and Underground Drainage for the Roads	104/7
	Part (8): Road Equipments.	104/8
	Part (9): Rules of Road Works Inside and Outside Cities.	104/9
	Part (10): Roads Maintenance	104/10
4	Calculation of Loads and Strengths in Construction and Building Works	201
5	Soil Mechanics, Design and Execution of Foundations:	202
	Part 1: Study of the Site	202/1
	Part (2): Laboratory Teats	202/2
	Part (3): Shallow Foundations	202/3
	Part (4): Deep Foundation	202/4
	Part (5): Foundations on soils with problems	202/5
	Part (6); Foundations subject to Vibrations and Dynamic Loads	202/6
	Part (7): Retaining Structures	202/7
	Part (8): Slope Stability	202/8
	Part (9): Earth Works and Dewatering	202/9
	Part (10): Foundation on Rocks	202/10
	Part (20): Technical Terminology	202/20

6	Design and Execution of Reinforced Concrete Constructions	203
7	Design Criteria and Rules of Building Works:	204
	Part (1): Retaining Walls	204/1
	Part (3): Bearing Walls	204/2
	Part (4): External non-bearing walls used as external curtains.	204/3
	Part (5): Bearing Walls used as Partitions	204/5
	Part (6): Arches, Domes and Vaults	204/6
	Part (7): Resistance of building with bearing walls to earthquakes “Constructional and Architectural Rules”	204/7
	Part (8): Technical Terminology	204/8
8	Steel Construction and Bridges	205
9	Design Criteria and Rules of Sanitary Installations Engineering in Buildings:	302
	Part (1): Sanitary Installation of Buildings	301/1
	Part (2): Water supply and sanitary drainage treatment in small communities.	301/2
	Part (3): Supply of Hot water and Swimming Pool Works.	301/3
	Part (4): Equipping of kitchens, hospitals and disposal of wastes.	301/4
10	Design Criteria and Rules of Electrical Connections and Installations in Buildings:	302 302/1

	Part (1): Basics Part (2): Basics Part (3): Tables and Annexes Part (4): Earthing Part (5): Prevention of lightning Part (6): Power Factor Correction Part (7): Harmonics Part (8): Conductors and Starters used in control of 3-phase induction motors. Part (9): Lighting Control Part (10): Emergency Generators	302/2 302/3 302/4 302/5 302/6 302/7 302/8 302/9 302/10
11	Design Criteria and Rules of Electrical and Hydraulic Elevators in Buildings (English)	303
12	Design Criteria and Rules of Electrical and Hydraulic Elevators in Buildings (Arabic)	303

13	Air Cooling and Conditioning Volume (1): Air Conditioning Volume (2): Cooling Volum2 (3): Control and Electricity Works	304 304/1 304/2 304/3
14	Design Criteria and Rules of Protection of Constructions from Fire Part (1): Design Criteria and Rules of Protection of Constructions from Fire. Part (2): Building Service Systems Requirements to Reduce fire Risks Part (3): Fire Detection and Alarm Systems.	305 305/1 305/2 305/3
15	Design Criteria and Rules of External, Internal and Special Painting	401
16	Design of External Areas and Building for the Disabled.	601

List of Annexes and Dictionaries Complementary for the Codes

No	Annex Name
1	Design aids with examples according to Egyptian Code
2	Concrete Materials Lab Tests Guide
3	Dictionary of Soil Mechanics and Foundation Engineering (3 Languages)
4	Construction Data and Drawings Preparation Guide

List of Works Specifications and Contract Documents Issued from the Center

No	Specification Name	Code No
Contract Documents		901
1	Consultation, studies and design contract	901/1
2	General conditions of contracting works contract	901/2
3	Engineering consultation services contract for supervision of implementation “Construction Department”	901/3
4	Engineering consultation services contract for studies, designs and continuous supervision of implementation.	901/4
5	Design and implementation contract (financed by the owner)	901/5
Works Specifications		902
6	Sanitary Works Specifications	902/1
7	Marble Works Specifications	902/2
8	Architectural Woodworking Specifications	902/3
9	Aluminum Works Specifications	902/4
10	Earth Works Specifications (Excavation and Backfilling)	902/5
11	Soil Insulation Specifications	902/6

12	Reinforced Concrete Works Specifications	902/7
13	Painting Works Specifications	902/8
14	Public expenditure and financial commitments specifications	902/9
15	Plastering Works Specifications	902/10
16	Architectural blacksmith works specifications	902/11
17	Specifications of electrical connections and installations (Part 1 and Part 2)	902/12
18	Specifications of thermal insulation work “Design criteria and rules”.	902/13

General Introduction

Cities and villages water supply projects, as well as treatment and disposal of sanitary drainage liquids in modern communities, represent urgent priorities in development programs, where many of Egyptian cities and most villages suffer from non-existence of all sanitary drainage services for disposal of the liquid waste. It was severely increased and had inverse impact with the supply of the cities and villages with fresh water and increase of population.

So, the State and its concerned authorities give special interest to potable water supply and sanitary drainage projects. Due to the change of urban patterns, it is important to choose appropriate systems for the purification of drinking water and liquid waste treatment.

As sanitary drainage projects are carried out according to special conditions and specifications followed by each administrative entity in cooperation with the authorities and bodies implementing these works, this has led to a multiplicity of jurisprudence in the preparation of design criteria and rules for potable water implementation works (pumping stations and purification plants) and also for the sanitary drainage projects (pumping stations and treatment plants) due the multiplicity of agencies working in this area, which led to differences in the criteria and rules to be followed for the same type of works.

Therefore, it was issued decree of Minister of Construction, New Urban Communities, Housing and Utilities No. 79/1991 on formation of the of the standing committee concerning design criteria and rules of potable water and sanitary drainage treatment plants and pumping stations.

The committee has divided the Code into four volumes:

Volume 1: Sanitary Drainage Pumping Stations

Volume 2: Sanitary Drainage Treatment Plants

Volume 3: Potable Water Purification Plants

Volume 4: Potable Water Pumping Stations.

Volumes 1, 2, 3 and 4 are divided into three chapters:

Chapter (1): The Studies

Chapter (2): Design Criteria

Chapter (3): The Rules

This code indicates design criteria and rules of pumping stations. It also indicates the maximum requirements that must be taken into considerations in design, implementation and achievement efficiency of sanitary drainage projects. This should not conflict with the recommendations and conditions added by the Consultant suitable and appropriate for the projects. Subjection of the design and implementation to the provisions of this code does not exempt from any legal responsibilities and obligations.

Thanks and Recognition

Standing committee for the preparation of Egyptian Code Concerning Design Criteria and Rules of Potable Water and Sanitary Drainage Treatment Plants and Pumping Stations extends thanks to Housing & Building Research Center for its effort and facilities provided for production of this work in a decent form.

The committee also extends recognition to the authorities who have contributed their opinion in enriching this work through discussions and technical views, they are:

- National Authority for Potable Water and Sanitary Drainage
- Cairo General Organization for Sanitary Drainage
- Consultation Office for Sanitary Engineering (SANIS)
- Faculty of Engineering, Cairo University
- Faculty of Engineering and Technology, Suez Canal University

Chairman of Standing Committee

Prof. Dr. Eng. Ibrahim Hilal El Hatab

Contents

(G)

Figures Index | Page

(M)

Page

Page

Tables Index

Chapter 1
The Studies

Introduction

At the beginning of design pumping stations for liquid wastes coming from a city, village or community, the following studies should be performed:

1. Number of people and different activities.
2. Determination of the design period.
3. Selection of pumping station site.
4. Determination of the serviced locations.
5. Calculation of design flows.
6. Determination of types of pumping stations
7. Control and protection methods.
8. General layout.
9. Survey works.
10. Soil studies

1. Number of people and different activities.

1-1 Stages of population growth

When studying population of a city, village or community for the purpose of design the pumping stations, the population growth will be studied according to the following stages:-

1-1-1 Start-up and prosperity stage

This stage characterized by increased rate of population in the form of geometrical increase.

1-1-2 Stability stage

In this stage population attraction factors are stable and requires fixed population expansion and the population growth will be calculate by the arithmetic method.

1-1-3 Saturation stage

It is the reach to the decreased increase of population growth due to stop of attraction factors or as a result of construction of other adjacent residential communities with stronger attraction factors. The designer should take into consideration the difference between prediction in the population growth for existing urban community and new urban community.

1-2 Future estimation of population

Population at the end of design periods is estimated by using the statistics performed by the governmental bodies concerned with population studies in order to know the current and future population taking into consideration the expected growth and the expansion of different industrial, service and commercial activities. To reach to this purpose, there are different practical methods, some of them are performed through application of mathematical equations and others are through applying the statistics on the graphical drawings. The following are some of the mathematical methods used in predication of the number of people:

1-2-1 Arithmetic Increase Method

The applied equation is:

$$P_n = P_1 + K_a (t_n - t_1) \quad \text{...} \quad (1)$$

This method is represented graphically by a straight line

1-2-2 Geometrical Increase Method

The applied equation in this method is:

$$\ln P_n = \ln P_1 + K_g (t_n - t_1) \ldots\ldots\ldots\ldots \text{(2)}$$

It is represented graphically by an increasing curve of first order

1-2-3 Decreasing rate of increase

The applied equation in this method is:

$$P_n = S - (S - P_1) e^{-K_d (t_n - t_1)} \ldots\ldots\ldots\ldots \text{(3)}$$

It is represented graphically by decreasing curve of first order. The symbols used in equations 1, 2 and 3 are as follows:

P_n: The population served by the project in the target year.

P_1: Last population for the region taken according to Mobilization and Statistics statement.

K_a: Annual population increase rate in the arithmetic method (fixed rate)

K_g: Annual population increase rate in the geometric method (increased rate)

K_d: Decreased annual population increase rate in decreasing rate of increase method.

S : Maximum value of expected population (saturation limit)

$(t_n - t_1)$: Time period served by the project.

$\ln$: Natural logarithm for the base (e).

Fig (1-1) represents population growth curve for the city and shows the relation between the population and the time periods that represented by each of the above methods.

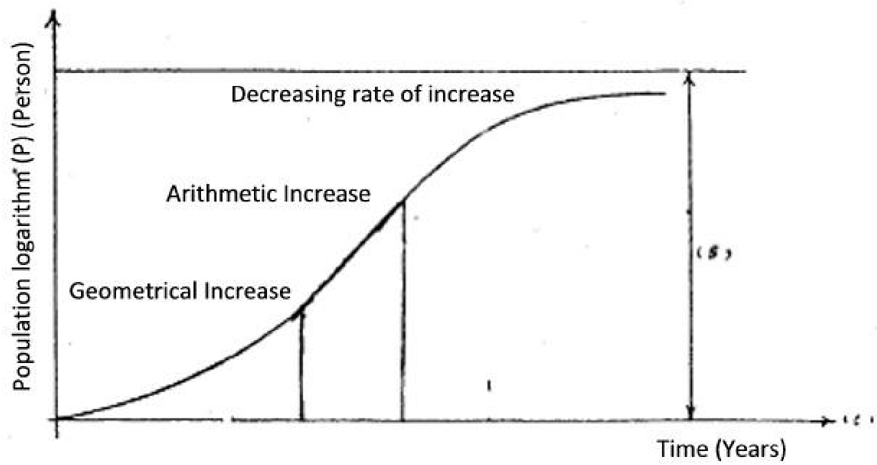


Fig (1-1) Population growth curve for the city

From the figure it is clear that the population growth of the city has an increase rate at the beginning then decreases by the growth of the city and decrease of the activities. The increase occurs with the geometric method in the growth periods due to the urban expansion or planning for new city with industrial, commercial or agricultural attraction regions, followed by a fixed increase expresses the stability of the city after the expected expansions. This increase is represented by the arithmetic method, and then followed by decreasing rates of increase due to decrease of economic resources of the city and being saturated and the lack of employment and migration from the city. This is represented by decreasing rate of increase method.

This is in addition to the following methods for estimation of population in the future.

1-2-4 Estimate of population by assuming population densities associated with land uses

This method depends on the method of planning of the city or region

Table (1-1) Shows population densities according to land uses

Table (1-1) Population densities used when calculating the expected population in planning of a city or region

Population Densities (Person/Hectare)	Land Uses
20-50	1st Class Villas
50-100	2nd Class Villas
100-250	Small Residential Buildings
250-700	Medium Residential Buildings
700-1200 or more	Big Residential Buildings
50-75	Commercial Areas
20-30	Industrial Areas

1-2-5 Graphical Extension Method

It is an approximate method resulted from it the future population by drawing population growth curve of the region in the past then it is extended to conclude the population at the required target year.

1-2-6 Graphical Comparison Method

In this method, population growth curve for the area under study is drawn for a city similar in activities with greater population then a curve similar to the curve of the population growth of the greater city is drawn, hence the required population growth in the future is deduced.

2- Design Periods

2-1 Civil Works

Civil works for pumping stations and service building are designed to achieve service requirements until the target year which ranges from 40-50 years.

2-2 Mechanical and Electrical Works

Determination of the design periods for the pumping stations depends on the nature of current and future graduation of the flows coming to these stations until the target year as follows:

- For the plants that serve existing residential communities and have approximate fixed population increase in addition to the increase of water consumption rates, flows of these plants increase gradually over the design period with limited rate, hence the pumping units are designed for a design period commensurate with the lifespan of these units, and is taken 15 years added to it design and implementation period (start operation). Then these units are replaced by new one taking into consideration the flows of the next design period.
- For the plants that serve new residential communities, the population increase is steady, which leads to irregular changes in the flows coming to the plant at successive time periods that needs the existence of implementation stages to install the pumping units to meet the development of the coming flows until the target year taking into account the lifespan of the pumps.

- For the plants that serve areas with special nature and the main plants that is hard to continuously change their pumping units, or the tourist villages that have flows coming to the plant which differ considerably over the seasons, in this case pumping stations with different flows are installed and operated in the seasons for which they are designed, and consequently the lifespan of the equipments must be increased and the design period will be 20-30 years.

3- Selection location of Pumping Station

The location must have the following conditions:

1. The location must be in the places with low levels to decrease construction costs whether for the networks or the plant and it is prefer, if possible, to be in the middle of the drainage area.
2. It is prefer to be the location on lands owned to the state to avoid expropriation procedures.
3. Paths of the gravity networks that serve this location must not intersect with the obstacles of deep water, if possible.
4. The access road to the plant passing with the gravity lines and discharge lines must be wide enough to accommodate these lines and for easy access to the plant. It should avoid the highways as paths for the lines, to the possible extend.
5. Non-existence of obstacles on the site (gas pipelines, power lines, etc)
6. The site must be as close as possible from source of supply of electricity and water.
7. Depth of the inlet pipe to the plant must not exceed 6.5 m except in the cases that its technical and economic study requires increase of the depth more than this.
8. The site must be away from the existing facilities by a sufficient distance.
9. Environmental aspects must be taken into account, while avoiding overlap of plant location especially with locations of drinking water supply facilities.

4- Determination of the serviced areas

Preparation of the general plan of the sanitary drainage networks for the city or the village depends on the urban plan, structural planning and topography of the area. When preparing the general plan of the sanitary drainage networks must take into account to get full benefit from the topography of the region to reduce the number of stations to the lowest possible number. Each station must serve in an area clear of obstacles (railways, canals) and shall pour directly to the treatment plants (main plants) or to any other near plant or to the main collectors (sub stations).

5- Design Flows

5-1 Flows received at pumping station

Flows will be calculated according to the Egyptian Code concerning design and implementation of pipe lines for potable water and sanitary drainage networks.

5-1-1 Average Flow (Qav)

It is (0.8-0.9) of the average daily consumption of water for the cities and population communities with residential nature, including industrial and commercial activities that serve the people, taking into consideration the difference of consumption in winter and summer.

5-1-2 Peak Factor

The peak fact or (P.F.) is calculated from the following equation (at maximum dry summer flow):

Peak Factor = $1 + 14 / (4 + \sqrt{p})$

Where (P) is the population in thousand

5-1-3 Min Flow Factor

Min Flow Factor (M.F.) is calculated from the following equation (at minimum dry winter flow)

Min Flow Factor (M.F.) = $0.2 \sqrt[6]{P}$

Where (P) is the population in thousand

5-1-4 Industrial Flow Qindust

In case of existence of areas for industrial activities for the city, the industrial flow is taken 1-2 l/s/hectare in case of unavailability certain data about the type of the industries. But, in case of availability of this data, the flow will be taken according to the type of the industry.

5-1-5 Commercial Flow Qcomm.

In case of existence of commercial centers, the maximum flow is taken between (0.5-1.7) l/s/hectare.

5-1-6 Infiltration Flow Qinf.

Infiltration water flows received at the network are calculated according to the head of infiltration water level over the upper trace of the pipe in the network taking into account to exclude the area at which infiltration water level is lower than the pipe line. In case of unavailable enough data, it will be taken as follows:

- 0.46 m^3/day/ 1 cm of pipe diameter / 1 km of the pipe line
- Or, 0.2 l/s/ hectare
- Or, 5-15% of the average flow.

5-1-7 Rain flow (Qrain)

Rain flow (Qrain) is calculated from the following equation:

$Q_{rain} = 2.75\ C*I*A$ (lit /s)

Where:

C: Excess Rainwater Factor

I: Intensity of rainwater fall (mm/hour)

A: The area exposed to rainwater fall served by the line (hectare)

Table (1-2) Excess Rainwater Factor

Type of Surfaces	(C) Values
1. Roofs and paved streets	0.70-.095
2. Clay soils, gardens and unpaved streets	0.10-0.40
3. Sand soil	0.2-0.05
4. Residential areas (flat)	0.30-0.50
5. Residential areas (Rocky)	0.50-0.70
6. Industrial areas (Light industries)	0.55-0.65
7. Industrial areas (Heavy industries)	0.60-0.80

5-2 Flows Calculation

5-2-1 Maximum Flow Qmax

It is taken equal to max dry summer flow at target year and calculated from the following equation:

Qmax = P.F. * Qav summer + Qidust. + Qcomm. + Qinf.

Where:

Oav summer = (1.2-1.3) Qav

Omax = P.F. * Oav winter + Oidust. + Qcomm. + Qinf+ Qrain

Where:

Qav winter = (0.7-0.8) Qav

5-2-2 Minimum Flow Qmin

It is taken equal to minimum dry winter flow and is calculated form the following equation:

Qmin = (M.F. * Qav) + Qidust + Qcomm + Qinf.

6- Determination types of pumping stations

Flows of sanitary drainage networks are poured into the collection sump, where the pumps are installed directly in this sump (wet well) or part of the sump is allocated for installation of the pumps (dry well). The following factors shall be taken into consideration when determining type of the station:

- The available area for the pumping station.
- Type of soil of station site.
- The flows incoming to the station.

On this basis, sanitary drainage pumping stations are divided according to the type, shape and capacity of the sump as follows:

6-1 Type of the sump

6-1-1 Dry sump

It is used in pumping stations with medium and large flows.

6-1-2 Wet sump

It is used in pumping stations with small and medium flows.

6-2 The shape

Sump shape will be determined rectangular or circular according to soil type, level of groundwater and the used method of construction. The sump can be divided from inside according to the used type of pumps.

6-3 Capacity

6-3-1 Small flows: up to 40 l/s

6-3-2 Medium flows: 40-300 l/s

6-3-3 Large flows: more than 300 l/s

7- Protection and Control

7-1 Protection

The purpose of protection is:

- Protection of the environment from pollution from liquid wastes, sediments and the emitted gases, by covering all the holes in the plant with appropriate means, putting barriers and fences around the plant to prevent unauthorized persons from entering and using suitable ventilation which does not cause direct impact on the environment surrounding the plant.
- Protection of the persons working in the plant from the dangers resulted from their direct deal with the liquid wastes which may cause drowning, disease and epidemics by using protective devices such as oxygen cylinders, insulated suits, gloves, safety boots, etc.

- Protection of pumping units and discharge lines from blockage and corrosion by using screens, sand sedimentation basin, filtration and sedimentation units, if necessary.
- Protection of pumping units and discharge pipelines from water hammering by using the appropriate devices.
- Protection against electrical shocks resulted from touching the life units and the risks of the accidents resulted from the rotating parts of the mechanical equipments in the plant by applying industrial safety instructions and procedures.
- Protection of the mechanical equipments and electrical devices by using current and voltage indicators and automatic circuit breakers to disconnect the electrical supply in case of overload, voltage variation and short circuit.
- Protection against decrease or increase level of the liquid wastes in the collection sump by using suitable sound and visual alarm.

7-2 Control

Control systems are used in the pumping stations to regulate the use of the equipments for better performance that ensures optimum operation of these equipments without affecting rates of the operation of the plant that may lead to flood phenomenon or storage of the wastes in the network (gravity pipes) which may cause their blockage and corrosion due to accumulation of sediments inside them or in the sumps and inspection chambers in addition to emission of odors and pollution of the environment.

Usually manual and automatic operation systems are combined together in all plants to achieve this purpose.

Operation and control system is selected according to the condition of operation whether it is continuous operation matched with the pumps and the associated devices or in case of temporary faults or to face any unusual large loads at peak flow, heavy rains or breakage in the pipelines. Different control systems are divided into the following:

7-2-1 Mechanical Control

Such as mechanical indicators, regulators, floats, pressure and flow indicators.

7-2-2 Electrical Control

Such as control and signals transfer devices, computers, PLC and smart devices to control operation of pumping units.

7-2-3 Hydraulic Control

Such as the devices that control operation of valves, gates and control of levels and measurement.

8- Layout

After determination and selection of the site, layout of the plant is prepared to distribute the main components according to the type of the plant, main or substation, taking into consideration survey, hydraulic, constructional, mechanical and electrical elements as follows:

- Survey of the site and its levels.
- Connection of the site with the public roads.
- Direction of entrance of gravity lines and exit of discharge lines.
- Distribution of plant units and their linkage with each other to facilitate the operation to perform their purpose with keeping suitable distances between plant units and the associated buildings to ensure easy constructional works and facilitate installation, operation and maintenance of the mechanical and electrical equipments and disposal of the wastes resulted from disinfection and filtration works inside collection sump.

- Provision of the necessary utilities on the site such as drinking water and sanitary drainage supply networks to the administrative building, fire fighting, irrigation of green areas, lighting of the site and communication.
- Construction external fence for protection of the site against external effects, including guarding and reception office.
- Provision of administrative, service buildings and sufficient areas for the tanks (fuel and cooling) and the equipments installed outside the buildings.
- Architectural coordination between plant units and buildings regarding heads, dimensions and distances necessary for ventilations and natural lighting as well as beatification of the site.
- Construction of suitable internal roads.

9- Survey Works

Survey works are performed on the pumping stations site in order to:

- Survey the main features around the site such as roads, drains, canals, etc.
- Determine known level bench marks inside the site in suitable place to be described to refer to it.
- Determine the datum line for the plant to calculate static head of the plant.
- Determine the required leveling of the sump location for the service road of the plant.

10- Soil studies

When design and implementation of the pumping stations, it is required to perform soil and foundation studies in order to:

- Determine the stresses necessary for design the foundations of the pumping stations and service buildings.
- Determine type and depths of foundations.
- Determine method of implementation and construction of the sump.

- Determine level and type of groundwater and soil type to determine quantity and type of the used cement and the insulation materials for the protection of the constructions.

In addition, must comply with the code on foundations and soil tests.

Chapter 2: The Design

1. Hydraulic and mechanical design
2. Design of electrical works
3. Architectural and constructional design
4. Contract documents.

1- Hydraulic and Mechanical Design

1-1 Determination of Sump Volume

The calculated volume is considered the minimum safe operation under severe conditions according to the number of starts of pumping units per hour (or rate of operation). When determining the sump volume in the pumping station, the following factors should be taken into consideration:

1. The relation between the inflows and the capacity of the operating pumps in addition to the number of starts and stops per hour rated to pump motors and starters.
2. Sudden excess flows to prevent adverse hydraulic conditions or any surcharge in the drainage network.
3. Design dimensions and places of distribution of the pumps, pipes and valves inside the sump.
4. Provision of emergency volume to be used in case of faults to accommodate peak flows incoming to the plant.

The main factor is the calculation of sump volume then the provision of the other factors to ensure save operation.

1-2 Calculation of the Active Volume

Active volume of the sump in the pumping station is calculated according to the number of starts and stops of pumping units per hour according to the following rule as shown in fig (2-1)

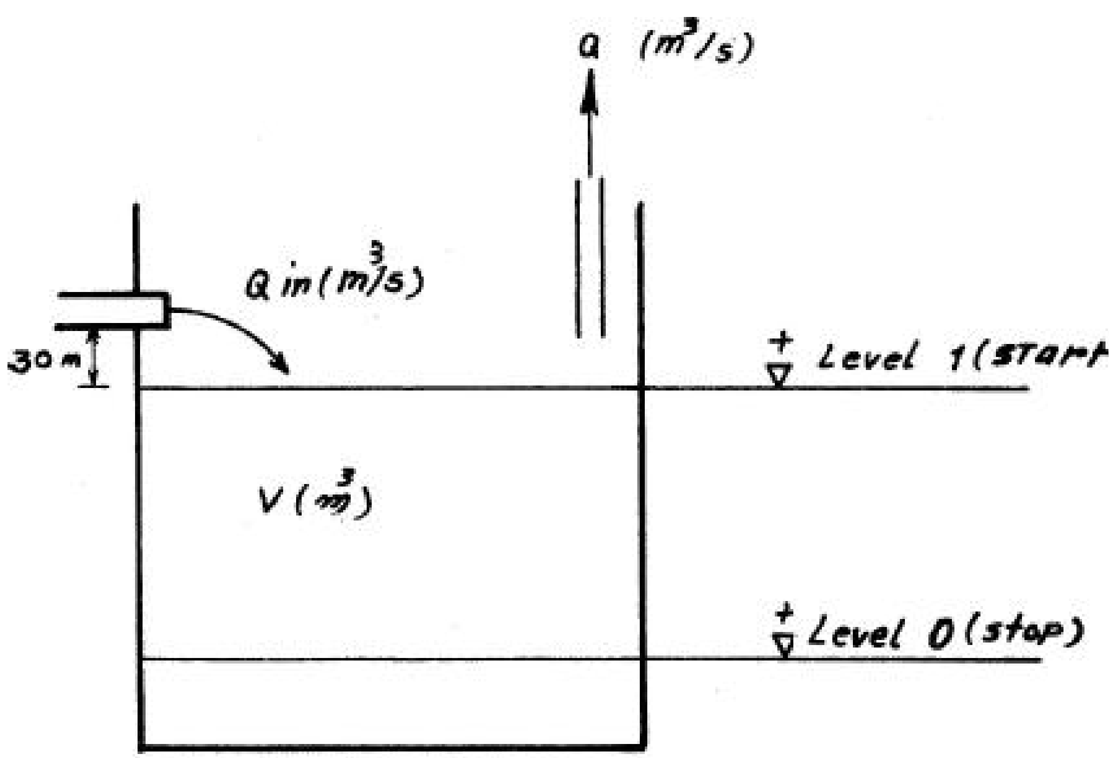


Fig (2-1) Start and Stop Levels

$$T = \frac{V}{Qin} + \frac{V}{Q\text{-}Qin} \qquad \text{.....................(1)}$$

T = Time between two successive starts, and it is the time of pump operation cycle (in second)

V = Sump Active Volume, is the volume between start and stop levels for the operating pumps in the plant (in cubic meter).

Q = Capacity of the operating units in the plant (the flows pumped by these units (cubic meter / sec)

Q_{in} = Maximum flow incoming to the plant (cubic meter / sec). (Average Flow × corresponding Peak Factor)

- Operation cycle time (**T**) is divided into operating time of the pumps (**t_P**) and stop time of the pumps to fill the sump (**t_S**) (Off Time).

$$T = t_p + t_s \qquad \text{.........................(2)}$$

$$t_s = \frac{V}{Q_{in}} \qquad \text{.........................(3)}$$

Where:

t_S = is the time required to fill volume of the sump between the stop level (Level-0) and start level (Level- 1).

$$t_p = \frac{V}{Q - Q_{in}} \qquad (4)$$

Where:

t_P = The time required to discharge the sump between start level (Level -1) and stop level (Level – 0) when $Q \geq Q_{in} \geq O$

When $Q < Q_{in}$, the water level inside the sump will increase even in the case of continuous operation of the pumps.

Equation (1) can be written in the following form:

$$T = V \left\{ \frac{1}{Q_{in}} + \frac{1}{Q - Q_{in}} \right\} \quad \text{..........................} \quad (5)$$

From the equation, it is clear that operation cycle time (T) is function of the inflow (Q_{in}) for certain constant volume (V) and capacity of the operating pumps (Q).

The inflow can be calculated at minimum operation cycle when:

$$dT / d\,Q_{in} = 0$$

By substitution in equation (5), then:

$$Q_{in} = \frac{Q}{2} = \varphi \qquad \text{..................................... (6)}$$

φ is called the (Critical inflow)

That means operation cycle time is minimum when the inflow **Q_{in}** is half the capacity of the pumps. By substitution in equation (5) from equation (6), then the minimum operation cycle time will be:

$$Tmin = \frac{4V}{Q} \qquad \text{... (7)}$$

Then, the minimum operation cycle time will be determined in advance and then sump volume is calculated which achieves cycle time T greater than T_{min} for the inflow to the plant.

Therefore, the minimum active volume for the sump is:

$$Vmin = \frac{Tmin.Q}{4} \qquad \text{... (8)}$$

From this formula, minimum active volume for the sump can be calculated for certain number of starts of the pumps per hour.

The same formula (8) can be used in the following form:

$$Vmin = \frac{0.9\ Q}{Z} \qquad \text{... (9)}$$

Where:

V_{min} = Is the minimum sump active volume (in cubic meter)

Z = Number of starts of the pumps per hour (rate of operation)

Q = Flow of the operating pumps (Liter / sec)

Determination of number of starts for the pumps per hour depends on pumps capacity, type and manometric head against which it works, taking into consideration that as the number of the required starts per hour increase as the cost of the electrical motors and control devices highly increase.

Accordingly, as the capacity of the pumps increase the power of their motors increases, this requires decreasing the number of starts per hour (operation rate) to preserve the economic terms in the construction of the plant.

1-3 Rate of operation of the pumps

Number of starts/ hour will be according to the following limits (according to the electrical motors power necessary to turn the pumps).

Less than 5 KW	25 starts / hour
More than 5 – 20 KW	20 starts / hour
More than 20 – 50 KW	15 starts / hour
More than 50 – 100 KW	10 starts / hour
More than 100 – 200 KW	6 starts / hour
More than 200 KW	4 starts / hour

When preparing specifications of the electrical motors, it should mention the required number of starts per hour.

Fig (2-2) shows the relation between operation cycle time T (or number of starts per hour Z) and the ratio of inflow Q_{in} to flow of the operating pumps in the plant Q and stop times t_S and start times t_P for the pumps in the three cases

$Q_{in}/Q = \varphi$, $Q_{in} < \varphi$, $Q_{in} > \varphi$

1-4 Calculation of the volume is divided into the following three cases:

- Pumping station with single pump
- Alternating use of two pumps
- Multi-pump system

A) Pumping station with single pump

Inflow volume during one cycle

$$V = Q_{in} \cdot T$$

As it is required to pump the same volume from the station during the operation time, then:

$$V = Q\, t$$

Where:

Q = Pump flow

t = Pump operating time

Therefore:

$$Q_{in} \cdot T = Q\, t$$

$$t = \frac{Q_{in}\ T}{Q}$$

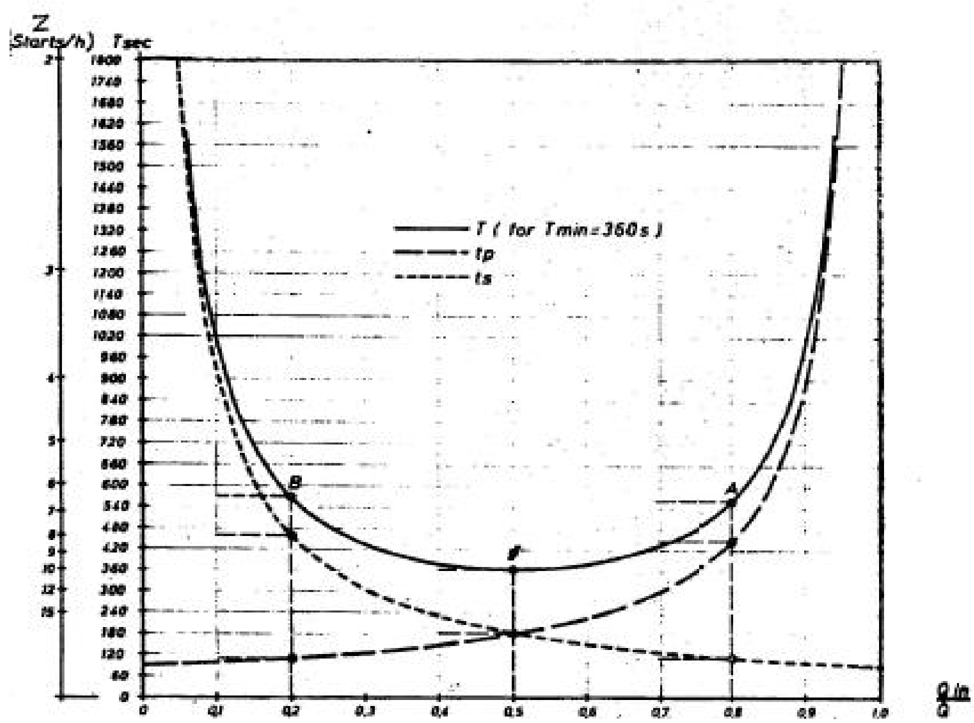


Fig (2-2) the relation between operation cycle time T (or number of starts per hour Z) and the ratio of inflow Qin to flow of the operating pumps in the plant Q

When the pump stops, the volume V_h, which is equivalent to the actual volume between start and stop levels will be filled during a time equal to (T-t).

Therefore, cycle time is:

$$T = \frac{V_h\ Q}{Q_{in}\ Q - Q_{in}^2}$$

And, the operation rate (z) which is the reciprocal of (T) is:

$$Z = \frac{Q_{in}\ Q - Q_{in}^2}{V_h\ Q}$$

From this formula, it is clear that the operation rate (Z) is a function of the ratio Q/Q_{in}

Fig (2-3) shows the relation between operation rate and pumps flow

The maximum operation rate can be calculated by differentiating the previous relation:

$$\frac{dZ}{dQ_{in}} = \frac{Q - 2\ Q_{in}}{V_h\ Q}$$

This ratio is equal to zero when $Q_{in} = 1/2\ Q$

By substituting with this value of the inflow Q_{in} in the operation rate equation:

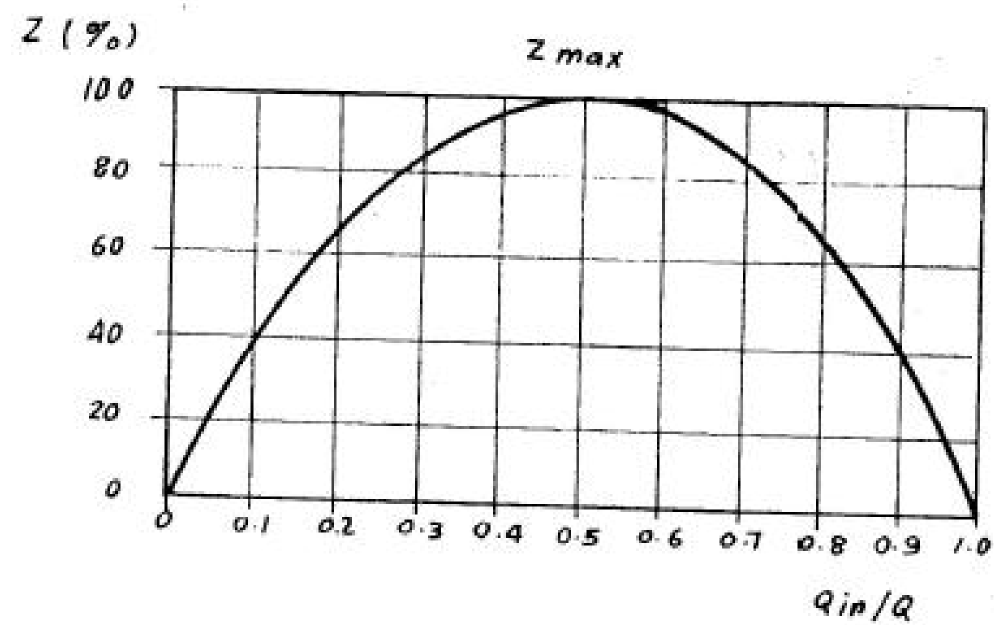


Fig (2-3) Relation between operation rate (Z) and the ratio of inflow to pump flow

Q_{in}/Q

$$Zmax = \frac{Q}{4\ V_h}$$

Therefore, the actual volume, which equivalent to the maximum operation rate is:

$$V_h = \frac{Q}{4\ Zmax}$$

Fig (2-4) shows the relation between the active volume and pumps flow at the required operation rates

B) Alternating use of two pumps

Fig (2-5) is an illustration diagram for operation of two similar pumps in the pumping station.

When the water level in the sump reaches to the first start level, one of the two pumps starts to operate (Pump A). If the pump flow Q_I is greater than the inflow Q_{in}, the water level continues to decrease until the stop level at which (Pump A) stops operation, then the water level starts to increase again until reaches to the first start level at which the second pump (B) starts operation, in other word the two pumps are operated alternately.

If the inflow Q_{in} is greater than the flow of one pump Q_I then the water level increases to the second start level, and the other pump starts to operate. If the flow of the two pumps together (combined flow of the two pumps) Q_{II} is greater than the inflow then the water level decreases until it reaches to the stop level and the two pumps stop operation together.

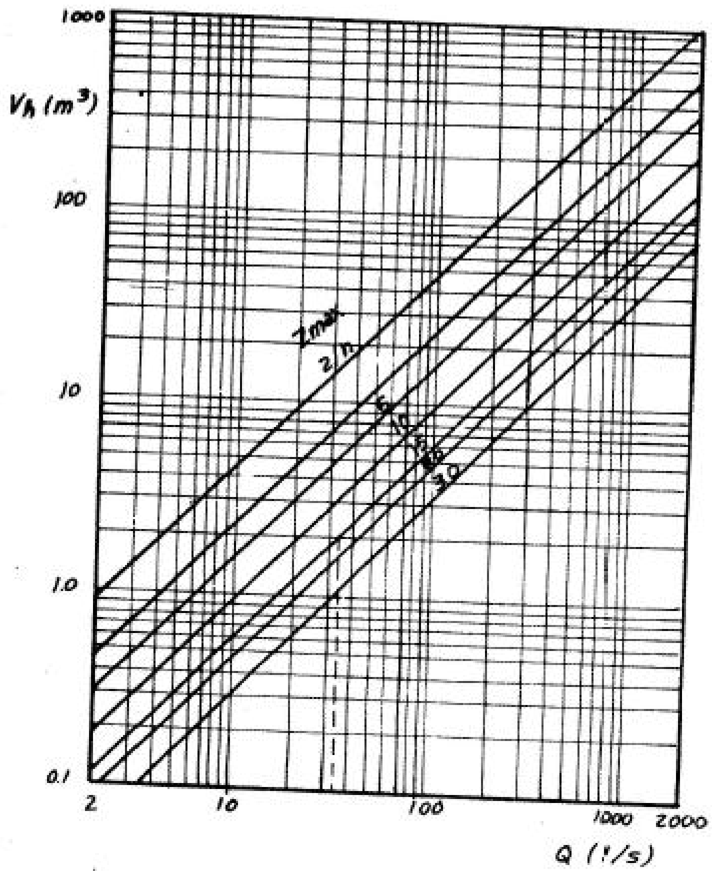


Fig (2-4): Relation between the active volume and pump flow at the required operation rates

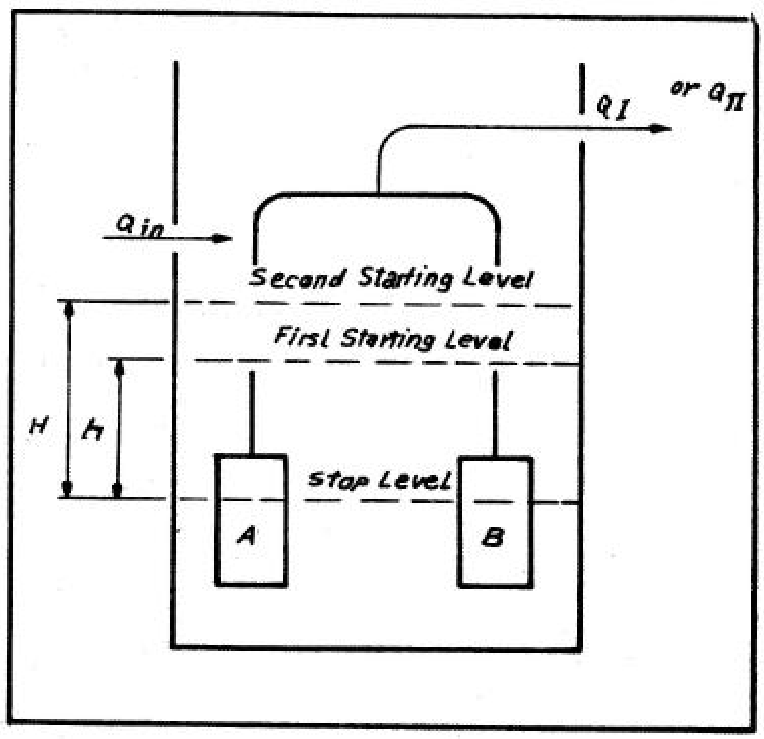


Fig (2-5) Illustration diagram for operation of two similar pumps in the pumping station

From fig (2-6) it shows the following:

1- When $Q_{in}/Q_I < 1$

In this case, the active volume V_h can be calculated from the following formula, provided that the two pumps are operated alternately:

$$V_h = \frac{Q_I}{8 \quad Z_I max}$$

Fig (2-7) shows this.

2- When $Q_{in}/Q_I > 1$

In this case, there are two other factors affecting the operation rate, the ratio V_h/V_H and the combined flow of the two pumps together Q_{II} (which is determined by the friction loss inside discharge pipe)

The volume V_h is corresponding to the head H in fig (2-5).

Therefore, the following formula can be deduced:

$$Z_{II} = \left\{ \frac{Q_I (V_H - V_h)}{Q_{in}^2 - Q_I Q_{in}} + \frac{Q_{II} V_H}{Q_{in} Q_{II} - Q_{in}^2} \right\}$$

The right side of the nomogram in fig (2-7) shows the maximum operation rate $Z_{II\,max}$ by solving the previous equation using the computer.

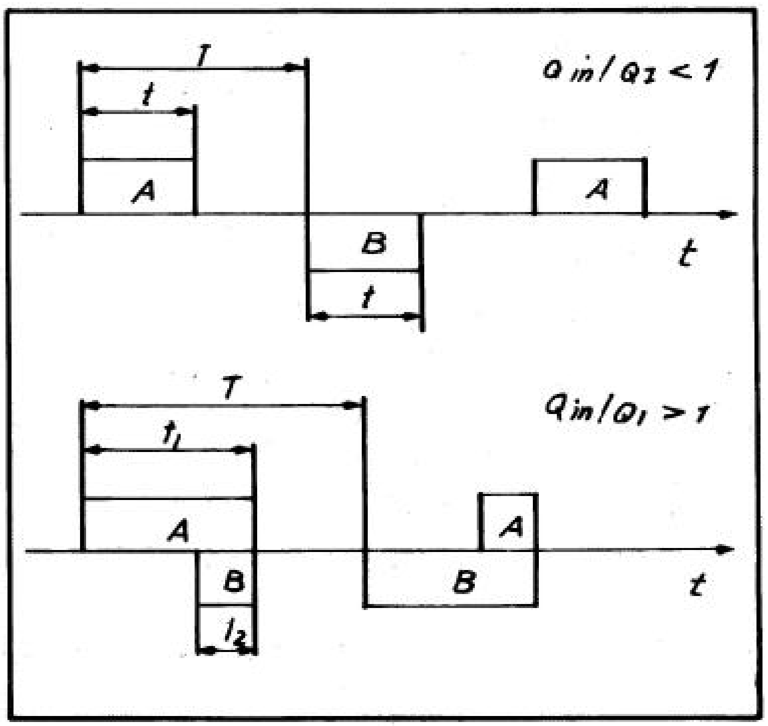


Fig (2-6): Illustration diagram shows alternating use of two pumps

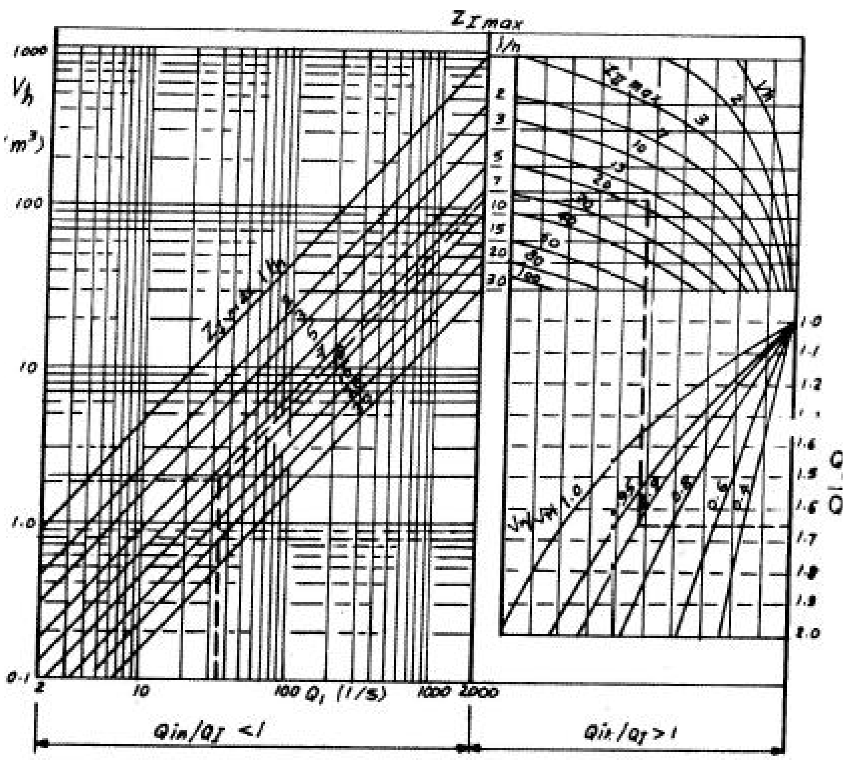


Fig (2-7): Nomogram for operation rate of two pumps operate alternately

Fig (2-8) shows the relation between operation rate and the ratio Q_{in} / Q_I. It shows that the operation rate is sharply increase when the two pumps are operated together in parallel and the maximum operation rate $Z_{II\ max}$ is very critical.

Fig (2-9) shows the effect of the ratio V_h/V_Hon the operation rate curve Z when V_H is constant and V_h is variable.

Fig (2-10) shows the effect of the ratio Q_{II}/Q_I on the operation rate curve Z when the ratio V_h/V_H equals 0.8. It shows that the value of $Z_{II\ max}$ decrease with the increase of the losses in the discharge pipe.

C) Multi-pump system

In this case, there are two operation systems:

- When the operating pumps have common stop level
- When the operating pumps have stepped stop levels.

The first system, common stop level

Fig (2-11) shows the first system when the pumps are operated in stepped starting levels but have common stop level (in this case, the pumps must be operated alternately in order that the number of operating hours is equal for the all pumps).

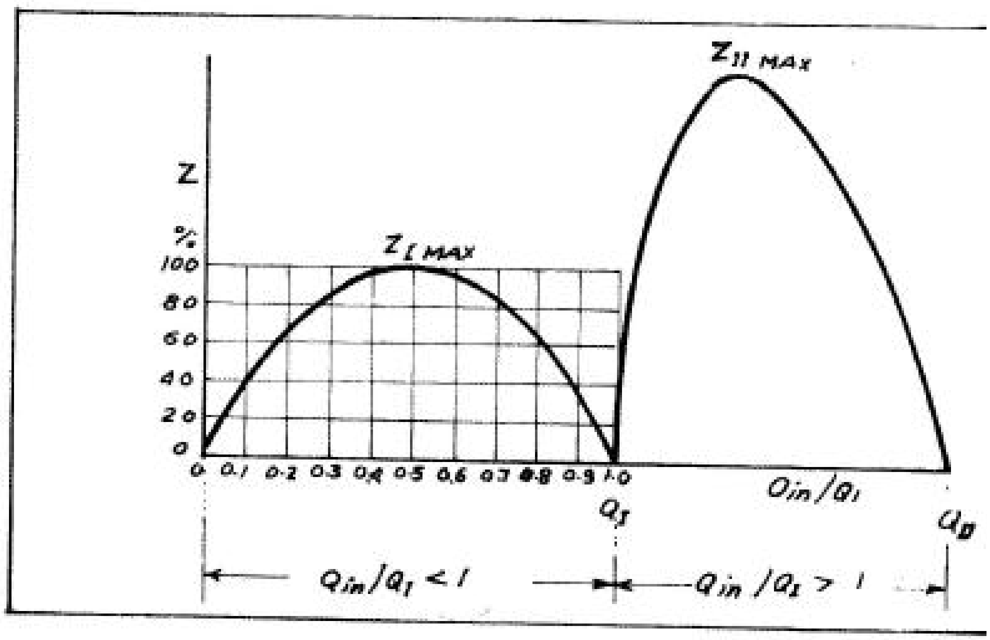


Fig (2-8): Relation between operation rate and the ratio Q_{in}/Q_I

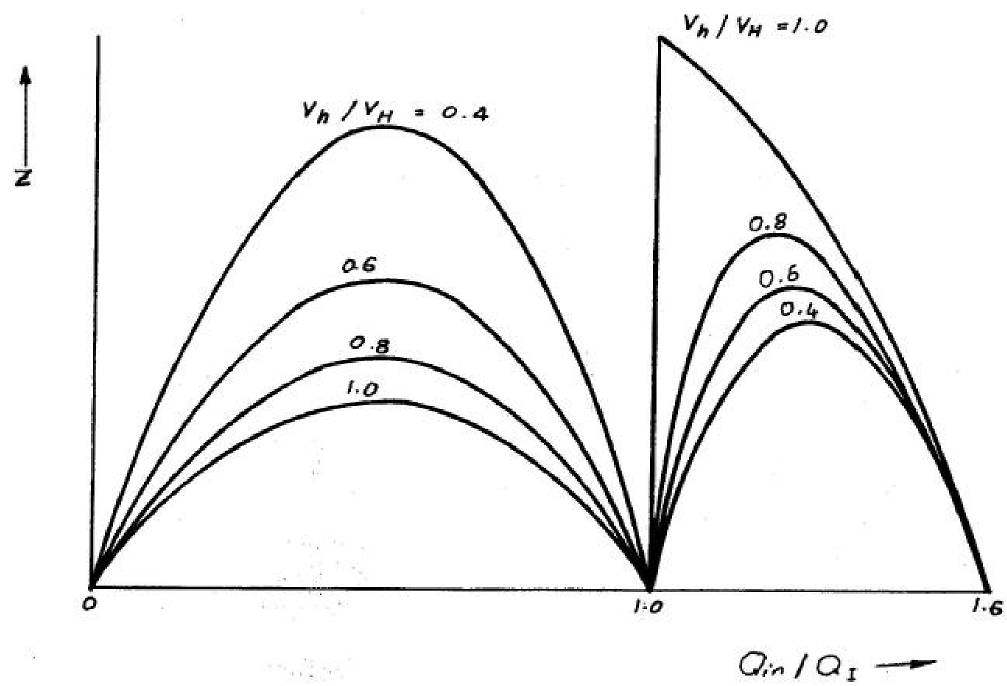


Fig (2-9): Effect of the ratio V_h / V_H on the operation rate curve Z when V_H is constant and V_h is variable

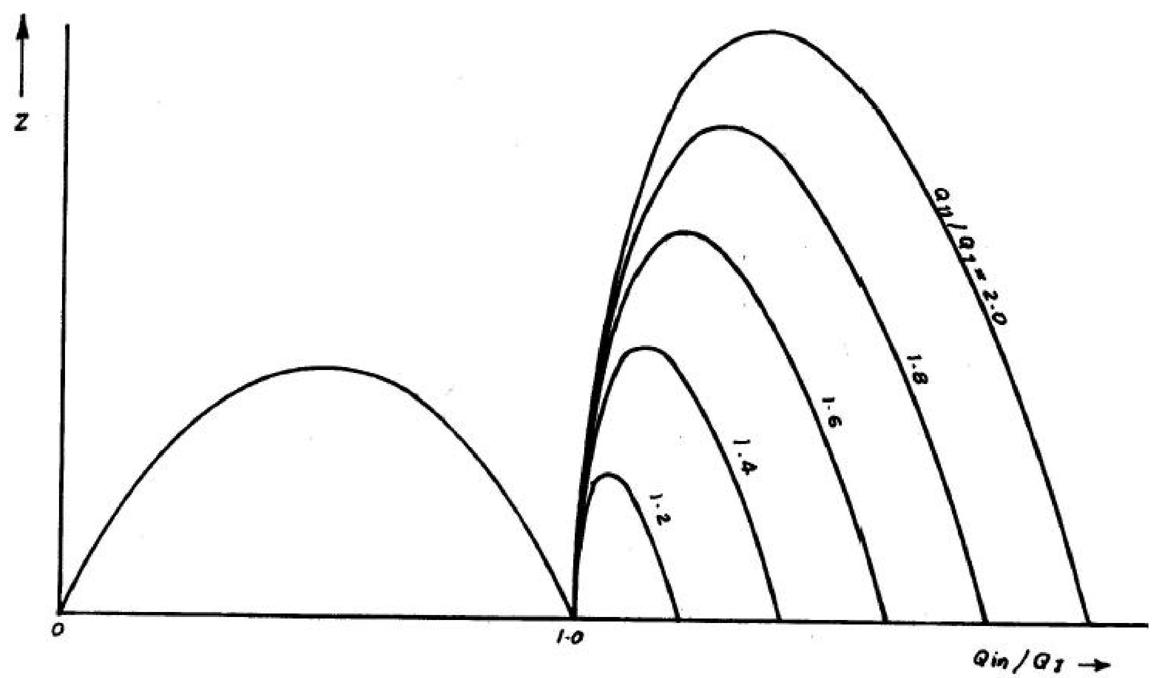


Fig (2-10): Effect of the ratio Q_{II}/Q_I on the operation rate curve Z when the ratio V_h/V_H equals 0.8

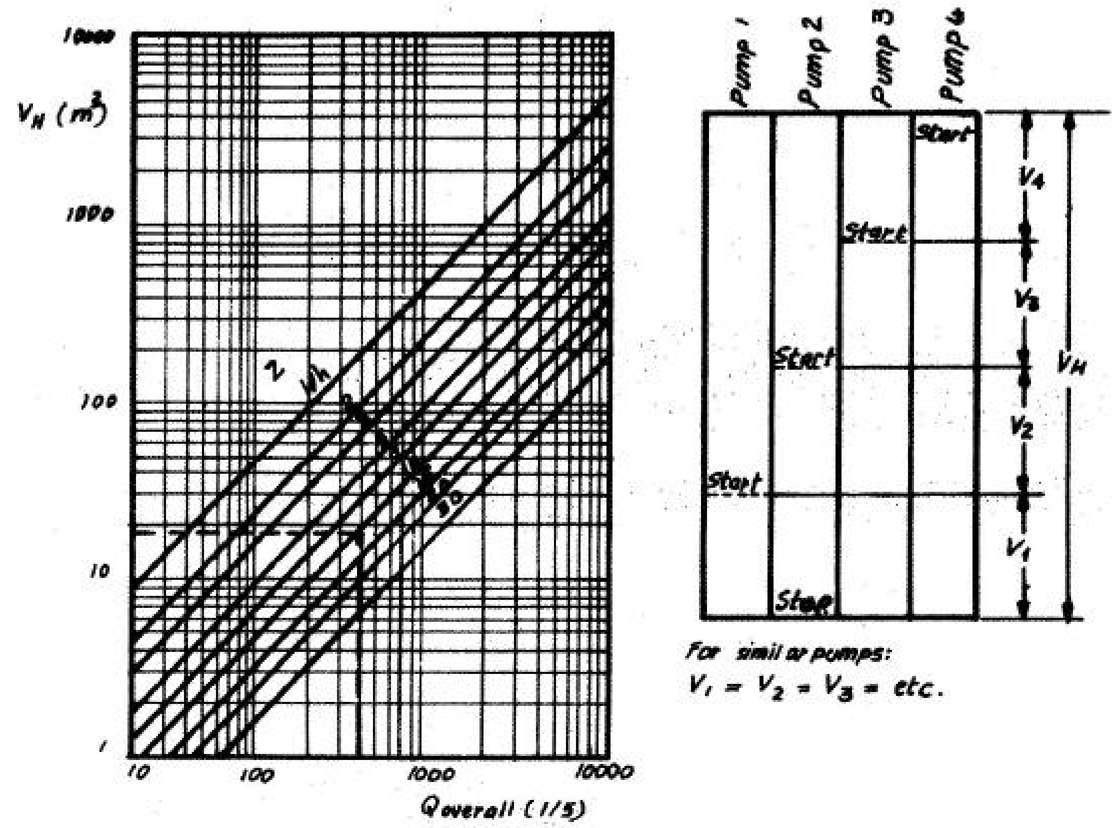


Fig (2-11): The pumps are operated in stepped starting levels but have common stop level

The first system can be applied in the design of the pumping stations with multi-pump when the sump volume is small.

Advantages of this system:

- Avoidance of occurrence of floating flocks or sludge sediments at the bottom of the sump.
- Easy balance between operation hours for the operating pumps, but this system requires the existence of effective system for prevention of water hammering.

Disadvantages of this system:

- It requires expensive system for prevention of water hammering.
- Failure to obtain continuous flows from the pumping station.

The second system, stepped stop levels

Fig (2-12) shows the second system with stepped start and stop levels.

This system is applied in case of design of pumping station with multi-pump when the sump volume is relatively great.

Advantages of this system:

- The ability to obtain regular flows from the station without sudden changes (such as in the cases of pumping flows to the treatment plants)
- Avoidance of construction of expensive water hammering system.

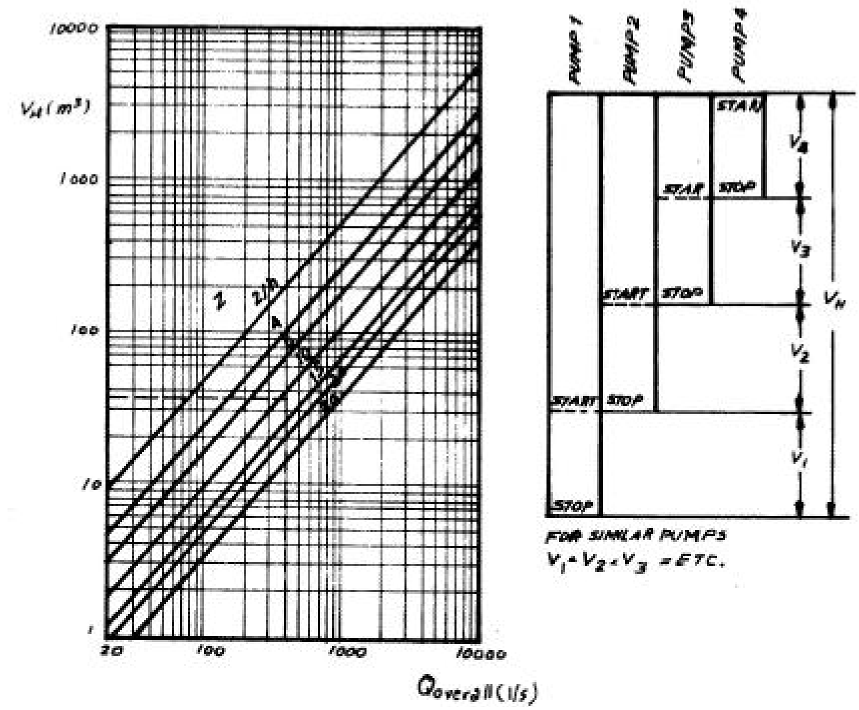


Fig (2-12): Stepped start and stop levels for pumps

- Overlook the existence of a layer of floating flocks or sediments in the sump, where this can be treated with other methods.

Calculation of sump volume in the first system (common stop level)

1- Relation between the default flow of pump k and capacity of pump 1

$$q_k = \frac{Q_k}{Q1} \qquad (1)$$

2- Relation between the default actual volume for pump k to volume of pump 1

$$v_k = \frac{V_{k\ min}}{V1\ min} \qquad (2)$$

3- Relation between the flow of pump k and the sum of flows of the previously operated pumps (flow factor)

$$\eta_k = \frac{q_k}{\sum_{i=1}^{k} q_i} \qquad (3)$$

4- Volume factor for k pumps

$$G_k = \frac{Q_1 \sum_{i=1}^{k} V_i}{4 \sum_{i=1}^{k} Q_i}$$

$$= \frac{\sum_{i=1}^{k} V_i}{4 \sum_{i=1}^{k} q_i} \qquad (4)$$

Fig (2-13) shows the relation between volume factor G_k and flow factor η_k for two, three or four pumps operate with the first system.

To calculate minimum active volume for a pumping station operates with the first system, formulas (1), (2), (3), (4) shall be applied with the curves shown in fig (2-13).

First Case

If the operating pumps are similar and pump their flows in separate discharge lines

$Q1 = Q2 = \ldots\ldots = Q_k$

Hence,

$T1\ min = T2\ min = \ldots\ldots = T_k\ min$

From formula (1)

$q1 = q2 = \ldots\ldots = q_k = 1$

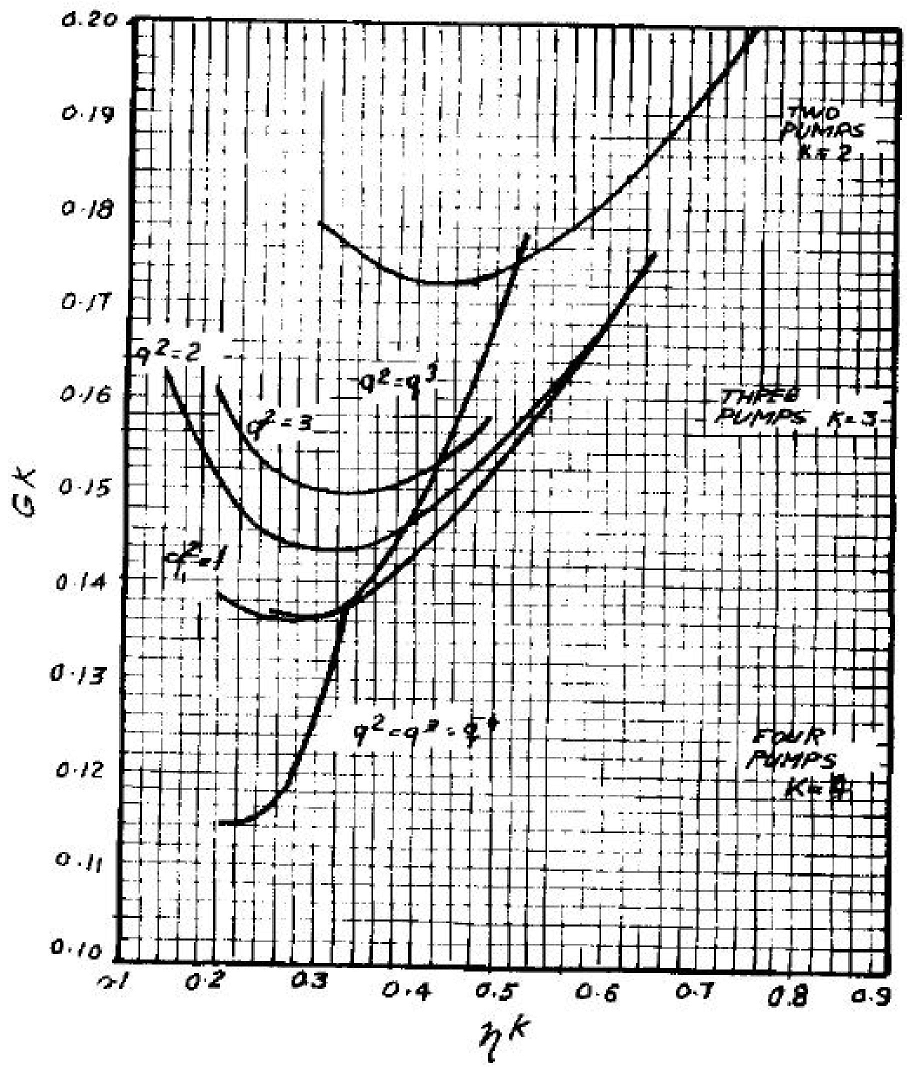


Fig (2-13): Relation between volume factor G_k and flow factor η_k for two, three or four pumps operate with the first system.

A) Active volume for pump (1) is calculated from the formula:

$$V_1 min = \frac{T_1 min \; Q_1}{4}$$

B) The factor η_k is calculated from formula (3) for all operating pumps, and from the curves shown in fig (2-13), G_k for these pumps can be calculated.

C) By substituting in formula (4), v_k can be obtained for all pumps,

D) From formula (2), V_{min} can be calculated for all pumps, where:

$$V_k \; min = v_k \; V_1 \; min$$

E) By summing active storage size for all pumps from 1 to K, the total storage size $V_T$min can be calculated for the plant.

F) Storage head H_k can be calculated for each pump from the formula:

$$H_k = \frac{V_k \; min}{Sump \;\; Area}$$

G) By summing storage head from H_1 to H_k, the total storage head H_T can be calculated for the plant.

Second Case

If the operating pumps are similar and pump their flows in common discharge line, in this case also:

$$Q1 = Q2 = \ldots\ldots = Q_k$$

And,

$$T1\ min = T2\ min = \ldots\ldots\ldots = T_k\ min$$

A) Values of q_k, then values of V_k can be obtained as in the first case.

B) As the flow of each pump decreases as the number of the operating pumps increases at the same time, that means calculations of the partial volumes $V_k\ min$ will be done for different values of the volume $V1\ min$, which depends in turn on different values of the flow $Q1$.

$$V1\ min = \frac{T1\ min \quad Q1}{4}$$

$$V_k\ min = V_k \quad V1\ min$$

$$H_k = \frac{V_k\ min}{\text{Sump area}}$$

C) The sum of $V_k\ min$ for all pumps is the total actual volume $V_T\ min$, and the sum of H_k for all pumps is the total head H_T

Fig (2-14) shows nomogram links the above formulas

By applying this nomogram, more accurate results can be obtained for the actual operation cases.

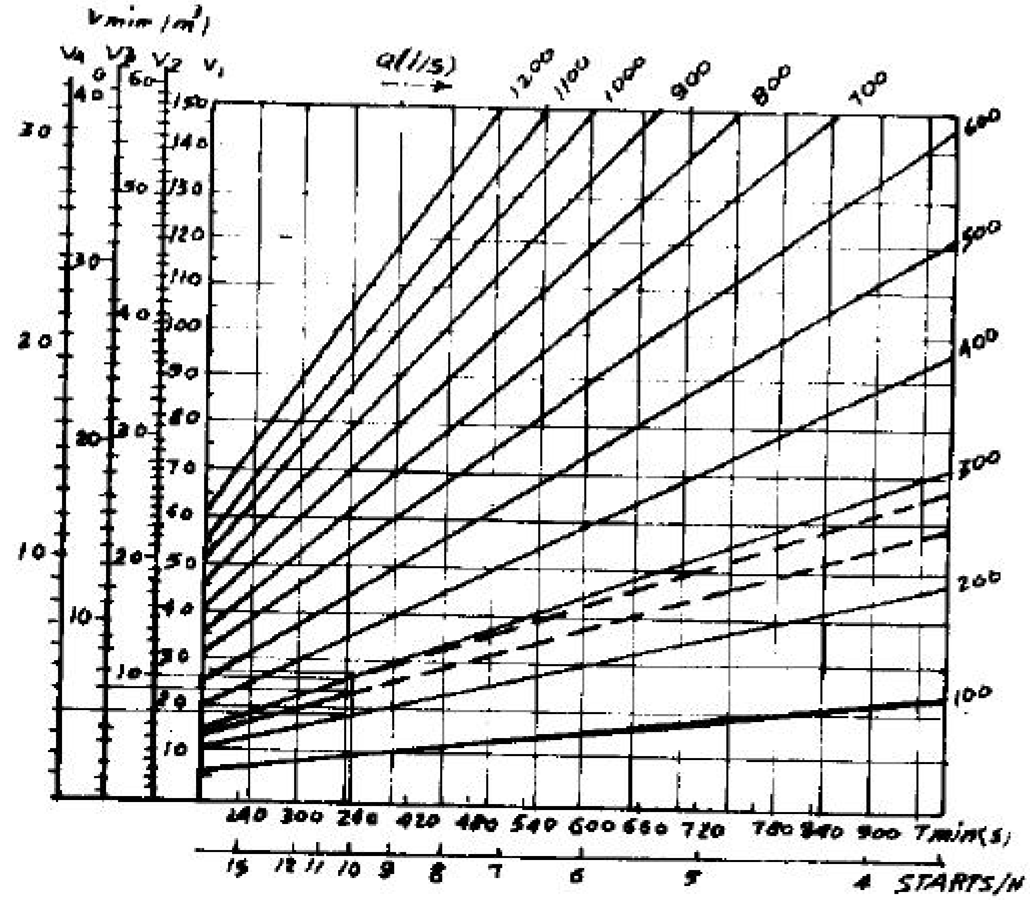


Fig (2-14): Nomogram for the relation between V_{min} and T_{min} in case of using similar pumps that pump their flows in common discharge line

Third Case

If the operating pumps are not similar and pump their flows in separate discharge lines

Fourth Case

If the operating pumps are not similar and pump their flows in common discharge lines

* In third and fourth cases, the same steps used in first and second cases shall be applied respectively to obtain the active storage volume and the corresponding head.

Calculation of sump volume in the second system (stepped stop levels)

The following formulas will be used in this case:

$$VT = \frac{\sum_{i=1}^{n} V_i}{\sum_{i=1}^{n} T_i\ Q_i} = 1/4 \qquad (1)$$

Where:

n = Number of the operating pumps

$\mathbf{V_T}$ = Minimum total sump volume

$\mathbf{V_i}$ = Minimum volume for pump P_i that achieves operation cycle time:

$\mathbf{T \geq T_i}$

$\mathbf{T_i}$= Minimum operation cycle time for pump P_i

Q_i = Flow of pump P_i

Hence, the distance between start and stop levels for pump P_k can be calculated from the following equation:

$$H_k = \frac{V_K}{A_K} \quad (2)$$

Where:

V_k = Sump volume necessary for pump P_k

A_k = Area of the sump corresponding to volume V_k

The total water head inside the sump is:

$$H_T = \sum_{i=1}^{n} H_i \quad (3)$$

First Case

If the flows of the operating pumps are equal and pump their flows to separate discharge lines equal in length.

In this case:

$$Q1 = Q2 = \ldots\ldots = Q_k$$

$$T_1 min = T_2 min = \ldots\ldots = T_k min$$

From formula (1), the total storage volume V_T can be calculated.

Also, the distances between start and stop levels are equal for all pumps

$$H_1 = H_2 = \ldots\ldots = H_k$$

From formula (2), the total head of start and stop levels can be calculated

Second Case

If the operating pumps in the plant pump their flows in common discharge line.

In this case, flows of the pumps are different for different number of pumps operating at the same time.

Fig (2-15) shows the difference in the value of pumps flow for different number of operating pumps.

(A) Flow of each pump Q_k will be calculated.

(B) Equivalent volume V_k for each pump Q_k will be calculated.

By applying formula (1), total storage volume V_T can be obtained.

(C) The distance between stop and start levels H_k can be calculated for each pump. By applying formula (2), the total head H_T for start and stop levels can be obtained.

Fig (2-16) shows the relation between pump flow Q and minimum active storage volume V_{min} that achieves operation cycle time T_{min}.

It is clear from the figure that the total minimum storage volume for certain total flow depends only on minimum operation cycle time T_{min} and not on the number of the operating pumps and their corresponding flows.

- Hence, sump volume deceases only by the decrease of the operation cycle time.

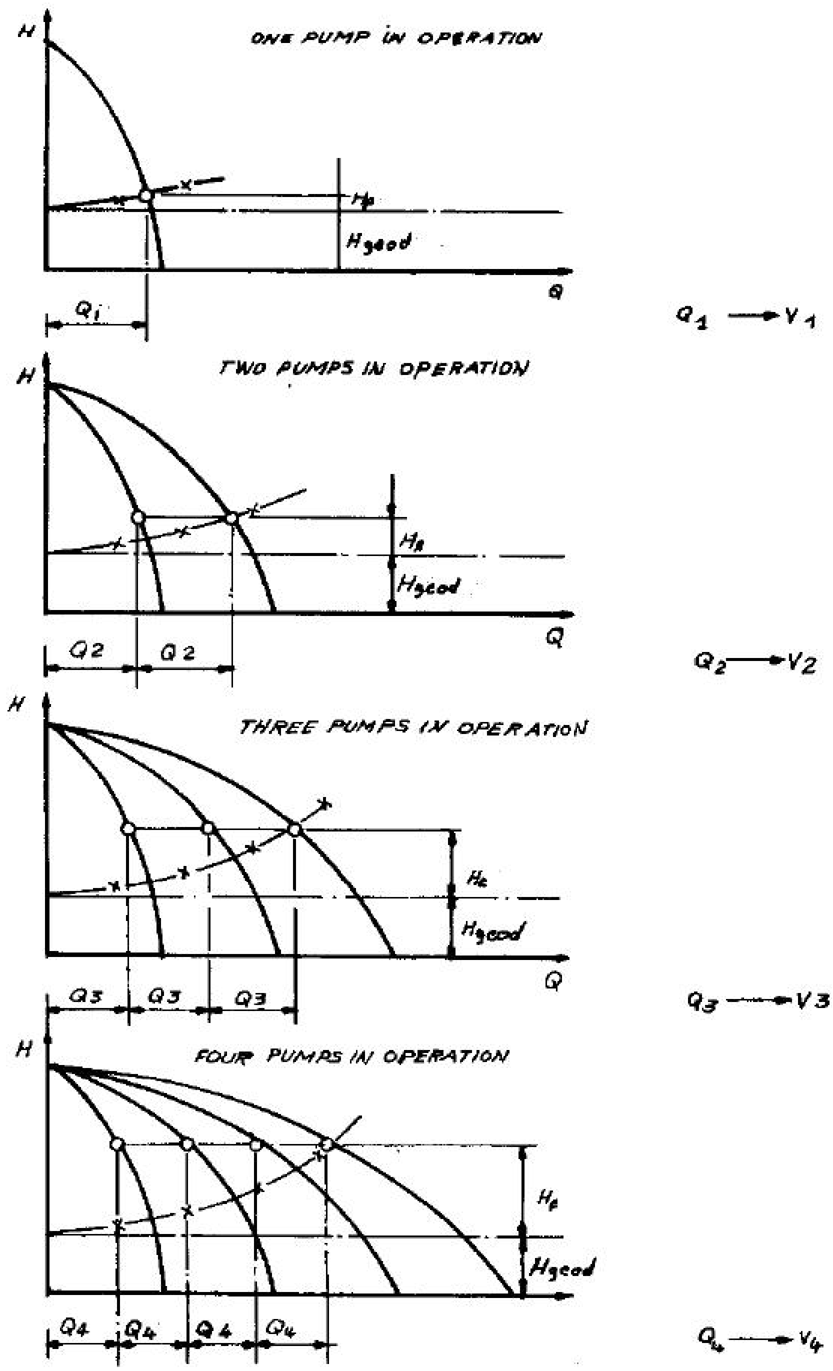


Fig (2-15): Difference in the value of the pumps flow for different number of operating pumps

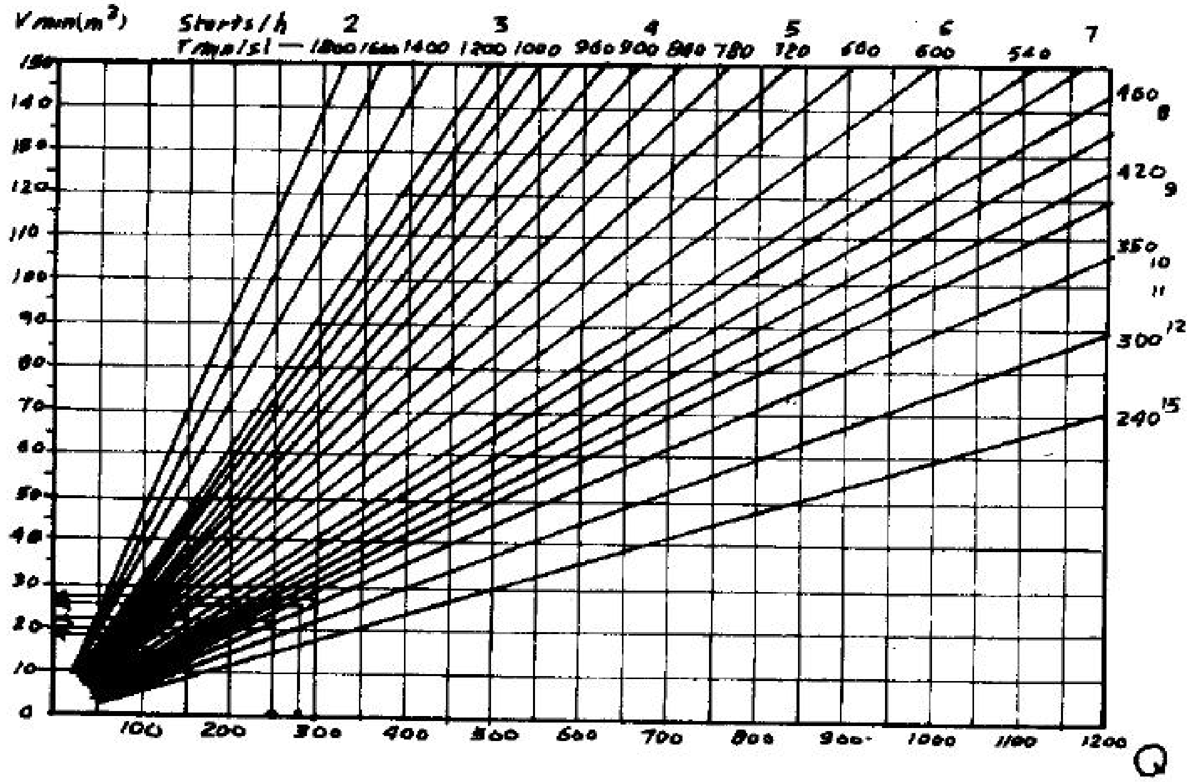


Fig (2-16): Relation between pump flow Q and minimum active storage volume V_{min} that achieves operation cycle time T_{min}.

- The same diagram shown in fig (2-16) is used to ensure from the minimum operation cycle time for certain pump installed on the sump.
- The same diagram is also used to test the pumps of suitable flows if it is determined the sump volume and minimum operation cycle time.

For the first and second systems, the following must be taken into consideration:

1- Addition of head of minimum stop level to the total head H equivalent to the active storage volume to calculate sump storage depth.

2- Taking into consideration change of water level inside the sump, and hence change of static head H_0 in the calculation if the difference between start and stop levels is big.

2-5 Distance between start and stop levels

Must take into consideration that the start and stop levels are not near to each other to avoid occurrence of surface waves on the water inside the sump that may affect accuracy of adjusting start and stop levels. Generally, the distance between start and stop level must not less than 20 cm.

1-6 Minimum level of water in the sump (Stop Level)

Minimum allowable level inside the sump is determined according to the required NPSH. In all cases, this level must not less than top of pump casing to ensure that pump impeller is totally submerged in water.

1-7 Maximum level of water in the sump (Start Level)

The maximum level of water in the sump is determined to a level that does not allow fullness, stoppage of water flow inside the collection network connected to the plant, occurrence of back water curve or surcharging. So, the start level must not exceed bottom of the sump inlet pipe.

1-8 Volume Head

After determining sump active volume V_H, stop level and start level are determined according to what mentioned above. The difference between the two levels H is the water head inside the sump which is equivalent to sump active volume V_H. As the start level is determined by sump inlet pipe, the stop level, and hence the sump head, are determined by the designer and should take into consideration the following factors:

1- Land area available for construction of the sump.

2- The surface area required to install pumping units (pumps and their components) which is an effecting element in determining sump dimensions.

3- Level of main inlet gravity line to the plant.

4- The possibility to reach to the required level of sump bottom from construction point of view by considering nature of the soil, level of groundwater and the economic cost in comparison to the increase of the surface area of the sump and safety of the adjacent buildings.

Usually the head H between start and stop levels is from 0.8 to 3 m according to capacity of the plant.

1-9 Determination surface area of the submerged sump in case of circular sump

After determining sum active volume V_H and the head H, equivalent to this volume according to what mentioned above, the surface area of the submerged sump can be calculated from the following formula:

$$A_W = \frac{V_H}{H} \qquad (1)$$

For the circular sump, the sump is usually divided into submerged part and dry part by a ration of 1:1 or 1:2 respectively.

That means surface area of the submerged sump is represented by a segment of a circle area with height (h), arc length (b) and chord (S). To calculate the area of the circular segment, the following formula is used:

$$A_W = \frac{h}{2} \quad r - \frac{S}{2} (r - h) \qquad (2)$$

Where:

r = Radius of the circular sump

h = Height of the circular segment

When the height $h = \frac{2r}{3}$

Therefore,

$$A_W = 0.906\ r^2 \qquad (3)$$

1-10 Calculation of circular sump diameter

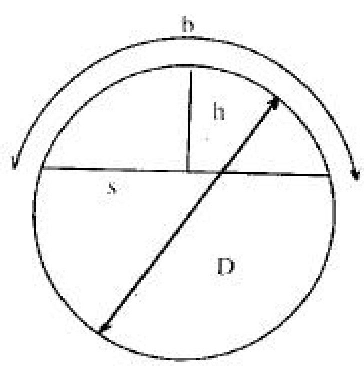
After calculating surface area of the submerged sump according to equation (3)

Circular sump diameter (D) can be calculated (submerged + dry) from the following formula:

$$D = 2\sqrt{\frac{A_W}{0.906}}$$

Or,

$$D = 2.1\sqrt{A_W}$$



1-11 Centrifugal Pump Design

1-11-1 Symbols, Units and Designations

	Symbol	Unit
Impeller diameter	D	Mm
Nominal bore of pipe or pump nozzle	DN	Mm
Conversion factor for total head	F_H	-
Conversion factor for flow rate	F_Q	-
Conversion factor for efficiency	F_η	-
Gravitational constant = 9.81	G	m/s^2
Total head	H	m
Total system head	H_A	m
Static head	H_{geo}	m
Shut-off head	H_o	m
Head at best efficiency point	H_{opt}	m
Static suction lift	Hs_{geo}	m
Static positive suction head.	Hz_{geo}	m
Head loss	H_J	m
Head loss- suction side	H_{J1}	m
Differential head	ΔH	m
Speed	n	Min^{-1}

NPSH required	$NPSH_{req}$	m
NPSH available	$NPSH_{av}$	m
Specific speed	n_q	l/min
Pump power input	P	Kw
Pressure at outlet suction of plant	P_{av}	N/m^2(bar)
Barometric pressure	P_b	N/m^2(bar)
Pressure at pump discharge nozzle	P2	N/m^2(bar)
Vapor pressure of liquid	P_v	N/m^2(bar)
Pressure at inlet section of plant	P_e	N/m^2(bar)
Pressure at pump suction nozzle	P_l	N/m^2(bar)
Differential capacity	Q	(m^3/h)
Flow rate	Q	(m^3/h)
Minimum flow rate	Q_{min}	(m^3/h)
Optimum flow rate	Q_{opt}	(m^3/h)
Flow velocity	V	m/s
Flow velocity at outlet section of plant	V_{av}	m/s
Flow velocity at discharge nozzle	V2	m/s
Flow velocity at inlet section of plant	V_e	m/s
Flow velocity at suction nozzle	V_j	m/s

Height difference between pump suction and discharge nozzle	Z1,2	m
Loss coefficient	τ	-
Pump efficiency	η	-
Friction coefficient	λ	-
Kinematic viscosity	υ	m^2/s
Density	ρ	Kg/m^3

1-11-2 Pump Percipients

1-11-2-1 Pump flow rate

The flow Q is the volume of the outlet liquid per unit time and is measured in cubic meter per hour or liter per second.

1-11-2-2 Pump head

The head H of the pump is the active mechanical energy (potential energy) transferred by the pump to the liquid required to be pumped and is measured by meter and does not relate to the specific weight of the liquid.

1-11-2-3 System head

Total head for the system H_A consists of:

1-11-2-3-1 Static head H_{geo}, is the difference in height between suction and discharge levels of the liquid. If the pipe pours over the liquid level, the static head will be referred to the axis of the pouring pipe.

1-11-2-3-2 Differential pressure between suction and discharge levels of the liquid in the closed systems

$$= \frac{P_{av} - P_e}{\rho . g}$$

1-11-2-3-3 Sum of losses in pressure ΣH_J

Is the friction loss in the pipe and the losses in the valves and special pieces in both suction and discharge pipes.

1-11-2-3-4 The pressure resulted from the difference in velocities at inlet and out let of plant.

$$\frac{V^2_{av} - V^2_e}{2g}$$

Therefore, the total head of the system is:

$$H_A = Hgeo + \frac{p_{av} - p_e}{\rho \cdot g} + \frac{V^2_{av} - V^2_e}{2g} + \Sigma H_J$$

In practical application the pressure resulted from the difference in velocities at inlet and outlet is neglected. Equation (1) will be used for the closed systems and equation (2) for open systems.

$$H_A = Hgeo + \frac{P_{av} - P_e}{\rho \cdot g} + \Sigma H_J \qquad (1)$$

$$H_A = H_{geo} + \Sigma H_J \qquad (2)$$

1-11-2-4 Speed

In case of using electrical motors, the speed depends on the number of poles of the winding of these motors. The available actual speeds are approximately as follows:

Number of Poles	2	4	6	8	10	12
Speed (RPM)	2900	1450	960	725	580	480

To calculate these speeds, see electrical motors chapter.

1-11-2-5 Calculation of pump absorbed power

1-11-2-5-1 Pump power input

Pump power input P is the mechanical power on pump shaft absorbed from the driving device. It is calculated from the following equation:

$$P = \frac{\rho . g . Q . H}{1000 . \eta} \text{ KW}$$

1-11-2-5-2 Drive Power

Due to change of pump flow and change of operating point from that specified in the design, that means increase of pump power input, it is required to use safety margins in the practical applications when determining motor power. These margins should not less than the following limits:

- Motors up to 7.5 KW	30%
- Motors greater than 7.5 to 40 KW	25%
- Motors greater than 40 to 100 KW	20%
- Motors greater than 100 KW	15%

This increase is calculated from the maximum absorbed power on pump shaft over the expected operation range on Q-H curve, taking into consideration the following:

- Required impeller diameter.

- $NPSH_{av}$ must be greater or equal to $NPSH_{req}$
- Value of P/n for pump fulcrums.

1-11-2-6 Pump Curve

At fixed sped for the centrifugal pumps, pump flow Q increase as the head H decreases. Hence, the pumps have the feature of self-regulation. Pump power input P, the efficiency η and $NPSH_{req}$ depend on the capacity.

Theses parameters are represented on the pump curve which shows its operation features.

- The curves are drawn taking into consideration that the density is ρ and the viscosity is ν, unless otherwise stated.

Fig (2-17) (A, B) shows this relation between the parameters of centrifugal pumps.

Operation conditions of the pump are determined if it is better to use flat curve or steep curve. In case of steep curve, pump capacity is changed lesser than in case of flat curve under the same conditions of differential head ΔH

Fig (2-18) shows the two curves, where it indicates that the steep curve has better control features.

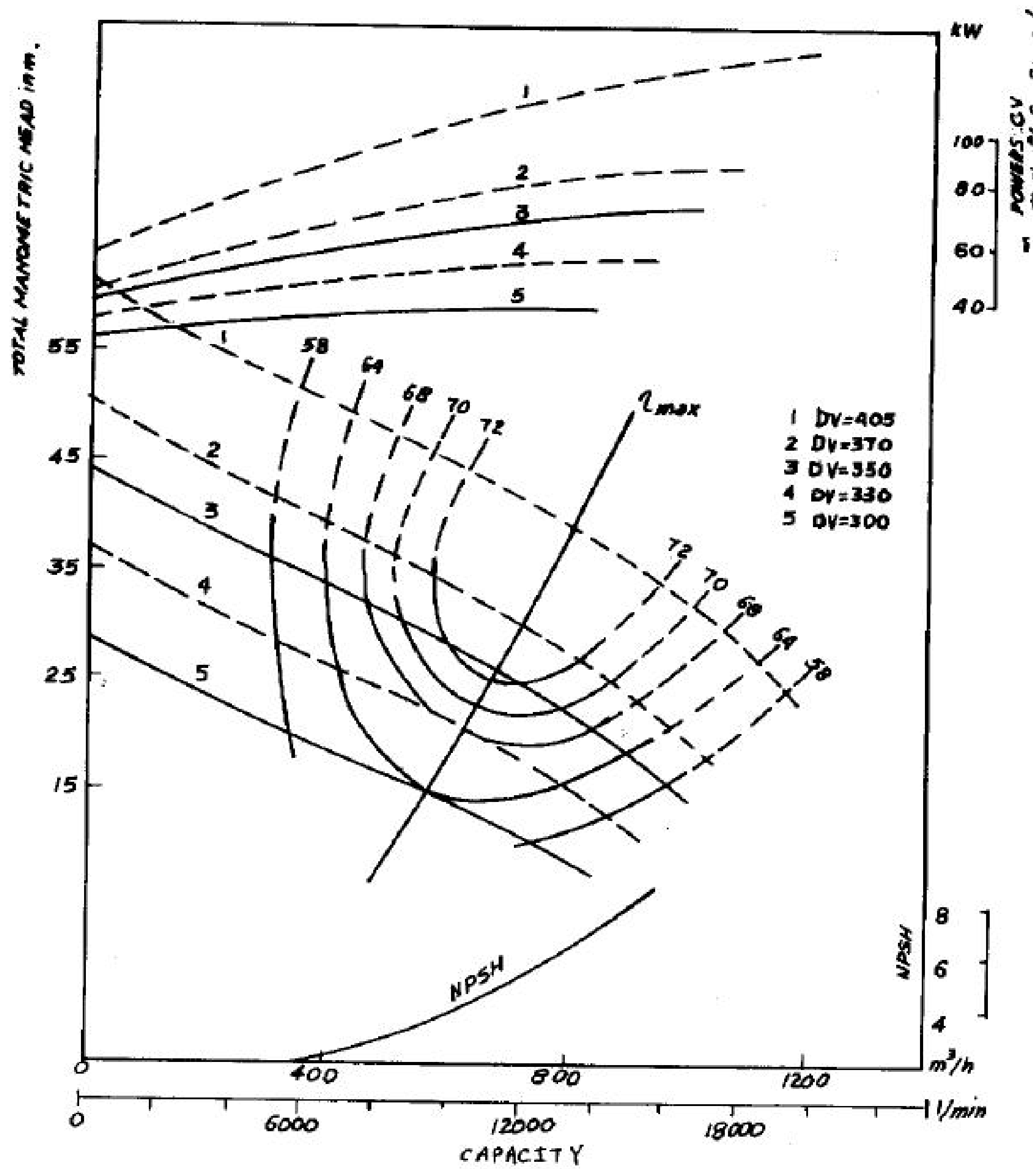


Fig (2-17 A) Centrifugal Pump Curves

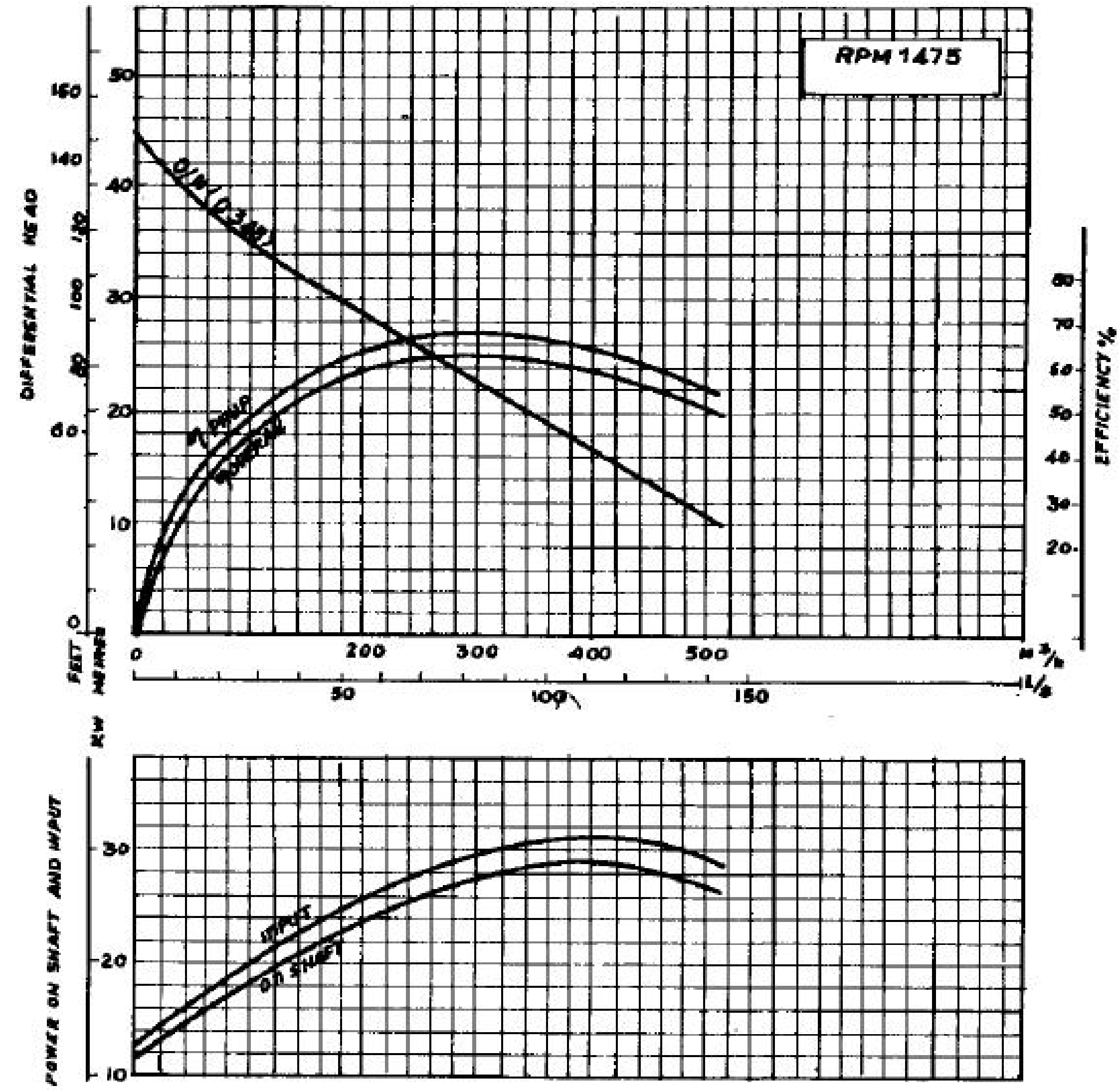


Fig (2-17 B) Centrifugal Pump Curves

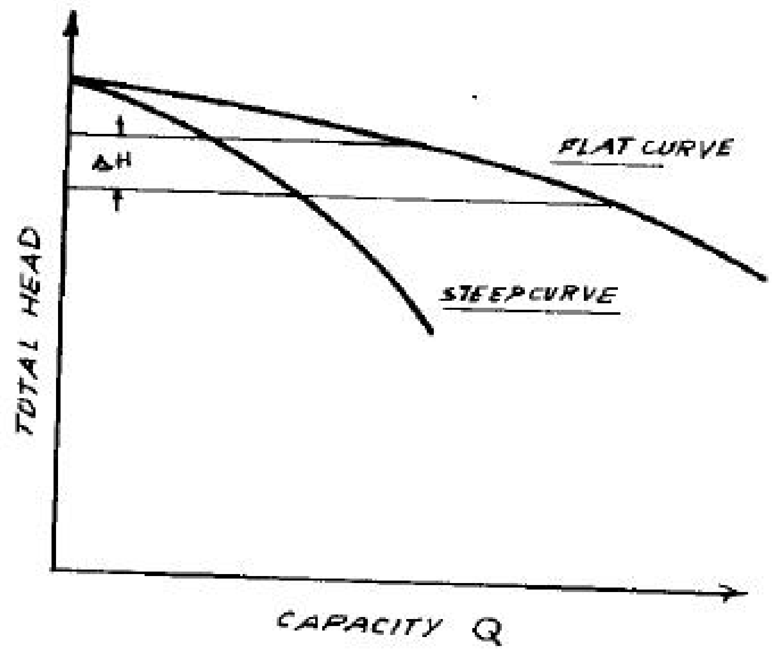


Fig (2-18) Flat and Steep Curves

1-11-2-7 System (Piping) Characteristic

- Total system head H_A is drawn against pump capacity Q to give system (piping) curve. This curve represents both static and dynamic heads of the system.

- Static part consists of static head H_{geo} (which does not depend on pump capacity) added to it the difference in pressure between pressure at outlet section of plant P_{av} and pressure at inlet section of plant P_e (in case of closed system only and not used in open system).

- Dynamic part consists of head loss H_J which is increasing with square of the capacity added to it the difference in velocities between Flow velocity at outlet section of plant V_{av} and Flow velocity at inlet section of plant V_e

$$\frac{V^2_{av} - V^2_e}{2\,g}$$

Fig (2-19) shows System (Piping) Characteristic.

1-11-2-8 Duty operating point

Duty operating point will be determined for each pump, which is the point of intersection of pump curve (Q-H Curve) and system (piping) curve. This point is not changed (and hence the flow Q and the head H) for the pump unless the pump speed n, impeller diameter D or system characteristic are changed.

Fig (2-20) shows change of the operating point by the increase in speed n, while fig (2-21) shows change of the operating point by using gate valve.

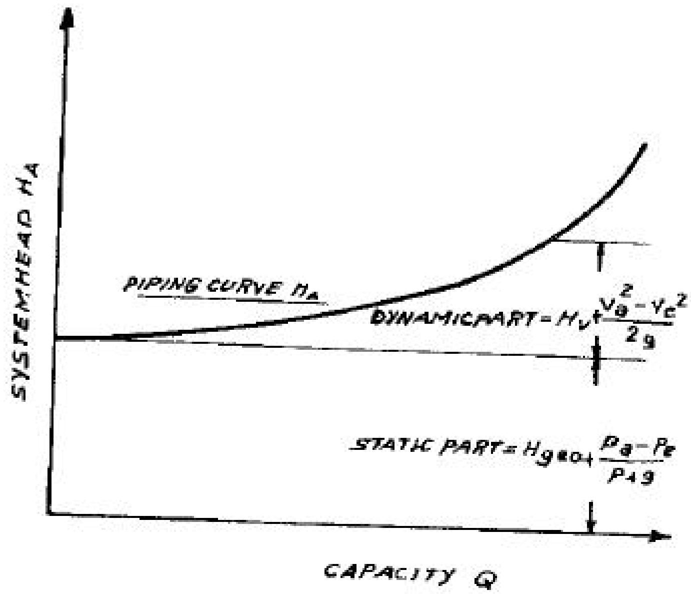


Fig (2-19) Discharge Pipe Curve

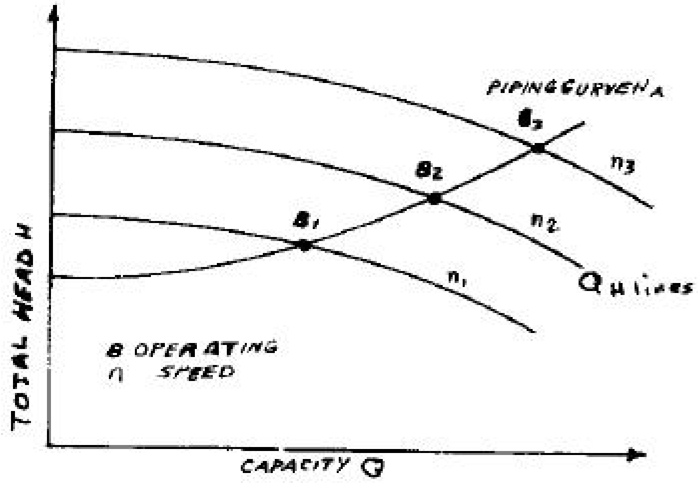


Fig (2-20): Change of the operating point from B_1 to B_3 on discharge pipe curve by increasing pump speed from n_1 to n_3

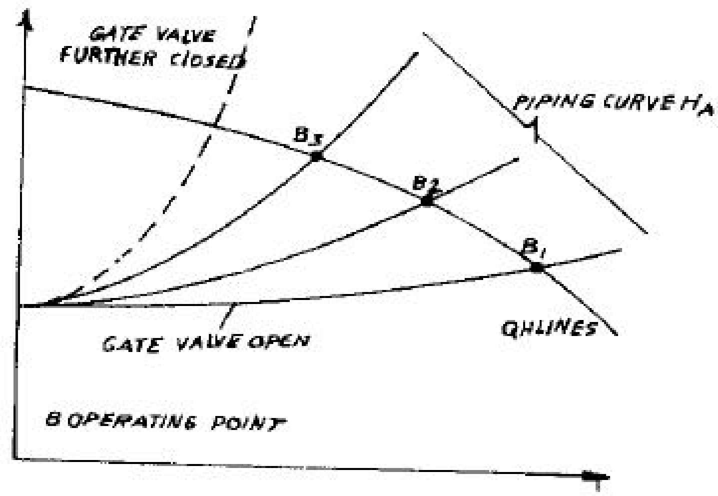


Fig (2-21): Change of operating point location from B_1 to B_3 on Q curve and H_A curve by changing gate valve open

1-11-2-9 Parallel Operation

In case of inability of one pump to give the required flow Q at the operating point B, it is possible to obtain it by operating two or more pumps in parallel and all will be pumped in the same pipes system. In this case, it is preferred (for economic reason) to be the pumps of same size (symmetrical).

Fig (2-22-A) shows operation of two symmetrical pumps in parallel to give each half the required flow Q at the same head H, while fig (2-23) shows the use of two pumps have different flows Q_I and Q_{II}, where they are pumping in the same pipes system at operating point B. Flow Q_I of pump I and flow Q_{II} of pump II are added to obtain the total flow Q which is equal to ($Q_I + Q_{II}$) at the same total head H.

1-11-2-10 Series Operation

In case of inability of one pump to give the required head H for the plant for certain flow Q, the required head can be achieved by operating of two or more pumps in series, where the first pump is pumping in the suction line of the second pump, and so on. The head H_1 of the pump 1 is added to the head H_2 of pump2, and so on, to obtain the total head H at the same flow Q.

Fig (2-22-B) shows operation of two symmetrical pumps in series.

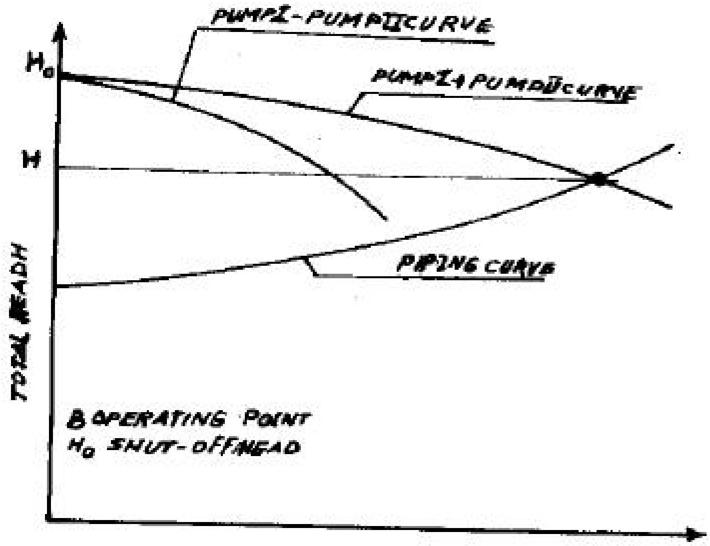


Fig (2-22A): Operation of two symmetrical pumps in parallel

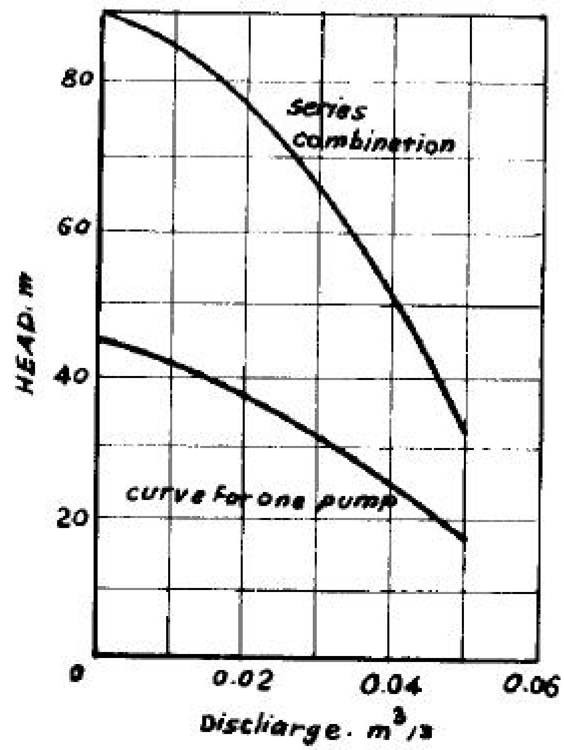


Fig (2-22B): Operation of two symmetrical pumps in series

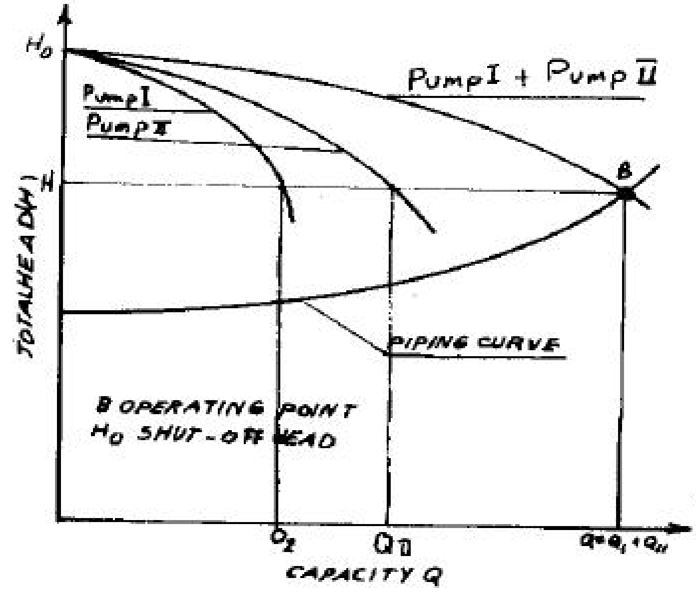


Fig (2-23): Operation of two pumps have different flows in parallel

1-11-3 Suction Characteristic

1-11-3-1 NPSH required

Centrifugal pumps are not operating safe unless there is no vapor inside the pump. Therefore, the pressure at the datum level point of NPSH must not exceed liquid evaporation pressure. Datum level point is measured from the axis of pump impeller.

NPSH required is expressing the value of the pump measured in meters and is plotted on pump curves and added to it 0.5 m as safety factor.

1-11-3-2 NPSH available

Datum level point of NPSH available is pump suction nozzle axis. In case of horizontal pumps with volute casing, suction nozzle and impeller axes are located at the same level. Any difference must be taken into consideration.

1-11-3-2-1 Determination of NPSH available in case of existence of suction lift. In this case, pump axis is higher than the level of the liquid required to be pumped.

$$NPSH_{av} = \frac{p_e + p_b - p2}{\rho \cdot g} + \frac{V_e^2}{2g} - H_{J}1 - H_{s}geo$$

Provided that the liquid is fresh water and using open system, then:

P_b = 1 bar (105 N/m 2)

P_e = 0 bar

ρ = 1000 kg / m^3

g = 10 m/s ^{2} (including 2% error)

By neglecting the value $\frac{V_e^2}{2g}$, where the velocity inside suction tank can be neglected, then:

$$NPSH_{av} \simeq 10 - H_{J1} - H_s geo$$

This is shown in Fig (2-24)

1-11-3-2-2 Determination of NPSH available in case of existence of positive suction

In this case, the pump will be under the level of the liquid required to be pumped.

$$NPSH\ av = \frac{P_e + P_b - P_2}{\rho \cdot g} + \frac{V_e^2}{2g} - H_{J1} + H_s geo$$

By taking the same assumptions in 1-11-3-2-1, then:

$$NPSH_{av} \simeq 10 - H_{J1} + H_s geo$$

This is shown in fig (2-25).

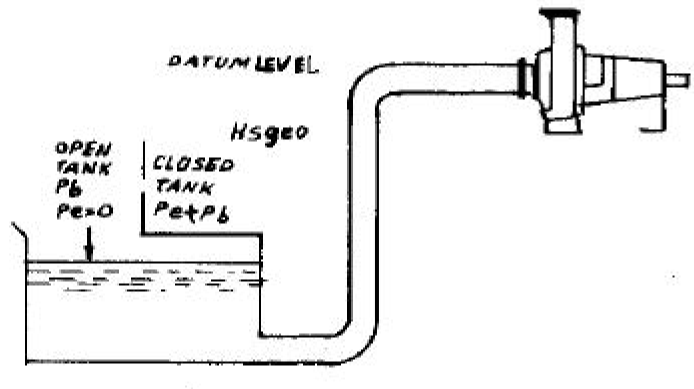


Fig (2-24): NPSH available on suction head

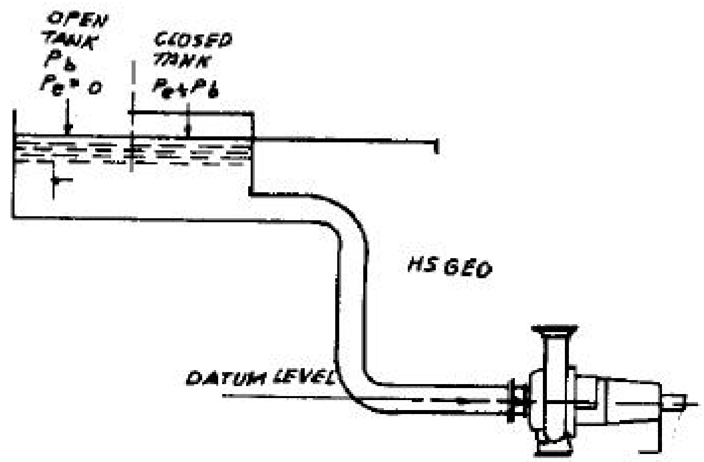


Fig (2-25): NPSH available at positive suction

1-11-4 Head Loss H_J

1-11-4-1 Head loss in the straight pipes

Head loss is calculated in the pipes from the formula:

$$H_J = \tau \frac{V2}{2g}$$

- Fig (2-26) shows nomogram of the head loss H_J for each 100 m of the cast iron pipes as a practical application for this formula. The values extracted from this nomogram are applied when using clean (fresh) eater at 20°C, provided that the pipes are fully filled and manufactured from grey cast iron lined with bitumen.
- The nomogram shown in fig (2-27) can be used to extract the loss head H_J for other types of pipes according to surface roughness coefficient (K). Also, the tables or the curves shown on Colebrook equation can be used.
- The tables attached with Annex (5) are used to determine the head loss for each linear meter of the pipes to extract the value of H_J directly (as a practical method).

1-11-4-2 Head losses in valves and special pieces

- By applying the same formula in 1-11-4-1, the nomogram shown in fig (2-28) can be used, and also the tables (2-1) and (2-2) to extract the value of the head loss H_J and the loss coefficient in valves and special pieces.
- The nomogram shown in fig (2-29) is used as a second practical application for this formula. Practically, friction loss for special pieces can be taken 10% of the friction loss.

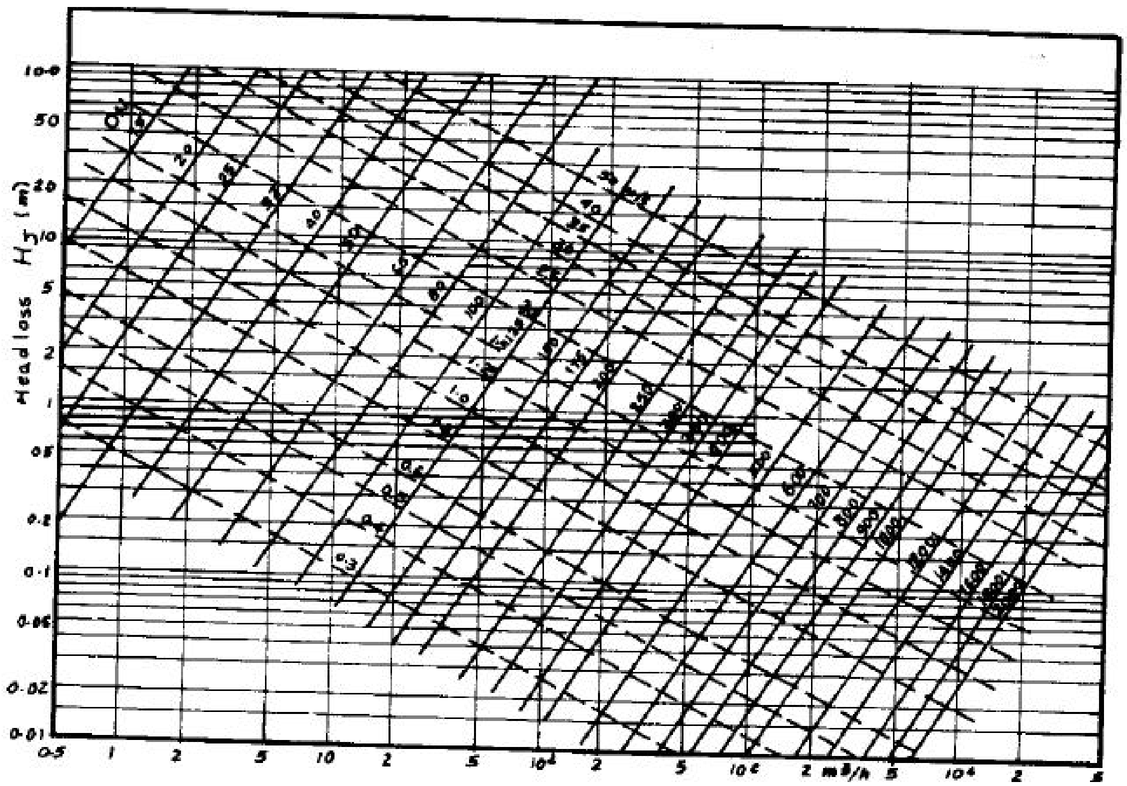


Fig (2-26): Head loss in straight pipes (cast iron) from inner diameter (15) to (2000) for flows from 5 to 50,000 m^3/hour

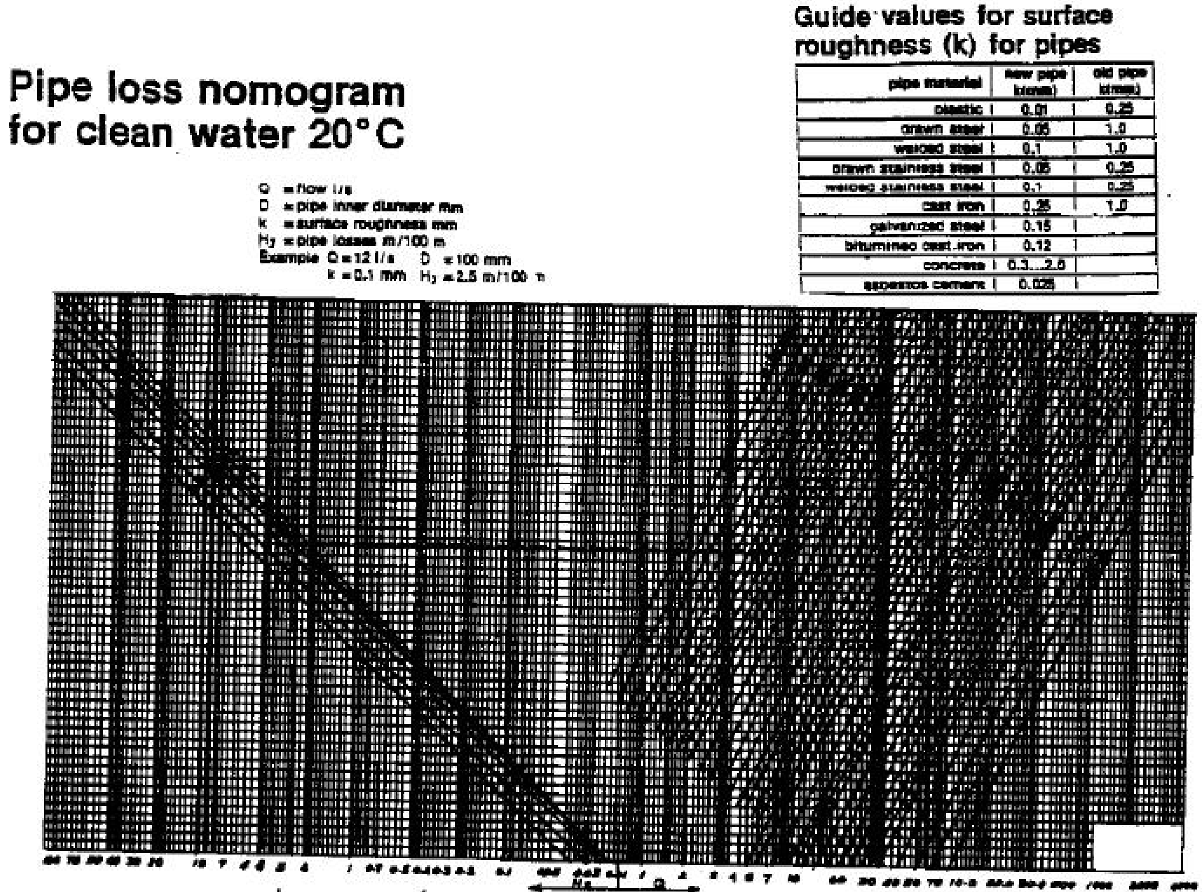


Fig (2-27): Head loss (H_J) for different types of pipes according to surface roughness coefficient

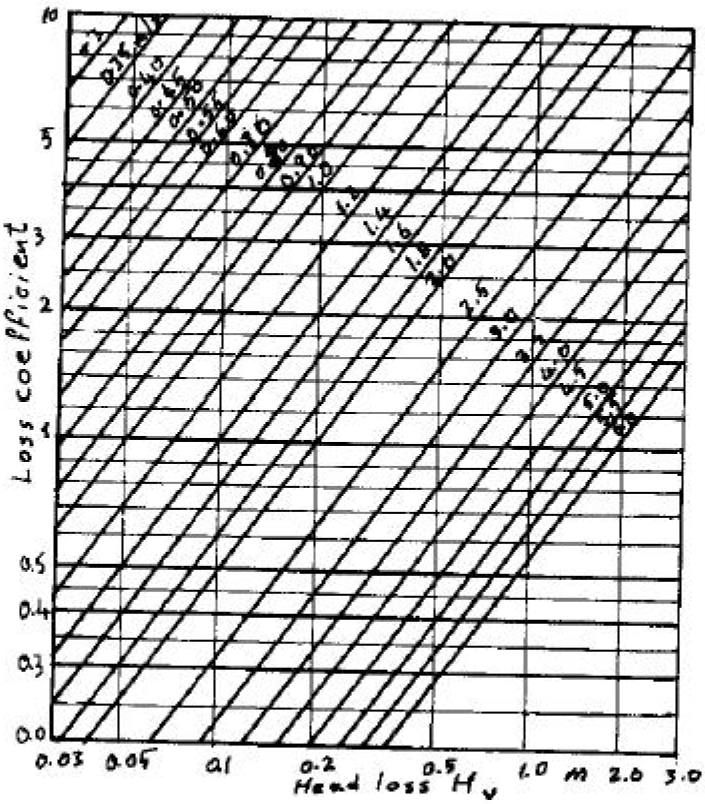


Fig (2-28): Extracting the head loss H_v in pieces and fittings and flow velocity (v) according to cross section area of water flow.

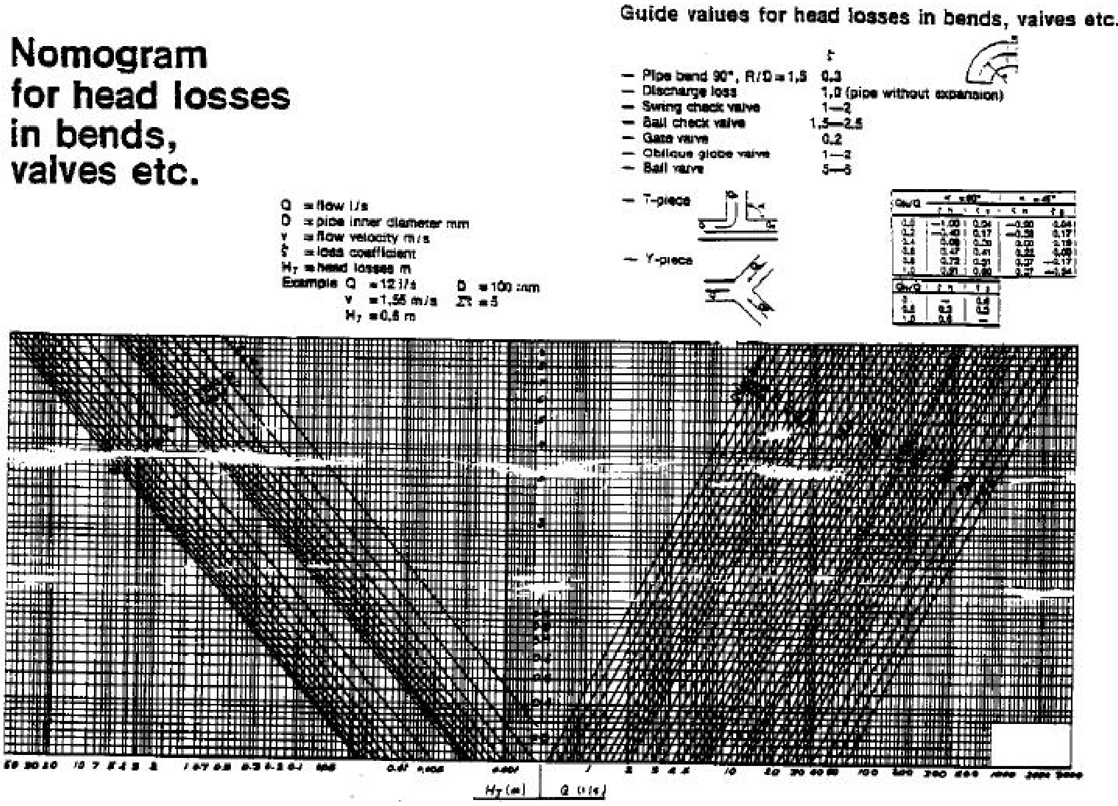


Fig (2-29): Nomogram for head loss in valves and special pieces

Table (2-1): Loss Coefficient in Valves

The values listed below are guideline values and apply to valves with a uniform distribution of the approach flow and which are fully open. The losses which arise in the wake of the valve over a length of piping equal to 12 x DN (nominal bore) as a result of the smoothing out of the disturbed flow in the pipe are included in these values (see VDI/VDE 2173 Recommendation).
Variations may occur depending on the approach flow and outflow conditions and type of design.

Type of valve	DN	ζ
Gate valves		
full port		
with guide pipe	all sizes	0.1 to 0.15
without guide pipe	all sizes	0.2 to 0.3
Hard-faced high pressure gate valve		
(contraction ratio		
1:0.45 to 0.74)	65 to 500	0.3 to 0.6
Cocks		
full port	all sizes	0.1 to 0.15
Throughway globe valves		
BOA-H (metal-to-metal sealing)	10 to 300	3.0 to 6.0
BOA-W (soft material sealing)	10 to 200	3.0 to 5.5
Hard-faced full-bore valve	25 to 200	1.0 to 1.5
Forged hard-faced valve	25 to 50	6.0
Cast steel hard-faced valve	65 to 200	3.0 to 4.0
Angle valves		
BOA-H (metal-to metal sealing)	10 to 150	4.5
	200 to 300	6.0
Non-return valves		
Full-bore (Y valves)	20 to 300	3.0
BOA-R (troughway pattern)	10 to 300	5.5
Suction strainer baskets		
with foot valve		
conventional type		2.2 to 2.5
KSB borehole strainer baskets		1.1 to 1.9
Water separators		
without/with baffle plate		4 to 7

Non-return flap valves:
The ζ values for non-return flap valves vary according to the velocity of flow in the pipe and the position of the pipe line — horizontal or vertical. At a given velocity v_H (horizontal) or v_V (vertical) the flap attains its maximum opening and lowest ζ value, which is valid for even higher flow velocities. When the velocity drops below v_H or v_V, the ζ value increases progressively. The values tabulated below apply to swing check valves not fitted with a lever and weight for 100 %, 50 %, and 25 % v_H or v_V.

Nominal bore DN			40	50	65	80	100	125	150	175
v_H	m/s		4.4	3.1	3.9	2.3	1.6	2.8	1.6	2.2
v_V	m/s		4.1	2.8	2.1	2.0	1.6	2.8	1.6	2.2
ζ at	v_H	100 %	0.5	0.4	0.3	0.7	0.6	1.0	0.9	0.5
		50 %	0.7	0.9	0.5	1.1	1.2	1.3	1.5	1.5
		25 %	1.2	2.5	1.4	3.5	4.0	2.3	—	—
ζ at	v_V	100 %	0.5	0.4	0.3	0.7	0.6	1.0	0.9	0.5
		50 %	0.6	0.6	0.8	1.1	1.2	1.3	1.5	1.5
		25 %	0.8	2.0	10.0	12.0	6.0	3.5	—	—

With non-return flap valves fitted with a lever and weight, the ζ values may be several times the values above depending on the position of the weight.

Table (2-2): Loss Coefficient in Special Pieces

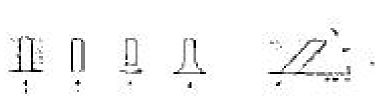
Branches
(Branch of equal bore)
The friction coefficient ζ_a for the diverged flow Q_a and ζ_d for the main flow $Q-Q_a$ relate to the velocity of the total flow Q in the nozzle.

Q_a/Q =		0.2	0.4	0.6	0.8	1
	$\zeta_a \approx$	−0.4	0.08	0.47	0.72	0.91
	$\zeta_d \approx$	0.17	0.30	0.41	0.51	—
	$\zeta_a \approx$	0.88	0.89	0.95	1.10	1.28
	$\zeta_d \approx$	−0.08	−0.05	0.07	0.21	—
	$\zeta_a \approx$	−0.38	0	0.22	0.37	0.37
	$\zeta_d \approx$	0.17	0.19	0.09	−0.17	—
	$\zeta_a \approx$	0.68	0.50	0.38	0.35	0.48
	$\zeta_d \approx$	−0.06	−0.04	0.07	0.20	—

Negative ζ values signify that there is a pressure rise

Spherical T pieces:
(Nozzles of equal bore)
$\zeta \approx 2.5$ to 4.5 related to velocity of total flow in the nozzle

Inlets:



Inlet edge

sharp $\zeta \approx$ 0.5 3
chamfered $\zeta \approx$ 0.25 0.55 0.20 0.05

for δ = 75° 60° 45°
$\zeta \approx$ 0.6 0.7 0.8

Outlets:
$\zeta \approx 1$ downstream of an adequate length of straight pipe with an approximately uniform velocity distribution in the outlet section.
$\zeta \approx 2$ with very unequal velocity distribution, e.g. immediately downstream of an elbow, a valve etc.

Bends:
Cast bends 90° R = D − 100 mm, all nominal bores ζ = 0.5

Pipe bends 90° R = 2 to 4 x D

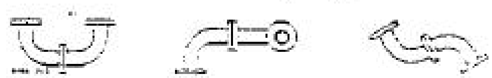
Nominal bore DN	50	100	200	300	500
ζ	≈ 0.26	0.23	0.21	0.19	0.16

	60°	45°	30°	15°
If angle is only the above ζ values should be multiplied by	0.85	0.7	0.45	0.3

Elbows:

Deflection angle	90°	60°	45°	30°	15°
ζ	≈ 1.3	0.7	0.35	0.2	0.1

Combinations of bends:
The ζ value of the single 90° bend should not be doubled but multiplied by the factors indicated to obtain the pressure loss of the combination bends illustrated.



1.4 1.6 1.6

Expansion joints:
Bellows expansion joint with/without guide pipe $\zeta \approx 0.3/0.2$
Straight pipe harp bend $\zeta \approx 0.5$ to 0.8
Bellows pipe harp bend $\zeta \approx 1.3$ to 1.6
Corrugated pipe harp bend $\zeta \approx 3.2$ to 4

1-11-4-3 Head losses for viscous liquids in straight pipes

Head loss for viscous liquid with, serial no. F1 can be calculated after obtaining the head loss of the fresh water as indicated in item 1-11-4-1 from the formula:

$$H_{JF_1} = \frac{\lambda F_1}{\lambda w} \quad H_{Jw}$$

Where, λ is the friction coefficient of the liquid.

Fig (2-30) shows values of the friction coefficient λ for the straight pipes (Viscosity of the liquid υ is known)

1-11-5 Changing the pump performance

1-11-5-1 Changing the speed

For the same pump, different curves can be obtained when using different speeds.

These curves are related to similarity law. If the values of the flow Q_1, head H_1 and the power P_1 are known at certain speed n_1, then the new values of these parameters at new speed n_2 can be obtained as follows:

$$Q_2 = \frac{n_2}{n_1} \cdot Q_1$$

$$H_2 = \left(\frac{n_2}{n_1} \right)^2 . H_1$$

$$P_2 = \left(\frac{n_2}{n_1} \right)^3 . P_1$$

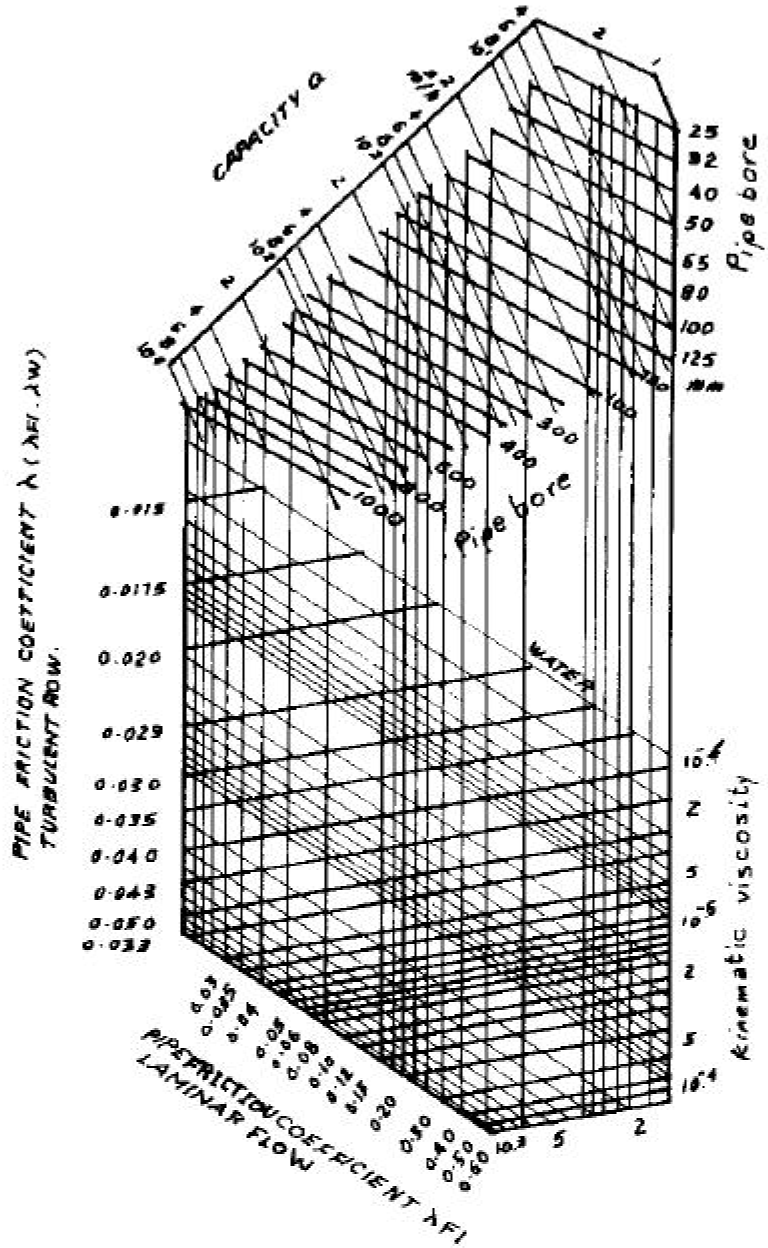


Fig (2-30): Friction coefficient (λ) for viscous liquids in straight pipes

- Changing the speed n leads to shift of the operating point B. Fig (2-31) shows three curves for the pump at three different speeds. Each curve intersects with system curve at three different operating points.

1-11-5-2 Trimming the impeller

To obtain permanent decrease in the output of the centrifugal pump that operates at fixed speed, this requires decrease of impeller diameter D.

- Pump manuals contain curves selected for these pumps at typical impeller diameters of these pumps. Any other curve in between can be obtained by trimming the impeller of greater diameter directly.
- When changing pump impeller diameter of radial flow, the relation between the flow Q, head H and diameter D is as follows:

$$\left(\frac{D_1}{D_2}\right)^2 \simeq \frac{Q_1}{Q_2} \simeq \frac{H_1}{H_2}$$

From this formula:

$$D2 \simeq D1 \sqrt{\frac{Q_2}{Q_1}}$$

Or,

$$D2 \simeq D1 \sqrt{\frac{H_2}{H_1}}$$

Fig (2-32) shows the effect of changing impeller diameter on head and flow of the pump. To determine new diameter for the impeller to verify the actual operating point B_2, it will be as follows:

- Use Q-H curve diagram. Connect straight line passing from the origin of the curve (at Q = 0 and H= 0) to the operating point B_2 and intersecting the original curve of the impeller of greater diameter (required to be trimmed) D_1 at the operating point B_1.

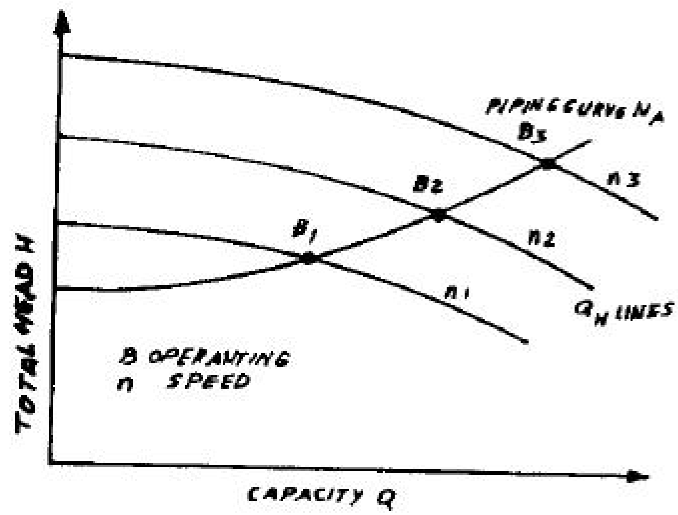


Fig (2-31): Effect of changing the speed on pump curve

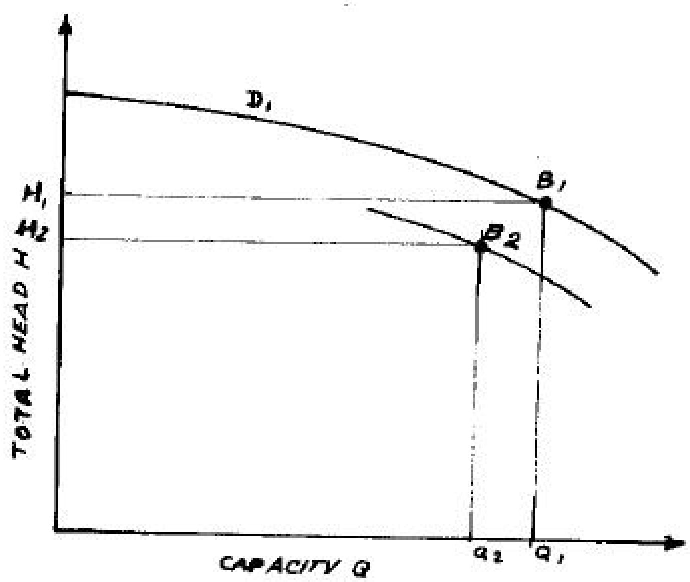


Fig (2-32): Effect of changing impeller diameter on the curve

- Determine the value of H and Q in the first case (1) and second case (2)
- Theses values are used to obtain approximate value for the new diameter D_2 by substituting in the previous formula.

1-11-6 Pumps description at pumping station

After determining the inflows to the pumping station during the design period starting from the existing flow to the expected future flows until the end of this period (target year) as well as inlet pipe level to plant sump and levels of outlet discharge line from the plant. The used pumps in the pumping station are described as follows:

(A) Number of pumps installed in the station

(B) Flow rate of all pumps.

(C) Head and operation range of the pump.

(D) Design requirements of the pump (Type- speed- water flow velocity at suction nozzle- diameter of allowed solids)

(E) Construction materials for the project.

(F) Method of pump installation (vertical installation with direct coupling through driveshaft- horizontal installation- submersed)

1-11-6-1 Number of pumps installed in the station

Number of pumps installed in the station depends on the volume of the inflow and the nature of the plant of being temporary, permanent, substation or main plant, and flow rates over the year and during day hours.

This also depends on the used pumps and their need to periodic maintenance works, assembly and disassembly of the pump, provision of spare parts and their continuous operation under normal operating conditions and in emergency cases, the effect of stop operation of the plant on the surrounding environment (site conditions), ability of the gravity network at the served area to store and provide disinfection means of this network, its ability of self cleaning of pipes according to their design. In all cases the number of the pumps installed in the station must subject to the following formula:

Number of installed pumps = Number of the operating pumps for lifting maximum flows to the plant in peak hours + emergency pump + one pump at least in maintenance.

Number of the operating pumps in the plant must not exceed 50% of the installed pumps. The emergency pump must has flow equal to the flow of the greatest pump installed in the plant in case of using unsymmetrical pumps in capacity (different flows) inside the plant. An additional pump of each used capacity will be put in maintenance in addition to the operating pumps and the emergency pump.

1-11-6-2 Calculation of pump flow rate

To calculate flow rate of each pump installed in the pumping station, the following must be followed:

A) For Symmetrical pumps in capacity

In case of using symmetrical pumps (similar flow at the same head point) to lift the inflow to the pumping station, this will be done using the following steps:

- Determine maximum flow of the plant Q_{max}
- Calculate peak flow Q_P by using suitable peak factor according to plant capacity (Studies Chapter).

- Determine number of the operating pumps to lift the peak flow Q_P

Usually:

1-2 pumps for flow rates up to 200 liter/s

2-3 pumps for flow rates form 200- 1500 liter/s

3-4 pumps for flow rates greater than 1500 liter/s

- Flow Q of one pump is calculated in liter/ sec from the following formula:

$$Q \text{ (liter/sec)} = \frac{\text{Peak flow Qp (liter/sec)}}{\text{Number of operating pumps in the plant}}$$

B) For pumps with different capacities inside the same station

Pumps with different capacities are used inside the same station in case of irregular inflows to the plant over seasons of the year or over day hours that can not be accommodated by the storage in the sump.

Therefore, the operating pumps over day hours are changed with the change of the inflows. Number and capacity of the used pumps are determined according to the graphical chart of plant inflows.

When determining the different capacities and number of the pumps, the following must be taken into consideration:

- One (or more) pump is used for lift average flows according to plant capacity (as in "A")
- One (or more) pump is used at certain level for the water collected in the sump (Level 1).
- One (or more) pump is used at level higher than the allowed level for collection of water in the sump (Level 2).

Capacity of the first pump Q_1 is calculated from the following formula:

$$Q_1 \text{ (liter/ sec)} = \frac{\text{Plant average flow (liter/ sec)}}{\text{Number of Pumps}}$$

Capacity of the second pump Q_2 is calculated from the following formula:

$$Q_2 \text{ (liter/ sec)} = \frac{\text{(Max daily flow } Q_{max} \text{ – Average Flow) liter/ sec}}{\text{Number of the additional Pumps 1}}$$

Capacity of the third pump Q_3 is calculated from the following formula:

$$Q_3 \text{ (liter/ sec)} = \frac{\text{(Expected emergency flow - Max daily flow } Q_{max}\text{) liter/ sec}}{\text{Number of the additional Pumps 2}}$$

Sum of the number of pumps in the three previous cases represents number of the operating pumps in the station.

1-11-6-3 Total head and working range

A) The total head is calculated according to Item (1-12) taking into consideration diameter of the discharge line and operation of the pumps in parallel, if any.

- In case of using two pumps in parallel to lift the peak flows, total head of each pump will be determined according to the operating point of the two pumps together.

The flow corresponding to this point is divided into two. This point is considered the design point of the required pump.

(This principal will be considered also when operating more than two pumps in parallel)

B) Working range of the pump is determined taking into consideration the following:

- The pump is given 30% of the design flow at least at maximum working range (upper point)
- Operation of the pump on a range from 80% to 110% of the design head at least.
- Maximum head of the single phase centrifugal pumps does not exceed 65 m.
- The lower point of the working range is safely covered in case of operation of one pump when operating two or more pumps in parallel.

1-11-6-4 Design Requirements

When describing the required pumps for the pumping station, the following must be specified:

1-11-6-4-1 Type of Pump

- Type of pump will be determined according to the total head of the plant (Item 1-13)
- When using centrifugal pump, its type will be determined according to the following:

Radial flow pump, in case of big head (more than 40 m)

Mixed flow pump, in case of medium head (from 10 to 40 m)

Axial flow pump, in case of small head (less than 10 m)

1-11-6-4-2 Speed

Pump speed is determined according to the required pump design by the producer. When selecting pump speed, it must achieve maximum possible efficiency for the pump at the specified operating point, durability of the rotating parts at high speeds, rate of its consumption, type of the materials used in lubrication, wear rates of fulcrums, the materials used in manufacturing the pump, in addition to the liquids required to be pumped and to what extend they contain solids and sands.

In all cases, the speed is:

750- 1500 rpm for pumps of capacity more than 50 liter/ sec

1500-3000 rpm for pumps of capacity less than 50 liter/ sec

1-11-6-4-3 Flow velocity at suction nozzle of the pump

Flow velocity at suction nozzle of the pump must not exceed 4 m/sec at design operating point.

1-11-6-4-4 Diameter of allowed solids

Diameter of the allowed solids passing through pump impeller is specified according to the expected suction nozzle diameter, flow rates, allowed velocity in suction pipes and suction nozzle of the pump taking into consideration type of pump impeller and pumps efficiency, where the efficiency deceases as the allowed solids size increases.

Usually, diameter of the allowed solids is:

- 50 mm, for pumps of flow up to 30 liter/ sec
- 75 mm, for pumps of flow from 30 to 100 liter / sec
- 100 mm, for pumps of flow from 100 to 200 liter / sec
- 125 mm, for pumps of flow from 200 to 400 liter / sec
- 150 mm, for pumps of flow more than 400 liter/ sec

1-11-6-4-5 Construction Materials

The following construction materials will be taken into consideration when specifying pumps for normal uses to lift liquid waste of the sanitary drainage:

Pump casing: Cast Iron

Impeller: Cast Iron

Drive shaft: St. St.

Wear rings: Bronze

When specifying pumps for special uses or the liquids required to be lifted contain chemicals (acids or alkalis), it is recommended to consult the producers to specify the suitable materials.

1-11-6-4-6 Pump Installation

Method of pump installation and design of suction sump are specified as follows:

- Vertical installation with direct coupling between the pump and the motor.

This method is used in case of small suction depths which does not exceed 5 m under ground surface.

- Vertical installation using cardan shafts to connect between the pump and the motor provided that the motors are installed over ground surface level.

This method is used in case of deep suction exceeds 5 m under ground surface or if the location is subjected to drowning.

It is not allowed to increase inclination of the cardan shaft more than 3° (three degrees) from vertical axis.

- Horizontal installation with direct coupling between the pump and the motor. This method is used when using self priming pumps installed over ground surface and suck from underneath collection sump or when using pumps installed in dry pit and suck from adjacent collection sump through suction pipe lines and to provide protection for these pumps from drowning.
- Submersed installation of the pumps inside wet collection sumps. This method is used for pumps with motors of protection degree IP68 submersed in water. This method is used in temporary pumping stations or stations with small flows.

Annex (1), attached with this volume, shows models of pumping stations with different installation methods for pumps.

1-12 Selection of pump suction and discharge pipes

When selecting pump pipes system, equipments, operation and maintenance costs must be taken into consideration over the lifespan of the pumps before specifying diameter of main discharge line of the plant as well as effect of diameter and position of the suction pipe on pump performance and its lifespan.

1-12-1 Design of suction pipes

Design of pump suction pipes system has great effect on pump performance. Wrong design causes problems during operation of the pump such as cyclone flow and entering air to the pump which leads to damages to the pumps and wears away in a period less than the expected lifespan.

As it is difficult to correct or rearrange suction pipes system after construction, it is important to care from the beginning of the design of this system and take the following points into consideration:

A) Immersion depth of suction pipe (Immersion Depth)

The suitable distance between suction pipe nozzle and suction sump bottom is greater or equal radius of suction pipe nozzle. This distance must be increased in case of existence of great accumulation of sands and sediments at sump bottom.

B) Water must cover suction pipe inlet to a suitable depth to prevent formation of vortex that may cause formation of air cave of tube shape extends from liquid surface to suction pipe.

- Minimum cover of the liquid over suction pipe nozzle (pipe free end) must equal to inlet velocity head added to it 0.1 m as a safety factor.

$$Smin = \frac{\upsilon^2 s}{2g} \quad + 0.1 \ (m)$$

Where:

υs = flow velocity in suction pipe (m/sec)

Smin = Minimum cover of the liquid over suction pipe nozzle (m)

* Maximum flow velocity in suction pipe must not exceed 3 m/sec.

C) Distance between free end of suction pipe and suction sump walls.

Distance between suction pipe axis and the wall must not less than one and half the diameter of pipe nozzle.

D) Distance between suction pipes axes must not less than three times the diameter of the pipe nozzle.

Fig (2-33) illustrates the distances mentioned in (A), (B), (C) and (D) above.

E) Suction pipe must be short to the possible extend and inclines toward the pump and to avoid existence of a valve in vertical position adjacent to pump suction section.

F) Avoid use pipes with head and tail and use pipes with flanges.

G) Do not use elbow just before the pump to ensure smooth flow of water at inlet of the pump.

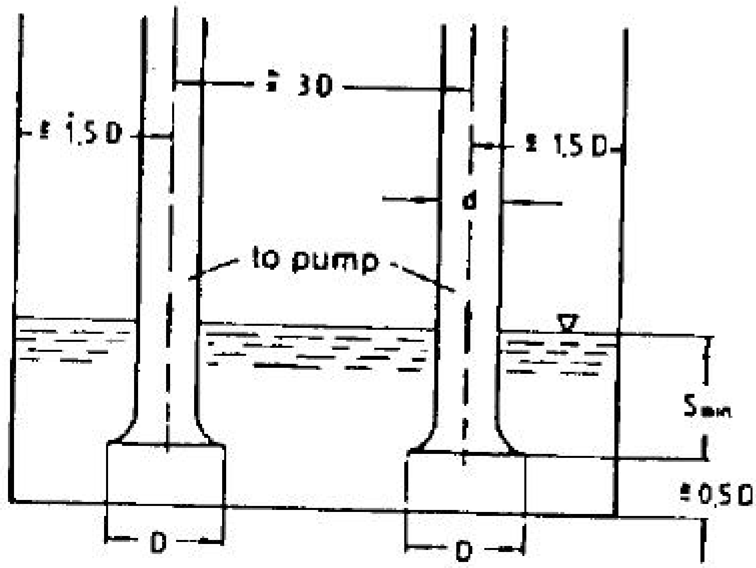


Fig (2-33): Distances between suction pipes and sump bottom and walls, distances between pipes axes and the cover over pipe nozzle

H) Pump suction pipe and sump inlet pipe must be apart from each other to prevent entrance of air in suction pipe and to ensure that the inlet pipe does not discharge directly in inlet of suction pipe.

I) When design pump water suction pit, the following should be taken into consideration:

1. Prevent entrance of sands and sediments to suction lines.
2. Arrange location of the pipes in order to ensure equal distribution of water to all pumps.
3. Arrange the pipes in a way that prevents overlapping between any pumps.
4. Laying pump suction pipes as far as possible from the center of the sump.
5. Smooth water flow in the direction of suction pipes.
6. Facilitate check and inspection of suction pipes and decrease risks that may subject the pipes to breakage.

Fig (2-34) illustrates correct design of suction pit.

1-12-2 Determination of discharge pipe diameter

When specifying diameter and type of the type, it is necessary to perform full study of the resistance in the pipe lines, effect of water hammering and future expansion plans for the pumping stations.

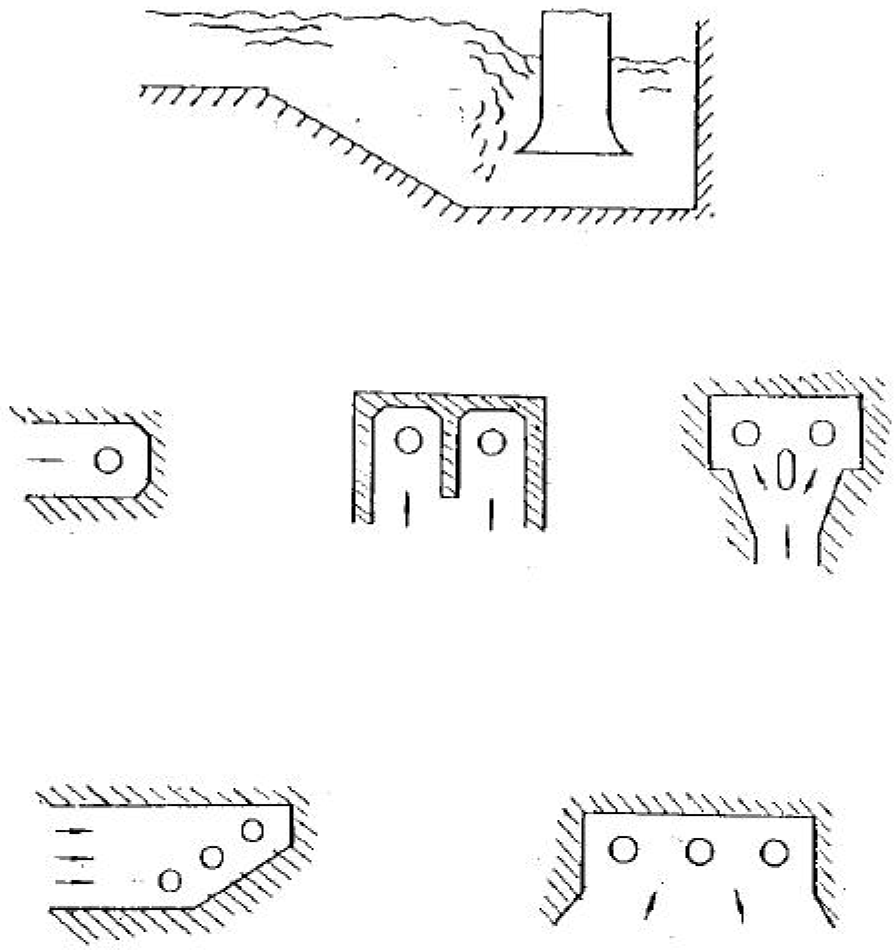


Fig (2-34): Suction Pit Design

As the resistance in the pipes line is inversely proportion to the fifth power of pipe diameter, the first matter that should be taken into consideration is the calculation of the friction loss in discharge line. So, when transfer the water for long distances, it is necessary to select greater pipe diameter, whatever the high cost of the big diameter, where the difference in cost can be compensated by decreasing operating cost over the long term.

For future planning, where the flows increase in pipes line, it is necessary to specify discharge line diameter carefully taking into consideration the expected increase, lifespan of the used pipes and cost of replacing these pipes in order to reach to safe more economic pipes line over operation period of the pumping station (lifespan of the plant or target year of the design period).

Therefore, to select discharge line diameter, follow these steps:

A) Determine the peak flow Q_{peak}

B) Discharge line diameter is initially calculated from the following formula:

$$D = \sqrt{\frac{4Qp}{\pi v}} \quad (m)$$

Where:

D = Discharge line diameter (m)

$\mathbf{Q_p}$ = Peak flow of the plant (m^3/sec)

V = Flow velocity in the pipe (m/sec)

Flow velocity is selected according to the length of discharge line and daily pump time. When transfer the water to a long distance (more than 1 km) for long period of time daily, the velocity is selected from 0.5 to 2 m/sec. When transfer the water to a short distance for short period of time (less than 8 hours daily), the velocity is selected from 2 to 3 m/sec. In case of existence of great percentage of suspended solids that may cause great sedimentation in the line, it is necessary to use maximum limits of velocity.

C) The nomogram shown in fig (2-35), which illustrates practical method to calculate the flow velocity V as a function of flow rate Q and the inner diameter of discharge line pipe D, can be used to obtain the velocity, by knowing the peak flow rate Q_p of the plant, and the standard discharge line diameter, the nearest value to the calculated one D in the previous step, to be compared with the expected velocity and ensure that it is within the correct range and the accepted limits.

D) Friction loss in the pipe is calculated from the following formula:

$$h_f = L \cdot \frac{\lambda}{D} \cdot \frac{V^2}{2g}$$

Where:

h_f = Loss due to friction (m)

L = Discharge line length (m)

V = Flow velocity in the pipe (m/sec)

D = Discharge line diameter (m)

g = Gravity Acceleration (m/sec^2) (9.81 k/sec^2)

λ= Friction coefficient of the pipe (or its value will be determined from Annex 5).

Note:

Loss due to friction can be calculated by one of the two following methods:

1- Hazen–Williams equation

$$hf = \frac{10.69\, Q^{1.85} \times L}{D^{4.87} \times C^{1.85}}$$

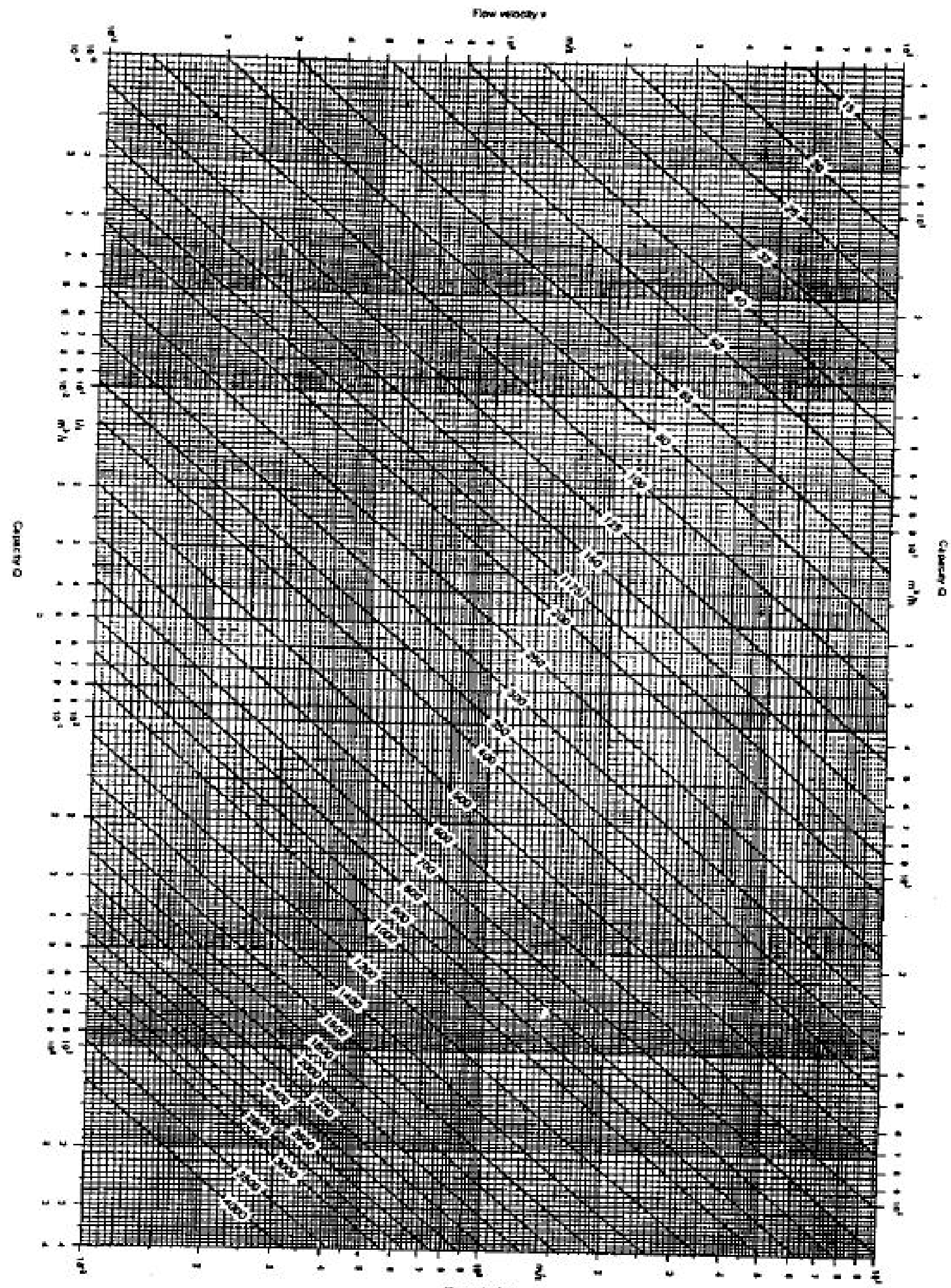


Fig (2-35): Nomogram for calculation of the flow velocity as a function of the flow rate Q and the inner diameter of the pipe D

2- Use of the approximate tables that determine this value for the linear meter of the pipe according to the diameter and the type. (Annex 5).

E) The total head is calculated from the following formula:

$$ht = hs + hf + \dots\dots$$

Where:

ht = Total head of the discharge line, including all the losses in the special pieces and velocity losses at inlet and outlet of the discharge line.

hs= Actual static head between suction and discharge levels.

F) If the value of the total head exceeded the allowed limits for the type of the used pumps, the greater diameter of the discharge line is selected and the previous steps are repeated. The total head must not exceed 65 m in all cases for single phase centrifugal pumps.

G) If the calculations showed the possibility to use more than one diameter within the accepted velocity limits, then the diameter is selected according to the consumed power in each case (for each diameter of the pipes) and to calculate cost of consumption in addition to determination power of the used motors in each case and calculation of the equipments cost (pumps + motors + pipes and their accessories) corresponding to each case and then the total cost is calculated for each diameter under comparison to select the more economic diameter.

1-13 Types of the pumps used in pumping stations

The following types of pumps are used in the pumping stations for sanitary drainage projects

A) Centrifugal pumps.

B) Screw pumps

C) Positive displacement pumps

D) Air lift pumps

1-13-1 Centrifugal pumps and Screw pumps

All features and limits of the centrifugal pumps are previously indicated in Item 1-11 also can see Volume (2) concerning treatment works of screw pumps.

1-13-2 Positive displacement pumps

This type is mainly used in pumping sludge or the liquid wastes to far distances and against very high total head. In all cases, must perform cost comparison between this type and the other types that can be used for the same function. The comparison will be performed according to the preliminary cost whether for the necessary constructions or for pumps price added to it the operating cost and periodic maintenance works taking into consideration the operating conditions to decide any of the possibilities.

These pumps are divided to the following types:

- Ram Pumps
- Mono Pumps or Helical Pumps

1-13-3 Air Lift Pumps

This type of pumps is not used in the practical applications to lift liquid wastes of the sanitary drainage due to the limited capacity and low head that can be obtained from these pumps, however they are characterized by low noise in the availability of compressed air, so they can be used in the places that require silence operation and reduction of the areas required for the equipments.

Information and some details of these types of pumps are indicated in Annex (2) of this volume.

1-14 Design of Pump Building

The following elements must be taken into consideration when design pumps building:

A) Building dimensions

B) Building ventilation

C) Lighting works.

D) Dewatering pumps.

E) Upper Cranes

F) Maintenance ladder and walkways.

1-14-1 Building Dimensions

Pumps' building is divided into two main houses:

- Pumps house
- Motors and switchgears house.

Dimensions of pumps house are determined by the dry part of pumping station sump, therefore this part must be suitable for installation of the pumps and their accessories, suction and discharge pipes system when determining station sump diameter in case of circular sumps, and the dimensions in case of rectangular sumps.

Generally, the distance between the pumps must be about 1.50 m for small pumps of flows up to 100 liter/sec, and to 3.50 m for the pumps of great flows more than 600 liter/sec. The distance between the axis of the first pump and the last pump and house wall must not less than the half distance between the pumps.

Motors house must have the same area as suction sump and its height is determined for a value that allows installation of an upper crane in the house, installed on concrete beam at height from 4 to 5 meter from the floor level of the house according to plant capacity. A distance not less 1.5 to 2 m must be kept between surface of crane beam and the bottom of the falling beams from motors house ceiling according to plant capacity, size of the motors installed and load of the used crane.

1-14-2 Ventilation of pumps building

1-14-2-1 Ventilation of pumps house under floor level

Two ventilation units at least are used, consist of air compressor, suction and discharge pipes, one is operated to blow the air outside the building to pumps house at a level not less than 2 m from house floor level. The other unit is operated to suck the air from inside the house to outside the building at a level not more than 0.5 m from house floor level.

Capacity of the ventilation units must be with a value that allows change of the air inside pumps house from 6 to 8 times per hour at pressure about 0.2 bar.

1-14-2-2 Ventilation of motors house over floor level

For this purpose, it is used suction fans installed on motors house wall with total capacity allows change of house air from 8 to 10 times per hour, taking into consideration that the temperature inside the house must not exceed 38°C in all cases. Capacity of the fans is determined according to a manometric pressure of about 0.2 bar.

1-14-3 Lighting of Pumps Building

1-14-3-1 Lighting of Pumps House

Lighting units of type caw eye fully sealed against water leakage are used for lighting of pumps house under floor level. These units are installed on the walls at height not less than 2.5 m from house floor level. Number of the used units and lamps power must be with values that allow light intensity not less than 200 Lux at any point inside the house.

1-14-3-2 Lighting of Motors House

Lighting units provided with (Flora) mixed lighting lamps or mercury lamps from 150 to 250 w are used for lighting motors house. These units are suspended from house ceiling with a number allows provision of light intensity not less than 300 Lux at any point inside the house. It is preferred to use additional fluorescent lights at the back of the switchgears installed on the walls at height not less than 3 m from house floor level to increase light intensity in this area to 500 Lux for maintenance and repair works of these switchgears.

1-14-4 Dewatering Pumps

Leaked water from the main pumps and the areas surrounding the plant as well as those leaked from pipe and valve connections are collected in collection tank at one corner of main pumps house, where it is drained using vertical dewatering pump of submersible type or self priming type to be ready for continuous operation, and must be operated automatically according to the level of the collected water in the collection tank.

Capacity of the dewatering pump must commensurate with the capacity of the pumping station, usually, it is from 5 to 10 liter/sec at manometric head about (6-8) m. In case of great pumping stations, two dewatering pumps can be used and installed in two opposed corners to help in quick suction of the leaked water.

1-14-5 Upper Cranes

- Pumping stations are provided with upper cranes installed in motors house used in repair and maintenance works of pumping units as well as in installation and dismantling works.
- Load of the crane will be selected to allow lift of full pumping unit (pump + motor) with safety factor not less than 25% of this load.
- Height of the crane beam from motors house floor will be with a value that allows moving the electrical motor freely inside the house and installing it on its base. Usually, it is (4-5) m according to capacity of pumping station.
- Crane lifting chain must allow reaching to pumps house floor to enable lift these pumps to floor level in motors house.

1-14-6 Maintenance Ladders and Walkways

- Pumping station must be provided by suitable ladder to access from motors house to floor level of pumps house. Opening of the ladder must be wide enough to allow bringing down all the pumps used in the plant if the roof of pumps house is not provided with maintenance openings. The ladder must be comfortable for use, if possible, and enables maintenance works and other technicians to use it in ascending and descending when carrying tools for assembly and disassembly works. It is preferred use spiral ladder if possible.
- Ladder rungs must be sliding-proof and in case of using iron rungs, it must be treated against rust and corrosion.

- Pumps house must be provided with metal walkways to access to all valves for easy opening and closing and access also to fulcrums for lubrication and perform the necessary maintenance. Walkways must be treated against wear and corrosion due to repeated use and exposure to drain vapors.

1-15 Screens

Pumping stations sump is provided with screens to prevent the suspended materials in liquid wastes coming to the station from sanitary drainage networks such as woods, dead animals, ropes, fabrics, plastic bottles, tin, stones, etc.

There are two types of screens:

A) Manual screens (grids)

B) Mechanical screens

1-15-1 Manual Screens

Spacing between bars of these screens is 80-100 mm. The design of these screens must allow easy access for performing cleaning and periodic maintenance works by providing walkways inside the sumps with handrails, if necessary, or to use removable manual screens that can be removed from the sump to ground surface level for performing cleaning and maintenance then returned again. This can be done using manual crane to raise the frames of these screens with the existence of guide.

In case of the removable screens, must exist double grids to enable continuous block of the impurities alternately between the working screens and that are removed for cleaning and maintenance.

- Bars and frames of the manual screens must be made from galvanized iron with sizes commensurate with plant capacity and dimensions of these screens.

1-15-2 Mechanical Screens

The specifications are the same as in sanitary drainage treatment plants volume (Item 2-1) taking into consideration to use reciprocating grab type mechanical screens for deep channels as indicated in the mechanical screens types in such volume (Annex 1).

1-16 Valves and Penstocks

Valves and gates are used to control entrance, exit and operation of the pumps inside the plant.

1-16-1 Valves

1-16-1-1 Sluice Valves

All valves used in the sanitary drainage plants must be of rising stem type, and it is not allowed to use any other types.

Valves are manufactured from the following materials:

Valve casing	: Cast Iron
Closing gate	: Cast Iron
Drive shaft and screws	: St. St.

Type of cast iron and St. St. are specified according to the content of the liquid wastes from acids, alkalis or the other chemical elements.

1-16-1-2 Non-Return Valves

Tilting disc or hydraulic type valves are used.

Materials of these valves are the same as in Sluice Valves.

The valves must provide with enough holes to remove the disc and perform cleaning and maintenance works.

1-16-2 Penstocks

All penstocks used in sanitary drainage plants are of wall mounted type and manufactured from cast iron for all parts except the drive shaft is manufactured from St. St.

1-17 Water Hammering

In case of sudden stop of a rotating pump, the pressure increases or decreases suddenly. This may lead to breakage of the pump or the discharge pipe. Under certain conditions the same phenomenon occurs when the discharge valve is opened quickly at start operation of the pump. Water hammering is an accidental phenomenon occurs when the pressures change due to the change in flow velocity at the time of change from a certain stable position to another stable position as previously described. Therefore, suitable precautions must be taken to prevent water hammering at the beginning when design high head or high capacity pump or when lifting water to a long distance, and also, when the discharge line is weak because of the manufacturing material or long period of use.

1-17-1 Calculation of water hammering

1-17-1-1 Speed of transfer of compression wave (α)

$$\alpha = \frac{1425}{\sqrt{1 + \frac{K}{E}\frac{D}{t}}} \quad \text{m/s}$$

Where:

α = Speed of transfer of compression wave (m/s)

E = Young Modulus for pipe material (kg/m^2)

It is as follows:

Cast iron pipe 1.1×10^{10}

Steel pipe 2.0×10^{10}

Concrete pipe 0.2 × 10^{10}

Asbestos pipe 0.3 × 10^{10}

For any other materials, this modulus is determined by the producer before calculation of the transfer velocity

K = Bulk modulus for water volume (kg.m²)

It is 2.03 × 10^{10}

D = Inner diameter of discharge pipe (m)

t = Thickness of pipe wall (m)

Transfer velocity may change slightly according to the method of installation of the pipe but it is possible to obtain an acceptable value using the above equation.

1-17-1-2 Wave Transfer Time Period ($2L/\alpha$)

$$2L/\alpha = 2 \times \Sigma \frac{L_i}{\alpha_i} \quad \text{(Sec)}$$

Where:

L = Discharge pipe length (m)

L_i = Discharge pipe segment (m)

α = Speed of transfer of compression wave (m/s)

α_i = Speed of transfer of compression wave in discharge pipe segment (m/s)

1-17-1-3 Pipes line constant (ρ)

$$\rho = \frac{Q_0 \Sigma \frac{L_i}{A_i}}{2g H_0 \Sigma \frac{L_i}{\alpha_i}}$$

Where:

Q_o = Drainage pipe flow rate at flow stability position (m^3/s)

A_i = Cross section area of discharge pipe segment (m^2)

L_i = Discharge pipe segment (m)

α_i = Speed of transfer of compression wave in discharge pipe segment (m/s)

H_o = Pressure inside discharge pipe at flow stability position (m)

g = Earth gravity (9.8 m/s^2)

1-17-1-4 Increase in pressure

A) When closing pipe valve momentary from flow stability position

$$\Delta H = \frac{\alpha}{g} \Delta V$$

Where:

ΔH = Increase in pressure (m)

α = Speed of transfer of compression wave (m/s)

g = Earth gravity (9.8 m/s^2)

ΔV = Change in the flow velocity in the pipe (m/s)

In this case;

$$T < 2L / \alpha$$

Where:

T = Time of valve closing (S)

L = Pipe length (m)

B) When closing the pipe slowly from flow stability position

$$\frac{\Delta H}{H} = \frac{n}{2}\left(n + \sqrt{n^2 + 4}\right)$$

Where:

n = $\frac{L \cdot \Delta V}{g\ TH}$

H = Static head (m)

In this case:

$$T \geq 2L / \alpha$$

1-17-2 Methods of calculation water hammering

Water hammering can be calculated by three methods:

1. Direct solution of the differential equation
2. Overlap solution method
3. Graphical solution method.

Graphical solution method is commonly used because it is relatively easier. In all methods, the calculations are performed using specialized computer software.

1-17-3 How to prevent water hammering

The main factor for prevention of water hammering is to minimize the change of the flow velocity. All water hammer prevention devices can be used to achieve this purpose.

Water hammering prevention devices are classified to three groups according to their nature of operation:

(A) Slow down the change of flow speed.

(B) Prevent sudden pressure drop.

(C) Prevent pressure rise

Therefore, simple device can be used to prevent water hammering in some cases or complicated device can be used in other cases. The following table shows planning principals to prevent water hammering.

How to Prevent Water Hammering

Method	Purpose	Actual Application etc.
(1) To select a slow velocity of flow in the piping.	To minimize the change of the flow velocity.	A slower velocity of flow in the piping is better. about 1 m/s or less.
(2) To make GD^2 large.	To slow down the change of speed and minimize the fluctuation of the flow velocity.	Add a certain value of GD^2 to the coupling. If it is not enough, provide a flywheel separately.
(3) To feed water into the discharge piping.	To prevent vacuum by pressure drop.	(1) Provide a surge tank. (2) Feed water from the suction water level by a separate pipe.
(4) To lead air into the discharge piping.	To prevent vacuum by pressure drop.	(1) Provide an air chamber. (2) Provide an air valve.
(5) To use a slow closing check valve.	To prevent pressure rise.	Close the check valve slowly. The structure of widely adopted check valves is that an oil dash pot is provided and the valve is closed by the counter-flow of water.
(6) Forced control of the main valve.	To prevent pressure rise.	Control the main valve by force by means of oil pressure, pneumatic pressure or water pressure, etc. and a DC power supply.
(7) Omission of the check valve.	To prevent pressure rise.	When the check valve and foot valve are not provided, the pressure rise is smaller than when they are provided. But, in that case, reverse running of the pump and motor may be caused.
(8) To use an automatic pressure regulator valve.	To prevent pressure rise.	This valve opens at the same time as the prime mover stops and prevents pressure change in the transitional period. After a specified time, it closes gradually. The discharge flow from it does not pass through the pump.
(9) To provide a safety valve.	To prevent pressure rise.	This valve is to release water when the pressure reaches a specified value. There are the balance weight type and spring-loaded type of safety valves.

2- Design of Electrical Works

2-1 Electrical motors used in pumping stations

One of the following two types of the electrical motors is used in the pumping stations:

A- Squirrel cage induction motors with powers up to 200 KW, and this value can be exceeded when using smart motor control systems.

B- Induction motors with slip rings with powers exceed 200 KW

The following conditions and specifications must be taken into consideration for the used electrical motors:

A- Motor windings must be with insulation degree (Class F) and the temperature rise for these windings must not exceed the allowed temperature for (Class B). Also can use motors with windings of insulation degree (Class H) and temperature rise must not exceed the allowed temperature for (Class F).

B- Motors Enclosure Protection

- For motors installed in motors house over floor level in the station, the used motors must be of closed type T.E.F.C. with enclosure protection IP44 or IP54

- For the motors installed directly over the pimp (Close coupled) and installed in pumps house under floor level, the used motors must be of (Flood proof) type with enclosure protection IP56.
- For motors installed outdoor and subjected to weather conditions, the used motors must be of (weather proof) type with enclosure protection IP55.
- For motors operating under water level, the used motors must be of (submersible) type with enclosure protection IP68. In this case, must specify the level at which the motor works under water level.

C- Motors must be provided with anti condensation heaters inside the windings to prevent condensation of water vapor in winter. These heaters work with the operating voltage 220 v.

D- When using vertically installed motors, they must be provided with thrust type ball bearings.

E- All used ball bearings must have lifespan 100,000 operating hours.

F- When using electrical motors with slip rings, they must be provided with brush lifting device with short circuit rings.

G- When using squirrel cage induction motors, commutating segments of the rotor which forming the cage must be from high quality copper.

H- Motor power required to drive the pump at the operating point is calculated from the following formula:

$$P = \frac{W\,Q\,H}{75\,\eta_T} \times 0.746$$

Where:

W = Liquid specific density

P = Absorbed power on pump drive shaft (KW)

Q = Pump flow rate (liter/sec)

H = Pump total manometric head (m)

η_T = Pump total efficiency at the operating point.

To calculate the rated power of the motor, must take into consideration the service factor of value 15-30% of the maximum power over operating time of the pump.

2-2 Switchgear

It includes closing and opening devices (switches) and their accessories, control devices, measuring devices, protection devices and adjustment as well as assembly of these devices and equipments, connections, supplies and the buildings containing them.

In the following is the definition of these equipments

A- Metal enclosed switchgears

Switchgears assembled inside external metal enclosure connected with the earth. Complete with connections except the external connections.

B- Metal clad switchgears

Switchgears assembled inside separate cubicles contained in metal clad connected with the earth. Must take into consideration existence of separate cubicles for the following components in the switchgear:

- Main switch.
- The components connected at one side of the main switch as supply circuit.
- The components connected at the other side out from the main switch.

C- Circuit Breakers

They are mechanical control devices able to connect, hold and break the electrical current passing through under normal conditions of the electrical circuit. They are able also to connect, hold and break the electrical current for a limited period under abnormal conditions of the electrical circuit (short circuit).

D- Indoor Circuit Breakers

They are the circuits breakers designed to be installed inside the buildings or enclosed place, where they are protected against winds, rains, dusts, vapor condensation and other weather conditions.

E- Outdoor Circuit Breakers

They are the circuits breakers designed to be installed in the open atmospheres and are able to withstand different weather conditions.

F- Switches

They are mechanical control devices able to connect, hold and disconnect the electrical current under normal conditions of the electrical circuit. They are also able to withstand short circuit currents for limited period.

G- Disconnectors or Isolators

They are mechanical control devices give in open position separate distance prevents passing the electrical current at the rated voltage. The disconnetor is able to open and close the electrical circuit at no load or when the passing current in neglected (less than 0.5 ampere) where the voltage difference across the two terminals of each pole neglected.

H- Circuit Breaking

Circuit breakers (CBs) are defined according to their design and method of operation to break short circuit currents in the electrical circuit. CBs are classified usually according to the medium used in distinguishing the spark generated at disconnection. The electrical arc (spark) generated at disconnection and method of extinguishing is the main element in the function of the CBs, where it allows the current to continue passing in the electrical circuit after disconnection of the contacts until the current reaches to zero.

The ideal CB is the one that works as conductor until reaching the current to zero, at this point it is converted into absolute isolator. Practically, it is difficult to reach to a CB that can meet this condition, but must take into consideration to reach as near as possible to this condition with the necessity to provide the required conditions to remove the arising ionization in the contacting cavity and to use a medium withstands transient recovery voltage.

2-2-1 High Voltage Switchgear

High voltage switchgear must contain a set of cubicles allow to contain the circuit breakers and voltage transformers (at the connection side) in addition to be provided with the necessary installations to hold the measuring devices and relays and to be prepared to connect terminals of the supply cables and output cables.

The switchgears must be of metal enclosed or metal clad. The difference between the two types is that the current transformers and cable terminals are installed in one cubicle in metal enclosed type. For all types of circuit breakers, must provide possibility to remove the circuit breaker from the bus bars with one of the following methods:

- Vertical pull
- Horizontal pull
- Using disconnector or witch between the circuit breaker and the bus bars.

- In Bulk oil CBs, vertical pull is used.
- In Magnetic air CBs and Min. or Low Oil CBs, vertical pull is used.
- In case of Gas CBs, vertical pull or horizontal pull can be used.
- When using Vacuum CBs, usually fixed type CBs is used with the existence of disconnector between the circuit breaker and the bus bars to get benefit from the feature of this type of less maintenance.
- Must take into consideration to provide safe installations to access to the main bus bars of the distribution boards to perform the required measurements and tests. In case of CBs of pull type, the access to the bus bars will be through the holes used in engaging the circuit breaker.

2-2-1-1 Interlocking & Padlocking

To ensue safe operation of the electrical switchgears, especially when it is required to access to the bus bars for troubleshooting or to connect a phase of the circuit or to test the cables, the board must be supplied with mechanical interlocking or padlocking to control connection of the main supply to these switchgears.

The first requirement for the interlocking in all types of switchgears provided with CBs of pull type, is to ensure that the CBs can not be pulled or engaged while they are connected (closed) with the current. The switchgears must be provided with metal shutters to cover connection holes to bus bars automatically when pulling the CBs from their operation cubicle. Similarley, preparation must be performed in order to close these shutters in disconnection position to ensure safety of all the equipments contained in the cubicle.

2-2-1-2 Types of Circuit Breakers

The common types that currently used are:

A- Oil Circuit Breaker

Is divided into:

- Bulk oil CB
- Minimum Oil CB

Hydrocarbon oil is used in this type of CB of low viscosity and good insulation properties.

Disadvantage of this type is the rise of contacts temperature which leads to oil evaporation and dissolution to its components of hydrogen and carbon, where the hydrogen is thermally ionized to produce electrons and positive ions have the ability to carry the electric current within the distance between the contacts causing electric arc. To control gas flow in the spark area, the contacts must be closed inside the control range of the arc by using arc control device to increase efficiency of operation of the circuit breaker.

B- Magnetic air circuit breaker

Its theory of operation depends on creation of very high voltage for the arc can not be kept by the used operating voltage, hence the arc can not continue. It can reach to this by enforcing the arc to extend to reach near to solid materials that extract the heat from the arc or by breaking the arc into series of arcs. The two methods can be used together in some designs, where the magnetic circuits create a field inside the arc range to guide the arc within this range. In case of low electric currents (about 100 A), air blower must be added and connected with vents below the contacts to guide the arc.

C- Vacuum circuit breaker

The contacts in this type are inside sealed air vacuumed container with insulating walls. One of the contacts is fixed with the terminal of the circuit breaker and the other contact is free in motion in axial direction through metal gaskets connected between the moving contact and the other connecting end. Performance of the vacuum circuit breaker depends on the following three factors:

- Existence of enough vacuum inside the device
- Select suitable material for the contacts.
- Provision of magnetic control in the arc.

Contact gap is about 10 mm for voltages up to 11 KV; therefore, the power necessary for operation is less than the other types of CBs. This type achieves the highest efficiency of operation as a current disconnecting device, where the insulation strength of contact gap is recovered within (1) microsecond within the rated break current. Because of the high strength of these CBs, they do not require any maintenance over their lifespan and there is no possibility of fire due to absence of any flammable materials.

D- Sulphur Hexa Fluoride CB (SF6)

It contains inert non-flammable, colorless, odorless Sulphur Hexa Fluoride gas. The gas is used at pressure of about 3 bar to reach to the same insulation strength of mineral oil. This gas is characterized by absorption of the free electrons generated in the path of the electric arc forming negative ions which speeds up recovery of the insulation strength after occurrence of the arc. The activated ammonia is used to absorb less degree fluoride gases (SF2 & SF4) which may be produced due to dissolution of the original gas SF6. For this reason, this type of CB can withstand a significant number of breaks in cases of short circuit without the need to change its active parts.

Table (2-3) shows comparison between characteristics of types of the CBs

2-2-2 (H.V) Switchboard Construction

Each board consists of number of cells; each cell consists of metal structure lined with cold rolled steel plates of thickness not less than 2 mm. The board is provided with front and rear doors for easy maintenance. It is also provided with the necessary precautions for safe operation and maintenance. Equipments of each cell are installed separated and insulted from the adjacent cell. The life parts are kept away of being touched after pulling the switch from inside the cell.

Distribution bars are made from good conducting copper completely insulated by suitable material. Contact point must be of self aligning type loaded with strong spring coated with thick layer of silver. The boards are provided with mechanical and electrical interlocking for safety of operation.

2-2-3 Low Voltage Switchgear

Low voltage switchgear are subject to IEC. Low voltage circuit breakers are designed, manufactured and tested according to IEC 157-1/1973 and amendments thereof. The following specifications must be taken into consideration:

(A) Short circuit categories.

Table (2-3): Comparison between types of H.V Circuit Breakers

<table>
<tr><th>No</th><th>Characteristics</th><th>Air circuit breaker
I</th><th>Oil circuit breaker
II</th><th>Vacuum circuit breaker
III</th><th>SF6 CB
IV</th></tr>
<tr><td>1</td><td>Connection and disconnection of inductive current</td><td>At low currents, it has the feature of quiet extinguishing of spark for many half cycles which produces current chopping then voltage-surge.</td><td>As the oil is a good insulator, extinguishing of the spark (electric arc) is more effective than the air CB. This give shorter time of the spark and higher degree of current chopping and considerable increase in voltage, but with insufficient value that may damage the insulation.</td><td>The breaker will disconnect regardless the value of the passing current. Stability of the electric arc (spark) at small currents depends on contacts material used in the CB, where spark plasma (medium) consists of vapor of the metal from which the contacts are made.</td><td>Path of the current chopping depends on method of extinguishing the spark, generally, of the same value as in oil CB and vacuum CB.</td></tr>
<tr><td>2</td><td>Connection and disconnection of capacitive current</td><td>Tends to recover the spark after distinguishing. It has very limited value in performing this function.</td><td>Has insulation strength for each pole enough to ensure break of the capacitive current without return of the spark</td><td>Very quick recovery of the insulation strength for the vacuum gap. This provides break without return of the spark to the capacitive currents until the full load of the rated current for the breaker.</td><td>Due to the negative electricity properties, the conduction gap is quickly re-ionized which provides break without return of the spark.</td></tr>
<tr><td>3</td><td>Mechanical aspect</td><td colspan="2">The standard specifications require achievement of 1000 connection and disconnection processes at no load without affecting the breaker in addition to neglected wear degree. Regular lubrication during this period must be taken into consideration in the design.</td><td>Short stroke for connection and disconnection and low power requirements, help the designer to develop strong mechanical structure for long lifespan without performing maintenance for these CBs. Usually, 10,000 connection and disconnection processes at least are achieved without maintenance.</td><td>Power requirements are located between those of oil CBs and vacuum CBs. Most of the required power is used to extinguish the spark. This power is increased as the rated current of the CB increases. Theses CBs require maintenance at periods usually reach to 10,000 connection and disconnection processes.</td></tr>
</table>

Table (2-3): Comparison between types of H.V Circuit Breakers (Cont.)

No	Characteristics	Air circuit breaker I	Oil circuit breaker II	Vacuum circuit breaker III	SF6 CB IV
4	Confusion in the CB during the fault				
	(A) Value of the produced pressure	Quick existence of the electric arc in the arc-chute produces high pressure and impact waves that must be taken into consideration in the mechanical construction of the CB which increases the cost.	Dissolution of the oil to hydrogen and hydrocarbons by electric arc current produces very high pressure inside the spark control device. This affects the ability of extinguishing. Part of this pressure is transferred to the metal tank, but the existence of suitable air pad near the tank cover helps to keep the pressure inside the tank. Using of cylindrical tank makes this increase in pressure simple matter.	Increase in metal vapor intensity produced during occurrence of the electric arc in contact chute is synchronized with the current and there is no general increase in pressure inside the CB.	Internal pressure formed during fault period reaches two or three times of the static pressure. This must be taken into consideration in design of insulation chamber.
	(B) Emission of exhaust gases	The great amount of ionized air flowed from the arc chute creates the need to cool down the insulation and the existence of trenches to allow safe flow of this air.	Medium amounts of exhaust gases are flowed, which can pass through blocking chamber at the upper surface of the CB. This cools and separates the gases from the oil.	The CB is completely enclosed and all the metal vapors produced during the electric arc (spark) are immediately condensed and there are no emissions of any type for these vapors.	The CB is completely closed and there is no emission of gas and may some of it dissolved to its components of sulphar, free sulphar, where they are absorbed by special filters inside the CB.

Table (2-3): **Comparison between types of H.V Circuit Breakers** (Cont.)

No	Characteristics	Air circuit breaker I	Oil circuit breaker II	Vacuum circuit breaker III	SF6 CB IV
	(C) Effect on CBs bases	Very small	Small	Neglected	Little
	(D) Production of Noise	Small	Medium	Neglected	Little
5	Possibility of Fire	As there is no oil used and non-flammable gases, the hot burning gases produced during the fault contain low degree of fire outbreak.	Using the oil as break medium and hence emission of inflammable gases (hydrogen, acetylene, methane, etc) during this process, this represents risk of fire outbreak. Good design of the CBs rarely give increase in the gases that may cause fire except in the occurrence of sever errors. It must exist controls and precautions against fire in case of using these CBs in environments that the fire has adverse effect.	Risk of fire outbreak is neglected, as there are no inflammable materials or gases from any sources.	As in Vacuum circuit breaker III.
6	Maintenance Requirements (A) Routine Maintenance	Routine maintenance in the traditional CBs includes cleaning and lubrication of the mechanical parts, inspection of the contacts, spark control device, insulation medium and replacement, if necessary.		Need non-periodic inspection to know the condition of the insulation material, electrical insulators and maybe CB contacts to check existence of wear.	These CBs are designed for long lifespan with non-periodic maintenance.

Table (2-3): Comparison between types of H.V Circuit Breakers (Cont.)

No	Characteristics	Air circuit breaker I	Oil circuit breaker II	Vacuum circuit breaker III	SF6 CB IV
		Rate of this procedure depends on the required performance, and it ranges from monthly service, in case of heavy duty (many connection and disconnection processes per day), to periods between 3-5 years for public supply. The oil must be replaced periodically in case of repeated use of oil CBs more than any other consideration, and the low oil types need more care especially the totally submersed types.		The number of operation processes can be recorded to determined periods of performing inspection. In case of public supply boards, replacement may be done during the lifespan of the CB, while in case of heavy duty (Daily repeated loading), replacement may be done every a number of years.	Mostly, maintenance cycle every 10 years is suitable for this type, but a visual inspection must be performed regularly. Safety measures must be taken in case of existence of existence of opening to provide the gas. Special equipments are used to do.
	(B) Post- Fault Maintenance	Usually, it is proposed to perform post-fault maintenance as soon as possible to recover the CB to its normal and safe condition.		It is not necessary to perform this maintenance, but it is preferred to inspect the CBs after operation during the normal operating period.	The same as vacuum CBs.
7	Maintenance suitable for risk environment conditions and repeated operation.	Required care and performing repeated maintenance for the CB insulator faces.	It is suitable, but always requires provision and adjustment of oil level and change of the contacts, especially in heavy duty cases. Maintenance will be repeated more in case of low oil CBs.	Features of the CB is more clear in these conditions, hence annual operation costs are less compared to the other types.	Does not need repeated maintenance, but care must be given to the mechanical parts in case of repeated operation, especially if the close power is high.

Table (2-3): Comparison between types of H.V Circuit Breakers (Cont.)

No	Characteristics	Air circuit breaker I	Oil circuit breaker II	Vacuum circuit breaker III	SF6 CB IV
8	Operation Facilities (A) Integral Fault Making Earthing Facilities	Rarely have this feature, but if necessary, separate earthing units are used.	Easy provision of integral fault making earthing for vertical pull CBs.	Are provided with this feature in case of fixed CBs, while for pull type CBs, the same as in I and II according to method of disconnection (vertical or horizontal)	As in I and II according to the type of pull, vertical or horizontal).
	(B) Injection- Test Facility	Requires removing the CB from the board then inserting the test stick into disconnection socket.		In case of fixed CBs, it will be provided with test openings that enable to insert test stick while the circuit is earthed. In case of pull type CBs, as in I and II.	As in I and II
9	Design of Switchboards Building	Width of the building depends on the depth of the switchgears with the existence of inlet path for cable terminals at rear of the board and wide passage at front of the board to give space to pull the CB and perform maintenance. According to the dynamic loads on the floor during operation, strong and expensive bases are constructed. Fire fighting equipments, such as carbon dioxide extinguishers are used, or using other systems as sprinklers or gas incase of risk of fire breakout. If there is no great risk of fire		In case of fixed CBs, there is no need for space in the design for pull or maintenance, so the width of the building is lesser than in case of pull type CBs. Loading on the floor is light and there is no need for fire walls or fire fighting equipments.	Operation group using gas CBs shall be of pull type CBs and the building requires a space for this purpose, but risk of fire breakout is neglected and there is no need for fire walls or fire fighting equipments, hence the building is more compact and simple.

Table (2-3): Comparison between types of H.V Circuit Breakers (Cont.)

No	Characteristics	Air circuit breaker I	Oil circuit breaker II	Vacuum circuit breaker III	SF6 CB IV
		If there is no great risk of fire, the great switchgears are divided by fire walls built across the building to reduce risks of damage of the switchgears in case of fire breakout. Length of the building depends on the width of each unit (cell) in the switchgear, in addition to the space necessary for the fire walls (if any) and the paths of the bus bars. Cells width must be lesser in case of the submersible CBs in oil than in the air CBs or low oil CBs.		As the width of cells is small, the length of the building is shorter and lighter in construction than in the conventional switchgears, which significantly decreases cost of the building. In case of pull type CBs, the building is wider, but saving in use of fire walls and fire fighting equipments is still exit and hence the building is more economic.	

(B) Short Circuit Tests Method

(C) Temperature-rise limitations / Thermal ratings

- Table (2-4) shows two short-circuit categories, and it is clear from the table that short-circuit category P1 is capable to select the two types O-CO at maximum short-circuit rating, while short-circuit category P2 is capable to select O-t-CO-t-CO. The main difference between the two categories P1 and P2 is that P1 is capable to operate after performing the specific test with reduced service, while P2 is capable to operate with normal service. Therefore, this difference must be taken into consideration and clearly specify the required category when developing the specifications of these CBs.
- When performing short-circuit tests for the CBs, must take into consideration to perform these tests in the same operating conditions as those applied during the service.
- Table (2-5) shows temperature rise limit according to IEC standard and must take into consideration always that temperature rise in the contacts does not lead to damage of insulation or to the parts adjacent to the contacts.

Table (2-4): Short Circuit Categories

Short circuit categories

IEC 157-1 has two categories of short-circuit performance outlined herein

Short-circuit performance category	Rated operating sequence for short-circuit making and breaking capacity tests	Condition after short-circuit tests
P1	O - t- CO	Required to be capable of performing reduced service
P2	O - t - CO - t - CO	Required to be capable of performing normal service

O represents a breaking operation.

CO represents a making operation followed, after the appropriate opening time (or immediately, that is without any intentional time delay, in the case of a circuit-breaker not fitted with integral overcurrent releases) by a breaking operation.

t represents a specified time interval.

Table (2-5): Temperature Rise Limit according to IEC Standard

Type of material, description of part	Temperature-rise limit (measured by thermocouple)
Contact parts in air (main, control and auxiliary contacts):	
copper	45°C
silver or silver-faced*	(1)
all other metals or sintered metals	(2)
Contact parts in oil	65°C
Bare conductors including non-insulated coils	(1)
Metallic parts acting as springs	(3)
Metallic parts in contacts with insulating materials	(4)
Parts of metal or of insulating material in contact with oil	65°C
Terminals for external insulated connections	70°C (5)
Manual operating means:	
parts of metal	15°C
parts of insulating material	25°C
Oil in oil-immersed apparatus (measured at the upper part of the oil)	60°C (6)

*The expression 'silver-faced' includes solid silver inserts as well as electrolytically deposited silver, provided that a continuous layer of silver remains on the contacts after the endurance tests and the short-circuit tests. Contacts faced with other materials, the contact resistance of which is not significantly altered by oxidation, are treated as silver-faced contacts.

(1) Limited solely by the necessity of not causing any damage to adjacent parts.
(2) To be specified according to the properties of the metals used and limited by the necessity of not causing any damage to adjacent parts.
(3) The resulting temperature shall not reach a value such that the elasticity of the material is impaired.
(4) Limited solely by the necessity of not causing any damage to insulating materials.
(5) The temperature-rise limit of 70°C is a value based on the conventional test A cb used or tested under installation conditions may have connections the type, nature and disposition of which will not be the same as those adopted for the test; a different temperature rise of terminals may result and this will have to be agreed.
(6) May be measured by thermometer.

2-2-4 Thermal rating and Enclosed rating

Is the rating of the CB in ampere listed in the data plate of the CB, such as thermal rating for the un-enclosed devices and provided with overload breaker, if necessary, which is the maximum current than can pass in the CB for 8 hours when tested in the open air provided that the temperature rise does not exceed the limits specified in table (2-5). So, must take into consideration that this rating does not express the rating of the CB at installation inside the switchgears. The enclosed rating of the CB is defined as the thermal rating inside the closed CBs, which is the maximum current, can pass through the CB for 8 operating hours when installed inside enclosure with certain specifications without temperature rise of its different parts over the limits specified in Table (2-5). Hence, normal full load current of the CB must not exceed the rating inside the enclosure, which is lesser than the thermal rating of the CB. To obtain acceptable operation of the CBs, rating in ampere of the CB must be taken into consideration inside the switchgear, where its rating is affected by the degree of ventilation and size of connections of this CB. Size of the cable used in connection depends on the number of CBs installed in the same raw. To reach to good and acceptable performance for switchgears, must ensure operating of the CBs in all surrounding operation conditions and performing the tests for them inside the same board they installed.

Therefore, the manufacturer of the switchgears, whether if it is the manufacturer of the CBs or that assembling the CBs inside switchgears of its design, must be given test certificate directly related the conditions surrounding the CBs when actually operated and ensure acceptable operation in actual operation conditions.

2-2-5 Construction of 380 v distribution switchgears

Walls and ceiling of the distribution switchgears are from steel of thickness not less than 1.5 mm and are painted internally and externally by two layers of approved paints. Its structure consists of strong steel corners welded or tied with the walls provided that the each cell is separated, and fixed with the other adjacent cells by suitable methods and contains all the necessary devices to allow easy operation and maintenance of all board devices by the operator. Each cell must be provided with rear steel door with key. The switchgear must be provided with the required switches and devices and all of their connections, insulators, CBs, fuses and terminal blocks for the inlet cell and what are necessary for its operation. All devices are fixed inside each cell at the rear of the front face of the board provided that only appear the meters of submersible type, switch handles and the indicator lamps. Distribution bars and their connections must be from good copper conductors installed on china insulators or bakelite suitable for the operating voltage and does not allow for temperature rise in distribution bars 40°C more than the temperature of the surrounding weather which is 45°C. It is not allowed welding in distribution bars and the cross section of the copper must be according to the design provided that the current density not exceed 2 A/ 1 mm^2 of the cross section. The cross section must not less than 250 mm^2. Connections system must be easy to be followed and each phase must have separate color, red, blue and yellow, respectively, and the neutral is black color. The main copper cross section must be the same in all board parts.

2-2-6 Earthing

All un-life parts of the switchgear, one terminal of current and voltage secondary windings and meters must be connected to the earth. These connections must be connected safely.

Earthing wire shall be made from ordinary copper or (braid) with suitable cross section connected to all doors of the switchgear and the devices subject to touch and one side of the secondary winding of voltage and current transformers, control and measuring devices, etc.

2-2-7 Earthing Well

Earth wires are connected to special well constructed adjacent to the plant according to the following specifications:

Earthing well consists of galvanized iron pipe of diameter not less than 2 inches buried inside the ground with length 4 meter or until it reaches below groundwater level with a distance not less than 80 cm. The length flooded by the groundwater must be perforated with not less than five holes on the circumference for each 2 cm of the axial length of the pipe.

The pipe is surrounded from outside by a mixture of sodium chloride and fine crashed coal in low humidity dry soil. Ordinary copper bar is extended inside the earth pipe and tied at the top of the pipe where a galvanized iron bush is installed. Welding is not allowed.

The upper part of the pipe of length 20 cm is protracted inside a cast iron box with hinged cover. The dimensions of the box is not less than 35cm × 22cm. This box is installed with the cover at the level of the ground surface.

Earth wire of the plant is connected to the earthing pipe by electric welding or with tying screws. Tin welding is not allowed.

2-2-8 Calculation of short-circuit current and overload current for electrical circuits

To determine rating of the protection devices against overload and short-circuit, it is required to calculate value of overload current and short-circuit current. These value can be calculated from electrical installations code Item (6-4) and Item (6-8).

2-3 Electrical Transformers

Distribution Transformers

Distribution transformers are used for public and industrial uses. They are usually of power 1600 KVA or less. Also, for economic reasons, transformers of power up to 2500 KVA may be used.

Definition of the Transformers

Transformers are defined as the static part of the devices, which through electromagnetic induction, transform the AC voltage and current between two or more windings at the same frequency, usually at different values of voltage and current.

2-3-1 Types of the used transformers

There are two types of distribution transformers:

- **First Type: Liquid Filled Transformer.** In which the core the windings are flooded inside enclosure filled with liquid which provides cooling and insulation at the same time.
- **Second Type: Dry Type Transformer.** In which the core and the windings are cooled directly with air (Dray Transformers).

The first type is divided into units use inflammable mineral oils and other use different types of fire proof liquids, such as silicon liquids or hydrocarbons compounds.

The second type is divided into two units. In the first unit the insulated windings are in direct contact with the cooling air, and in the second the windings are enclosed completely inside capsule of moisture proof materials made from cast-resin.

2-3-2 Common Powers of Transformers

Table (2-6) shows the power ratings commonly used in the commercial electrical transformers.

2-3-3 Tappings

High voltage windings of the transformers contain tappings to change windings ratio between the low voltage and high voltage windings to equate the change of the primary supply voltage to keep the secondary voltage for the consumer within the rating limits. The tappings are selected through external circuit. The transformer must be disconnected from the supply before change the tappings.

2-3-4 Transformer Windings

The transformer consists of three branches core made from electrically insulated steel laminations. Each branch holds two axially winded windings. The secondary winding (low voltage) is the inner part near from the iron core, the primary winding (high voltage) is the outer part. This combination is put inside steel enclosure.

In case of transformers of flood type, this enclosure consists of sealed tank filled with liquid. In case of dry transformers the enclosure consists of ventilated cover to contain the life parts.

Table (2-6): Power ratings commonly used in the distribution transformers

KVA	KVA	KVA
5.0	31.5	200
6.8	40	250
8	50	315
10	63	400
12.5	80	500
16	100	630
20	125	800
25	160	1000 etc.

The windings are mostly manufactured from copper except in special cases aluminum thin strips can be used.

2-3-5 Transforms Performance

When selecting the transformer, the preliminary cost must not be the only consideration. In most cases, small part is cost from the total cost.

The factors that control the selection of a certain transformer, must take into consideration the load factor, losses cost, efficiency, maintenance cost, fire fighting quality and the required building cost, the available area for construction and air temperature in addition to the preliminary cost.

2-3-6 Losses in the Transformers

- No-load and load losses in the transformer represent loss in the efficiency and is the reason for the great part of transformer operating cost. These losses are transferred to heat and usually removed through radiation in the environment surrounding the transformer.
- Different suppliers of the flood transformers are compared in terms of electricity consumption and the resulted no-load losses in case of continuous activation of theses transformers.
- Load losses cost depends on the load factor (L.F.), which does not differ significantly between products of the same power in case of oil transformers. In case of transformers immersed in fire proof materials, these losses are significantly different.

- Losses in the dry transformers are lesser than in case of the immersed transformers.
- Table (2-7) shows comparison between the different types of transformers of power 1000 KVA. The same comparison must be performed between types of transformers for all other powers before taking any decision for preference of a type from other one as a factor of reference.

2-3-7 Temperature Rise

- In temperate weathers, the difference in the temperature rise limits between the immersed transformers and dry transformers is neglected in the combinations.
- Rise in the ambient temperature of the transformers limits their power ratings, where they are less than the value indicated on the data plate of the transformers. The radiated heat due to losses affects also the electrical devices of these transformers.
- Table (2-8) and Table (2-9) show temperature rise limits for the two types of transformers.
- For the transformers installed inside the buildings, when the ambient temperature is very high, it is preferred to use dry transformers, reduce their powers to a value equivalent to this temperature and perform the periodic maintenance due to the sensitivity of this type and prevent pest from reaching to them.
- For the transformers installed in high temperature areas or inside very confined places, it is better to use transformers manufactured specially for high temperatures and immersed in silicone liquids.

Table (2-7): Comparison between electric losses in some types of transformers

(1000 KVA)

	No load	Losses in kilowatts at operating temperature 1/4 Load		1/2 Load		3/4 Load		Full load	
Oil / Askarel / Silicone	2.8	No load	2.8	No load	2.8	No load	2.8	No load	2.8
		Load	0.6	Load	2.3	Load	5.2	Load	9.1
		Total	3.4	Total	5.1	Total	8.0	Total	11.9
Dry-type, 150°C	3.2	No load	3.2	No load	3.2	No load	3.2	No load	3.2
		Load	0.8	Load	3.3	Load	7.4	Load	13.2
		Total	4.0	Total	6.5	Total	10.6	Total	16.4
Epoxy dry-type	3.2	No load	3.2	No load	3.2	No load	3.2	No load	3.2
		Load	0.7	Load	3.0	Load	6.7	Load	11.8
		Total	3.9	Total	6.2	Total	9.9	Total	15.0

* BIL = Basic insulation impulse level.

Table (2-8): Temperature-rise in dry transformers

1	2	3	4
Part	Cooling method	Temperature class of insulation*	Maximum temperature rise (°C)
Windings (temperature rise measured by the resistance method)	Air, natural or forced	A E B F H	60 75 80 100 125 150†
Cores and other parts (a) Adjacent to windings (b) Not adjacent to windings	All		(a) Same values as for windings (b) The temperature shall, in no case, reach a value that will damage the core itself, other parts or adjacent materials

Note. Insulating materials may be used separately or in combination provided that in any application each material will not be subjected to a temperature in excess of that for which it is suitable, if operated under rated conditions.

*In accordance with IEC Publication 85, Recommendations for the Classification of Materials for the Insulation of Electrical Machinery and Apparatus in Relation to their Thermal Stability in Service.

†For certain insulating materials, temperature rises in excess of 150°C may be adopted by agreement between the manufacturer and the purchaser.

Table (2-9): Temperature-rise limits in oil transformers

1	2
Part	Maximum temperature rise (°C)
Windings: class of insulation A (temperature rise measured by the resistance method)	65, when the oil circulation is natural or forced non-directed 70, when the oil circulation is forced and directed
Top oil (temperature rise measured by thermometer)	60, when the transformer is equipped with a conservator or sealed 55, when the transformer is neither equipped with a conservator nor sealed
Cores, metallic parts and adjacent materials	The temperature shall, in no case, reach a value that will damage the core itself, other parts or adjacent materials

Note The temperature rise limits of the windings (measured by the resistance method) are chosen to give the same hot-spot temperature rise with different types of oil circulation. The hot-spot temperature rise cannot normally be measured directly. Transformers with forced-directed oil flow have a difference between the hot-spot and the average temperature rise in the windings which is smaller than that in transformers with natural or forced but not directed oil flow. For this reason, the windings of transformers with forced-directed oil flow can have temperature rise limits (measured by the resistance method) which are 5°C higher than in other transformers.

2-3-8 Loading Guide of Transformers

- The ambient temperature and service conditions can be determined for the oil transformers without occurrence of damage for windings insulation due thermal effects in case of exceeding the allowed limits. The same units can be applied in case of use of other types of cooling liquids.
- Purpose of the loading guide is to give the allowed limit under certain conditions of cooling medium temperatures and the primary loading percentage of the rating power (of normal operation position) in order that the designer can select the rating power for any new constructions.
- Determine normal cooling medium temperature (e.g. 30°C) and the deviations from this value in order to achieve balance between elongating of the lifespan in case of operating under lower temperature and shortening this lifespan in case of operating at higher temperature.
- In the practical applications the transformers are not operated continuously under full load. The guide gives suggestions for daily loading cycle taking into consideration change in the ambient temperature during seasons of the year.
- Table (2-10) shows loading guide for the oil transformers at 20°C of cooling medium.
- By this table, overload of a transformer with certain rating power can be determined during certain period of time or determine the required rating power for a transformer with daily loading cycle through drawing a curve for the relation between K1 and K2 at different values for the loading periods (t) (Fig 2-36).

Table (2-10): Loading Guide for Oil Transformers

K_1 = initial load power as a fraction of rated power

K_2 = permissible load power as a fraction of rated power greater than unity)

t = duration of K_2 in hours

θ_a = temperature of cooling medium (air or water).

Note $K_1 = S_1/S_r$ and $K_2 = S_2/S_r$ where S_1 is the initial load power, S_2 is the permissible load power and S_r is the rated power.

Values of K_2 for given values of K_1 and t

	$K_1 = 0.25$	$K_1 = 0.50$	$K_1 = 0.70$	$K_1 = 0.80$	$K_1 = 0.90$	$K_1 = 1.00$
t = 0.5	+	+	1.93	1.83	1.69	1.00
t = 1	1.89	1.80	1.70	1.62	1.50	1.00
t = 2	1.59	1.53	1.46	1.41	1.32	1.00
t = 4	1.34	1.31	1.27	1.24	1.18	1.00
t = 6	1.23	1.21	1.18	1.16	1.12	1.00
t = 8	1.16	1.15	1.13	1.12	1.09	1.00
t = 12	1.10	1.09	1.08	1.07	1.05	1.00
t = 24	1.00	1.00	1.00	1.00	1.00	1.00

ONAN and ONAF transformers: $\theta_a = 20°C$.

Note In normal cyclic duty the value of K_2 should not be greater than 1.5. The values of K_2 greater than 1.5, underlined, apply to emergency duties.

The + sign indicates that K_2 is higher than 2.0.

2-3-9 Fire resistance

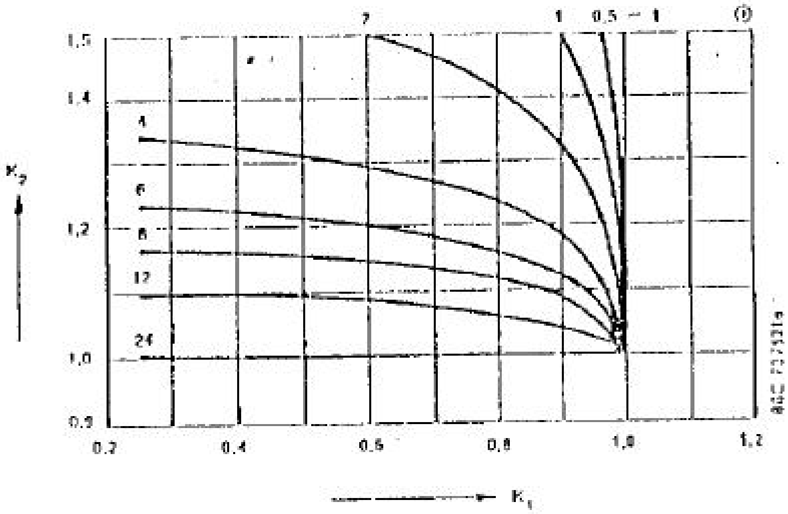
Dry and immersed transformers (except mineral oils) are considered fire proof, this does not mean these materials are non-inflammable although these materials have fire point (is the temperature at which occurs continuous burning of the material when subjects to flam at its surface). The most important factor that must be taken into consideration is material resistance to fire and to be the fire point of the material more high than the maximum temperature of the transformer at full load in worst weather conditions.

- Table (2-11) shows fire point for some fire proof materials (carbonaceous materials are excluded for their danger on the environment). From the table it is clear that there is no great difference between the materials except insulation Class H, which can be considered practically fire proof. Poisonous effect of the vapors emitted from burning of these materials and the resulted danger must be taken into consideration in addition of the other features for comparison purpose.

Removal Heat Rate (RHR) resulted from the burned material is considered an important factor, where depend on it size and nature of the transformer enclosure. This rate consists of two components, one is convective and the other is radiative. The first component is higher in value and is considered a measure of destruction to the ceilings of the transformers buildings, while the second component shows the destructive effect of the fire on the walls and the equipments surrounding the transformer.

- Table (2-12) shows values of these components for some fire proof materials.

Assuming the same service life as for continuous operation at rated power and at an ambient air temperature of 20° C, the transformers may be subjected to a load cycle as shown by the curves below.



The curves are in accordance with the IEC recommendation of 1972 which permits a hot-spot temperature in the windings of 140° C.

in which:

- K_1 = initial load referred to rating
- K_2 = max. permissible load referred to rating
- t = duration of K_2 in h

Note:

In certain cases the permissible overload obtained from the above curves may be limited by the tap changer and bushings. Therefore, if it is intended to operate the transformer with a load cycle involving overloads, the height of the latter and the nature of the load cycle should be stated.

Fig (2-36): Relation between K1 and K2 at different values of loading period t

Table (2-11): Fire point for some fire proof materials

Material*	Fire point (°C)
Silicone liquid	360
Midel 7131	310
Cast resin	350
Class H	†

*For comparison purposes mineral oil is 170°C. Askarel is non-flammable.

†These designs are virtually fire proof.

Table (2-12): Removal Heat Rate (RHR) values for some fire proof materials

Material	RHR	
	convective (kW/m)	radiative (kW/m²)
Silicone 561	53	25
High fire point hydrocarbon	546	361
Epoxy resin	-	-

2-3-10 Connections

- Secondary windings of the distribution transformers are connected at the low voltage side in star connection (Y) and the system is earthed at the neutral point to obtain single voltage.
- The primary windings are connected at the high voltage side in delta connection (Δ) to eliminate the triple harmonics.
- The commonly used connections, according to the shift between the same phase in the primary and secondary windings, are: Dy 11, Dy 5 or Dy 7. Dy11 or equivalent is the most commonly used in the world.
- Fig (2-37) shows these connections in addition to other connections.

  In this figure, HV vector diagram is taken as the original vector and the similar phase in the LV windings is related to it according to clock hour figure.
- Phase shift test for primary windings (High Voltage) and the secondary windings (Low Voltage) is neglected in case of use only one transformer for area network. If the network contains more than one transformer, all transformers must have the same phase relation, otherwise the transformers can not be operated in parallel or to covert the supply of the network from a transformer to another.

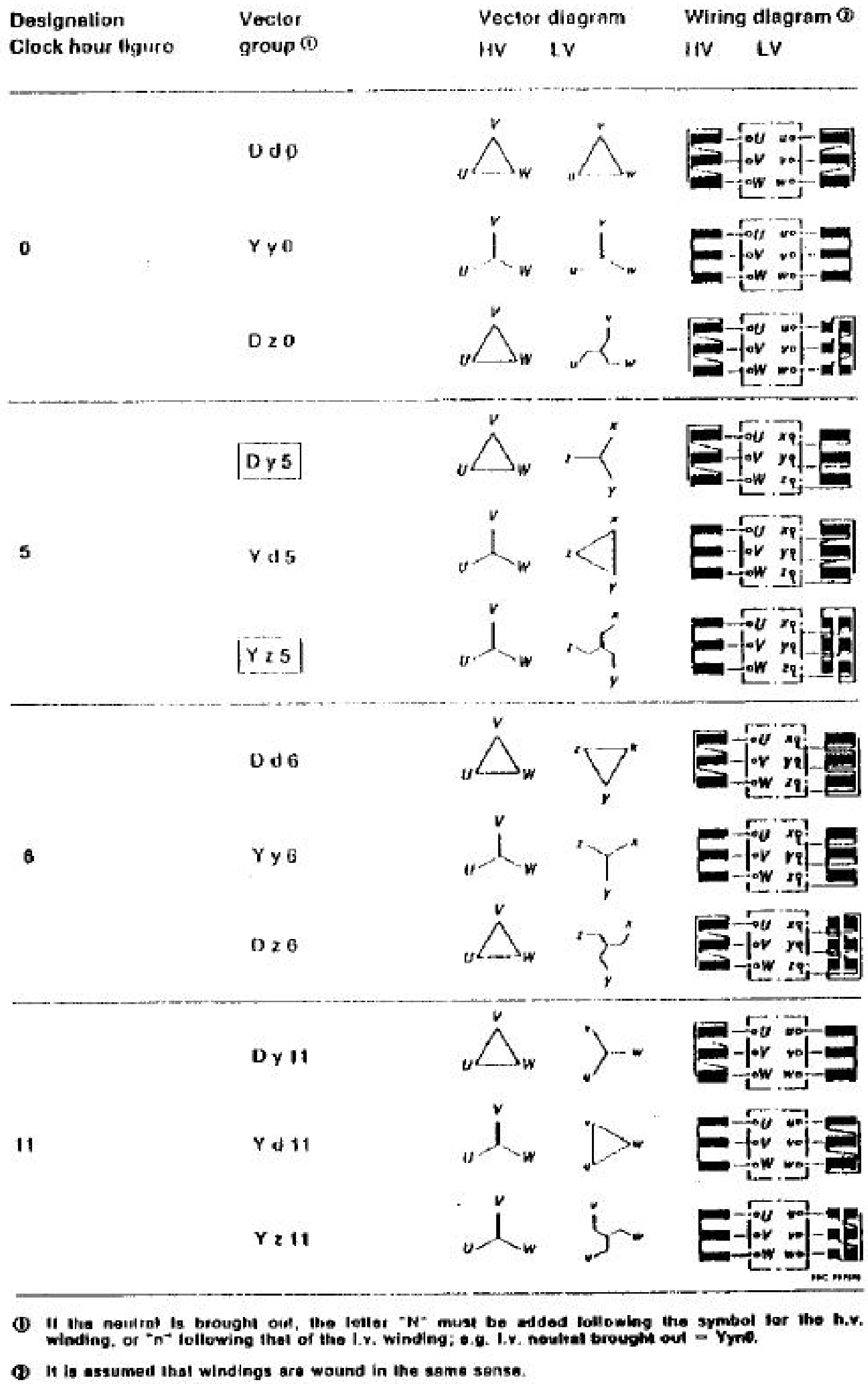


Fig (2-37): Commonly uses vector groups in distribution transformers

2-3-11 Terminals

- LV Terminals in the transformers are in the form of epoxy resin case contains set of pins connected to it cable terminals with screws.
- HV terminals are in the form of cables box filled with compound in case of paper insulated HV cables or upper cables box in case of XLPE or P.V.C cables provided with thermal shrinkable sleeves.

2-3-12 Transformers Cooling

Transformers are identified according to the used method of cooling. Table (2-13) shows the alphabetic letters used as symbols to indicate the cooling method.

- The simplest cooling methods are done by cooling the windings by natural air passing over the hot surfaces of the windings and transformer core, where heat is transferred to the air surrounding the transformer by convection of radiation. This method is described as Air Nature (A.N.).
- To overcome the obstacles that reduce heat transfer from the windings to air, forced-directed air is used over these windings to improve heat flow and increase cooling rates significantly. This method is known as Air Forced (A.F.).

Table (2-13): The alphabetic letters used as symbols to indicate the cooling method in distribution transformers

Kind of cooling medium	Symbol
Mineral oil or equivalent flammable synthetic insulating liquid	O
Non-flammable synthetic insulating liquid	L
Gas	G
Water	W
Air	A
Kind of circulation	
Natural	N
Forced (oil not directed)	F
Forced-directed oil	D

- These two methods can be combined in dry transformers by using natural air cooling with the operation of an automatic fan in case of temperature rise in transformers more than the normal limits. This method is called (AN/AF).
- In case of the transformers immersed in liquids, two groups of letters must be used to describe method of cooling, the first describes windings cooling and the second describes method of cooling surface of the liquid. In case of windings immersed in oil are cooled naturally and in the same time this oil is cooled naturally by air. The letters indicating this are ONAN. If the oil is cooled by the forced air, the cooling method is ONAF. The two methods can be combined through operation of an automatic fan to force the air over the surface of the liquid in case of temperature rise more than a certain limit. This method is known as ONAN/ONAF, so the power of the same transformer can be increased significantly.
- When using a pump to help in oil flow inside the transformer in addition to operation of a fan to force the air, the method is called OFAF.
- For transformers of power 50 KVA or more the natural method of cooling ONAN requires greater cooling surface for oil tank than the normal surface of this tank. This additional surface can be obtained whether by using pipes welded to the tank walls carrying the hot oil from upper most of the tank to the bottom of the tank as used in the past or to use cooling plates similar to that used for hot water, which are installed in the form of banks at the sides of the tank to increase the cooling efficiency and decrease the cost in case of using the pipes. Now, oil tanks made from deep tortuous thin plates (1.2 mm) are used to obtain the highest natural cooling efficiency for the cooling oil of the transformers.

2-3-13 Ventilation of transformer enclosure

- The transformers used inside closed enclosure, its temperature will be higher at the same load than that used in the open air. So, to increase service life of the transformers, this matter must be taken into consideration when design transformers enclosure to limit this temperature rise.
- A balance must be made between advantages of using ventilation fans for these enclosures to limit temperature rise and the advantages of natural ventilation that does not depend on efficiency of performance and maintenance of these fans and the dangers resulted from the sudden stop of the fans.
- Temperature rise in transformers enclosures depends on the following:

(A) Transformer total losses.

(B) Net area of ventilation openings (inlet and outlet).

(C) Active vertical distance between inlet and outlet openings.

- Ideal location of air inlet opening is lower and under the center line (C.L.) of transformer radiator and to install the transformer as near as possible from it.
- Air outlet opening is at high location and must not directly over the transformer, but is located on the wall apart from the inlet opening to enable pass of the cold air over the transformer while passing from inlet opening to outlet opening.

- Minimum distance of the outlet opening from the inlet opening in the ideal case is equal to one and half height of the transformer.
- Net area of the inlet opening or the outlet opening is calculated from the following empirical formula:

$$A = 0.06\ P \qquad (1)$$

Where:

P = Total loss emitted from the transformers (KW)

A = Area (m^2)

Also, the following formula can be used:

$$AL = 0.188 . \frac{P}{\sqrt{H}}$$

Where:

AL = Cross section area of both ventilation openings (inlet-outlet) (m^2)

P = Total loss of the transformer (KW)

H = Distance between center of the transformer to the center of the outlet opening (m).

- Fulfilling the above conditions, air temperature of transformer enclosure must not exceed the ambient temperature more than 7-8°C.

Fig (2-38) shows nomogram for determination of areas of air inlet and outlet.

Fig (2-39) shows installation of the transformers in sealed enclosure.

2-3-14 Transformers Insulation Strength

Transformers insulation strength is tested at 75 KV for the transformers installed inside the enclosures and the electrical current supply is connected through cables, and at 95 KV for the transformers installed on posts or outside the buildings and the electrical current supply is connected to them through upper lines.

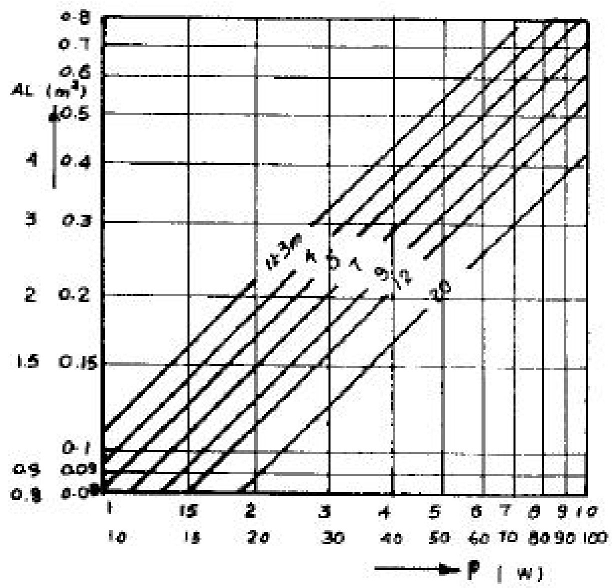
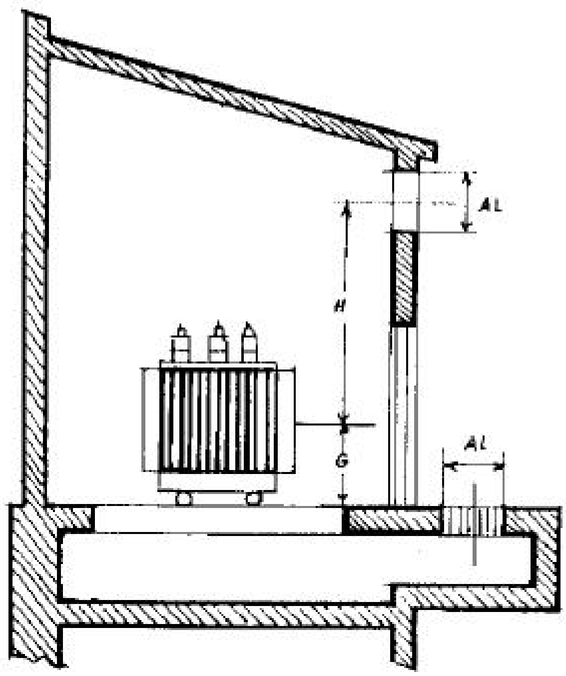


Fig (2-38): Nomogram for determination of areas of air inlet and outlet



Output KVA	63/100	160	250	400/500	630/800	1000/1750	1600/2000	2500
G mm	610	645	685	730	795	940	1075	1195

Fig (2-39): Installation of transformers in sealed enclosure

2-3-15 Parallel Operation of the Transformers

- Acceptable parallel operation of the transformers is that each transformer must carry its share of the rated power. To achieve this condition, the transformers connected in parallel must have the following:

- Same ratio of voltage transfer.
- Same phase shift.
- Same impedance.

Therefore, any two transformers of 3-phase transformers that have the same properties and same connection symbols can be operated in parallel (e.g. the two connections 11Yd and 11Dy can be safely operated in parallel).

The impedance controls the share of each transformer in the total load. In this case, the resistance of each unit must be symmetrical.

- There are other points must be taken into consideration such as:

A) Impedance of the transformers can be changed within $\pm$ 10% of the value of impedance test, accordingly they may exist two transformers have the same impedances according to the test although their difference in impedance of about 20%.

B) Length and type of the cable used in connection of the transformer must be taken into consideration when calculating the impedance in case of connection of new transformer in parallel if this transformer in located at location apart from the working transformers.

C) For the transformers that have division range exceeds 10%, change in impedance must be taken into consideration within this range.

In addition to above, there is great difference between transformer producers in terms of windings which give significant change in transformer properties.

2-3-16 Transformer Protection

The transformers are provided with the following protections:

2-3-16-1 Differential Protection

Differential protection depends on the comparison between the primary and secondary currents of the transformer. In case of unbalance, this means occurrence of external fault outside the transformer. As the connection of the primary and secondary windings is usually different, it must be balanced by connection of suitable current transformers (CTS).

2-3-16-2 Restricted Earth Fault Protection

Secondary windings of triple current transformers (CTS) are assembled at a side of the transformer windings with a relay connected across them. A fourth current transformer (CT) is connected on the neutral point of the windings connected in the shape of (T) connection. The relays are energized only in case of internal earth fault, where the output of the current transformers does not give zero sum which causes flow of current in relay circuit.

2-3-16-3 Unrestricted Earth Fault Protection

One current transformer (CT) is connected on the neutral point of the star (Y) windings gives measure of the earth fault protection, but the relay in this case energized also in case of occurrence of faults outside the transformer.

2-3-16-4 Over current protection

The positions of the over- current relay must be adjusted in order to be able to discriminate the protection at the load side of the transformer (and not to protect the network behind the transformer).

2-3-16-5 Gas and Oil Relay

Gas and oil relay is installed in the pipe connecting between main oil tank of the transformer and the compensation tank. It is usually exist in the oil transformers of power 1500 KVA and more. The relay is provided with two floats holding switches normally opened or normally closed. One float is operated when the oil level in the compensation tank, and consequently in the relay, reaches to undesired low level. The switch is connected usually at the low level with alarm circuit that gives alarm when the oil level in the transformer decreases. The other float is operated when there is sudden emission of gas inside the transformer in case of existence of a serious fault or burning of the transformer windings. Switch contacts in this float is usually connected to a trip circuit in the control board of the transformer, which disconnects the transformer from the source of current supply. It must take into consideration that at the start of the transform there is some gas emitting from the air bubbles exist in the oil that may energize the gas and oil relay and give false alarm.

2-3-16-6 Pressure-Relief Devices

The device in installed on the cover or the walls of the main tank of the transformer and is operated when the pressure inside the tank increases, where the seal snaps are opened and allow discharge of the collected gas through a wide nozzle with rate reaches 283 m^3/min.

2-3-16-7 Winding Temperature Indicators

As it is difficult to measure winding temperature by direct contact with the conductors of these windings, winding temperature indicator is considered the most accurate indicator through a narrow strip to load the transformer.

There are two main types of winding temperature indication:

A. Direct method: Where the device probes are put as near as possible from LV windings.

B. Indirect method: Where a thermal image device represents or simulates the temperature difference between the windings and over the oil level.

Method (A) is used in most cases with the dry transformers, where the wide cooling passages allow putting the thermal probes of the device in order not to damage the insulators of transformer windings.

- The indirect method uses a measuring structure consists of temperature indicator provided with disc and pointer and current transformer installed on the life terminal of transformer windings, where the corresponding current flows from its secondary windings to a thermal coil winded on the control winding of the measuring device. Through a calibration resistance the current flowing can be adjusted in the thermal coil to a value that produces the correct difference between the windings and the oil.
- There are other methods suitable for the large transformers, where a standard platinum resistance of value 100 ohm is used as a probe fixed as near as possible from transformer windings, and the device measures the resistance of this probe, where its value changes as windings temperature changes.
- The temperature indicators are connected to alarm circuits or disconnection circuits. They can also be connected to three or four switches to operate fans or pumps to force the air or oil to a cooling cycle outside the transformers.

2-4 Electrical Cables

2-4-1 Current Rating

* When an electrical current passes in the conductor of the cable, heat is produced in the conductor and is proportional to the heat quantity produced per unit time and the product of the current passing in the conductor and the conductor resistance.

Therefore,

$$\frac{W}{t} = I^2 R \text{ -- } (1)$$

$\frac{W}{t}$ = Produced heat quantity per unit time (W/Sec)

I = Current passing in the conductor (Ampere)

R = Conductor resistance (Ohm)

* The generated heat rises conductor temperature and produces a temperature difference in comparison with the ambient temperature of the conductor (air or ground), where the generated heat flows through the insulating material of cable conductor.

* Quantity of the flowed heat per second is proportional to the temperature difference produced from the current flow. Consequently, the temperature difference ΔT at a certain current increases in order to reach to balance in temperature at a point where the heat flow to the ambient environment per unit time is equal to the heat quantity generated in the conductor

That means:

$$\theta = \frac{W}{t} \text{ ———————————————— } (2)$$

Where:

θ = Heat flow per second

* By applying Ohm's Law, the heat flow is calculated as follows:

$$\theta = \frac{\Delta T}{Rth} \text{ ———————————————— } (3)$$

Where:

R_{th} = Thermal resistance of the conductor (thermal ohm) and is calculated in °C/Watt

The thermal resistance consists of internal thermal resistance (Rthi) from the conductor to the outer surface of the cable and external thermal resistance (Rthe) from the outer surface of the cable to the ambient environment.

* When reaching to balance in temperature and applying formulas (1), (2) and (3), then:

$$I^2 R = \frac{\Delta T}{(Rthi + Rthe)}$$

Or:

$$\Delta T = I^2 R \quad (Rthi + Rthe) \qquad (4)$$

Note:

In case of alternating current, conductor impedance must be calculated as well as the induced currents in the metallic enclosure of the cable, but to facilitate the calculations, formula (4) can be used to give practical acceptable and sufficient results.

* Maximum allowed temperature of the conductor must be specified in the insulating materials properties used in the cables, and consequently the temperature difference between the surrounding medium of the cable and the conductor is restricted. This can be achieved only by restricting the heat generated inside the conductor. From formula (4), the value I^2R must be decreased by the following:

A Restricting conductor resistance R by selecting a conductor of sufficient cross section area.

B Restricting the allowed maximum current I_{max} at a certain cross section area of the conductor.

* Internal thermal resistance (R_{thi}) depends on the cable construction and can be calculated from cable dimensions and specific resistance of the materials used in insulation and cladding. External thermal resistance (R_{the}) of the cable depends on many external factors that have effect on the thermal convection.

* There are difficulties in specifying the current flow in the cable, not only related to the cable itself, but also to heat flow rate θ, which are the cooling problems. These difficulties can be avoided in the ordinary cables used in the economic range by specifying the allowed current by using rules applied in the normal conditions. Current rating tables are prepared for standard cross section areas of the cables and are used to find the current.

The same tables are used for LV cables regardless of the used insulating material.

* It must discriminate between two systems of laying the cables:

- Cables laid in the air.

- Cables laid in the ground.

This principal is used in cables current rating tables.

* Maximum current flow in each cross section area of the copper conductors is prepared such that the temperature difference between the conductor and the surrounding medium ΔT in normal operating conditions must not exceed 35°C, hence in atmosphere temperature of 25°C for the cable laid in air, conductor temperature will be more than 60°C for the cables insulted by P.V.C.

* Insulation material can affect cable temperature, where the temperature increases as the thermal resistance of this material increases.

LV current rating tables are prepared for XLPE insulation for maximum temperature of copper conductor of 85°C.

* Table (2-14) shows current ratings for copper cables laid in air with P.V.C insulated conductors.

* Table (2-15) shows current ratings for copper cables laid in the ground with P.V.C insulated conductors.

* Table (2-16) shows current ratings for copper cables laid in air with XPLE insulated conductors.

* Table (2-17) shows current ratings for copper cables laid in the ground with XPLE insulated conductors.

* Table (2-18) shows current ratings for multi-core cables with XPLE or PVC insulated conductors in an ambient temperature of 25°C.

2-4-2 Derating Factors

If cooling of the cable is restricted to a certain limit, the current flow in this cable must be reduced to prevent reaching to a high temperature exceeds the limits specified to the used insulation.

The factors that restrict normal cooling rate are:

Table (2-14) Current ratings for copper cables laid in air with P.V.C insulated conductors

Current rating and protection for cables laid in air with rubber, PVC or paper-insulated conductors, in accordance with NEN 1010 (2nd edition), Art. 152[1])

Nominal cross sectional area of copper conductor	Single core cables[2])		Twin-core cables		Three- and four-core cables	
	Current rating	Highest nominal value of the fuse	Current rating	Highest nominal value of the fuse	Current rating	Highest nominal value of the fuse
mm²	A	A	A	A	A	A
1.5	27	25	24	20	20	16
2.5	40	35	31	25	27	25
4	52	50	40	35	36	35
6	65	63	52	50	46	35
10	88	80	72	63	62	50
16	115	100	96	80	80	63
25	150	125	—	—	105	100
35	185	160	—	—	125	100
50	230	200	—	—	155	125
70	280	250	—	—	195	160
95	335	315	—	—	235	225
120	385	355	—	—	270	250
150	440	400	—	—	310	250
185	500	450	—	—	345	315
240	565	500	—	—	385	355
300	670	630	—	—	425	400
400	790	710	—	—	490	450
500	900	800	—	—	—	—
625	1040	1000	—	—	—	—
800	1200	—	—	—	—	—
1000	1360	—	—	—	—	—

Table (2-15) Current ratings for copper cables laid in the ground with P.V.C insulated conductors

Current ratings and protection for cables, laid in the ground with rubber, PVC or paper-insulated conductors, in accordance with NEN 1010 (2nd edition). Art. 153[1]).

Nominal cross sectional area of copper conductor	Single-core cables[2])		Twin-core cables		Three- and four-core cables	
	Current rating	Highest nominal value of the fuse	Current rating	Highest nominal value of the fuse	Current rating	Highest nominal value of the fuse
mm²	A	A	A	A	A	A
1.5	34	35	30	25	25	20
2.5	50	50	38	35	35	35
4	65	63	50	50	45	35
6	82	80	65	63	57	50
10	110	100	90	80	76	63
16	145	125	120	100	100	80
25	190	160	—	—	130	125
35	230	225	—	—	155	125
50	285	250	—	—	195	160
70	350	315	—	—	245	225
95	420	400	—	—	295	280
120	480	450	—	—	340	315
150	550	500	—	—	385	355
185	625	500	—	—	430	400
240	730	710	—	—	480	400
300	835	710	—	—	530	500
400	985	900	—	—	615	500
500	1130	1000	—	—	—	—
625	1300	—	—	—	—	—
800	1500	—	—	—	—	—
1000	1700	—	—	—	—	—

Table (2-16) Current ratings for copper cables laid in air with XPLE insulated conductors

Current ratings and protection for cables laid in air with (cross-linked polyethylene) insulated conductors.

Nominal cross sectional area of copper conductor	Single core cables*		Twin core cables		Three- and four-core cables	
	Current rating	Highest nominal value of the fuse	Current rating	Highest nominal value of the fuse	Current rating	Highest nominal value of the fuse
mm²	A	A	A	A	A	A
1.5	30	25	30	25	25	20
2.5	45	35	40	35	35	25
4	55	50	52	50	45	35
10	75	63	70	63	60	50
6	100	80	95	80	80	63
16	135	100	125	100	105	80
25	185	160	—	—	135	100
35	225	200	—	—	165	125
50	270	250	—	—	205	160
70	340	315	—	—	255	200
95	400	355	—	—	310	250
120	480	400	—	—	355	315
150	550	450	—	—	405	355
185	615	500	—	—	450	400
240	745	630	—	—	505	450
300	850	710	—	—	—	—
400	1000	800	—	—	—	—

Table (2-17) Current ratings for copper cables laid in the ground with XPLE insulated conductors.

Current ratings and protection for cables, laid in the ground with cross-linked polyethylene) insulated conductors[1]).

Nominal cross sectional area of copper conductor	Single-core cables[2])		Twin-core cables		Three- and four-core cables	
	Current rating	Highest nominal value of the fuse	Current rating	Highest nominal value of the fuse	Current rating	Highest nominal value of the fuse
mm²	A	A	A	A	A	A
1.5	43	35	38	25	31	25
2.5	63	50	48	35	44	35
4	82	63	63	50	57	50
6	103	80	82	63	72	63
10	138	125	113	100	96	80
16	182	160	151	125	126	100
25	240	200	—	—	163	125
35	290	250	—	—	195	160
50	360	315	—	—	245	200
70	440	355	—	—	310	250
95	530	450	—	—	370	315
120	600	500	—	—	430	355
150	690	630	—	—	485	400
185	790	710	—	—	540	450
240	920	800	—	—	600	500
300	1050	900	—	—	670	630
400	1240	1000	—	—	775	710
500	1420	—	—	—	—	—

Table (2-18) Current ratings for multi-core cables with XPLE or PVC insulated conductors in an ambient temperature of 25°C.

Number of cores	Current per core in A			
	Rubber or PVC-insulated cables		(XLPE)-insulated cables	
	1.5 mm²	2.5 mm²	1.5 mm²	2.5 mm²
6	15	21	18	25
7	14	19	17	24
8	13	18	16	23
10	12	16	14	20
12	11	15	13	19
14	10	14	12	18
16	10	13	12	17
19	9	12	11	16
24	8	11	10	14
30	7	10	9	13
37	7	9	8	11

− Increase in ambient temperature.

− Effect of the adjacent cables carrying current whether the cables laid on the walls, trays or in the ground.

− Less of moisture in the ground in which the cables are laid.

− Circumference of the cable installed totally of partially on a reel or cylinder.

In all cases, maximum current ratings in the tables must reduced by a certain percentage.

* Table (2-19) is used as a practical guide for derating factors for rise in ambient temperature, effect of grouping of cables, variation of thermal resistivity of the soil due to changing in moisture percentage and for cables on reels.

* In case of existence of more than one affecting factor at the same time, the derating factors must be taken into consideration corresponding to these effects. .

* Precaution must be taken in case of installing more than one cable in the same trench or duct, where it is difficult to provide sufficient ventilation and specifying accurate derating factor.

2-4-3 Voltage Drop

The voltage drop in the cable is the difference between the voltages measured at the two ends of the cable.

Drop percentage of the circuit voltage rating is:

- Maximum 5% for lighting system
- Maximum 2% for power system.

Table (2-19) Practical guide for derating factors for rise in ambient temperature, effect of grouping of cables, variation of thermal resistivity of the soil due to changing in moisture percentage and for cables on reels

Derating factors for the variation in ambient temperature exceeding 25 °C.

temperature			25° C	30° C	35° C	40° C	45° C	50° C	60° C	70° C
derating factor	XLPE	f1	1.00	0.95	0.91	0.87	0.82	0.76	0.65	0.50
derating factor	PVC	f2	1.00	0.93	0.85	0.76	0.65	0.53		

Derating factors for grouping of cables laid in air

number of cables			2	3	4	5	6
clearance equal to cable diameter	XLPE and PVC	f3	0.94	0.90	0.87	0.85	0.83
cables laid side by side without interspace	XLPE and PVC	f4	0.81	0.79	0.77	0.75	0.73

Derating factors for grouping of cables laid direct in the ground (depth appr. 70 cm, distance between the cables appr. 10 cm)

number of cores and cross sectional area of the conductor				number of cables							
single core	three and four cores			2	3	4	5	6	7	8	9
95 mm² and less	35 mm² and less	f5	XLPE and PVC	0.90	0.82	0.78	0.74	0.72	0.70	0.68	0.66
120/300 mm² incl	50 and 70 mm²	f6	XLPE and PVC	0.89	0.80	0.75	0.71	0.68	0.66	0.64	0.62
400 mm² and more	95 mm² and more	f7	XLPE and PVC	0.87	0.78	0.72	0.68	0.64	0.62	0.60	0.58

Derating factors for variations in thermal resistivity of the soil

specific heat resistance of the soil in °C.cm/W			50 (damp)	100	150	200 (very dry)
derating factor	XLPE and PVC	f8	1.0	0.8	0.7	0.6

Derating factors for cables on reels

number of layers on reels			1	2	3	4	5
derating factor	XLPE and PVC	f9	0.50	0.38	0.32	0.27	0.24

* Accurate voltage drop can be calculated from the circuit vector diagram, and in most cases the accurate calculation is not necessary and it is sufficient approximate calculation as follows:

A) For DC

$$\Delta\upsilon = 2.I.l \quad \frac{r}{1000}$$

Where:

$\Delta\upsilon$ Voltage drop between the two ends of the cable in volt (measured between the poles)

I = Current rating in Ampere.

l = Cable length in meter.

r = Cable resistance in ohm/km

B) For single phase AC

$$\Delta\upsilon = 2.I.l. \frac{r \cos\phi}{1000}$$

$\Delta\upsilon$ Voltage drop between the two ends of the cable in volt (measured between the phase and the neutral point)

I = Current rating in Ampere.

l = Cable length in meter.

r = Cable resistance in ohm/km

Cosϕ = Power factor of the cable load.

C) For three phase AC

$$\Delta\upsilon = \sqrt{3}\, I.l \frac{r \cos\phi}{1000}$$

Where:

$\Delta\upsilon$ Voltage drop between the two ends of the cable in volt (measured between the conductors of the same phase)

I = Current rating in Ampere.

l = Cable length in meter.

r = Cable resistance in ohm/km

sin ϕ = Power factor of the cable load.

Note:

The above values are sufficiently accurate when the impedance of the cable (χ) can be neglected compared with cable resistance (r), which is the normal case of cables with cross section area not more than 70 mm^2.

For cables with greater cross section area, the voltage drop is calculated as follows:

(1) For single phase AC

$$\Delta\upsilon = 2.I.l. \quad \frac{r\cos\phi+\chi\sin\phi}{1000}$$

(2) For three phase AC

$$\Delta\upsilon = \sqrt{3}\ .I.l. \quad \frac{r\cos\phi+\chi\sin\phi}{1000}$$

Where:

χ is cable impedance in ohm/km

Can be taken 0.1 ohm/km

* The nomograms shown in Fig (2-40) and Fig (2-41) are used for practical applications.

2-4-4 Cables short circuit

2-4-4-1 Thermal short circuit rating with PVC insulted

Thermal short circuit rating is calculated from the following formula:

$$Ik= \frac{109}{\sqrt{t}} \quad .q$$

Where:

IK = Short circuit rating in KA

t = Short circuit time in second

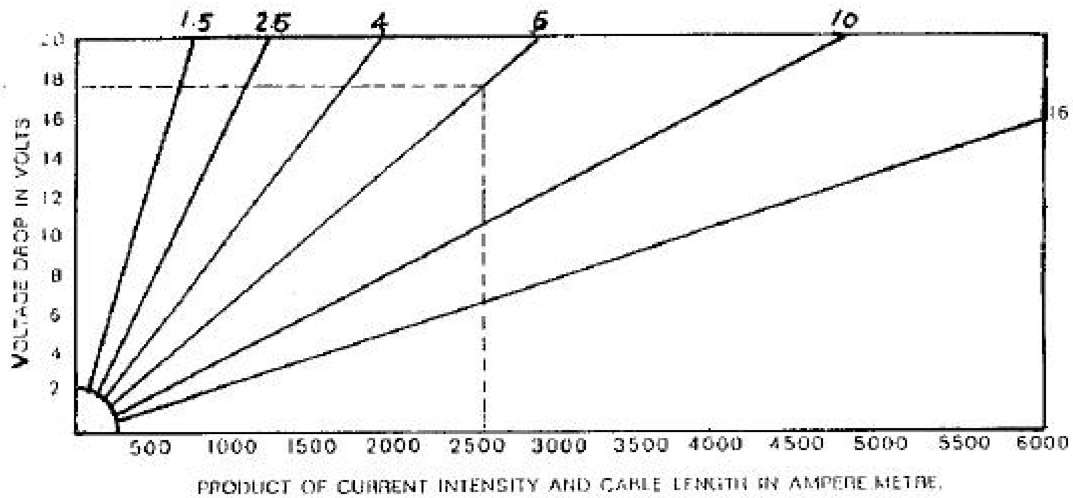


Fig (2-40): Nomogram for calculation of voltage drop for double cores cable, single phase alternating current, Cosϕ = 1.0

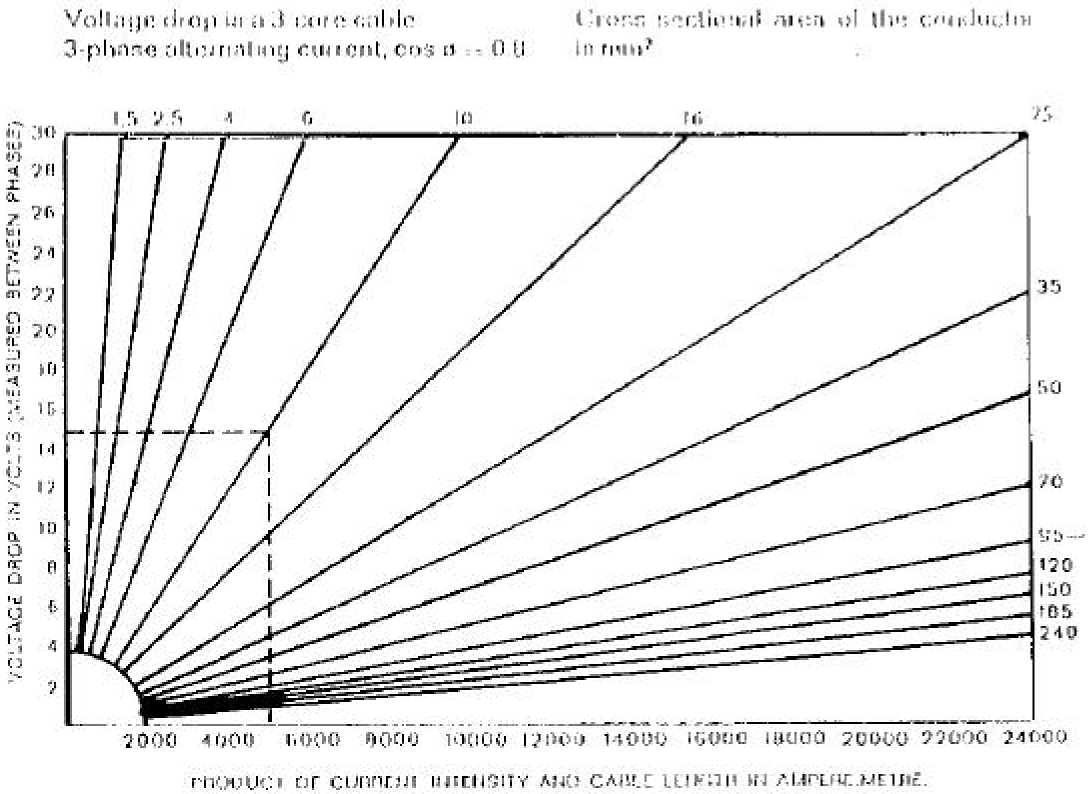


Fig (2-41): Nomogram for calculation of voltage drop for 3- core cable, 3- phase alternating current, Cosϕ = 0.8

q = Nominal cross section area of the copper conductor in mm^2

This formula is applicable for temperature rise between (70-150) °C

Fig (2-42) shows nomogram the relation between the short circuit, time and the cross section area of the cables with PVC insulated conductors by applying the above formula.

2-4-4-2 Thermal short circuit rating with XPLE insulted

Short circuit is calculated from the following formula:

$$Ik = \frac{\sqrt{t}}{144} \cdot q$$

IK = Short circuit rating in KA

t = Short circuit time in second

q = Nominal cross section area of the copper conductor in mm^2

This formula is applicable for temperature rise between (85-250) °C

Fig (2-43) shows nomogram the relation between the short circuit, time and the cross section area of the cables with XPLE insulated conductors by applying the above formula.

2-4-5 Design considerations for installation of cables, pipes and their dusts

Egyptian Code Concerning Design Criteria and Rules of Electrical Installation in Buildings must be taken into consideration when determine specifications of cables, fittings, pipes and their ducts.

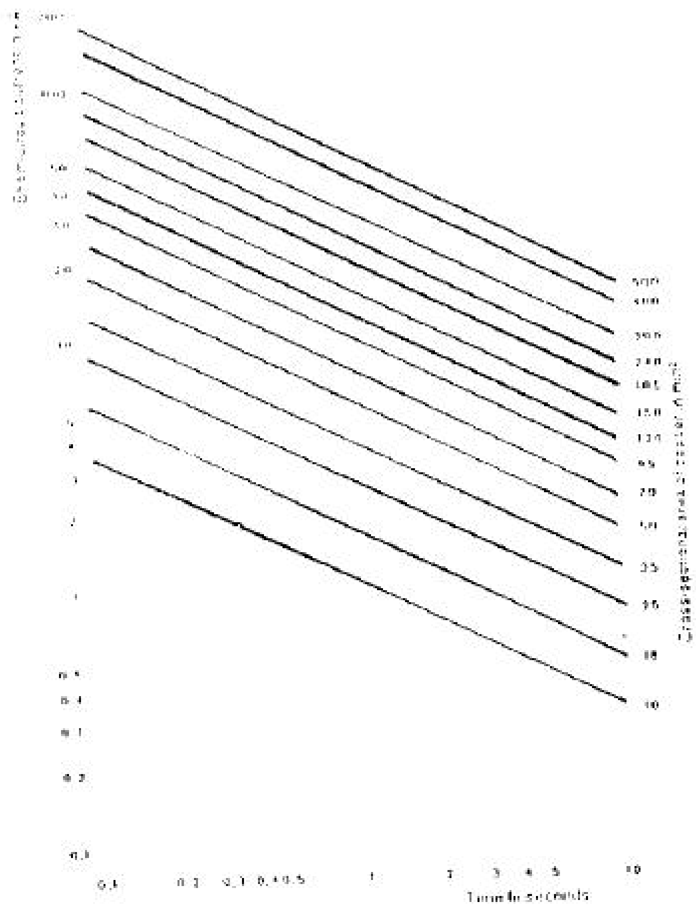


Fig (2-42) Nomogram the relation between the short circuit, time and the cross section area of the cables with PVC insulted conductors (LV copper conductor cables)

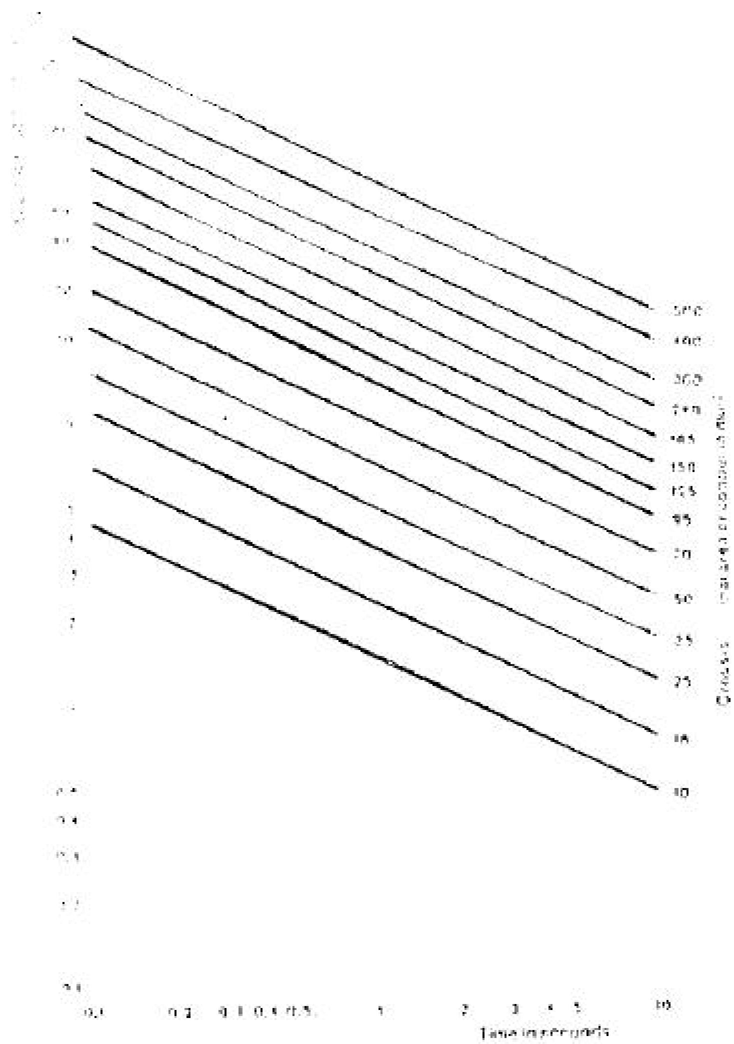


Fig (2-43) Nomogram the relation between the short circuit, time and the cross section area of the cables with XLPE insulted conductors (LV copper conductor cables)

2-5 Electrical Power Generation Station

Introduction

For the importance and necessity of continuous lift of the pumping station in case of current interruption from the city supply to the station, it must provide alternative power supply to the plant by construction of emergency electricity generation station as integral part of the plant for continuous operation purpose.

2-5-1 Power of the emergency power station

- Emergency power station must have a power commensurate with the operation of all pumps and operating devices in the pumping station.

2-5-2 Number of units of emergency power station

According to the above mentioned emergency power for operation of the pumping station, minimum number of the generation units shall be determined to achieve balance between economic aspects and secure of operation taking into consideration the available area.

2-5-3 Specifications of Generation Unit Motors

Power : Emergency power / number of generation units.

Cycle : Four strokes

Fuel : Diesel/ solar with sprincklers, fuel pump and Turbo charger.

Cooling : Water or air according to the location of the station and the availability of the cooling water.

Starter : Electrical or compressed air

Cylinders order : According to the power and the available area, row of V type will be selected.

Engine Speed N : Engine speed in specified in rpm according to current frequency (f) (50 c/s) and number of poles of the electrical generator (P) by the following equation.

$$f = \frac{P.N}{60} \quad Hz$$

Motor speed is taken as follows:

Less than 300 KW	: 1500 rpm
More than 300 KW up to 600 KW	: 1000 rpm
More than 600 KW up to 1500 KW	: 750 rpm
More than 1500 KW	: 600 rpm

2-5-4 Diesel Motor Components

Motor Intake

- Air requirements are estimated by 0.07 m^3/min/hour brake of the motor power.
- Air intake is provided by internal air filter.
- When using turbo charger, it must provide a straight length not less than 5 cm before connection it with the motor air intake.

- Air pipe connections must be designed in a way that facilitates replacement of the filter in addition to isolation of motor vibrations and noise.

Engine Exhaust

- Exhaust pipes and the silencer must be thermally insulated to protect the workers in generation house and prevent temperature rise in the house that may affect intake air temperature or starter batteries.
- Path of the exhaust pipes must be kept away from any flammable materials by a distance not less than 25 cm.
- Exhaust pipes must pass inside enclosure of diameter not less than one and half exhaust pipes diameter when passing through the walls or the ceilings.
- End of the exhaust pipes must be chamfered at angle from 30° to 45° to reduce formation of gas cyclones, reduce noise and protection from rains.

House Ventilation

- Generation units' house must be ventilated, as the good ventilation saves from 6% to 10% of fuel consumption due to the heat dissipation in the house, improves production of generation units and distribution boards and provide suitable atmosphere for operation and maintenance works in the house.
- Ventilation of the house must be kept at 38°C.

Engine Cooling

- Cooling cycle must contain thermostat allows operation over 80°C to keep the motor efficiency at starting up.
- Temperature difference between inlet and outlet cooling water must be between 5°C t0 8°C.
- Cooling water pressure must be between 0.25 to 0.45 kg/cm^2 to prevent formation of vapor inside the radiator and engine cooling chest.
- Temperature of the upper part of the radiator must be less than 100°C to prevent confinement of cooling water pump and increase its efficiency.
- Speed of pure cooling water is between 0.6 m/sec and 2.5 m/sec, while it is from 0.6 m/sec and 1.9 m/sec in case of raw water.
- Quality of cooling water (pure or raw) must be taken into consideration when determining the velocities inside cooling cycle pipes.

2-5-5 Fuel System

Main Storage

- Fuel is stored in large tanks with sufficient volume for operation of all generators at full load for a period ranging from one week to two weeks continuously according to the distance from supply sources.
- Main fuel tanks may be under or over ground surface.
- Fuel tank is made from treated steel plates and not from galvanized iron to avoid chemical reactions with the fuel.

- Main tanks must be over ground surface in case of availability of the necessary area away from the surface motion and under the ground surface in case of unavailability of the necessary area.

Tank Components

- Tank filling pipe installed in a way that achieves safe operation processes.
- Tank vent pipes.
- Measuring hole.
- Drain valve at the bottom of the tank to suck the sediments at regular intervals.
- Electrical pumps to transfer fuel from main tanks to daily tanks.
- Tank components are made from treated steel (and not galvanized iron), steel or copper.

Daily Storage

- Daily tank is installed in generators house.
- Fuel suction and return pipe diameters must not less than motor components and pipes diameters for the all pipe lengths.
- Pipe diameters are increased in case of supply fuel to more than one motor, and also in case of temperature decrease.

Filters

- Filters are installed to prevent fuel sediments which cause blockage of the fuel injection sprinkle nozzles and injection pumps.

- Filters are provided with grid screens with spacing 0.3 mm.
- Large motors are provided with two filters with a means of change of any of them to facilitate cleaning and replacement of the damaged filter during operation to avoid fault of the motor.

2-5-6 Starting Systems

The generator motor is started by one of the following two methods:

- Electrically (battery + starter motor) for the engines of power up to 500 KW
- Compressed air for the engines more than 500 KW.

Electrical Starting motion

The following points must be followed when using this method:

- It is preferred to use lead acid batteries because they are less expensive than the nickel cadmium batteries.
- Generators house temperature must not exceed 38°C to maintain the power and operation efficiency of the batteries.
- Copper cables must be used in the connections between the batteries and starter motor.
- Battery charger must be used in generators house to charge the batteries during stop operation of the generators, in addition to the DC generator which charges the batteries during operation of the engines.

Starting motion by compressed air

The following must be taken into consideration when using this method:

- Provision of air compression ranging from 7 kg/cm^2 to 16 kg/cm^2 from the an air compressor, air tanks and non-return valves between them.
- Volume of the air tanks must be selected according to air quantity necessary for each operation, number of operations, tank pressure and atmospheric pressure. This volume is determined by supplier of the engines.
- The main air compressor is operated by internal combustion engine turned by benzene, kerosene or solar.
- Provision of an emergency air compressor operated by electrical motor.

3- Design rules for and architectural works

3-1 Architectural Works

3-1-1 Layout

Units must be distributed on the site layout of the pumping stations in a way that allows the provision of the following rules:

A. Main roads and sub-roads must be with the width that allows entrance and exit of the cars and to perform the necessary maneuvering, taking into consideration levels of the roads and sidewalks with the constructions that will be implemented.

B. Existence of the guard rooms and information room adjacent to the main entrance of the plant.

C. Provision of green areas between the units.

D. Administrative building units must be away from the sump and to study wind direction to avoid subjection of the buildings to bad smells and gases.

E. The site must be provided with water, irrigation, fire, sanitary drainage, electricity and lighting networks.

F. Areas for car parking.

G. Construction of suitable fence.

3-1-2 Project Units

The following are the design rules for some units that consider the aesthetical aspects (color and heights coordination of project units):

3-1-2-1 Motors House

- Floor level of motors house must be at height 30 cm from road level.
- Easy electricity supply taking into consideration the economic aspects.
- The distance between crane beam and the lowest point of ceiling beam must not less than 1.5 m.
- Provision of sufficient ventilation and lighting inside the house.
- Provision of handrails around sump roof openings inside motors house.
- Cable trenches must be submersed in the floors.
- Motors house floor must be from ceramics resistant to acid and friction and the walls from faience at suitable height.
- Stairs opening at sump roof must be of size 1.20 × 1.20 m
- Existence of 2 openings at sump roof at the sides of the dry part with size not less than 30 × 30 cm for suction and air circulation.

3-1-2-2 Generator and Transformers Building

- Easy access to transformers building doors at the external fence and at the main roads and sub-roads.
- The distance between crane beam and the lowest point of ceiling beam must not less than 1.5 m
- Provision of sufficient ventilation and lighting inside the house

- Internal finishing must be from materials suitable to the building. Floors must be from ceramics resistant to acids and friction and cable trench covers at the ground level to not hinder the motion.

3-1-2-3 Workshops and Stores

- The distance between crane beam and the lowest point of ceiling beam must not less than 1.5 m
- Provision of sufficient ventilation and lighting inside the house
- Easy access of cars, equipments and instruments to workshops and stores entrance.
- Near from workers rest room and toilettes.
- Internal finishing must be from materials suitable to the building. Floors must be from ceramics resistant to acids and friction and cable trench covers at the ground level to not hinder the motion

3-2 Construction Works

Refer to Egyptian Codes concerning construction works.

4- Preparation of Tender Documents

4-1 Introduction

Released tender documents must contain technical information of the project, general and special conditions, which are the provisions referred to them contract parties, if necessary.

4-2 Contents of tender documents

Tender documents contain the following volumes:

- General and special conditions and technical specifications.
- Estimated bill of quantities
- As built drawings.
- Any other documents prepared by the designer, such as borings report, analyses of soil and groundwater.

4-2-1 Volume (1): General and special conditions and technical specifications of the project

This volume shall contain:

(A) Invitation to tender.

(B) Tender form.

(C) Instructions to bidders.

(A) Invitation to Tender

Invitation to tender will be in one or two pages with brief description about the project and tender procedures. It also contains method of obtain copy of tender documents, price, date and place of submitting these documents. The tender is published in the daily newspapers (two widely spread newspapers) in two consecutive days.

(B) Tender Form

Tender form determines standard format for the contractors to submit their prices and offers to the employer which facilitates technical and price comparison works for equal opportunities.

(C) Instructions to Bidders

Instructions to bidders are the standard base of the bids that help to arrange bid contents in standard order according to tender form. These instructions shall cover the Following:

- Definitions.
- Offer of bidders.
- Tender documents.
- Tender procedures.
- Tender requirements.

- Mail instructions.
- Primary and final insurance
- Contract form between the owner and the contractor.
- Additional instructions.

4-3 Insurance Forms

Tender documents contain format for primary insurance submitted with the bid and the final insurance that shall be submitted by the winner contractor from approved bank. The format shall contain a provision states that the employer has the right to issue this insurance for his benefit at first statement from the bank in this regard without any objection from the contractor. This insurance must be valid to cover its purpose.

4-4 Contract between the owner and the contractor

This contract is considered an independent document and shall cover five main principals as follows:

- Legal capacity and competence of the parties to act and conclude the contract. Sufficient number of copies must be signed for the owner, contractor, the engineer (if any), contract and purchasing department and state counsel.
- Clear brief description of the project.

- Expected implementation period. This part is very important, as according to it fine delays or contract extension, etc. may be imposed.
- The price, whether a fixed price covers the entire project, price for each item of works or LS price for each group of similar items of the works, as agreed upon.
- Terms of payment through periodic payments according to work progress and what agreed upon such as deduction of certain percentage accumulated until the preliminary handover, the deduction from the advance payment paid to the contractor, etc.

In addition to the closing payment of the project, this is considered from the most important legal payment during the project.

This contract contains also to what extend the relation between this document and other tender documents in terms of legal capacity, as this document is the only one signed by contract parties.

4-5 Contract Conditions

Conditions of the contract are divided into two parts: general conditions and special conditions (completing conditions).

4-5-1 General Conditions

General conditions cover rights and obligations of both the owner and the contractor and determine scope of work and responsibilities of the consultant who supervises the implementation (if any), works and responsibilities of project manager.

Contents of general conditions are:

A- Definitions

Important items are defined accurately and clearly, such as:

The owner- The contractor- Subcontractor- The engineer- The works- The Project- Tender documents- drawings- Completion date of the project- Project commence Date.

B- Rights and Responsibilities

Rights and responsibilities of each party are explained in detail to know each party his rights and responsibilities under the contract as well as the relations with the sub contractors, where rights and responsibilities of the contractor extend to them.

C- Using others

In general, the owner has the right to perform some works of the project by himself or by independent contractor.

Therefore, the problems resulted from overlapping or efforts cooperation that affect works of other must be added and detailed in the general conditions.

D- Settlement of Disputes

Conditions shall be laid in detail to determine method of settlement of disputes resulted from the work whether amicably or by arbitration.

E- Duration of the project

Project start up date and completion date is determined and accordingly the period necessary for execution of the project. On the basis of this, the contractor shall make the time schedules necessary for completion of the project to be approved from the owner or his representative. According to these schedules shall specify any delay in works, its reasons and to what extend the contract needs to amend the time schedule according to the delay or to impose delay fines, as the case requires. The force Majeure must be specified for the circumstances out of control of the management during which the work is stopped. It must also specify working hours, official holidays and occasions for the contractor to be aware in this regard.

F- Payments

Payments will be prepared according to work progress in a defined and clear way, date of submitting these periodic payments and its least value, period necessary for their revision by the owner or his representative in technical and financial affairs and return procedures of these payments in case of mistakes in different stages of revision.

Also must state that approval of the owner for issuance of these dues does not consider approval of acceptance the work.

Also must state that the contractual and legal reasons that allow to the owner to seize and hold issuance of contractor dues against failure to repair the defected works, claims filed from the third party and failure of the contractor to comply with conditions and provisions of the contract.

G- Procedures of preliminary and final handover

(A) Preliminary Handover:

- After completion of works, the contractor or his representative shall notify the owner in writing that all works are under operation and ready for commissioning procedures which shall be performed by the contractor in the presence of the owner or his deputy and the engineer who supervising the execution (if any).
- After successful commissioning and supply of the spare parts, auxiliary devices and as built drawings by the contractor, this must be proved in project commissioning report.
- After stability of the commissioning during the necessary period agreed upon between the owner and the body that shall take over the project for operation and get benefit thereof, or if the contractor shall perform the operation for certain period under the contract.
- In case of failure of the commissioning, the contractor adheres to repeat the commissioning at his own expensive under performing successful commissioning during the necessary period.
- Preliminary handover is performed to get benefit and operate the project and note any remarks or unimplemented works by making remarks list provided that these remarks have no effect on operation and getting benefit from the project. If the contractor failed to supply any auxiliary devices, spare parts, preparation of drawings or documents, the contractor undertakes to complete them within an agreed period. This period is within warrantee year.
- The owner has the right to deduct or hold any amounts from the dues of the contractor against completion of these works or continuation of the guarantee letter. These amounts will be returned to the contractor after completion of these obligations.

- If any part is defective or damaged during guarantee year, the contractor shall replace the defective or the damaged part or perform repair if there is benefit from the repair. If the contractor fails to perform the repair, the repair will be performed by deducting the cost from his dues or according to the provisions of the contract in this regard. Warrantee of the replaced part extends to one year from date of replacement.

(B) Final Handover:

- Before the end of warrantee period and the contractor has completed all of his obligations, the contractor shall notify the owner in writing to specify date for inspection and form final handover committee to include the owner and the body benefited from the project which was trained on operation and maintenance during the warrantee year.
- In any works or obligations are not completed, final handover is postponed until the contractor fulfills all the obligations according to the contract, technical conditions and workmanship. The warrantee period will be extended accordingly.
- If the inspection proved that the works are in conformity with original technical conditions and specifications or amendments thereof that added during execution of the project and the committee decided that the contractor has completed all of his obligations, final handover report shall be issued and signed by the contractor, beneficiary body that shall be responsible about future operation and the engineer (if any).
- This final handover does not prejudice the responsibility of the contractor under Egyptian civil law.
- After completion of the final handover, a closing payment is made between the owner or his deputy and the contractor or his representative.

H- Insurance

The general conditions determine the areas that must be covered by the insurance for the works, workers and the third party against the risks, including accidents, theft, fire, etc by an insurance company approved from the owner. The insurance certificates are issued in the name of the owner and shows also suitable compensation for each case. It also covers owner, contractor and third party obligations. Insurance certificates are sent to the two parties of the contract.

I- Changes

The general conditions determine method of making the change orders of works that change in the contract and the time period necessary for this change by addition of deletion from contract duration without affecting the contract agreement itself.

The general conditions also determine method of negotiation between the different parties to agree upon the effects resulted from the change in terms of time and cost.

G- Correction of works

This item of the general conditions gives the right to the owner to reject the defective or unconformable works to terms of contract that must be replaced or repaired by the contractor at his own expense.

K- Contract Termination

The general conditions must contain an item that gives the right to the owner to terminate the contract due to failure of the contractor to complete the works on the specified time or non-execution of the works.

It gives also the contractor the right for termination in case of failure of the owner to fulfill his obligations.

4-5-2 Special Conditions

The special conditions are completing the general conditions to conform to the local laws, environmental conditions and special conditions of each separate project. Item numbers of these conditions are similar to what in the general conditions when adding or deleting some provisions of the general conditions.

A- Drawings

The drawings express the relation between different components of the construction, where they illustrate their locations and dimensions and contain information about the sizes, locations and quantities, which means design drawings.

The drawings must be complete to a large extend, accurate, with suitable scales and include sufficient dimensions. They are considered guide for the contractor in his estimations and calculation of the quantities when preparing the bid, construction and execution of works. They also contain separate working drawings for all constructional, architectural, internal sanitary drainage, electricity, conditioning and cooling works.

B- Shop Drawing

As the working drawings do not contain accurate details for each part of the different components of the construction, the executor (contractor, subcontractor, supplier, manufacturer, etc) must prepare accurate and clear shop drawings contain all the detailed information necessary for execution, including graphical curves for method of performance, spare parts lists for the components, method of installation and method of operation that shall be approved and used.

C- As Built Drawings

The contractor shall prepare drawings complete with accurate dimensions and details according to what actually executed on the ground to be submitted to the owner as documents kept as a reference for maintenance and operation works.

D- Technical Specifications

Technical specifications are completing the shop drawings, where they express the requirements in words and shows quality of the materials, supplies, equipments and technical construction methods.

Technical specifications are considered the greatest part of the contract according to the following categories:

General requirements, site works, concrete works, masonry works, metal works, wood works, insulation and protection, doors, windows, finishing, special works, equipments, furniture, special construction, conveying systems, mechanical works and electrical works.

These works are divided into four sections:

General, materials, execution and method of calculation.

"**General**" section contains definition of the scope of work in this section, including quality control, information about the supplies and equipments, handling and storage requirements and warrantees.

"**Materials**" section contains brief description of the materials used in this section as a guide for the producers. "**Execution**" section contains details of methods of construction, performance of works, inspection, acceptance and tests. "**Calculation**" section verifies if this party of the works are loaded on contract items, item price, LS, etc.

E- Estimated Bill of Quantities

- Estimated bill of quantities contain work items, brief description of each item, method of calculation, whether with unit of area, volume or LS, and the estimated quantity of each item.
- The contractor shall price each item.
- In bill of quantities, if the contractor did not price an item, the price of this item is loaded on the prices of the other items of the contract upon execution, however specifying the highest price for this item in the other offers when evaluating this offer by evaluation committee.
- The quantities listed in the bill of quantities are estimated and the owner is entitled to increase or decrease these quantities by 25% with the same contract prices, and the quantities that exceed this percentage, their new prices shall be agreed upon.

Chapter 3: Implementation Conditions

1. Project implementation management
2. Site planning and preparation
3. Civil and architectural works
4. Mechanical and Electrical Works
5. Tests
6. Performance Tests and Handing Over

1- Project Implementation Management

Success of any project is measured by its completion on time according to contract documents, technical conditions, specifications and shop drawings.

The access key to project success is the provision of continuous communication and explanation means between the parties working in the project through a relation between project owner, consultant and contractor that helps execution of the works according to the time schedules specified for completion of this project.

Volume of labor required to complete the project depends on volume and condition of each project. Fig (3-1) illustrates organizational structure of project management.

For good coordination between the three parties, the following system shall be followed:

A. Project owner shall contract with the contractor entrusted to execute the contract according to the applicable rules and laws.

B. Project owner shall form execution unit for technical revision of all execution steps and know the obstacles and problems and provide their technical, financial, administrative and legal solution.

C. The execution unit shall coordinate with the project consultant who performed studies and design works and preparation of contract documents for supervision of execution.

D. Chairman will be appointed for the execution unit (project manager) to coordinate between the staff inside the unit and put work rules for the relation between the execution unit and the consultant.

E. Project consultant shall coordinate between owner, contractor and consultant works. Fig (3-2) shows project execution unit and specifies its responsibilities as follows:

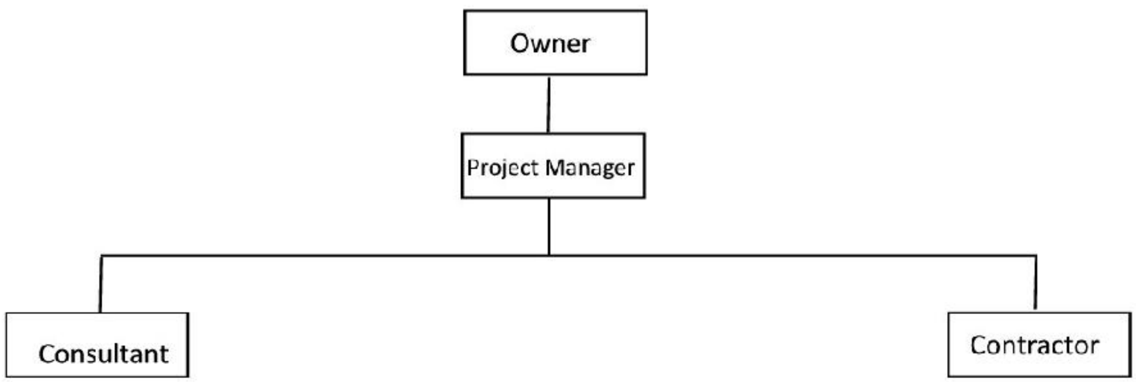


Fig (3-1): Organizational Structure of Project Management

Execution Unit

Project Manager

Financial and Administrative Affairs

Technical Affairs

Fig (3-2): Project Execution Unit

1-1 Project Manager

A. Competent and can act to manage the project.

B. Responsible about supervision of execution all works and activities and has the authority to control, familiarize and coordinate between different technical, financial, administrative and legal activities.

C. Select the ideal method to execute the works and take into consideration the economic aspects, time and effort to achieve the objective towards completion of the project on a timely manner and take the measures needed to correct the course of implementation to complete the project successfully on time within the limits of the available funding.

D. Project manager shall select the technical manager and financial and administrative affairs manager and authorize them to form and approve the assisting staff for both of them.

E. Approve issuance of consultant dues under the contract.

1-2 Technical Affairs

1-2-1 Design Engineers

Revision works of the drawings submitted from the consultant office shall be conducted by specialized engineers for conformity of the hydraulic, architectural, civil, mechanical and electrical drawings and ensure availability of sufficient number of shop drawing copies.

1-2-2 Execution Engineers

A. Execution works will be conducted by specialized engineers in different specializations to follow up execution stages.

B. Prepare periodic reports about work progress, revise and sign daily follow up records by the consultant and the contractor and list any technical remarks or problems that may hinder progress of execution.

C. Revise and compare the periodic payments according to the actually executed quantities with the shop drawings and the records submitted from the contractor and approved from the consultant.

1-3 Administrative Affairs

1-3-1 Financial and Administrative Manager

A. Specialized accountant shall be appointed to perform this work in terms of financial and administrative aspects of the project and shall provide assistance and advice to the project in his scope of work.

B. Shall follow up project financial and administrative works; submit periodic reports to the project manager and proposals on how to solve the financial and administrative problems that object progress of work.

C. Shall select financial and stores audit staff.

1-3-2 Financial Audit

Specialized accountants shall be appointed to perform the following works:

A. Review the payments from an accounting point of view and conformity of the rates with the contracts.

B. Follow-up the financial position of the project up to date and maintain records that indicate the amounts available, what has been disbursed and the remaining.

C. Compare expenditure with the execution timetable.

1-3-3 Stores Accounting

Specialized accountants shall be appointed to perform the following works:

A. Maintain regular records show all the supplies, their dates of supply and value.

B. Review the supplied equipments according to the contract on the packing lists.

C. Maintain regular records about the adjustments of each documentary credit.

1-4 The Consultant

Responsibilities of the consultant are determined in the following:

A. Prepare typical report forms, methods and procedures of work progress.

B. Prepare rules to control how to sound managing of the project within its actual budget.

C. Select high efficient technical supervision team in different specializations.

Fig (3-3) shows organizational structure of the consultant.

1-4-1 Technical Supervision

A. Follow up the daily works being carried out by the contractor and take the necessary samples for test.

B. Follow up the execution situation and its conformity with the approved execution schedule.

C. Review and approve works counting books submitted from the contractor

D. Review the submitted payments from the contractor and approve them for issuance.

E. Study any additional works or amendments required for implementation of the works to take the full advantage of the project and to be presented to the project manager for approval.

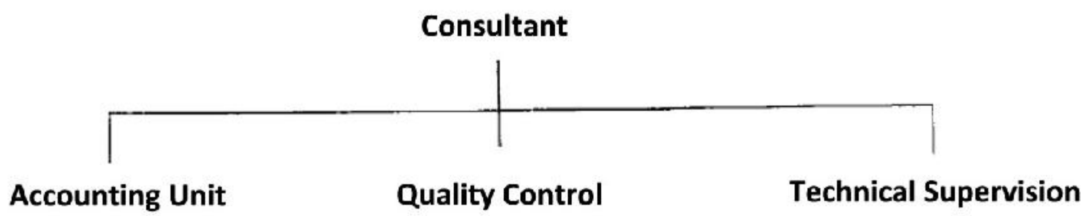


Fig (3-3): Consultant Organizational Structure

F. Study any claims submitted from the contractor whether they are financial or regarding any amendments in execution period of the project after the contractor has fulfilled all the documents necessary to prove his rights in these claims and present the result to the project manger.

G. Participate in preliminary and final handover works and prepare list of remarks that does not prevent the preliminary handover.

1-4-2 Quality Control:

A. Ensure fitness of equipments and supplies materials supplied to the site, revise test certificates and perform the necessary tests on random samples of materials and equipments to ensure their conformity to the specifications stipulated in the contract.

B. Supervise preparation experimental concrete mixes, follow up their treatment and test to determine their breaking strength according to the value specified by the designer and stipulated in contract documents.

C. Perform supervision and periodic follow up works on pouring and treatment of the executed concrete constructions.

D. Ensure calibration of the devices used in test and measurement works.

1-4-3 Accounting Unit

It performs the following:

A. Revise the payments submitted from the contractor.

B. Follow up project financial situation.

C. Revise expenditures and revenues of the consultation office.

1-5 The Contractor

Responsible about execution of all works until completion of the project successfully and shall have efficient stuff in different specialization areas as follows:

Fig (3-4) shows organizational structure of the contractor.

1-6 Resident Engineer

He is responsible about the following:

A. Management of the project.

B. Coordinate between his assisting staffs and specify their duties.

C. Revise the executed works through time schedules, revise and approve the payments prepared by executing engineer.

D. Revise the financial situation and stores stock.

E. Approve workers allowance on the light of the achieved works.

1-6-1 Technical Office

The technical office has the main role in preparation of all technical, design, planning, follow up, requirements and performance rates data for execution and full completion of the project according to the approved schedule. Role of the technical office is summarized in the following:

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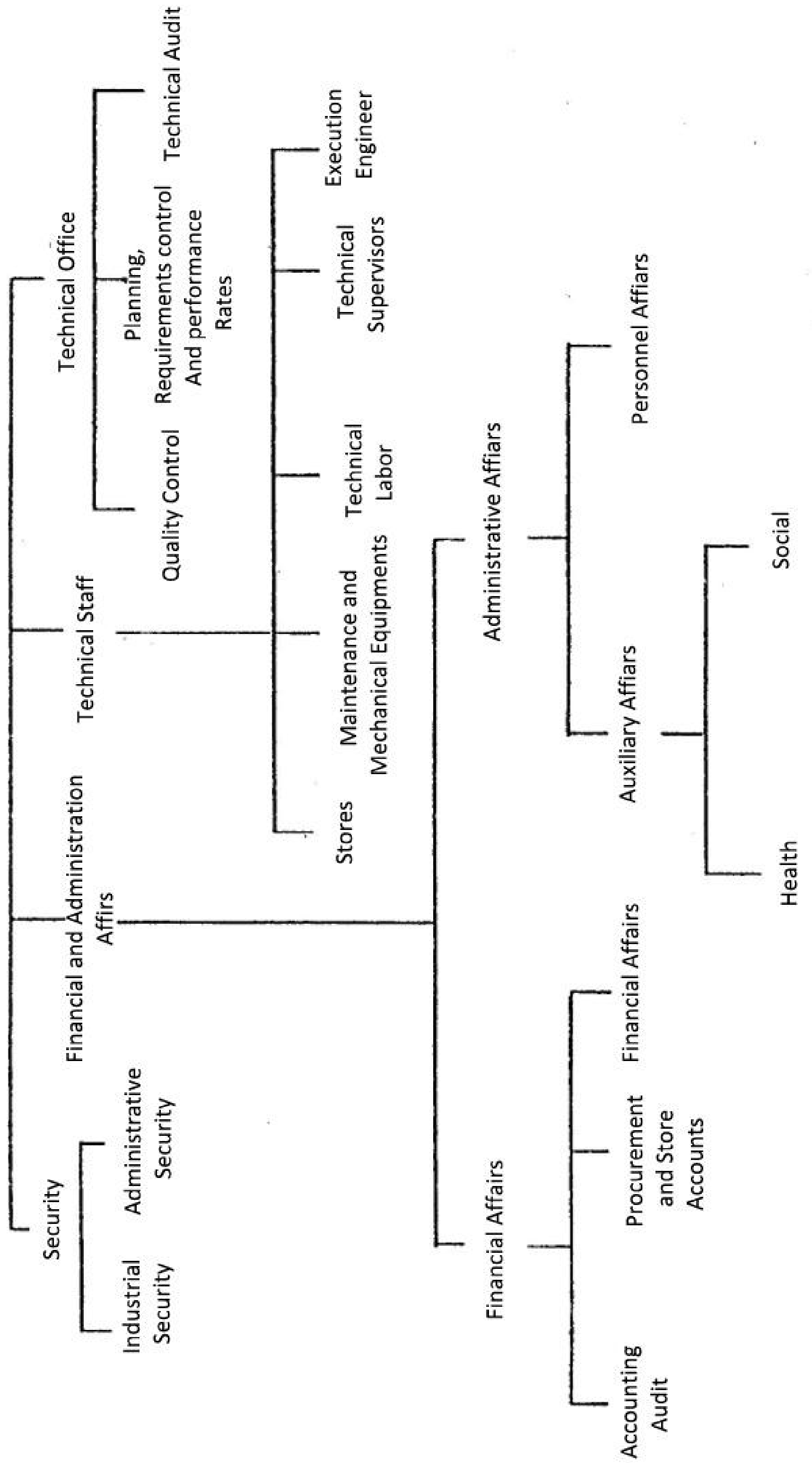


1-6-1-1 Technical audit: It is responsible about the following:

A. Revise conditions, specifications and provisions dossiers.

B. Prepare and count all work items required to be executed in the project.

C. Revise bid documents, prepare and release tenders to subcontractors.

D. Prepare and revise the payments according to the actually executed quantities and compare them with the shop drawings and collection records before submission to project consultant.

E. Follow up execution of the project according to the time schedules.

F. Prepare closing payments and preliminary handover reports of the project.

G. Revise hydraulic drawings with the mechanical and electrical drawings and their conformity with the architectural and construction drawings with provision of copies of the shop drawings.

H. Revise soil research report and ensure that locations of the executed borings are in conformity with what shown in the drawings and shall perform soil researches, if required, at his expensive.

I. Prepare copies of as built drawings according to what actually executed for approval from the consultant.

1-6-1-2 Planning, control, requirements and performance rates

It is responsible about the following:

1. Prepare the planning budget and identify the obstacles and problems, if any, to be solved in timely manner.

2. Prepare different time schedules, use systems, such as personal computer, to facilitate revising all the information required to execute different stages of the

project, provide the necessary requirements as well as communication and continuous cooperation between the concerned parties to complete the project on time.

3. Determine the resources necessary for the project, provide the materials and equipments according to the specifications with the necessary quantities on suitable times to execute the project in accordance with the specified time schedule.
4. Follow up execution of the project, action plan and all execution steps through the time schedules and performance rates and amend their course in case of any delay in execution of the project.
5. Follow up collection of financial claims.

1-6-1-3 Quality Control

Perform inspection and test works on the materials and revise manufacturing works to ensure that they are in conformity with contract documents.

1-6-2 Technical Staff

1-6-2-1 Execution Engineers

Execution engineers, with the required engineering specializations, shall perform accurate technical direction and revise the quality according to contract documents.

Duties of execution engineer are summarized in the following:

A. Takeover, plan, determine axes and directions of the site.

B. Prepare the necessary detailed sketches that help in execution of the project.

C. Demand the equipments, materials, labor and supplies on suitable times according to time schedules.

D. Direct technical supervisors and distribute labor according to work needs.

E. Execute all the works according to time schedules.

F. Prepare daily reports on work progress and the obstacles that face the execution and methods of their solution.

G. Periodic count of the executed works and payments.

H. Give directions for better use of the materials, equipments and instruments and their storage on the site.

I. Stores supervision.

J. Prepare as built drawings.

1-6-2-2 Technical Supervisors

Duties of the technical supervisors are summarized in the following:

A. Implement instructions of execution engineers

B. Control and direct technical labor.

C. Report the obstacles immediately.

D. Receive materials and equipments from the stores and settle the custody.

E. Maintain the equipments and execution tools and their proper use.

1-6-2-3 Technical Labor

Technical labor shall carry out the works accurately according to the instructions issued from the execution engineers and supervisors.

1-6-2-4 Maintenance and Mechanical Equipments

Duties of maintenance and mechanical equipments unit are summarized in the following:

A. Prepare, maintain and operate the equipments.

B. Perform periodic maintenance works for mechanical equipments.

C. Train the workers on maintenance and operation works.

1-6-2-5 Stores

It performs the following duties:

A. Keep store records that show all the supplies, their dates of supply and values and the issued quantities.

B. Receive and store all the materials and equipments supplied to the project according to technical principals after completion of inspection and addition procedures.

C. Receive the materials and equipments necessary for the works.

D. Prepare item cards, their quantities and put them in clear places on the site.

E. Demands provision the stores with items that their stock reach to the critical limit.

1-6-3 Financial and Administrative Affairs Unit

It consists from the following:

1-6-3-1 Administrative Affairs

It consists from personnel affairs and auxiliary services.

1-6-3-1-1 Personnel Affairs

It has the following duties:

A. Provide the necessary labor required for the work.
B. Prepare and follow up workers pay roll
C. Prepare production allowance lists according to work progress.
D. Prepare and equip the offices and rest rooms necessary for service of all workers in the project.
E. Prepare monthly and annual lists on technical and administrative competency of the workers.
F. Follow up attendance of workers
G. Follow up attendance of workers
H. Determine and follow up leaves according to instructions.
I. Prepare decisions on transfer and service termination of workers.
J. Perform Social insurance procedures
K. Issue work permits and complete security procedures, if necessary.

1-6-3-1-2 Auxiliary Services

It includes social and health services.

A- Social Services

It has the following duties:

- Supervise workers welfare fund, where all the workers of the project participate and get benefit from it in the cases that require this.
- Organize recreational, cultural, tourism and religious excursions and field visits to similar work sites.
- Organize different sport activities.

B- Health Services

It has the following duties:

- Prepare health unit for first aids and treatment of injuries and quick cases.
- Transfer injured people with serious cases to the specialized hospitals.

1-6-3-2 Financial Affairs

It consists from the following:

1-6-3-2-1 Financial Accounts

It has the following role:

A- Revise the payments and follow up letters of credit.

B- Perform follow up works and collection from the employer.

C- Prepare record for accounts of suppliers, revenues and expenses

D- Prepare the budget and determine work results.

E- Supervise the purchases.

1-6-3-2-2 Procurements and Stores Accounting

Role of procurements department is summarized in the following duties:

A- Purchase the materials and equipments, ensure their supply to the site on the suitable time and keep regular records in this regard.

B- Report any shortage of supply of the materials and equipments.

C- Calculate delay fines imposed on the suppliers.

Role of stores accounting is summarized in the following duties:

A- Revise the supplies, their prices and quantities according to the contract.

B- Revise notes payable submitted from any department with the approved forms and send them for auditing.

C- Keep a record of stores accounts for comparison with the inventory record.

1-6-3-2-3 Auditing

Its role is summarized in the following:

A- Revise the payments with the count records and conform the rates to the contracts.

B- Revise project financial claims.

1-6-4 Security

It consists from administrative security and industrial security.

1-6-4-1 Administrative Security

Role of the administrative security is to monitor work sites, gates and guard works, including entrance and exit of personnel and equipments, prepare security arrangements to ensure proper and smooth progress of work and revise work permits.

1-6-4-2 Industrial Security

Role of industrial security is to secure the project as follows:

A- Fire resistance, provision and maintenance of the necessary equipments.

B- Secure workers during the work against injuries and work risks.

2- Site planning and preparation:

Introduction:

The best way to reach the desired goal starts from good planning and analysis of project components to the executive steps prior to the implementation process which create the site to work, including handover of the site, survey the site, preparation, coordination and overall planning and layout of the site including temporary buildings that must be completed before starting implementation of the works so that the project contractor can do the main works easily.

These works are divided into three stages:

A. Determination and handover the site, survey works and preparation of the studies.

B. Planning, coordination and preparation for the layout.

C. Temporary buildings works.

2-1 Determination and handover the site, survey works and preparation of the studies

2-1-1 Determination and handover the site

- Takeover the allocated area of the site from a committee consists of the owner, the consultant, the contractor, representative of the beneficiary body of the project and representative from survey department in the governorate by putting iron fence around the site by representative of survey department.
- Determine the obstacles that hinder execution of the works whether over or under the ground.
- Determine takeover situation of the site "one stage" or "several stages" and date of takeover of each stage.
- Determine water and electricity supplies around the site, if any.

2-1-2 Survey works and preparation of the studies

- Current condition of the site is photographed before start implementation.

- Takeover the bench marks under takeover record signed from owner representative, the consultant and contractor representative after accurate revision of the levels, directions and site dimensions and compare them with the layout drawing to ensure from the correct dimensions.
- Construction of concrete blocks around the bench marks taking into consideration to be away from the excavation area to be hard to removed.
- Perform studies on quarry and workers near from the project to determine the best elements that can be used at least cost.
- The site is divided into net of squares to perform initial network level by preparing sectors of this level to determine excavation cubes, backfilling and leveling.
- Perform the main axes of the site away from the temporary buildings and internal roads of the site.
- Prepare a drawing includes all the obstacles on the site.
- Removal of all obstacles on the site that hinder the implementation process, such as wastes, trees, old buildings, etc.
- Perform the necessary leveling for the site, including excavation and backfilling according to site conditions taking into consideration the proposed implementation methods, project execution level, weather conditions, rain flow directions, etc.
- Perform coordination records with the different bodies before start implementation and the necessary diversions, if required.

- Perform additional soil borings, if necessary according to contract terms.
- Perform geological study to determine the faults and storm water drains.

- Fencing the site and construct a gate for entry and exit of equipments, as well as the Security Office.
- Supply the site with water, electricity, sanitary drainage, communication, etc.
- Perform network level again after leveling and reaching to the design level.
- Study situation of the adjacent buildings and their effect on excavation processes to avoid any cracks and submit report in this regard to the owner to take the necessary actions.
- Issuance of the necessary permits and licenses.
- Select the best places to put project sign in coordination with owner representative and the consultant.

2-2 Planning, coordination and preparation of the layout

Success of any project is measured by allocation of sufficient time for planning and applies implementation methodology as follows:

2-2-1 Studies required for proper planning of the site

The following studies are prepared by project consultant and must be used before start implementation:-

- Site, contract terms, project shop drawings, proposed construction methods and plan for the required services.

- Specifications and details of the drawings of the required equipments.

- Time and technical schedules for the equipments, materials, labor, etc. to determine supply periods for project needs in order to decrease the areas used in the stores, losses and motionless items and implement the works on the specified dates.
- Construct concrete mixing station on the site according to implementation conditions.
- Details and requirements of the temporary buildings “Offices, accommodation, stores, workshops, etc”.
- The proposed alternatives in case that site area can not accommodate the temporary buildings, such as rent another lands or administrative units, etc.
- Requirements of industrial security and administrative security in site planning.

2-2-2 Elements to consider when studying perform proper planning for the site

- Effect of wind direction on determination places for welding workshop, storage areas, office building, residential units, etc.
- Effect of rainfall direction, inclination of site land and methods of storage on the ground.
- Motion flow inside employee offices, stores, workshops, etc.
- Determine suitable places for car parking and allocate reception office for visitors.
- Planning of temporary internal roads to facilitate motion of equipments, individuals, raw materials, etc.

Temporary roads network on the site must be on the same route of the main roads network of the project and not intersect with project constructions.

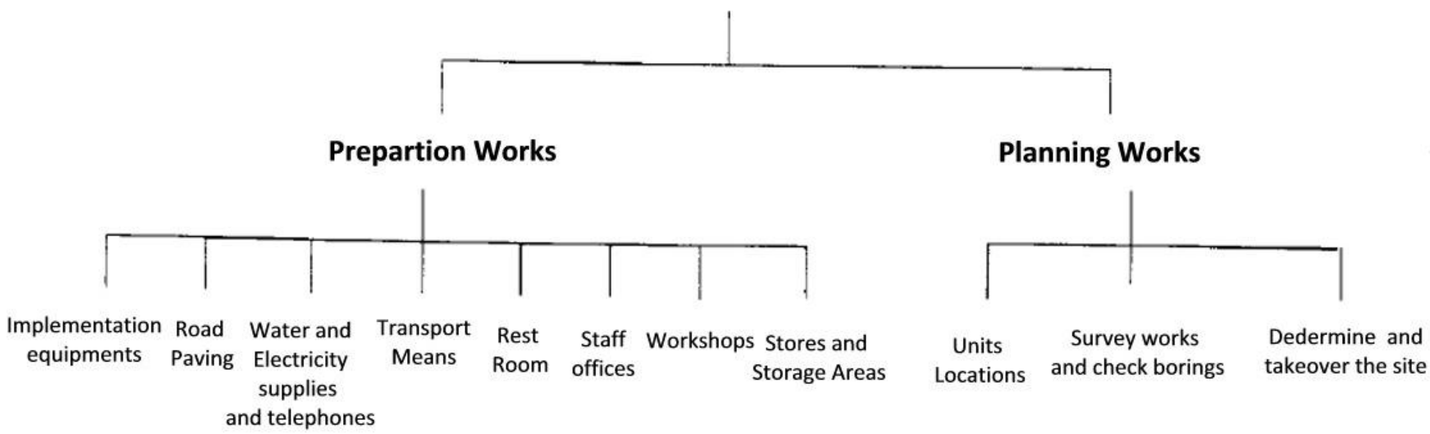
- Take measures to protect the adjacent constructions, such as using dewatering methods and digging piles, poles, etc.
- Provision of places and utilities lines on the site (water, electricity, sanitary, telephones, etc).
- Perform study to analyze well water on the site.
- Determine places for materials storage, including mixing stations and workshops to decrease losses and transport costs. Storage areas must be in places that do not hinder the work and communication inside the site and to avoid storage on excavation areas and reduce as much as possible relocation of stores throughout the project implementation period.
- Raw materials entry cycle for "check, classification and storage" and exit for implementation.
- Study size, motion and height of heavy and fixed equipments inside the site during construction process.
- Provide lighting, guarding, warning signs, banners, etc.
- Equip a laboratory for materials and concrete researches inside the site and fuel station for equipments according to the importance of the project.
- Provide signboards identifying locations of the project "administration offices, rest rooms, visitor's office, toilettes, unbalance unit, mosque, stores, workshops, working areas, etc".

2-3 Temporary buildings

2-3-1 Factors affecting construction of the temporary buildings

- Contract terms.
- Wideness of the layout.
- Type of the project.
- Implementation period and time schedule stages.
- Method of construction and type of the used equipments.
- Location of the project “remote or civilian area”.

Fig (3-5): Site Planning and Preparation



3- Implementation of civil and architectural works

Introduction

Pumping station sumps are divided into circular, rectangular or square pumps which are a concrete construction implemented under the ground with dimensions specified in the shop drawings to accommodate the inflows from the city, village or district. Over this construction is constructed motors house. The purpose of the sump is temporary storage of the liquate wastes incoming to the sump for short time. Fig (3-6) illustrates vertical section in circular sump.

Shape of the pumping stations differs according to the used pumping units. Most of the pumps used in the pumping stations are centrifugal pumps and are divided to the following:

- Vertical centrifugal pump.
- Horizontal centrifugal pump.
- Submersible pump.

3-1 Methods of sumps implementation

- Caisson sinking boring method.
- Wash boring method.
- Compressed air boring method.
- Open hole boring with shoring method.

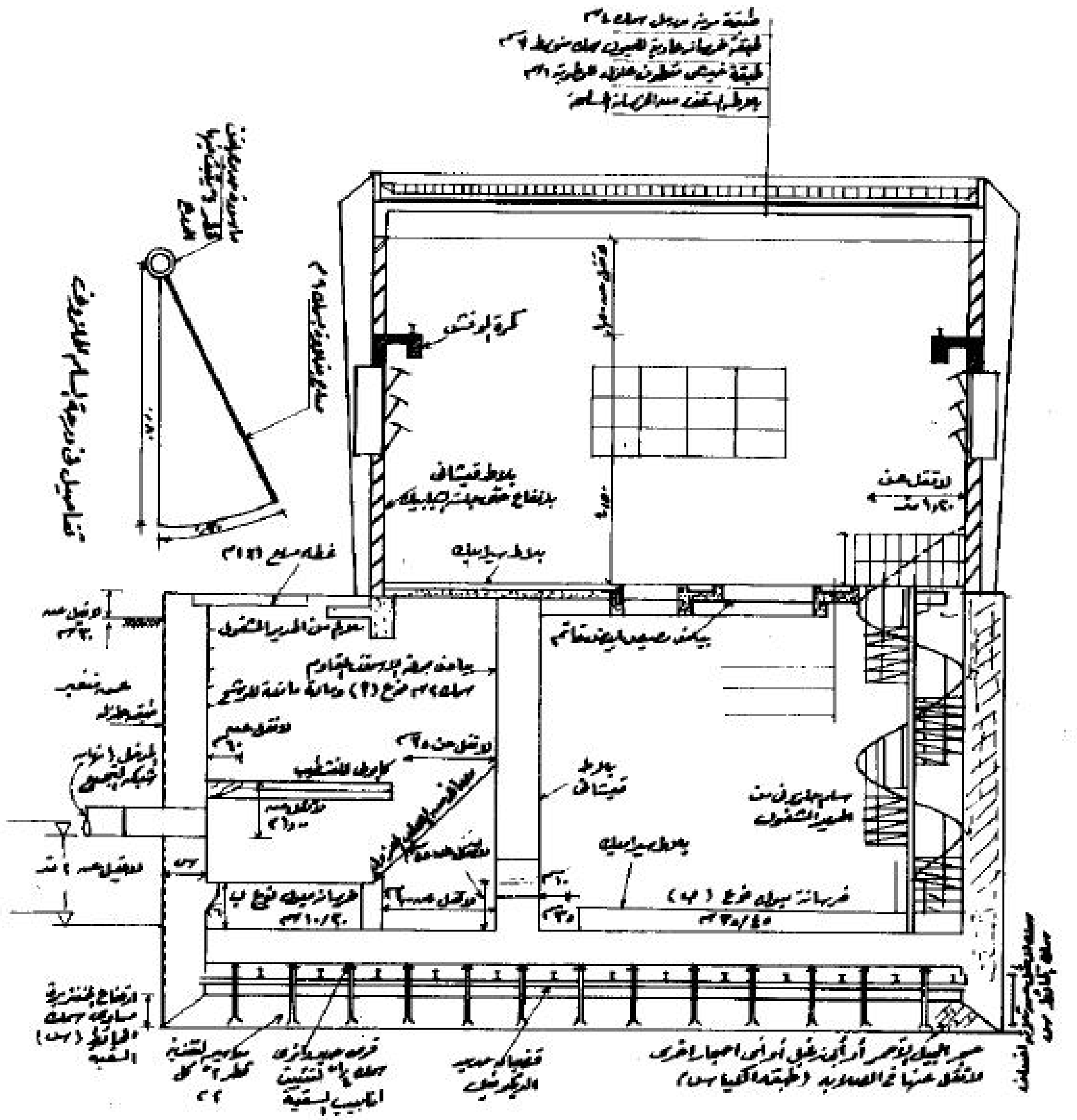


Fig (3-6): Detailed Section of Circular Sump

3-1-1 Methods of sump implementation

3-1-1-1 Caisson sinking boring method

A. Open boring works are carried out in the normal ground (not rocky ground) according to borings report with diameter equal to the outer diameter of the sump added to it one meter before reaching Infiltration water level by 25-50 cm and the bottom of the boring is completely paved.

B. A framework of wrought Iron (with diameter equal to the external diameter of the sump) is constructed on the bottom of the boring in the form of circular structure from steel manufactured in the shape of triangles with internal diameter equal to the internal diameter of the sump and thickness of the structure base is equal to sump wall taking into consideration top of the triangle is pointed and sharp and put anchored on the boring bottom for ease of sinking. The framework must be assembled be welding and not riveting. Fig (3-7) illustrates details of the framework.

C. Rebar are installed inside the framework and fixed according to the shop drawings and then the reinforced concrete is poured inside the circular structure.

D. Wood framework is prepared inside the frame for the full height of the sump, while the external carpentry are prepared in the shape of pallets then the concrete is poured in layers such that height of each layer does not exceed 2 m. In case of wood forms, external pullers must be used and not internal pullers that pass inside the concrete. If necessary, the pullers that pass through the concrete can be used but must be treated according to workmanship (See code of concrete).

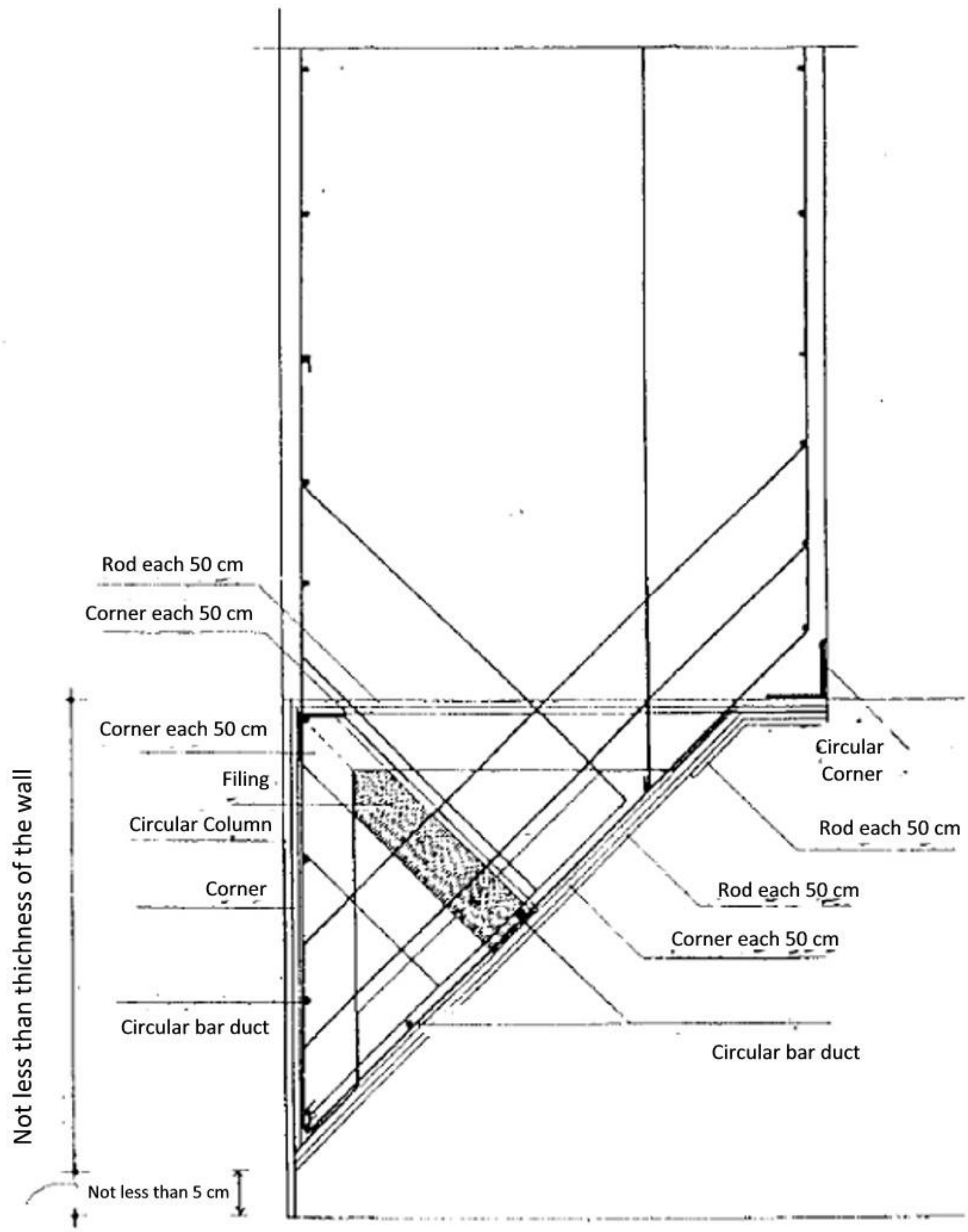


Fig (3-7): Details of the Framework

In case of iron forms, the rebar is prepared for sump walls and the forms are put on structure base such that height of the forms does not exceed 4m.

E. Reinforced concrete is poured in layers to the end of the wall. Iron splices at reinforced floor level must be the same as the splices of the iron in the upper and lower grids and to put water stops while pouring the walls. Also, pouring of the external and internal walls of the sumps must be stopped at level beneath the roof by 1-2m to enable tie the external roof by the sump structure.

F. Openings of the buried services (inlet and outlet pipes, ventilation pipes, cables, etc.) must be left uncovered while pouring the concrete structure according to the dimensions and the levels shown in the shop drawings.

G. After removing wood formworks or iron forms, the sump must be externally insulted either by bitumen or by the insulating materials as recommended in the submitted drawings and soil report.

H. Determine the part that required to be sunk by making external gradation on the sump structure.

- When approaching from the designed sinking level, a daily level is made on the sump structure by the post scale.
- To ensure vertical sinking, four vertical levels are made at the sides of the sump structure (a string with weight). Any other suitable method can be used to achieve this purpose.

  In case of inclination of the sump at any side, the boring will be deeper at the opposite side to balance the sump.

I. Seven days must be left from date of pouring last layer until setting of the concrete before start sinking process.

J. Prepare the equipments necessary for sinking of the sump manually or mechanically.

K. Start boring works inside the sump using hoe crane from ground water level (boring cubes by sinking are calculated from this level) with extraction of soil from inside the sump as you-go taking into account to perform boring works fully and regularly in the sump.

L. Concrete body of the sump shall not be executed except after make sure that the sump shall be sunk easily without obstacles (stone, rock land, etc) so as sump body does not stuck in this kind of soil. In case of existence of rock or stone land, it will be removed by the appropriate technical methods, then the boring sector is fully filled by clean sand to a height from 25-50 cm over groundwater level and then the sump is executed by the same previous steps.

M. Groundwater must not be sucked from the inside of the sump to maintain safety of the adjacent constructions and vertical inserting of the sump during sinking period.

N. In case of not fall of the sump while sinking, a grid of iron beams is made around the sump at the upper part of sump walls, then additional loads are put to increase the weight taking into account to leave a hole sufficiently wide for descent of the divers and hoe crane and not to remove the additional loads except after full pouring of the reinforced floor and partition and hardening of the concrete for a period not less than 14 days.

   If the boring exceeds the design level for any reason, the sump will not be sunk (where the place of entry of inlet and outlet pipes for both drainage and gravity lines are specified by levels) and then the plain concrete is poured while the sump is suspended to fill this excess boring with the plain concrete.

- Iron bars are put in the duct around sump body arranged in the shape of floor and cover iron grid by trained drivers.

O. Pouring pipes are prepared from galvanized iron of diameter 2” and their lower ends are flattened and perforated with the same height of the stone layer taking into account that to keep the pipes in a vertical position distant at 2m start at the beginning of the stone layer and end at a point over the infiltration water level by about one meter.

   Pouring pipes are fixed from the lower part by deco fell iron and from the upper part by a grid (from iron beams and wood runners) around the sump to keep the pipes in a vertical position during injection process.

P. Stone layer (from basalt, red mountain, Abo Zabal or any other stone not less in rigidity) are put at the bottom of the sump in the existence the groundwater up to the level of the plain concrete core of the floor then leveled by the divers taking into account that the diameter of the stone layer does not exceed 100 mm and well compacted before putting the deco feel iron.

Q. Plain concrete is poured under the water with the required thickness up to level of reinforced concrete floor core level by vertical gutters in the shape of pipes start at the plain concrete floor level and end at ground level to avoid mix of the concrete with water and dissolution of the cement in the mixture, or to use the concrete pump by connecting its hose directly to the plain concrete floor level, then the plain concrete level is leveled in all corners of the sump by divers taking into account to pour floor concrete continuously without stop whatever the surrounding conditions.

R. After complete setting of plain concrete for the floor for a period not less than fourteen days from pouring the concrete, injection process starts by cleaning pouring pipes at first by clean water, then the stone layer is injected by mortar cement using sulfate proof cement with ratio 1:1 (cement: sand) under pressure 6 m over infiltration water level or using injection device (consists of sealed metal container with lid can be opened and closed, compressed air inlet pipe and injection materials outlet provided with valve and high pressure hose connected to injection pipes) (Fig 3-8).

S. Each pipe is injected individually to avoid rejection of any new injection. This indicates injection completion in this area then the pipe is closed by a wooden plug or isolating valve installed on the pipe to prevent return of the injection material from coming out, then transferred to the next pipe and so on without stop until completion of the injection process in stone layer, noting that the first pipe must accommodate large quantity of the injection materials compared with the rest of the injection pipes so that some areas do not accept injection, which indicates that the adjacent pipes have injected this area.

T. After not less than 28 days and completion hardening of the plain concrete, the seized water inside the sump is sucked until the floor appears without leakage of water or damage of the plain concrete.

U. After treating of any leakage in the floor and non-appearance of any leakage, the pouring pipes used in the injection are cut to the end level of the plain concrete.

V. The walls are coarsen at the part confined by the thickness of the reinforced slab, then splices of the reinforced rebar are put inside the slab, then reinforcing of the slab is completed taking into account to put splices for the screens bases and then the concrete is poured on the reinforced floor.

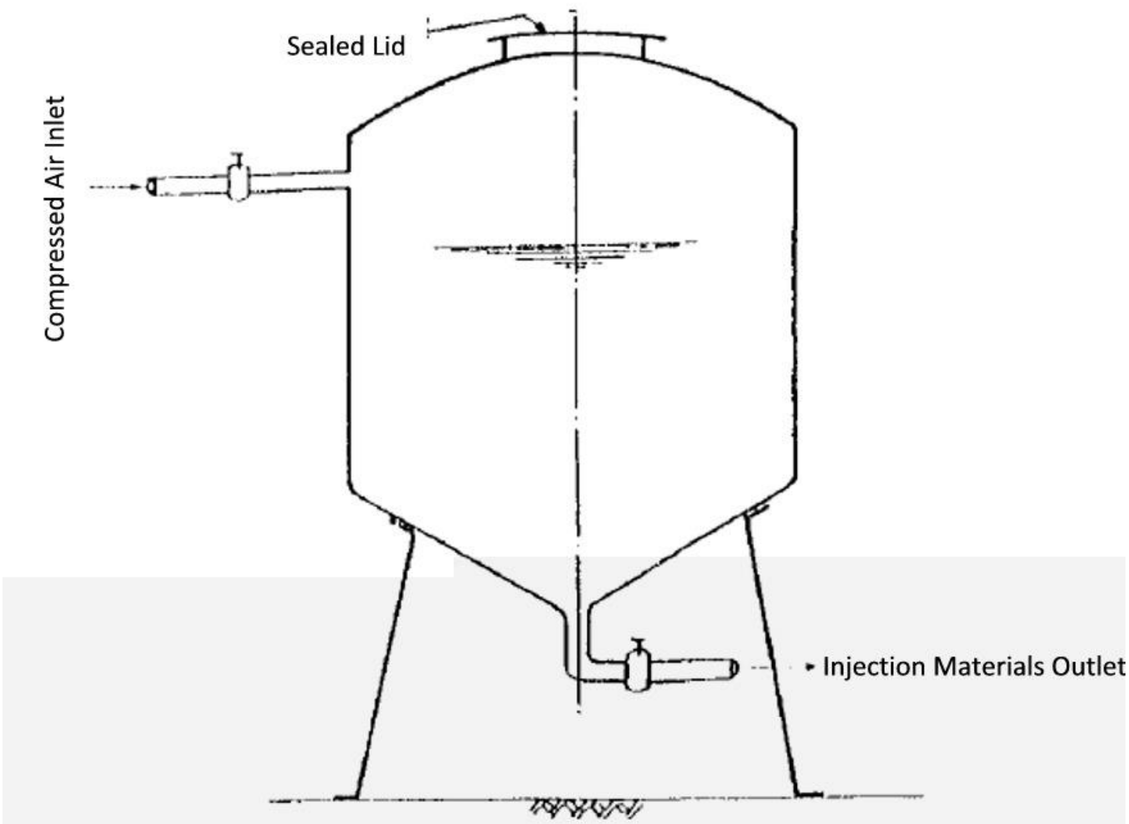


Fig (3-8): Injection Container

W. Splices of the partition separating between the wet part and the dry part are extended inside the sump, reinforcing and pouring of the concrete of the partition is completed as well as the required works.

It is preferred to use infiltration proof materials to improve concrete infiltration resistance with the necessity to use sulfate proof cement and to care with every step during construction of the sump, including mixing and mechanical compaction according to the agreed materials and the mixtures as in the design and cleaning just before pouring.

- Wood formworks or forms must be, in all aspects, suitable for the type of construction and the type of the final surface required for the concrete and must be sealed to prevent leakage of the mortar cement from the concrete during pouring and compaction stages. Concrete cover over or under the reinforced rebar must be maintained as well as the concrete thickness sections according to the drawings.

3-1-1-2 Wash boring method

The same steps above are used in this method with the only difference in the method of sinking, which is executed by using wash pump according to the following:

A- Wash pump is lifted by the crane and put down inside the sump taking into account to be put with constant rate in all places in the sump to ensure regular slump of the sump.

B- Long hose is installed at the outlet of the pump to pour in a tank prepared for this purpose away from the sump, where the water laden dust is poured in this tank and the dust sediments in the tank. Floated water is sucked from this tank and poured again inside the sump.

C- Level of water inside the sump must be the same as the infiltration water level. This level must not sharply decrease due to suction of the water laden dust, where the wash pump will not work except if it is submersed in the water.

D- It must avoid severe suction of water during operation in order not to make fountains at the floor of sump and cause disturbance in the level of the foundation due to pressure increase of the groundwater from outside more than the infiltration water pressure from inside.

3-1-1-3 Compressed air boring method

A- As the sumps coming down to great depths under ground and the existence of infiltration water that hinders dry execution of the sumps and to overcome the infiltration water, it must exist source of compressed air inside the sump to equate the existing water column (i.e. if there is water column, it must exist equal air column equal in magnitude and opposite in direction) for the workers to be able to complete boring works in dry ground without obstacle and existence of infiltration water during implementation.

B- Open boring works are executed with diameter equal to the external diameter of the sump added to it one meter before infiltration water level by 25cm then boring bottom is leveled.

C- Formwork is constructed with diameter equal to the external diameter of the sump on the boring bottom with the same above specifications mentioned in caisson sinking boring method and then the rebar is put and the reinforced concrete is poured inside it.

D- Internal and external wood form is made for the walls up to the lower level of the roof and then the rebar is put and reinforced concrete is poured.

E- Walls formwork is removed then backfilling up to under roof level by 5 cm.

F- Plain concrete (cleaning) of thickness 5 cm is poured before putting floor rebar taking into account to leave openings in the reinforced floor (lower roof) to put two circular pieces called (lost piece) and two air inlet pipes from air compression station to equate water column in addition to putting vertically group of different pipes of diameter 2” for injection process such that the spacing between each one about 6m as shown in fig (3-9), Fig (3-10) and Fig (3-11).

G- Carpentry and blacksmithing works are completed and pouring of sump body as well as the upper roof and to leave the same opening places that are executed in the reinforced floor (lower roof) in the sump.

H- After removing walls and roof formworks, boring works are executed without using compressed air up to infiltration water level.

I- After that, boring works are executed using the compressed air. There are two methods for boring works, either manually by workers or by entering disassembled bulldozer equipment inside operation chamber then is assembled at the lower part of the sump and then operated electrically to protect the workers from being affected from the exhaust of the bulldozer. This equipment will remove and disturb the soil to facilitate the process for the workers. The cylindrical bucket (diameter about 0.50 m and length 1.0 m) is filled with dry soil then lift by the electrical crane up to upper the vertical pipe noting that to tight close the door between the vertical pipe and soil exit chamber in order to keep the atmospheric pressure. Then, the door is opened to allow soil to exit. The same method is repeated again.

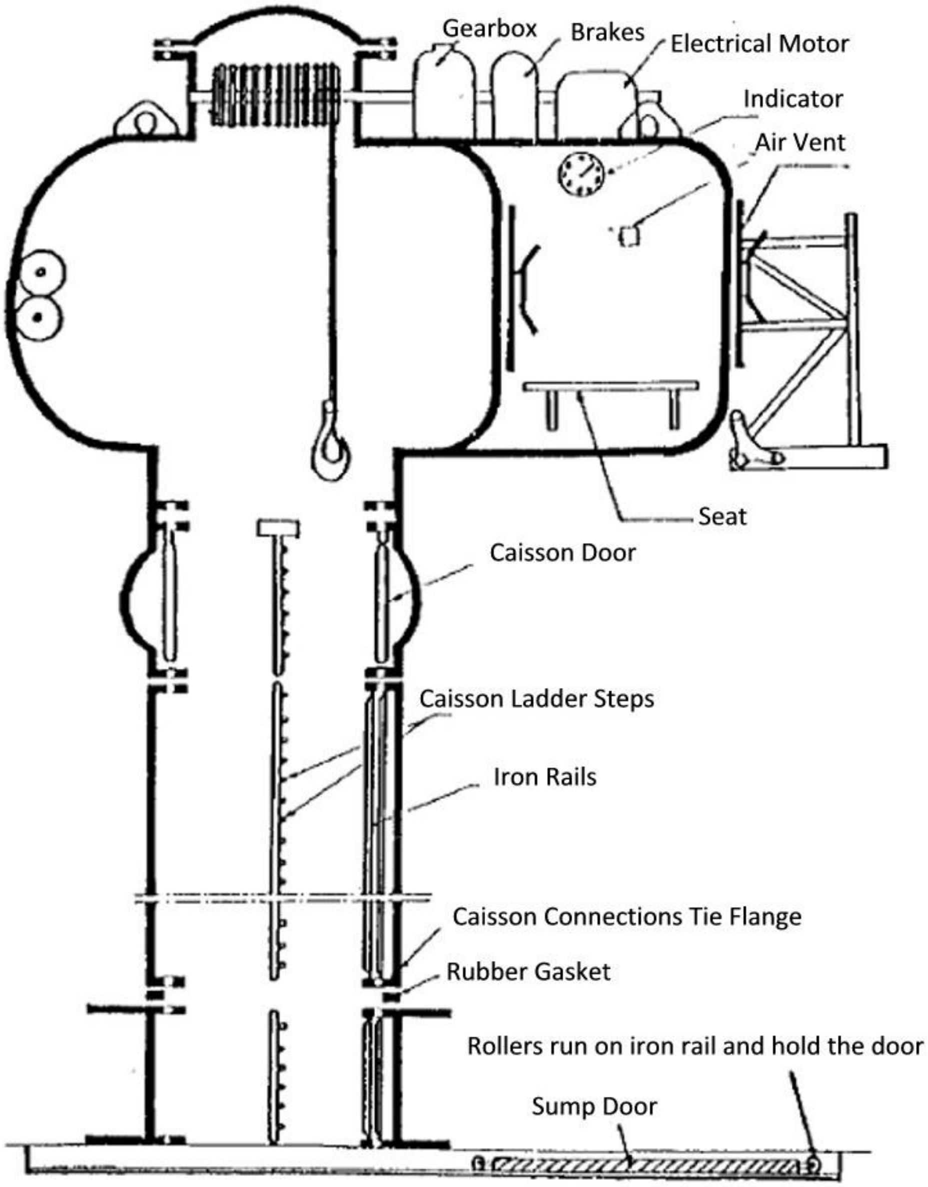


Fig (3-9): Illustrated diagram for pressure and caisson chamber

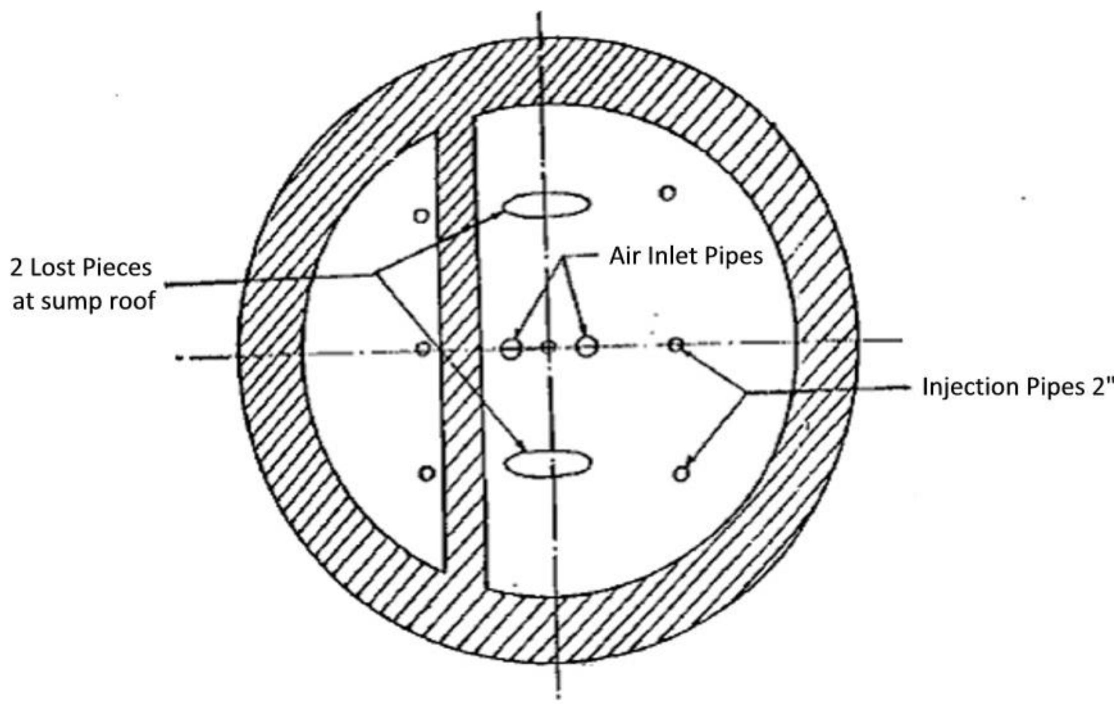


Fig (3-10): Plan view for sump floor illustrating the openings

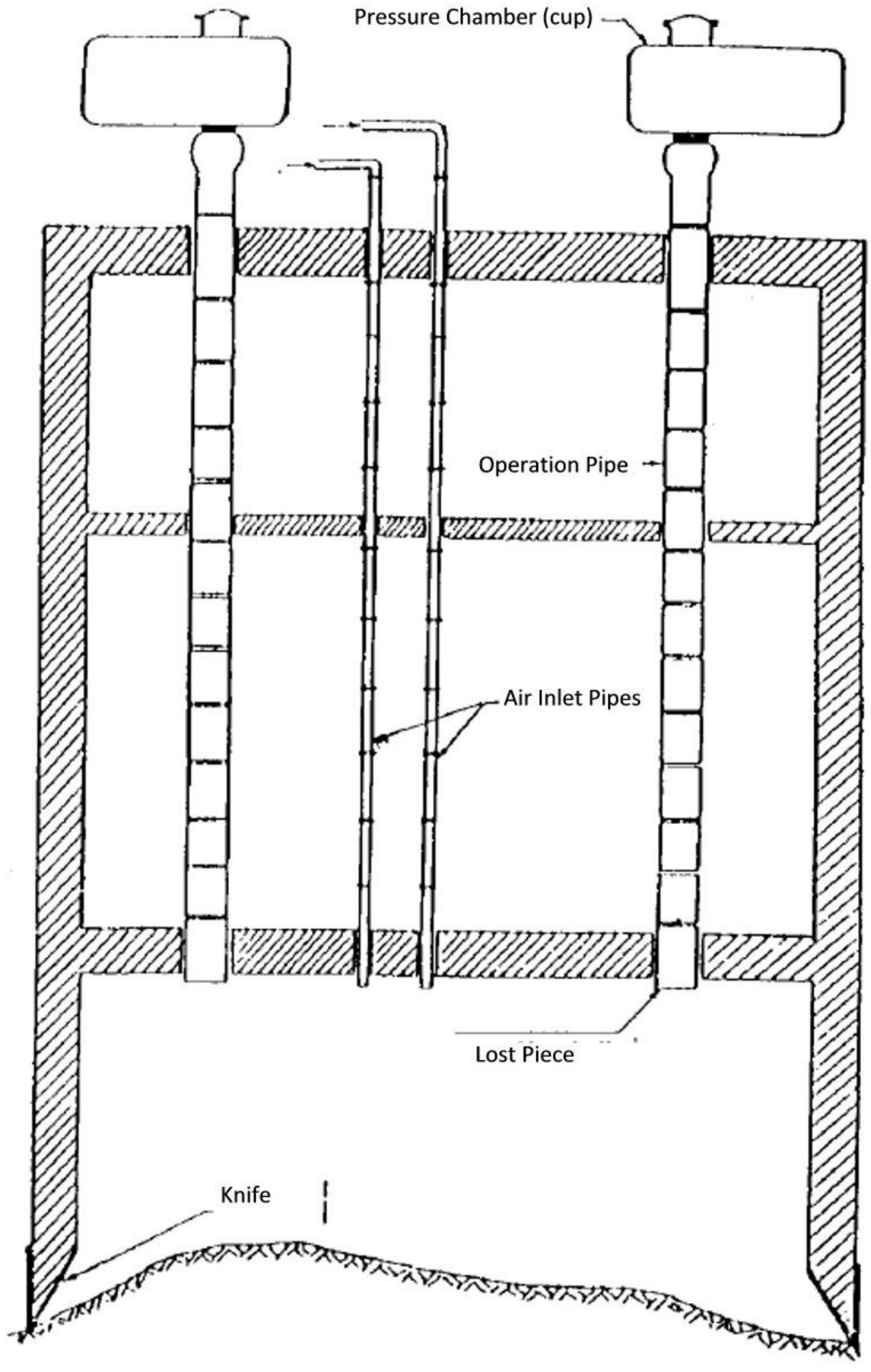


Fig (3-11): Vertical section for the sump illustrating the openings

J- Batteries are used in the operating equipments. Equipments operated with diesel are not used because they produce exhaust very harm to the workers.

K- After the sump reaches to the final level of construction, plain concrete is poured inside the operation chamber, consists of sulfate resistant cement with the addition of a catalyst material to resist water infiltration and cement ratio of 400 kg/m^3 executed by the same method for soil exist but reversed.

L- After setting of the plain concrete by a period not less than 14 days, injection process is started with the same method used in caisson sinking boring method Fig (3-12).

3-1-2 Open hole boring with shoring method

This method is used with square and rectangular sumps with shoring and dewatering of the groundwater with the technical methods. Boring works are executed manually by the workers or by using diggers in dry soil. The following different methods are used in shoring:

- Sheet piles.
- Combined sheeting.
- Contact sheeting
- Diaphragm Wall
- Piles Wall.

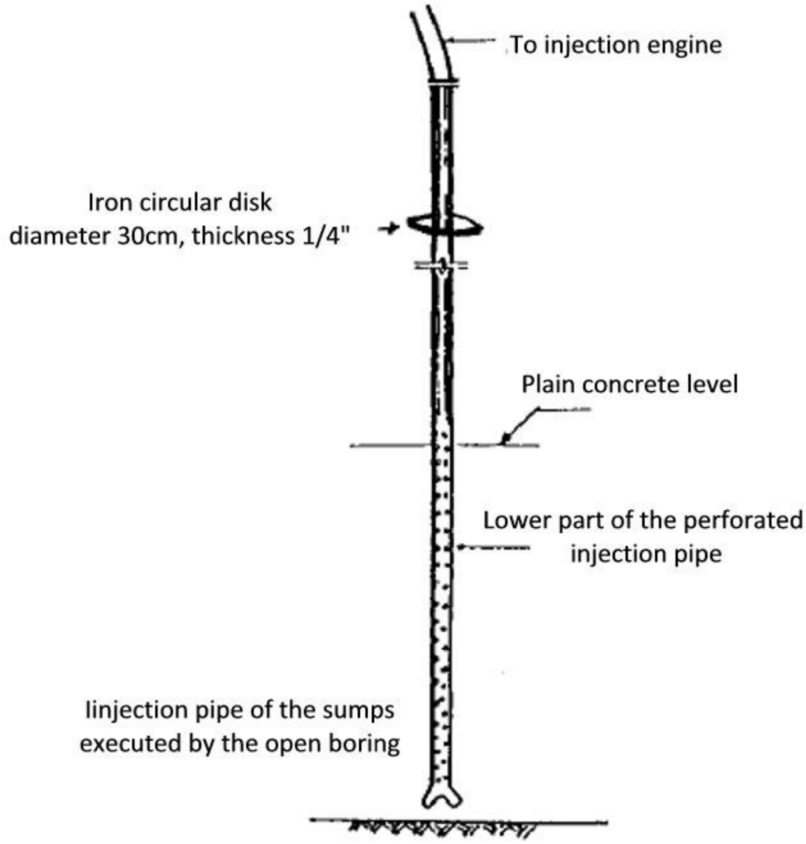


Fig (3-12): Injection process in the sump executed by open hole

3-1-2-1 Sheet Piles

They are from the main solutions of shoring for any depth of the sumps with large dimensions. Back anchors are used with the sheet piles, combined sheeting, contact sheeting, diaphragm wall and piles wall. The following is a simple idea helps the executer to better select the equipment suitable for digging the piles.

- Vibrators are used to dig the piles in sand, silt or pebble layers in the presence of water. Water can be injected below the piles under water pressure during digging process if the infiltration water level is far. For the other types of soils, such as silt soil or combined soil, vibrators can also be used in the presence of water, where it helps to decrease the friction between the soil and piles body. Piles can be removed by the same equipment. The vibrator is operated electrically. This equipment must be carefully selected, where the strength of the vibrator causes vibration and risk for the adjacent buildings (Fig 3-13).
- Diesel hammers are used to dig the piles. These hammers are available in different sizes and different dig powers according to piles sector, soil type and dig depth, taking into account to select hammer with power commensurate with piles sector to maintain head of the piles and prevent it from twisting.

Diesel or air hammers are provided with a cap installed under the hammer to secure piles sector from the continuous digging and distribute digging power over the entire piles sector. There are other types of hammers, such as air hammers and steam hammers.

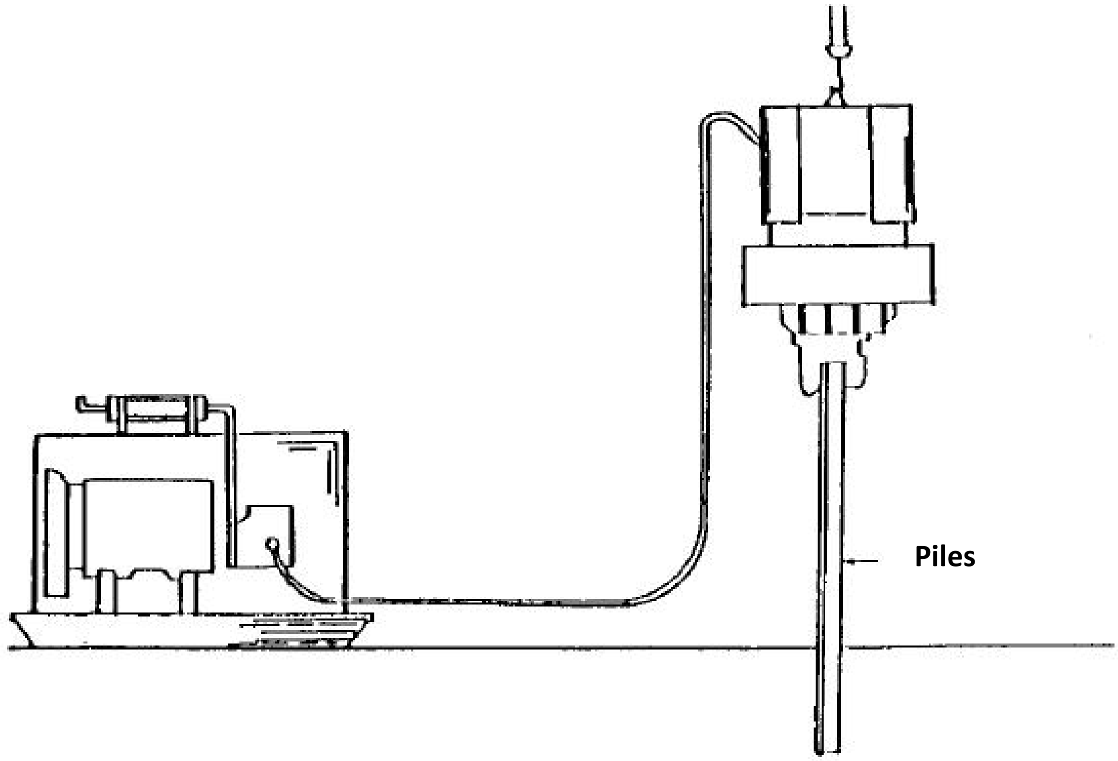


Fig (3-13): Installation of the piles by the vibrator

Sheet piles execution method

- Sump dimensions and sheet piles axis are determined.
- Metal structure is manufactured of length 4m, height 3m and width 2m, and is vertically adjusted by water bubble scale to put the sheet piles inside it, to ensure accurate vertical position during digging process. The metal structure can be replaced by any equipment such as digger or crane with vertical guide for digging process (Fig 3-14).
- The first pile is dug until reaches to the metal structure then the next pile is dug and so on until the piles group is dug on the metal structure.
- Then, the metal structure is removed and digging works are completed again. If the digging process is difficult, air is injected below the piles to decrease friction resistance of piles body while digging. This method is used only in the sand layer in the presence of water. In case of clay cohesive layers, water is injected under very high pressure, noting that to stop water injection before the piles reach to the final level by one meter in order to avoid disturbance of the soil at the foundation level (fig 3-15).
- After completion of the sheet piles, boring works are performed for the entire surface of the sump until reaching to the first row of the rear anchors then boring works are stopped.
- Holes of the sheeting are made by a drilling machine with the required diameter, length and inclination according to shop drawings.
- The sheeting consists of three parts, bond length, free length and anchor head, which is the part tying the anchor with the wall (Fig 3-16).

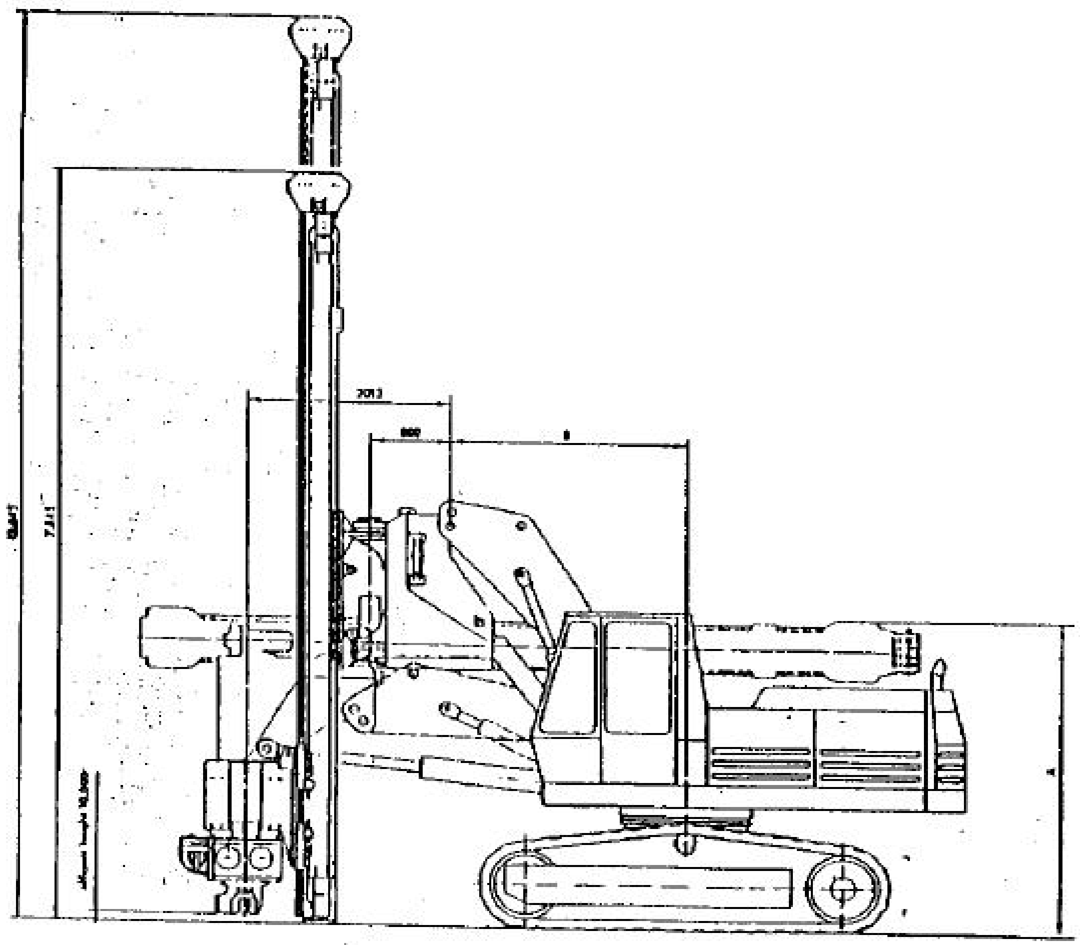


Fig (3-14): Installation of the piles using vertical guide installed on the digger

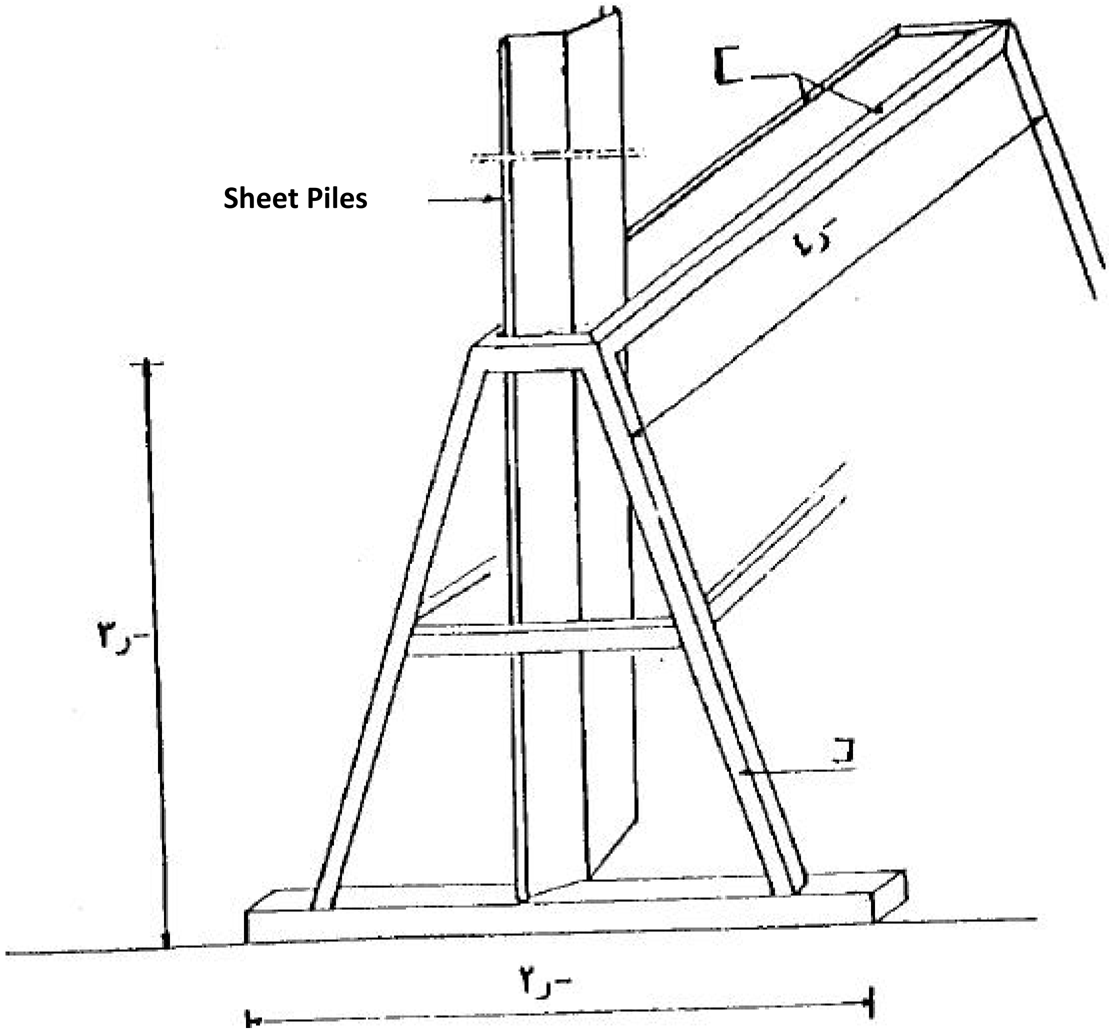


Fig (3-15): Metal Structure

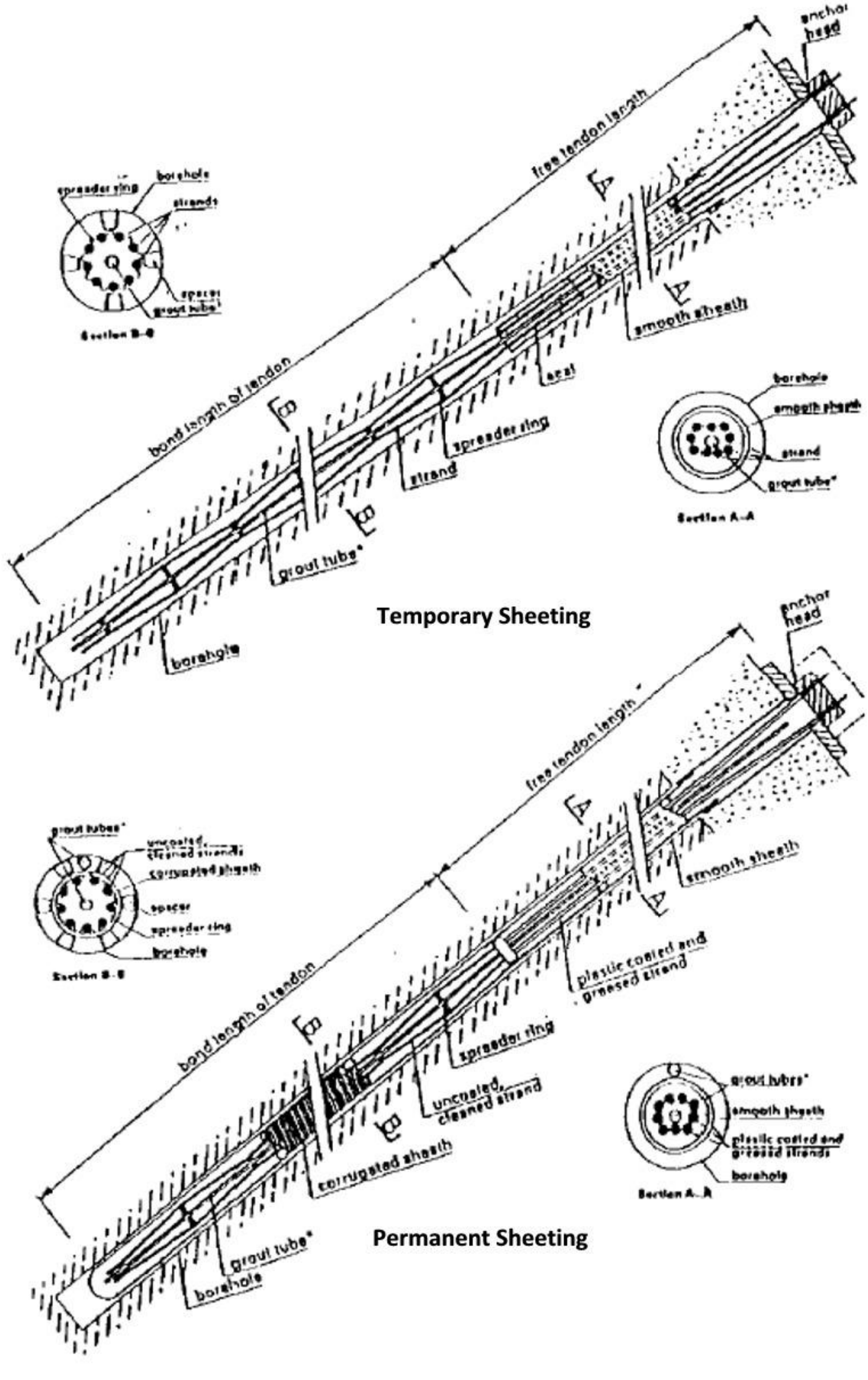


Fig (3-16): Permanent and Temporary Sheeting

- After making the holes, the metal tube with corrugated wall is inserted inside in the hole to its end. Cables group is inserted with the tube in one strand distributed on circular rings. Also, the injection tube is inserted in the middle of the metal pipe.
- After putting the cables and tubes, mortar cement is injected under high pressure to ensure filling the tube and the boring sector completely with injection materials.
- Sheeting is left for a period until the mortar is hardened, then anchor heat is put on the wall and then the cables is pulled by hydraulic pulling machine until reaching to the required tension (Fig 3-17).
- After reaching to the required tension, conical shape metal cotters are put at each tensioned cables strand, and then the hydraulic pulling machine is topped. The cables try to return to their original position due to the high tension force, but the metal cotter prevents the cables from returning to their original position before tension, also the metal circular ring resists the motion of the cotters group.

3-1-2-2 Combined Sheeting

Method of Execution

- Sump dimensions are determined then the axis of boring sides and sheeting thickness is calculated.
- Beams are dug vertically and horizontally around boundaries of sump axis. The distance between the beams is determined according to the design. It is usually 1.5 m and then boring works are started to a depth commensurate with the nature of the soil (Fig 3-18).
- The short sheets (4” × 4” or 5” × 5”) are put at the distance between the axes of the vertical beams.

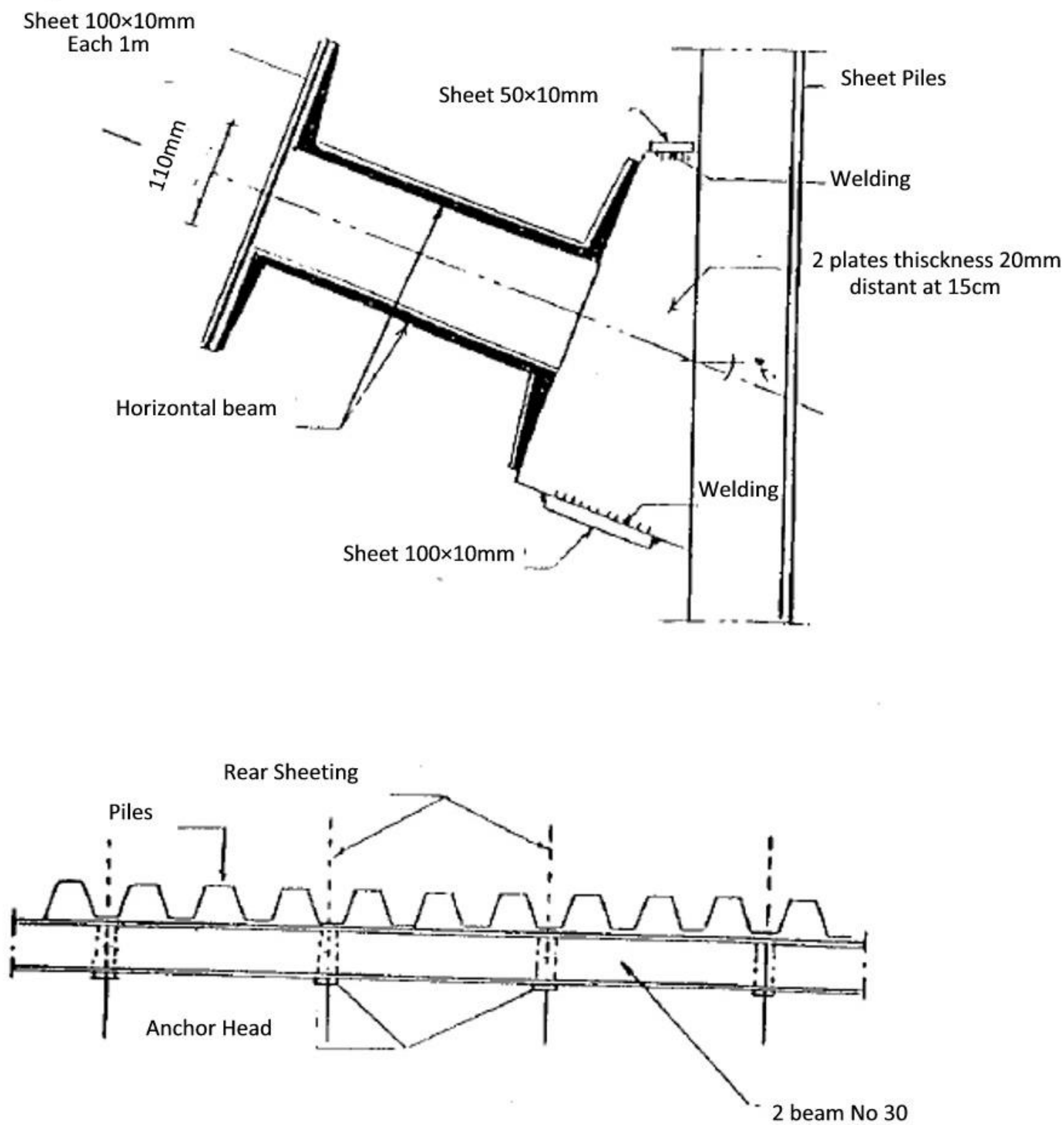


Fig (3-17): Anchor Head

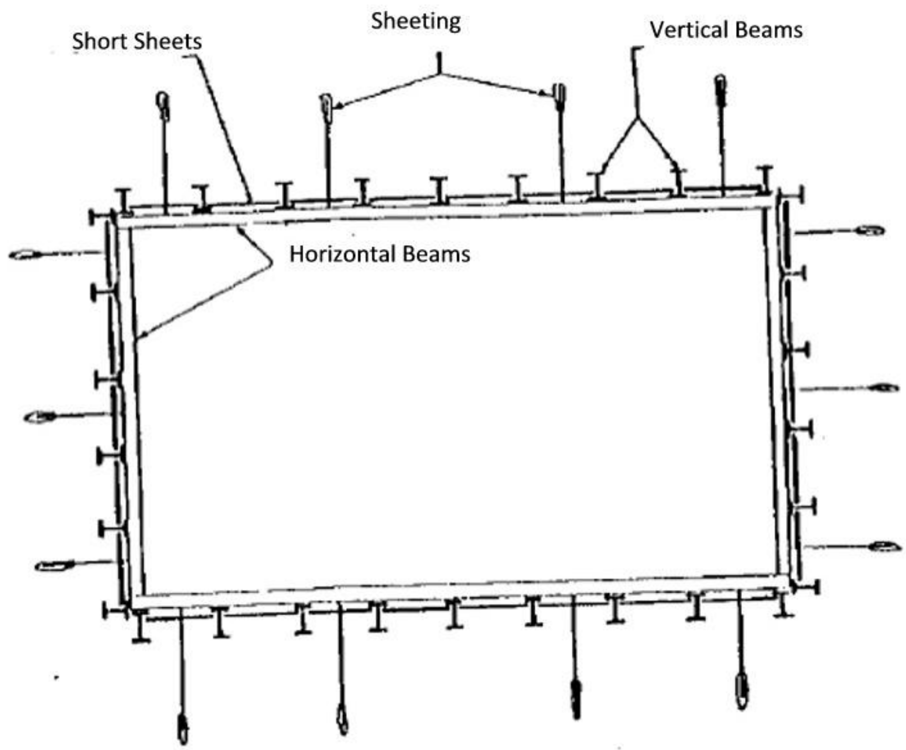


Fig (3-18): Different Sheeting for the projects

- Rear sheeting in executed by the same method in sheet piles method (Fig 3-19).

3-1-2-3 Contact Sheeting

- Axis of each side of boring is determined for the sump and thickness of wood sheeting is calculated.
- Sector I beams are dug on each axis and the distance between the beams is determined according to the design and it is usually between (1.5-2.0) m.
- After digging all the beams, boring works are started.
- Sections of pine wood (3” × 10” and 3” × 11”) are put and tied with clips fixed on the vertical beams as shown in Fig (3-20), Fig (3-21) and Fig (3-22).
- When reaching to the first raw of the horizontal beams, the horizontal beams are put and tied with chain to keep their level unchanged and then fixed by compaction or by rear sheeting as mentioned above in sheet piles taking into account the following points:-
- All elements of the sheeting are designed to determine its sector and the distances between them.
- Plats links must be staggered and not being tied by the clips with great strength.
- In case of existence of gaps between the wooden sheets and boring sides, these gaps are filed with soil.
- Boring works are commenced and by increasing the depth, pine wood are put as mentioned above.
- Upon completion of works, sheeting is removed from bottom to top and follow up of backfilling at each removed part.

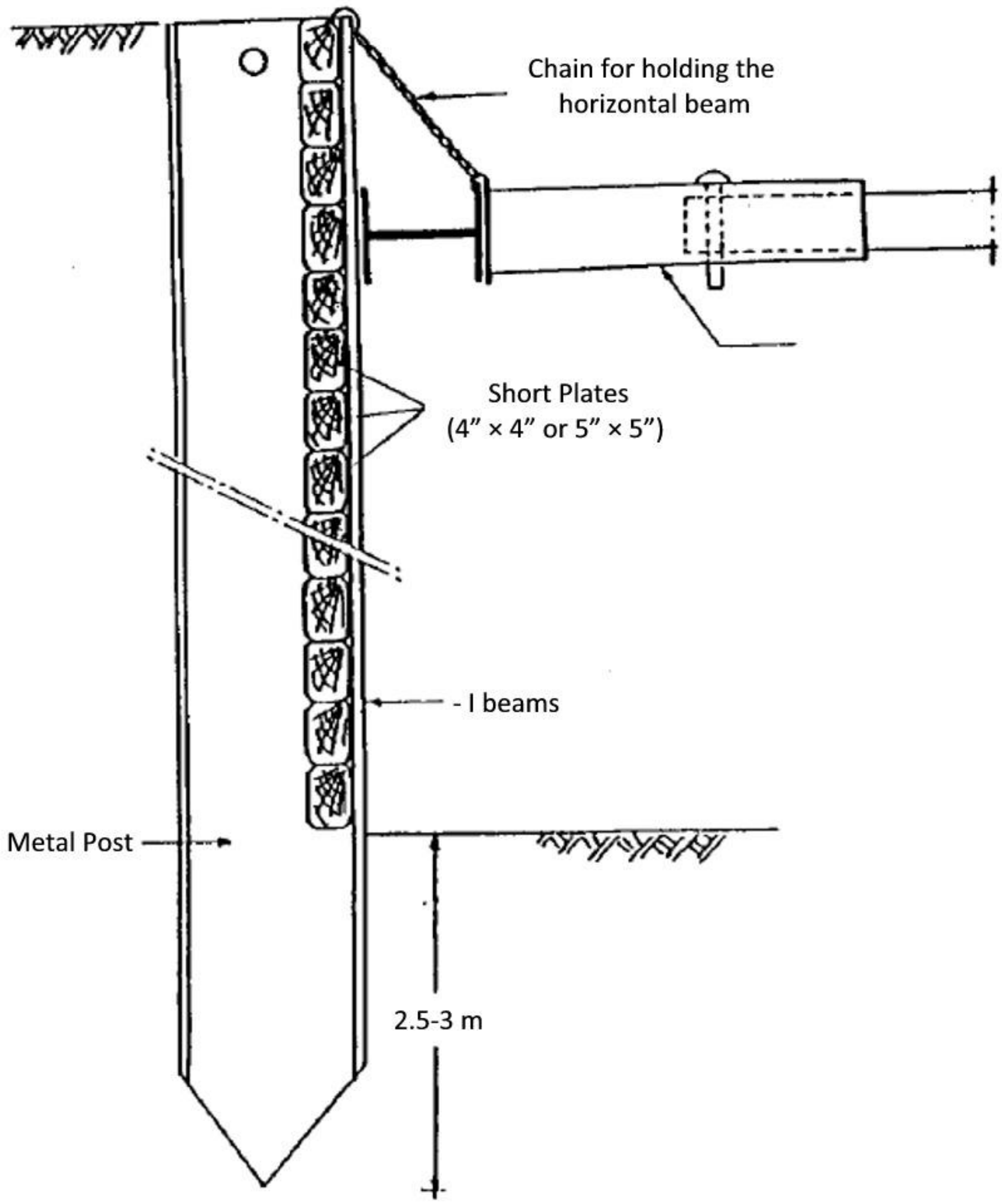
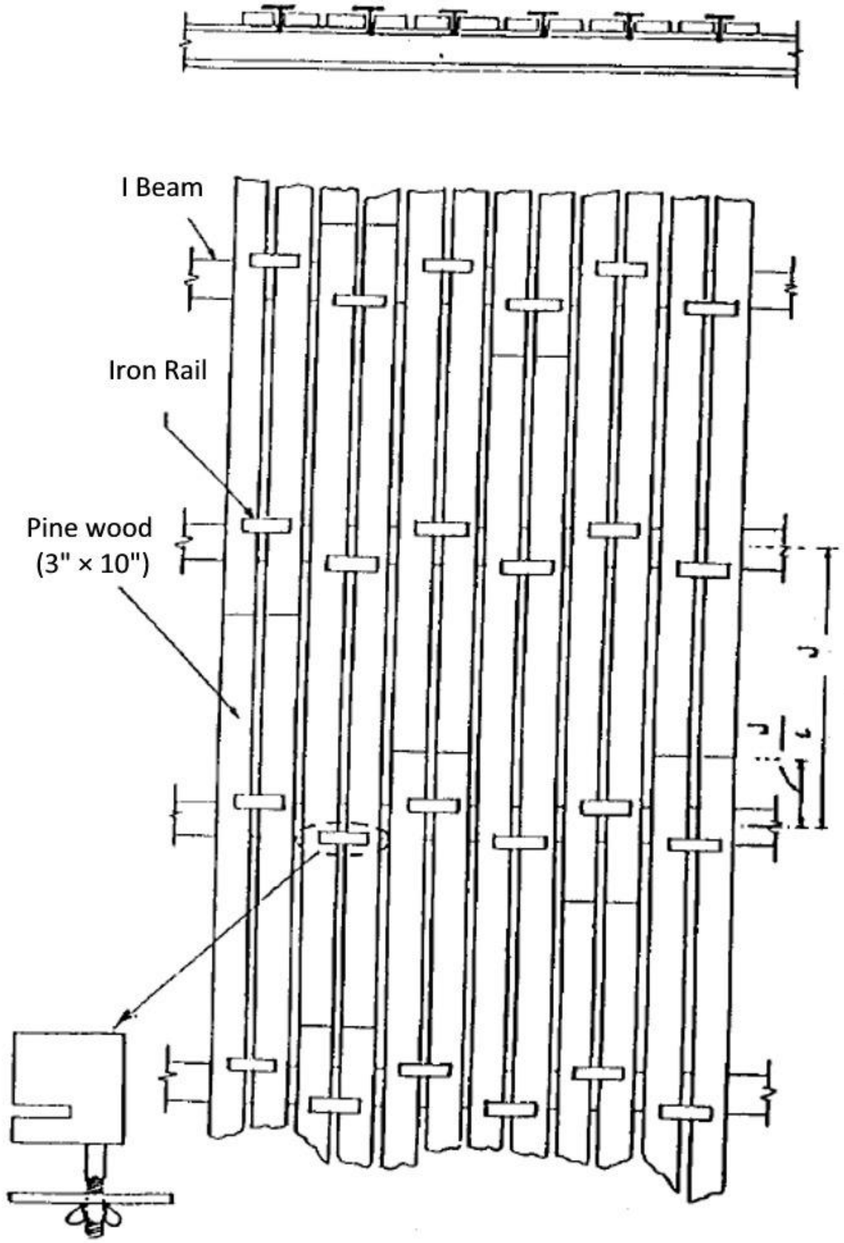


Fig (3-19): Section in the combined sheeting and its compaction


I Beam
Iron Rail
Pine wood
(3" × 10")
Metal Clip

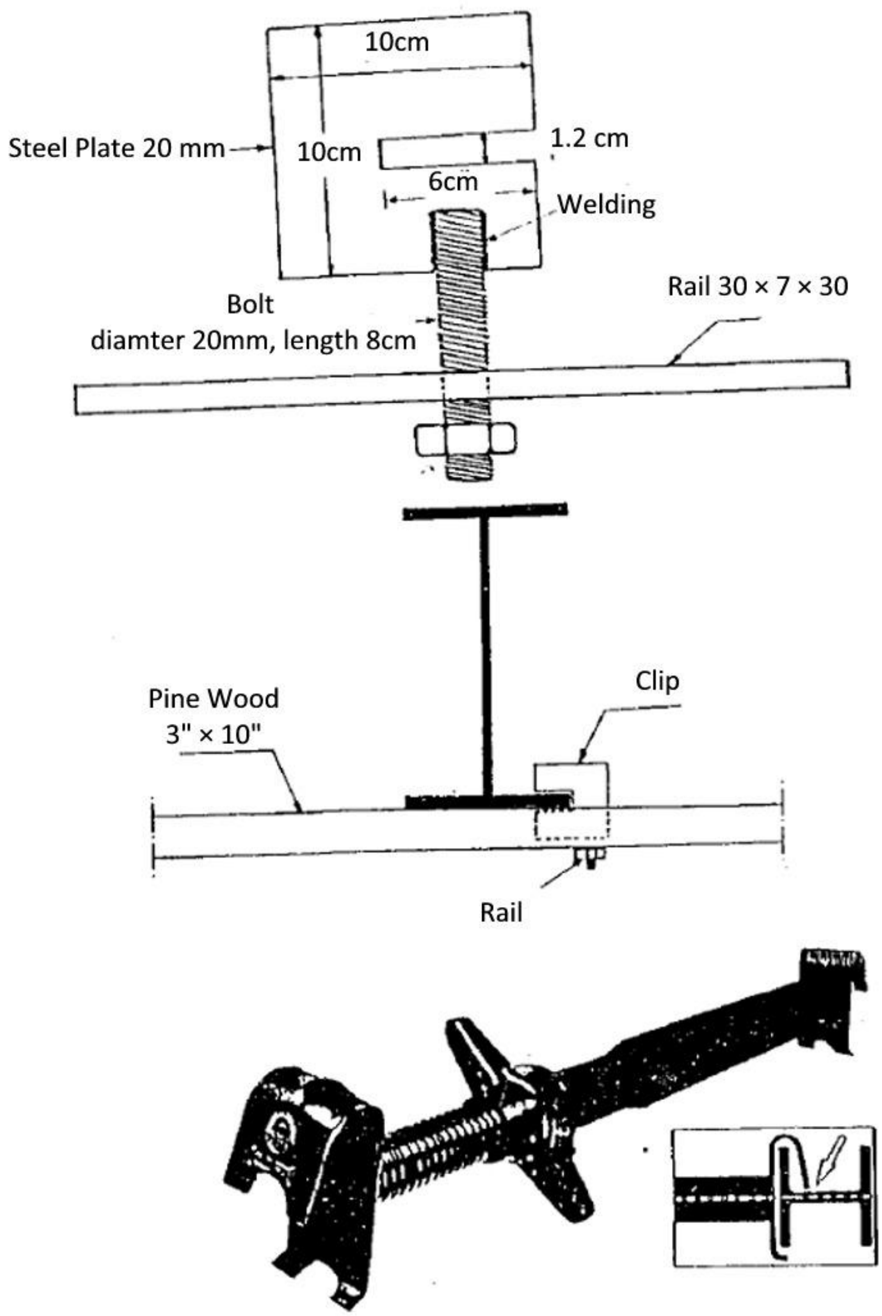


Fig (3-21): Clip on the Contact Sheeting

3-1-2-4 Diaphragm Wall:

Pre-cast or site cast in diaphragm walls.

3-1-2-4-1 Pre-cast diaphragm walls:

- Sump dimensions are determined and then walls axis.
- Reinforced beams are poured at the two sides of the axis which work as guide for the digger then boring works are started between the two guides and the distance between them is equal to the thickness of the retaining wall + 5cm clearance. Boring works continue until the end of the required level.
- Mixture of Betonayat is injected to the soil during boring works to avoid collapse of boring sides.
- Diaphragm wall is downed inside the boring after reaching to the required level and putting rubber tape at the center of the diaphragm wall in the circular gap along the wall before coming down inside the boring (this tape is tie between the diaphragm walls and infiltration water resistance(Fig (3-23).

3-1-2-4-2 Site cast in diaphragm walls

- It is required walls with certain dimensions to complete the work in case of execution of a wall with width smaller than the pre cast diaphragm wall or with greater depth that needs greater section and different reinforcement.
- Wall axis is determined and guides are made at the two sides of the axis (Fig 3-24)
- Boring works are started by injecting mixture of Betonayat until reaching to foundation level.
- The iron cage is downed to reinforce the wall inside the boring (Fig 3-25)
- Concrete is poured inside a vertical gutter to the depth of the wall (it consists of tubes connected to each other and ended by conical funnel) such that end of gutter tubes is higher by 50cm from boring bottom. Pouring starts slowly and the concrete fills the wall from the bottom until covers end of the gutter tube, then the gutter is slowly lifted up by the crane while the pouring is continued taking into account that height of the gutter tube does not exceed depth of the

last surface of the concrete to avoid mixing of the concrete with any sediments, dusts or Betonayat.

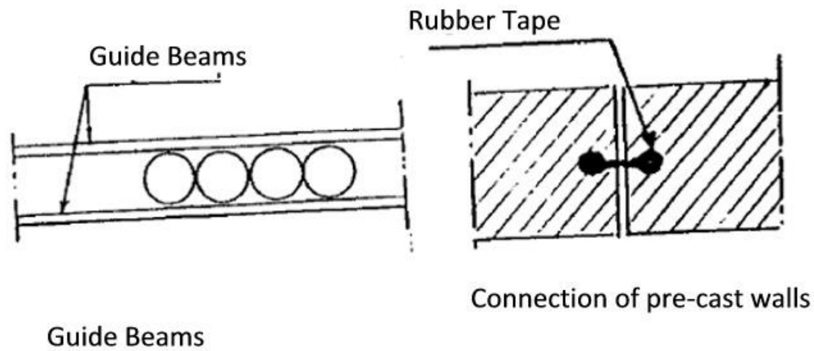


Fig (3-23):

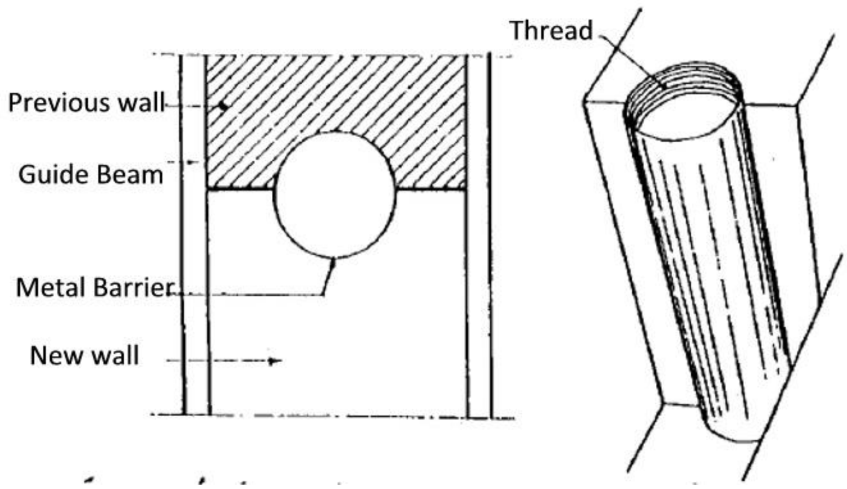


Fig (3-24): Metal barrier for pouring of diaphragm walls

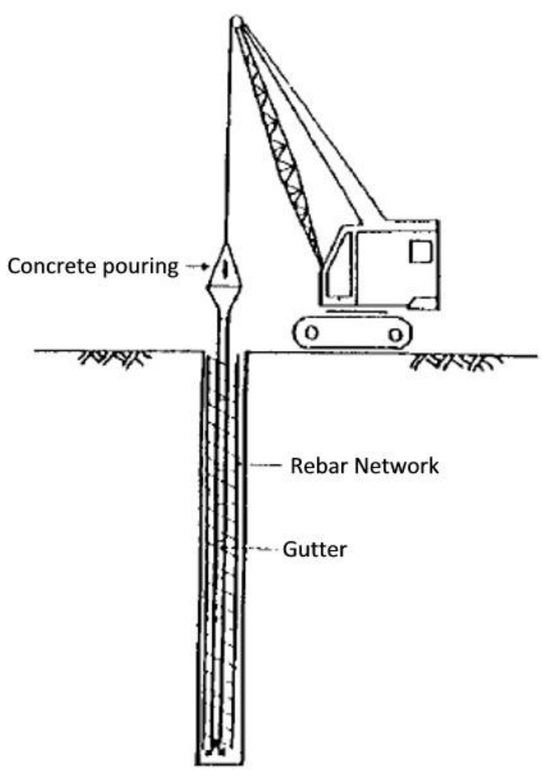


Fig (3-25): Pouring of Diaphragm Walls

One of the connections can be removed while pouring then the funnel is reinstalled on the gutter until the wall is completely filled with the concrete (Fig 3-26).

- Excavation is made until reaching to the first row of the rear sheeting with the same method in sheet piles.

3-1-2-5 Piles Wall

They are vertical adjacent piles to form retaining wall.

3-1-2-5-1 Execution Method

- Sump axis is determined then reinforced beams are made at the two sides of the axis (guide).
- First pile is excavated with the injection of mixture of Betonayat in the soil to maintain boring sides from collapse.
- Iron cage is downed for the pile then the concrete is poured using the gutter until the pile is completed.
- Excavation for pile (4) is made then pile (7) and so on until completion of the work (Fig 3-27).

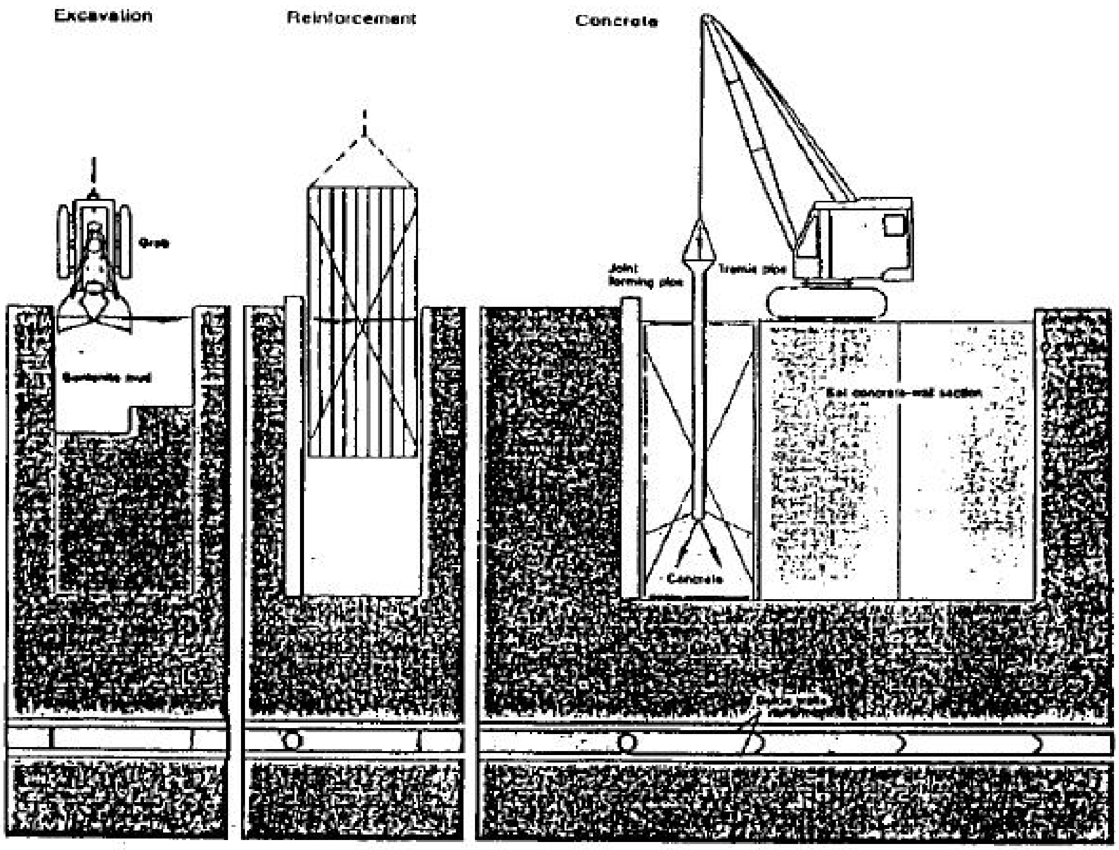


Fig (3-26): Execution steps of diaphragm walls

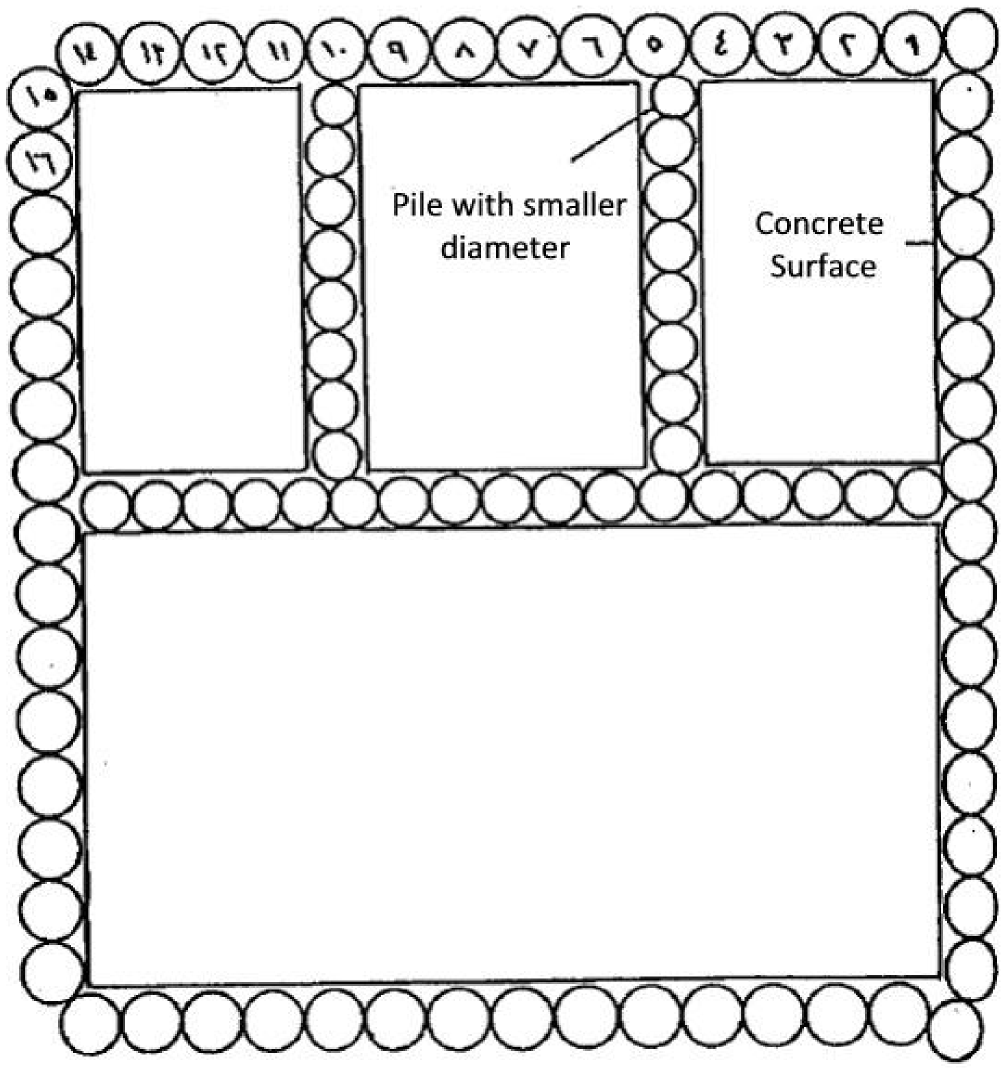


Fig (3-27): Plan view of sump from adjacent piles

- The work is repeated for excavation of pile (3) then pile (6) and then pile (9) and so on until completion of the work and execute the entire boundary of the sump.
- For great depths, rear sheeting is designed to resist soil pressure and thus pile section decreases (Fig 3-28).
- Excavation is executed inside the sump with provision of groundwater dewatering system. When reaching to foundation level, piles body is cleaned from the suspended mud using high pressure water hose or sand blast.
- Plain concrete is poured for the floor.
- Concrete cover is removed form the piles until the thickness of the reinforced slab and exposure of the rebar.
- Rebar splices are welded in the form of corner, i.e. welding one of its branches with the pile rebar and the other branch inside the slab in order to provide good cohesion between the slab and the piles.
- Rebar will be completed for the entire slab according to the shop drawings then the slab is poured.
- Vertical rebar net is executed on the surface of the piles then wood sheeting is made for the sump walls on the surface of the piles and then the concrete is poured up to the end of the sump walls.

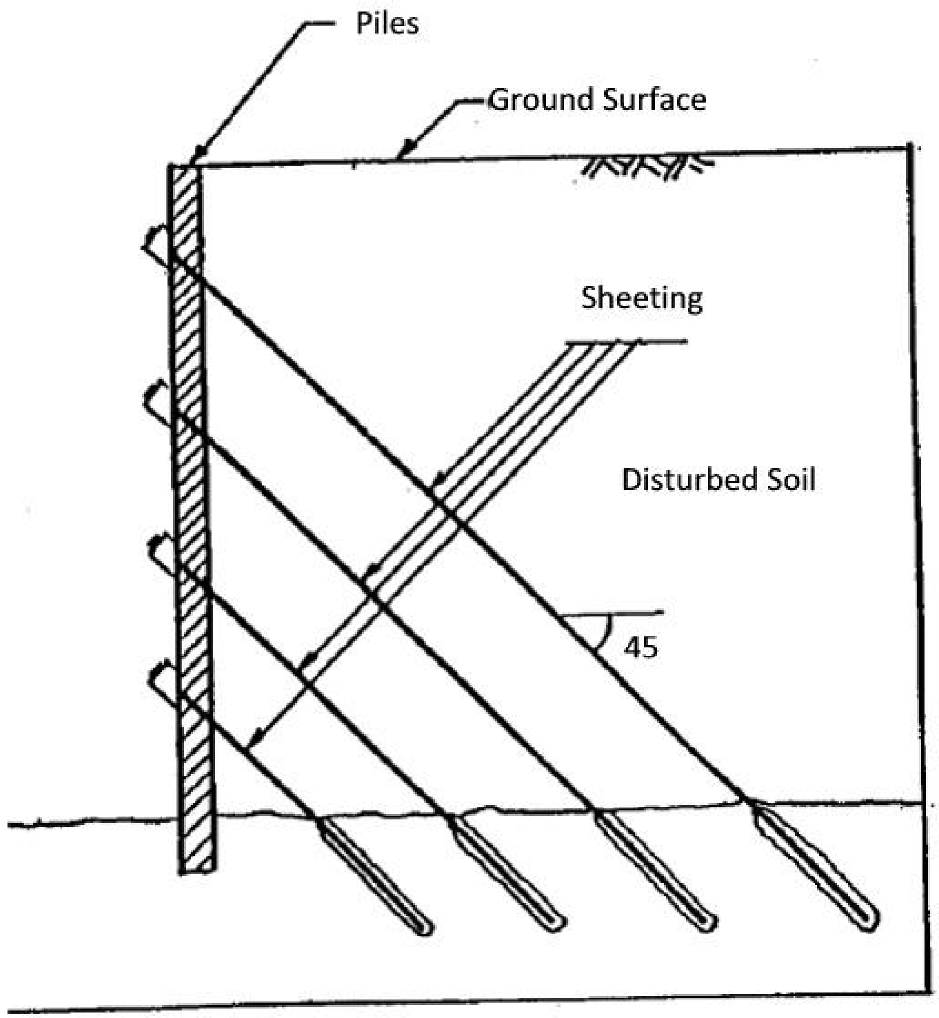


Fig (3-28): Rear sheeting with executed piles wall

4- Mechanical and Electrical Works

4-1 Pumps

- Before installation of the pumps, must ensure at first, fitness of the pumps after shipment and transportation to the site and non-existence of breaks or cracks on the pump body or any defects in any part thereof.
- Must conform the data listed on the data tag of the pump to the data and specifications stipulated in the contract.
- It is necessary to obtain full information about correct installation of the pump, including all details of the pipes, corresponding water levels, maximum and minimum operating conditions from pump manufacturer manual. Pump base must be implemented according to instructions of the manufacturer and if it is necessary to make a layer (structure) of steel sections, the measurements must be adjusted and keep a degree of levelness and take into consideration level of the concrete base on which the steel structure will be installed.
- Must give great care for alignment of the axes to reduce periodic maintenance works for the glands, and by using flexible coupling, effects of misalignment can be avoided.
- In all cases, must follow manufacturer instructions when align the axes to avoid usage of axes bearings which have rapid corrosion and damage.
- Pump must not be used as a tool for fixing the pipes and care must be taken when installing pipes and valves system for the pumping station and ensure that there are no strains transferred to pump nozzles (due to misalignment) which causes clutching of the pump or breakage of the parts made from castings.

- Position of the pump (mounting level) with respect to the suction water level must be taking into consideration and existence of separate suction pipes for each pump in case of multi-pump stations.
- If it is necessary to execute common suction line for the pumps, must take into account that maximum hydraulic inclination of the suction pipes occurs at maximum operating conditions and not to decrease the pressure in the common suction pipe at any point less than the value at which the pump is at the standby position under suction pressure less than the atmospheric pressure and leads to be escaped through the glands and the pump becomes air locked and unfit for operation where it needs reset.
- Must take into account the allowed percentage of suction pipe reducers.
- Suction pipes must be put inside the sump and ensure that their levels are in accordance with the design, as uncover of the suction nozzle with appropriate minimum level leads to formation of air bubbles enclosed inside the pump and causes lose of priming while the pump is running.
- Must avoid existence of high suction pressure on the pump whether by changing its mounting level or using high friction pipes or existence of blockage at the suction side whether at the suction inlet or existence of gate valve not completely open and leads to confinement in the pump and cause wearing for pump metal surface due to formation of steam sinuses inside the liquid and accumulate on the solid surfaces of the pumps.

4-2 Electrical Motor

Before installation, must inspect the motors and make sure that they are not damaged due to improper storage for long periods.

- Motor must be clear of any symptoms of corrosion before installation.
- Resistance of motor windings must be measured by megger device to ensure that they are not affected by humidity during storage. The resistance must not less than 1 Mega, and if it is less than this value, the winding must be dried and re-measured again.
- Ratings of the motor must be checked and compared with the data tag and supply documents.
- Must make sure that the place of motors installation is safe and is not subject to fire, risks or corrosion conditions except if the motors are designed to operate in these conditions.
- Must remove any dust or deposits on motors parts before installation and check fulcrums, connection points and slip rings to ensure their fitness and not being subject to corrosion or cracks.
- Must check motors bearings grease (except the sealed types and those designed to work over life span of the equipments) and ensure their fitness or replace it if necessary.
- Motors must be mounted on solid and flat base to avoid vibrations. Usually, the base consists of a bedding from steel sections mounted on reinforced concrete sill taking into account to be the tying screws carefully commensurate and to assemble the bedding such that the surface is flat and their axes are aligned when putting on the concrete sill and sealing of the bedding after leveling and alignment.

- If the cost of the bedding is high, the motor can be mounted directly on the concrete base using wedges inserted in the concrete, usually from cast iron with smooth top and longitudinal reduced hole and cracks on the body to ensure good cohesion with the concrete. Wedges are tied with motor legs and the motor is mounted on the concrete base for proper adjustment. Permanent mortar cement is used for sealing. After final adjustment and leveling, holes are punched in opposite direction of motor leg inside base wedges and insertion of pins to facilitate re-installation works of the motor on the base.

- Simple adjustment, height adjustment or motor replacement can be achieved by using shims under motor legs.

  Doweling is also used after sealing (alignment) and final adjustment of the motor in case of using steel bedding.

- Large motors with axes mounted on a manufactured base usually have bedding with lower structure from cast iron to be mounted directly on the reinforced concrete bases prepared for this purpose.

- Motors with flanges or vertical motors are installed usually on lower structure. Vertical motors are mounted on pre cast skirts especially for driving the pumps and are considered motor stool.

4-2-1 Alignment

- Fine adjustment is the main requirement to avoid faults of bearings and couplings. Alignment is performed between the motor and the pump before tying the joints.

- Faces of the joints must be in parallel and to take into account any spacing between the faces recommended in manufacturer instructions.

- Alignment is finally performed for the joints and revised using pointer meter.

- Double bearing motors are connected with the pump by flexible joint to decrease transfer of shock loading to bearing.

- Single bearing motors are connected with the pump by using solidly bolted joint and not flexible joint because these motors are not designed to withstand downward thrust resulted from rotor weight.

- Mechanical mounting of the motor is completed when the two halves of the joint are connected. It is required more inspection before supply the electrical current and to make sure that the motor cooling air is flowing without obstacles whether from the air inlets or exhaust outlets, as the insufficient space between air inlets and the adjacent walls leads to temperature increase.

- Must ensure that all covers are removed and any gates must be kept open during motor operation.

- All auxiliary equipments must be checked and properly fixed, such as air compressors, rpm meter, external coolers, filters, bearing vibrations or temperature probes and bearing oil circulation equipments.

- Must test cross section areas of motors power and control cables and conductors according to the design and to check and compare the operating voltage with the design.

- Must check cable terminals to ensure that they are properly connected for good conduction of electricity.

- Must connect earth screws carefully with the motors according to instruction of the competent bodies, applicable regulations and manufacturer proposals.

- Must adhere with safety rules, fire and explosion risks prevention.

4-2-2 Start Motion:

- After installation of motors and proper connection of their cables, addition check is performed to insure that the bearing is good greased, efficient operation of the cooling system, air inlet and outlet without any obstacles and the electrical current is connected to all ventilation fans with separate drive to ensure they are rotating in the correct direction.

- Must ensure that motor cooling fan is rotating in the correct direction according to the specification illustrated in the connection circuit with respect to motor rotation as indicated in motor data tag or on motor body.

- After initial check of the motor after installation, operation and loading of the motor, the necessary inspection must be performed to ensure from vibration rate, monitor and control reading of speed and measuring meter.

4-3 Motor Control Center (MCC)

- Before start installation works, must revise manufacturer drawings and compare them with contract drawings.

- Must inspect location of installation of MCC and its relation to cable trenches and paths.

- Must carefully plan for future cables installation before installation of MCC.

- If MCC is of floor mounted type, must provide with flat base.

- Must take into account total height of MCC and compare it with building height and upper cable trays.

- Must take into account ventilation of MCC in order that MCC is working in low temperature and decrease vapor condensation inside it.

- For performing preventive and periodic maintenance and to facilitate troubleshooting, must take into account easy access to MCC when putting the equipments.

- MCC must be installed in places with low vibrations and to be fixed vertically and firmly in order not to affect MCC components. Screws, nuts and terminals must by firmly tied before operation of MCC. Before connection of the motor with the control panel and starter motion, must ensure their capacity according to data tag for each of them.

- Cable terminals (power and control) connected and going out from the MCC must be marked according to the numbers indicated in the detailed drawing of MCC to facilitate and ensure correct connection.

- Cable paths must be kept away from any hot parts or bodies such as heater grids and resistance block, and if it is difficult to avoid this, must use heat resistant cables.

- Must be cared not to scratch the cables by sharp tools such as iron tools, screws, etc.

- When laying the cables, must adhere with the specified number according to design drawings to prevent over heat that affects cables efficiency.

- Must put marking, warning and safety tags and different covers after installation.

- Must earth all parts of MCC.

- Before connection of the electrical current, must take the necessary steps:

• Perform insulation resistance test for all terminals and distribution bars and to isolate or disconnect measuring and control devices before apply the high tension.

• Operate all the magnetic devices manually to ensure that all the moving parts are working freely.

• Revise electrical connection terminals to ensure correct and safe operation.

- Disconnect the temporary connections that required for transport of the boards (or any fittings) for the bridge connected on current transformers.

- Revise ratings of the relays on the actual loads of the MCC according to data of the working motors connected on MCC.

- Revise operating times for the timing devices.

- Clean all internal parts of MCC.

- Test operation of all control and safety (protection) circuits.

4-4 Cables:

- Method of cables installation depends on the place that will be laid on taking into account that the shortest path is not the most economic one. Soil nature has direct effect whether it is rocky or aggressive.

- Method of installation of mains cables are:

- Direct buried in the ground.

- Withdrawn inside ducts buried in the ground.

- Laid inside troughs

- Air installation on cable holders and cable trays or on the ascending or descending ladders.

- Direct burying in the ground leads to high cost of excavation and the cables should buried at sufficient depth to avoid damage of the cable from the surrounding conditions. Soil around the cable must not contain any rocks with sharp edges or any other similar materials. Discriminated markings must be put on the cables to know path and place of the cables when performing future excavation to avoid them.

- If group of cables are laid beside each other in the trenches, must keep sufficient distance between them in order not to affect their efficiency for carrying the current (see distances table in code annexes).

- Trenches are backfilled as soon as possible after laying the cables to reduce possibility of damage.

- If the cables are passing under the roads that move on them heavy vehicles, it is preferred to pass the cables in ducts and to leave paths for an additional cables in the future without the need to excavate the road again.

- When laying the cables inside troughs, must take into consideration effect of adding more cables in the future that may adversely affect cable load (current density).

- Cables installed in the air must be fixed at near distances in order not to apply stress on the cable (see code annexes)- IEC instructions. When passing the cables on trays and stairs, must take into consideration places of these trays and stairs as the workers at the site consider them as walkways to access to the surrounding areas that may damage the cables.

- For all method of cables installation, must not bend the cables with radius less than that indicated in the tables for this regard and specified in the international standard IEC or Egyptian standards.

  It is preferred to be the radius little greater that than specified in these specifications.

- When passing the cables across the walls and partitions, must be passed through holes lined with fire resistant material. This shall be applied when ascending or descending the cables across different floors ceiling of the building.

- It is preferred to use cables with lead sheath in a ground saturated with hydrocarbons to prevent its leakage through cables insulation or reach to the electrical boards and cause fire.

- When passing (drawing) cables inside ducts, must take into consideration, in addition to the generated heat, easy drawing of cables inside the ducts without causing any mechanical stresses.

- Distance between the draw boxes and the used number of elbows in the path affect on the required tension for cables laying, so this must be taken into consideration where the increase of stresses leads to damage of cables insulation. Code annexes show duct factors according to the standard specifications and cables factors for different sizes.

4-5 Transformers:

- Before installation, transformers must be checked to ensure that there is no fault or breakage resulted from transportation. For oil transformers, must check oil level and any leakage.

- Must check painting of the transformers and note any defects.

- Must check transformer terminals and note any mechanical defects.

- Must check the connections and windings and note any defects in the insulation.

- Must carefully check resin of the dry transformers, as it is easy to be scratched or cracked and ensure there fitness before installation.

- For oil transformers, must provide passes for the leaking oil for collection of the leaking oil taking into consideration possibility of occurrence cracks or holes affecting main tank of the transformer.

- Shape, size and type of the materials used in construction of the transformer enclosure are determined according to rate of disposal from the heat resulted from the fire of transformer oil.

- All types of dry transformers must be installed inside the buildings and surrounded by metal frame connected with the earth (or metal grid barrier).

4-6 Distribution Panels:

- Before installation, must ensure existence of the drawings and instructions issued from the manufacturer of these panels that give directions for installation.

- Must ensure that the chamber in which the boards will be installed is clean and dry and to remove any existing wastes.

- Must close and cover any unused cell in the board that may left for emergency.

- Must keep all insulations in the board clean and dry and cover them during installation works.

- Must use the correct method of handling and mounting must be on the points specified by the manufacturer in order not to subject any parts of the board to stresses or sudden load that may lead to damage or defects to board body or its components.

- Proper installation of the boards and safety of operation depend to a great extend on accurate implementation of the bases of the boards.

- The best method for implementation if distribution boards bases are the steel sections shaped in the form of channel buried under the ground below the boards and provided with screws (bolts) and nuts and must take into consideration that these sections are parallel and leveled and little jut out over the level of the floor surrounding the boards.

- The board is installed on the base by direct mounting on the steel structure of the base after being leveled.

- Base steel structure can be replaced by bolts put inside pits prepared during pouring of the board's chamber flooring and the bolts are put inside it and then perform sealing around them and then the boards are installed and fixed by these bolts and their suitable nuts.

- If the switchboards are supplied in parts to be assembled at the site, middle parts are installed first then the sides to ensure non-accumulation of mistakes that can not be noted in case of non-matching between the different parts of the board. Water pipe is used to ensure alignment of the board parts during assembly, taking into account to leave the screws between the parts untied until completion of parts assembly.

- After installation of the board, must check and ensure that all the movable components of the board can be easy removed and also easy open and close of the doors and covers of the board cells.

- Devices and components supplied disassembled must be inserted in their specified places to be maintained during transportation and then connected after installation and mounting of the board.

- When connecting the cables to and from the board, must avoid any severe bending or squeezing of the cable. Cable terminals must be installed in a way that not allow for any stresses or excess tension on the cable terminals after connection, taking into consideration maximum diameters of bending for these cables according to the measurements determined in the standard specifications.

- Earth of each board must be connected to all metal parts in the boards, enclosures of the measuring instruments and earth points of the switches through tying or riveting and never by welding. Earth wire must be continuous and fixed firmly with the main earth through tying or riveting also.

5- Tests:-

All materials and equipments used in construction of the pumping stations are subject to tests necessary to ensure their fitness for use and their required purposes.

These tests are divided into two parts, one is performed inside production facilities and the other is performed in implementation sites.

The following are types of materials and equipments required to be tested inside production facilities and implementation sites.

5-1 Materials:

They include sand (small aggregate), pebble (large aggregate), cement, mixing water, pipes and fittings, lime, gypsum, insulating materials, stones, tiles, marbles, granite, painting materials, chemicals, asbestos, wood and glue, glass, iron sections, aluminum sections, welding materials, screws and accessories, laid grids and wires, construction partitions, ceramics and faience, rubber products, vinyl flooring, cork, metal and non-metal plats, steel sections, hoses, paving materials and metal products and their alloys.

5-2 Architectural accessories

They include hinges, lockers, handles, latches, faucets and valves.

To test the materials and equipments inside the factory or in the places of extraction, the owner or his representative shall monitor the manufacture process, if necessary, whether at the workshops of the contractor, factory or quarrying from which the contractor obtain these materials, and he has the right to enter and remain in these places during manufacture or extraction of these materials.

5-3 Equipments:

They include motors, pumps, generators, cables, distribution and control boards, valves, cranes, measuring and alarm devices, gates, transformers, conveyors, screens, protection devices, tools, control devices, workshop instruments and fire fighting equipments.

These tests are performed at the expense of the contractor to ensure that each part of these equipments is manufactured according to Egyptian standard specifications for the equipments manufactured in Egypt, and according to terms and conditions of the contract. For the equipments imported from abroad, the engineer or his representative shall present at manufacturing facilities for accurate inspection. The contractor shall notify the owner by the names of the factories, workshops and suppliers from which shall obtain these materials before start in the works trusted to him. The contractor shall submit certificates from the approved inspection committee for the imported equipments from abroad and it is not allowed shipment of any equipments or supplies without being inspected by owner representatives.

The contractor shall provide the owner with copy of the drawings and specifications approved for this purpose and the owner is authorized to test theses equipments and supplies which will be supplied by the contractor according to contract conditions. The owner is entitled to reject any equipment that are not in conformity with the specifications and shall approve the inspected samples and put discriminated mark to prove that they are passed the tests successfully and on the basis of them the equipments will be supplied to the site.

5-3-1 Equipments test at production facilities

- These tests are performed for all equipments that are contracted to be supplied before transportation from the contractor or producer factories.

- Different equipments shall be installed and operated (to the most possible extend) according to actual operation conditions at the work site.

- Mechanical equipments that are driven by electrical motors must be tested on the same motors except if the operating voltage of these motors is not available in the production factories or contractor test laboratories. In this case, tests can be performed on typical motors and the available calibration for such tests taking into account to calculate the actual consumed powers to ensure operation of the equipments when being driven by their motors at work site with the same efficiency and accuracy.

- The above item is applied in case of different measuring instruments that must be used to calculate the measurements of the mechanical equipments which shall be supplied for the project, if possible.

- The measuring instruments used in performing the tests in production facilities must be calibrated and to check the supporting certificates from the certified bodies in the manufacturing country, taking into consideration ratings accuracy and compare it with the accuracy indicated on the data tag from the producer.

5-3-1-1 Hydraulic Pressure Tests

All castings, valves, pipes, special pieces and any other pieces in the equipments subject to pressure must be tested under a pressure equal to double maximum pressure designed for the work.

5-3-1-2 Tests of materials and apparatuses

All materials used in the manufacture and any apparatuses necessary for the equipments must be tested according standard specifications of the producing country or to international standard specifications ISO and to obtain approved certificates from the competent bodies.

5-3-1-2-1 Mechanical Screens

A- Revision and approval of execution documents.

B- Steel manufactures

- Revision of manufactured materials certificates.

- Visual inspection of welding and their dimensions.

- Inspection of 10% of LP/MT welding.

- Inspection of surface treatment against external effects.

C- Assembled parts (materials and components)

- Visual inspection of the assembled parts and their dimensions.

- Electrical and mechanical test (try installation at the workshop).

D- Electrical motor and gearbox

- Revision of conformity certificate.
- Inspection of dimensions and paintings
- Drive test.

E- Before shipment

- Final visual inspection and revision of markings and ensure fitness of equipments sealing.
- Revision of final dossier.

5-3-1-2-2 Gates

A- Revision of execution documents.

B- Revision of the materials for (gates, frame, post and seating)

C- Installation

- Visual inspection of welding and their dimensions.
- Inspection of 10% of LP/MT welding.
- Visual inspection and dimensions
- Inspection of surface treatment.

D- Assembled Parts

- Visual inspection of the assembled parts and revision of their dimensions.

- Performance verification.

E- Before shipment

- Final visual inspection and revision of markings and ensure fitness of equipments sealing.

- Revision of final dossier.

5-3-1-2-3 Electrical Motor Test

Motors are inspected according to the following particulars and properties:

- Implementation.

- Manufacturing and finishing

- Main dimensions.

- Air gap measurement

- Paintings

- Correctness of documents.

These particulars are compared with specifications, drawings, accepted bid, codes and standard specifications.

The following routine tests are performed for the motors:

- Measurement of windings cold resistance.

- Measurement of cold insulation resistance (megger test)

- Measurement of detectors cold resistance (if any)

- Measurement of open circuit voltage of the rotor.

- No load properties.
- Closed circuit properties
- High voltage test (Dielectric test)

High voltage test is performed according to the voltage specified in the standard specifications for both stator and rotor.

The following performance tests are performed for the motors:

- Hot drive test.
- Load and efficiency properties.
- Over current test.
- Break down torque.
- Warm insulation resistance test (by megger).
- Pulse test for stator windings voltage.
- Inspection of radio interference.
- Inspection of vibrations and noise level.
- Measurement of motor resistance.
- Measurement of GD.
- Mechanical test.

Motor withstands over current for 15 seconds at least without sudden change in speed (under credit torque increase) at maximum torque of at least 60% over this corresponding to full load rating.

The following inspection and tests are performed for rotor starter at the factory:

- Same inspection items as mentioned in the motors.

- All starters are subject to performance and high voltage tests.

5-3-1-2-4 Tests of electrical distribution boards (assembled)

Inspection is performed for the following:

- Acceptance test for manufacturing and assembly.

- Revision of dimensions.

- Paintings.

- Revision of connections and wires.

- Correctness of documents.

- These items are compared with specifications, drawings, accepted bid, workshop drawings, codes and standard specifications.

The following tests are performed for the boards:

- High voltage test.

- Performance safety for the following:

Operation- Control and protection circuits.

5-3-1-2-5 Generators

A- Preliminary inspection

- Revision of motor test certificate.

- Revision of generator test certificate.
- Revision of electrical control devices test certificate.

B- Group trial test

- Visual inspection and dimensions.
- Load test.
- Over load test.
- Speed regulation test.
- Voltage regulation test.
- Inspection of functional parameters.
- Inspection of clutched starter and components.
- Inspection of performance accuracy of electrical control panel

C- Before shipment

- Final visual inspection and revision of markings and ensure fitness of equipments sealing.
- Revision of final dossier.

5-3-1-3 Submerged Pumps

- Revision of routine test certificates
- Performance test

(Flow- head- speed- motor power analysis- efficiency- functional diagram- vibration- materials- paintings and surface treatment)

- Visual inspection and dimensions.
- Inspection of indicators panel.
- Inspection of documents and sealing.

5-3-2 Equipments tests at site

5-3-2-1 Mechanical equipments test

Tests at sit are performed for all mechanical and electrical equipments installed in pumping stations to ensure fitness of the supplied equipments and supplies to perform their function by performing the following tests at site.

5-3-2-2 Electrical Motors

Reliability test is performed for the motors at site by driving the motor at full load for 10 days and any changes or adjustment are not allowed during the test.

Motors must be rotated freely without existence of any vibrations and the temperature of each part of the motor must be within the specified limits according to original design of the motor.

5-3-2-3 Electrical distribution boards

The following tests are performed after installation of the boards at site:

- Inspection of external interconnections.
- High voltage test
- Ensure performance safety according to check list indicated in item 5-3-2-6-1.

5-3-2-4 Electrical Cables

After installation and laying the cables, the following tests are performed:

Isolation test with megger using a voltage of 500 V, to be sure of the following:

A- Conductor continuity for the full length.

B- Start and end of the connections according to the approved drawings.

C- No short circuit between any phase conductors inside the same cable or between the conductors of the adjacent cables inside the same duct.

D- Value if the insulation resistance between the conductor and the earth or between the conductors inside the same circuit must tends to infinity.

E- Order of the phases when connected to the motors must be in the positions that ensure correct direction of rotation.

5-3-2-5 Pumps

The following operation tests are performed for the pumps after installation to ensure correctness of installation according to implementation conditions for a period not less than 24 hours of continuous operation.

5-3-2-5-1 Pumps installed on dry well

At the end of the specified operation period, must ensure that the pumps have passed the tests satisfactory without any problems and to measure the following parameters and compare them with warrantee tables for these pumps:

- Consumed power at different operating points over the approved operation range.

- No existence of any wears on the impeller or pump shaft.

- No existence of any vibrations or abnormal sounds at any operation point including stop point of the pump.

- Measurement of bearing temperature for the pumps and connection shafts and compare them with the standard values shown in the supplier catalog and the approved technical data of the pumps.

Suitable measuring instruments are used to record these readings. The measured vibrations (peak to peak) at any point of the equipment must not exceed 0.10 mm.

5-3-2-5-2 Submersible Pumps

For this type of pumps, operation test is performed twice, the first in air (without submersion in water) and the second after submersion. In the first case, water level inside the sump is kept under pump motor level. In the second case, the water level covers the motor completely during the operation period.

The following parameters are measured and compared with warrantee values for the pumps according to the contract:

- Motor temperature increase.

- Electrical power inlet to the pump and measured on the control board.

- Inspection of the bearing and mechanical seal and ensure non existence of wear or corrosion.

- No existence of vibrations or abnormal sounds during operation period and over pump operation period including stop point and to use the necessary devices for record.

5-3-2-5-3 Screw Pumps

After installation and lining of suction and operation screed, the same tests of the vertical pumps installed on the dry well are performed and the readings are recorded and compared with the warrantee values approved for these pumps.

5-3-2-5-4 Mechanical Screens

After installation and adjustment of screens according to implementation conditions, tests at site are performed to ensure that the entire screen as a mechanical system, including means of protection, is designed to withstand the subjected torque and the protection means are worked to avoid any faults for the screens due to load that exceeds the rating power of the electrical motor and driving unit.

5-3-2-5 Lifting Units Equipments

All lifting units' equipments are operated for a period not less than 24 hours of continuous operation, where the following are monitored:

- No existence of vibrations or abnormal sounds at any part of the equipment and to use suitable measuring instruments for record. The measured vibration (peak to peak) must not exceed 0.10 mm at any part of the equipment.

- Measurement of angular and linear speeds of the equipment and compare them with the warrantee values according to the contract.

- Apply over load for the equipments and ensure that the protection devices are working efficiently according to warrantee values.

- Measurement of all bearings temperatures and compare them with the values indicated in operation catalogs and manufacturer data.

5-3-2-6 Electrical Switchgears

5-3-2-6-1 Check list

- Manufacturer name
- Production serial number.
- Operating voltage.
- Type of the switchgear.
- Components of the switchgear:
    - (Number of cells)
    - (Number of circuit breakers)
    - (Measuring instruments)
    - (Relays)
- External condition of the switchgear.
- Result of visual inspection
- External equipments.
- Cells lighting
- Motion of levers and switches
- Condition of doors and their hinges and locks.
- Interlock and interconnection between cells.
- Measuring instruments and glass covers.
- Earth connections.
- Mounting of bus bars and space between them.
- Heating elements.

- Terminals and their markings
- Safety instructions.
- Motion of switches and movable devices and ensure their fitness and greasing.

5-3-2-6-2 Measurements

- Measurement of electrical insulators resistance.
- Measurement of cables resistance by megger.
- Measurement of bus bars by megger
- Measurement of earth network resistance.

5-3-2-6-3 Inspection of the following:

- Cables and bus bars.
- Earthing equipments.
- Measuring and protection devices.
- Fittings of bus bars.
- Voltage and current transformers.
- Marking of the electrical circuits
- Cleaning of cells and devices.
- Motion of switches and relays.

5-3-2-7 Equipment Tests

5-3-2-7-1 High Voltage Test for Switchgear

- CB must operate at the normal operating condition using the manual switch then the automatic control to simulate the control devices from outside the equipments.

- Current and voltage circuits must be tested to ensure correctness of the transformation ratio and poles for connection with the devices connected to these circuits.
- Ensure operation and accuracy of each device using approved devices with valid calibration.
- One relay is only tested to ensure accuracy and calibration using calibrated and valid devices.

5-3-2-7-2 Transformers Test

The following tests are performed for the transformers:

- Measurement resistance of all windings at the rating load and maximum position of tapping.
- Ratio test for all tapping positions.
- Poles and phase relation test
- Load loss at the rating voltage and impedance voltage.
- Induction current at rating voltage.
- Voltage test
- When testing winding insulation, induction voltage is tested over the nominal voltage at increased frequency.

Additional Tests:

- Pulse voltage
- Noise level
- Temperature rise
- Insulation test at high voltage for cables and bus bars.
- Twisting test on the bus bars.

- Test ON and OFF of switches.
- Test of relays controls and prove the accuracy.
- Test energizing of the relays.
- Test of indicators and warning lamps of the measuring instruments.

6- Performance and handover Tests

Introduction:

Performance and handover tests of pumping stations are divided into two main parts:

- Equipments performance tests

Performance tests are performed for all mechanical and electrical equipments supplied and forming the units of the pumping station at start of operation of the equipments and before their permanent operation to ensure their correct performance, accuracy and conformity with warrantee values as well as their reliability for continuous operation of the plant before start preliminary handover of the plant.

Period of performance test is determined by not less than 10 days of continuous operation of the plant provided that operation period of each unit does not less than 24 hours of continuous operation then the necessary measurements are performed.

- Preliminary handover tests

Preliminary handover tests are performed to the pumping stage to ensure performance of its function as designed which is pumping of the liquid wastes through the discharge line to the final drain.

6-1 Equipments Performance Test

6-1-1 General Conditions

- All mechanical and electrical equipments supplied and installed in different units of the plant are inspected and compared with contract requirements and ensure their installation with all accessories according to the shop drawings, tender conditions and specifications and the contract made with supplies and installations contractor.
- Make as built drawings including any amendments by decrease or increase according to instructions of the consultant or owner representative and approved from project consultant.
- Ensure handover of the spare parts supplied for each equipment by a detailed list and fitness of these spare parts and their storage according to technical principals.
- Submit O&M manuals for the units.

6-2 Electrical tests before operation and connection of the current supply

A- Insulation tests by megger

- Measuring cables insulation and contents of distribution board according to standard values.

B- High Voltage Test

- All electrical equipments (motors, cables and distribution board components) are tested by calibration device transferred to the site. The test is performed by a voltage according to the standard specifications and not less than 1000 volt and measurement of the leakage current and verifies the standard result at site and their conformity with standard conditions, specifications and allowed limits.

C- Control circuits tests

Inspection of all control circuits to verify their efficiency according to tender conditions and specifications of the project.

D- Distribution board protection devices test

Protection devices installed on the distribution boards are tested according to following:

- Short circuit
- Voltage increase and decrease
- Missing of any phase
- Direction change.

In addition to any other protection tests mentioned in tender specifications such as suction level decrease for the pumps and any other details.

E- Earth resistance measurement

Earth resistance is measured by calibrated ohm meter. Earth resistance must not exceed 1 ohm/m except otherwise mentioned in tender specifications.

6-3 Tests after connecting electrical current supply

- No load test

Flexible joint between the motor and the equipment is removed and the motor is operated at no load for 3 continuous hours and measure no load current, motor vibrations, temperature and rectification time.

- Full load test

Flexible joint between the motor and the equipment is connected and perform alignment.

The motor is operated at full load for at least 24 hours / pump and measure the following:

- Rectification time by using timer.
- Test of over load protection devise and adjust it for full load. (motor rated power)
- Test of short circuit device and adjust it on 10 times motor nominal current.
- Measure of motor temperature over operation period for 24 hours.
- Measure of power factor using power factor meter.
- Measure vibrations of both motor and equipment.
- Calculate the difference value between motor power and maximum power of the equipment (service factor) and compare it with tender specifications.
- Measure and calculate total efficiency of the unit as well as electrical current consumption rate and compare them with design rates according to tender specifications

6-4 Pumps test

Flow and head are measured at the following points:

A- Operation when closing discharge valve fully and measure the head at zero flow of the pumps for only one stage.

B- Operation at duty point through control of the discharge valve and the flow is determined at this head.

C- Operation at maximum open of the discharge valve such that the value does not exceed motor rated current and adjust maximum control of discharge valve open at this limit.

6-5 Civil Works

A- In case of non-existence of groundwater on construction site at foundation level, the sump is tested from internal to external by filling the sump with water and monitor rate of decrease of water in the sump for maximum period of two weeks. For successful test, water level in the sump must not decrease more than 2 mm in addition to height of the lost water by evaporation.

B- In case of existence of groundwater on construction site, the sump is tested from external to internal (Ex. Filtration) by noting entry of water from external to internal of the sump with treatment of the fountains that may appear. Treatment process is continued by leakage proof compounds until there is no groundwater entering from external to internal of the sump.

Annexes

Annex 1: Models of sanitary drainage pumping stations

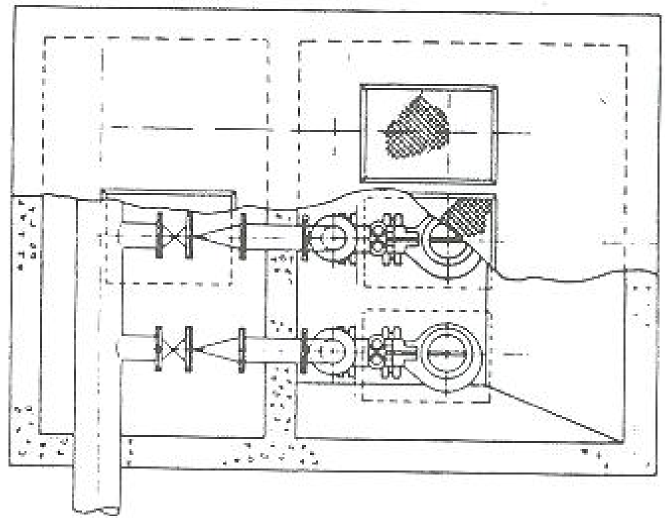
Annex 2: Types of pumps used in sanitary drainage pumping stations.

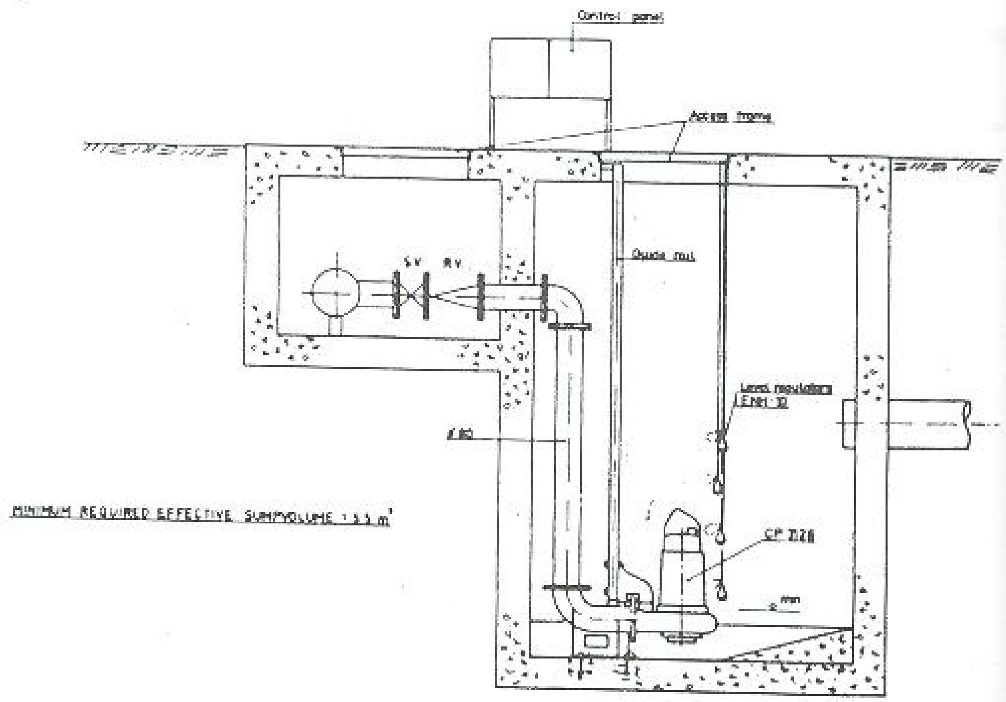
Annex 3: Protection degrees and temperature rise in electrical motors

Annex 4: Types of motor starting

Annex 5: Loss of Head in Ductile Cast Iron

Annex 1: Models of sanitary drainage pumping stations




Control panel
Access frame
Guide rail
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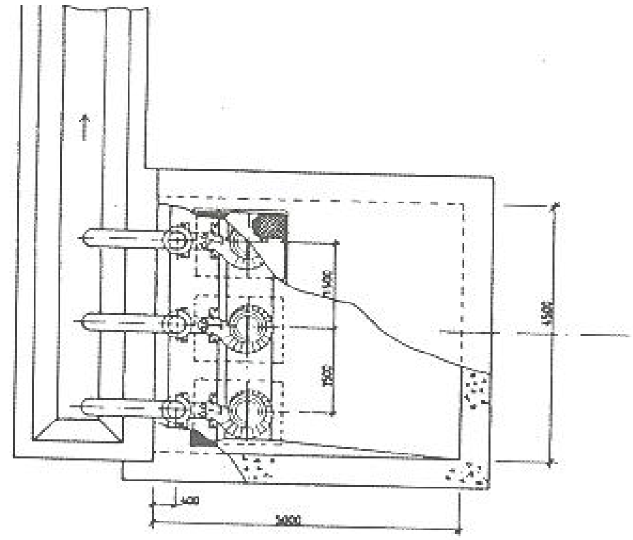
R V
Level regulators
ENM 10
MINIMUM REQUIRED EFFECTIVE SUMPVOLUME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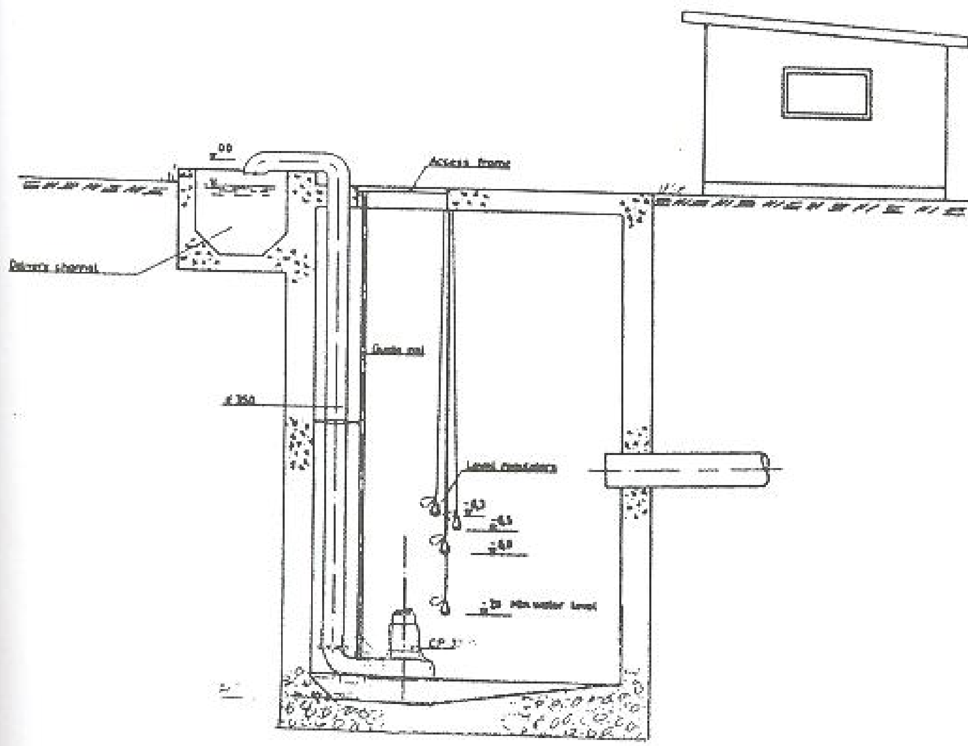
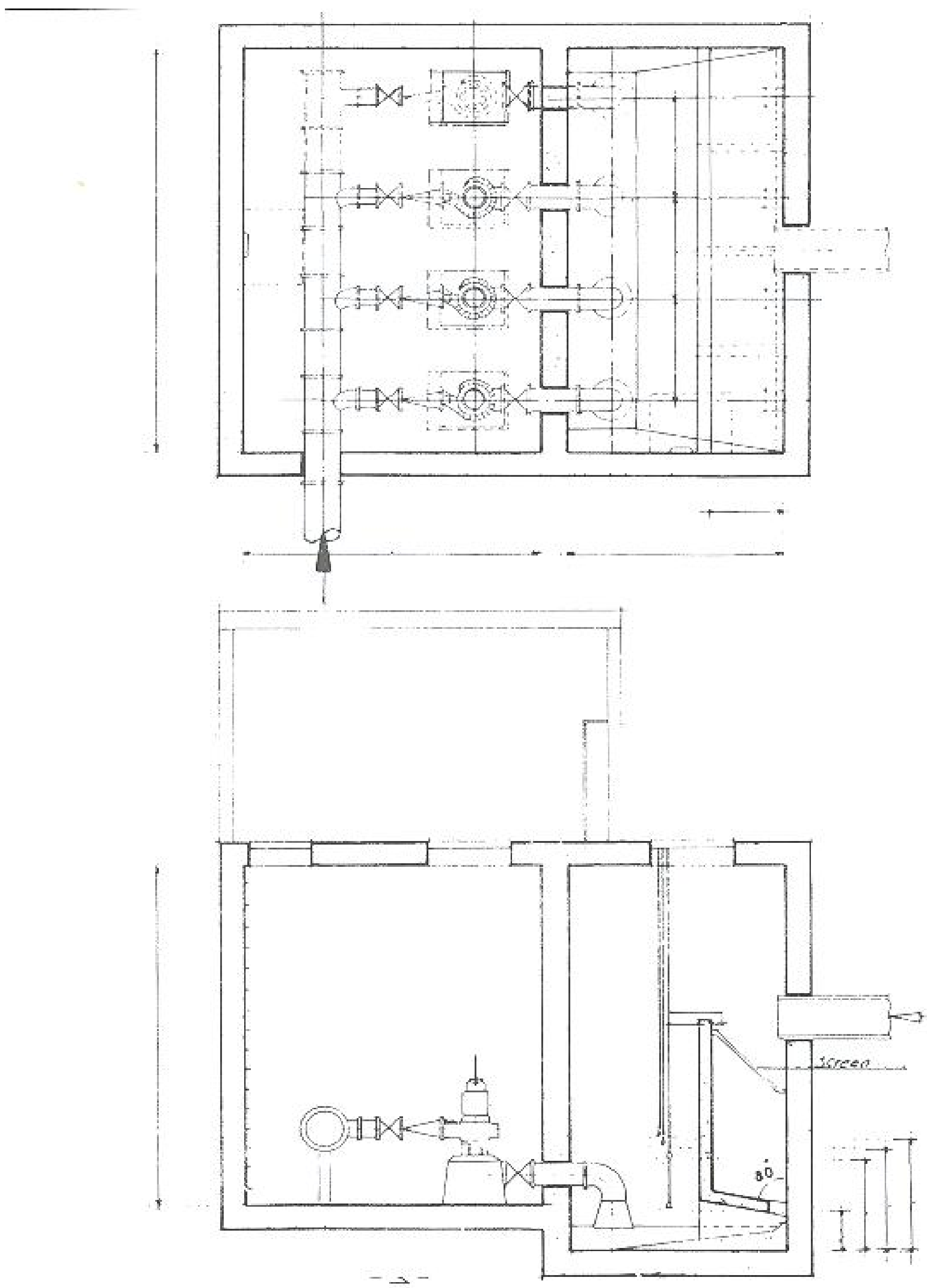

Access frame
Min water level



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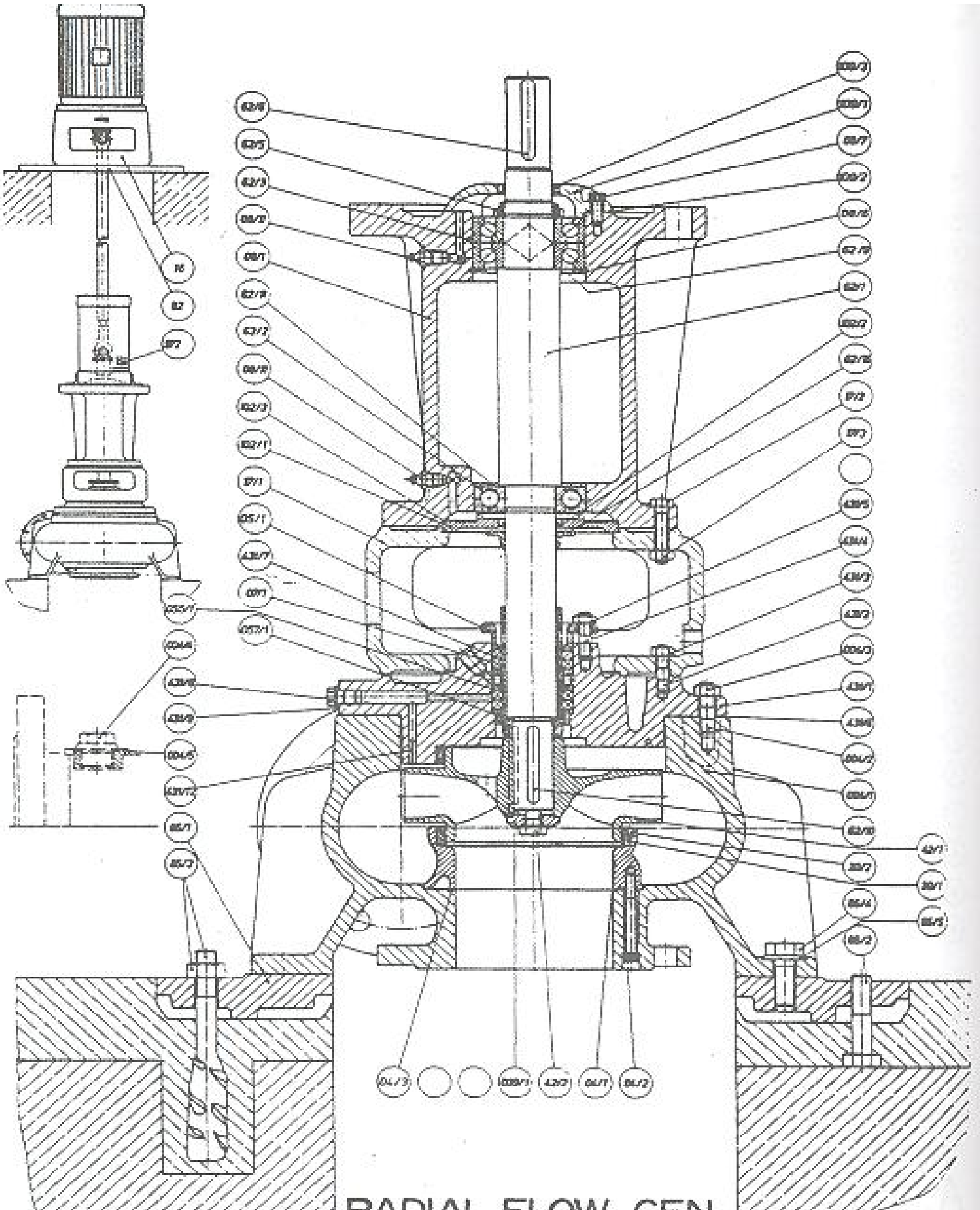
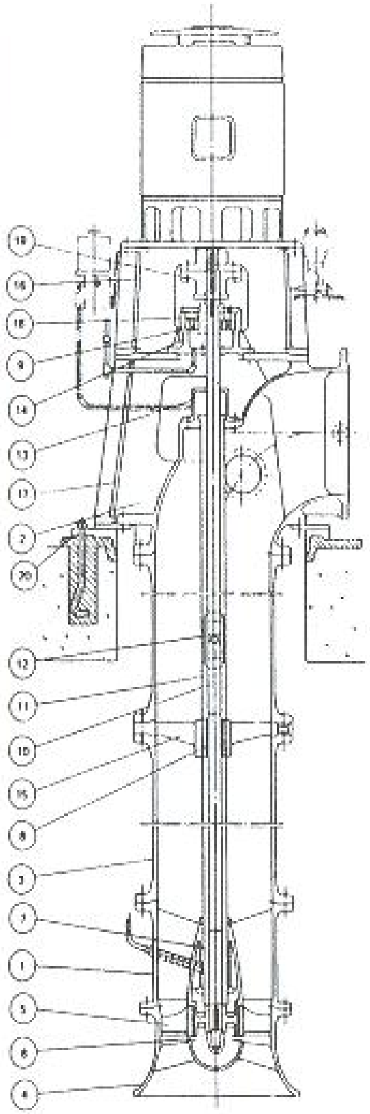
Annex 2: Types of pumps used in sanitary drainage pumping stations.

1- Centrifugal Pumps
Vertical and Submersible Pumps

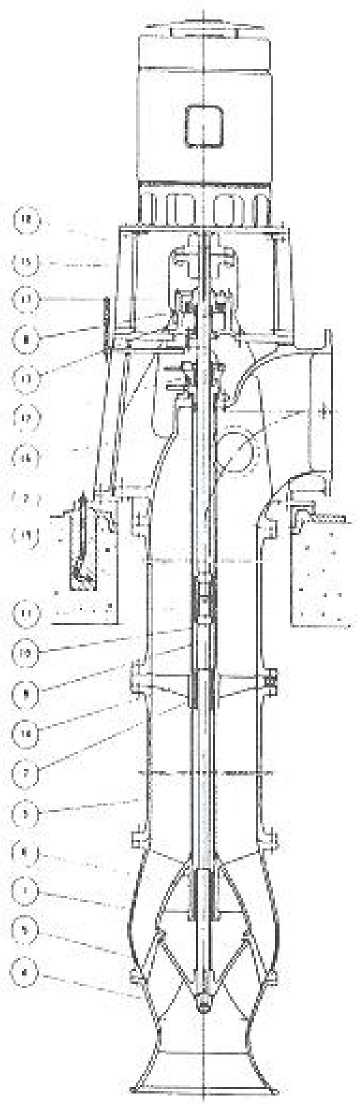


RADIAL FLOW CEN. PUIMPS

RADIAL FLOW CEN. PUMPS



1. Casing
2. Upper casing
3. Water rising pipe
4. Suction case
5. Impeller
6. Impeller boss
7. Lower plain bearing
8. Intermediate plain bearing
9. Ball bearing
10. Main shaft
11. Shaft enclosing tube
12. Intermediate shaft coupling
13. Oil cover
14. Bearing case
15. Spider
16. Motor base
17. Motor Base
18. Bearing adapter
19. Shaft coupling
20. Sole plate

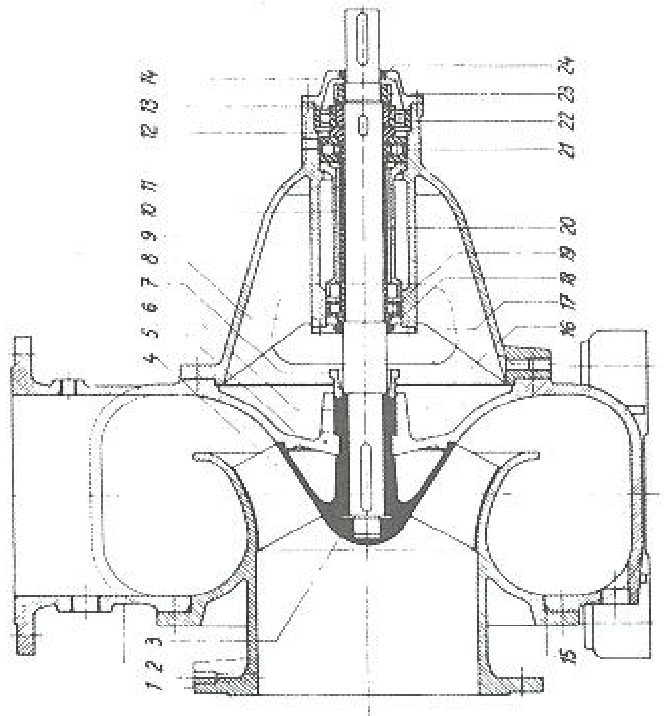


1. Bowl case
2. Upper casing
3. Water rising pipe
4. Suction cover
5. Impeller
6. Liner ring
7. Lower rubber bearing
8. Intermediate rubber bearing
9. Ball bearing
10. Main shaft
11. Protecting tube
12. Intermediate shaft coupling
13. Stuffing box
14. Bearing case
15. Motor base
16. Bearing adapter
17. Shaft coupling
18. Flexible coupling
19. Sole plate

AXIAL FLOW PUMP **MIXED FLOW PUMP**

AXIAL FLOW PUMP MIXED FLOW PUMP

MIXED FLOW CENTRIFUGAL PUMPS



List of Parts of vertical Section		
No.	**Item**	**Material**
1	suction piece	cast iron
2	casing	cast iron
3	lock nut	bronze
4	impeller	cast iron
5	main bush	bronze
6	shaft sleeve	bronze
7	stuffing box	cast iron
8	lock ring	steel
9	bearing casing	cast iron
10	throttle piece	cast iron
11	distance bush	steel
12	regulating ring	cast iron
13	ball bearing bush	steel
14	bearing box, outside	cast iron
15	casing joints	rubber
16	stuffing box packing	cotton
17	bearing box, inside	cast iron
18	packing ring, inside	felt
19	roller bearing	steel
20	shaft	steel
21	ball bearing	steel
22	ball bearing	steel
23	nut	steel
24	packing ring, outside	felt

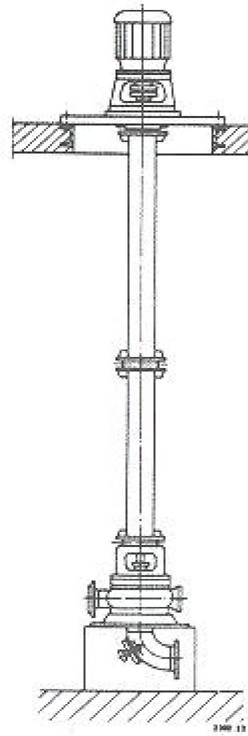


Fig. 3 Dry installation with intermediate pipe

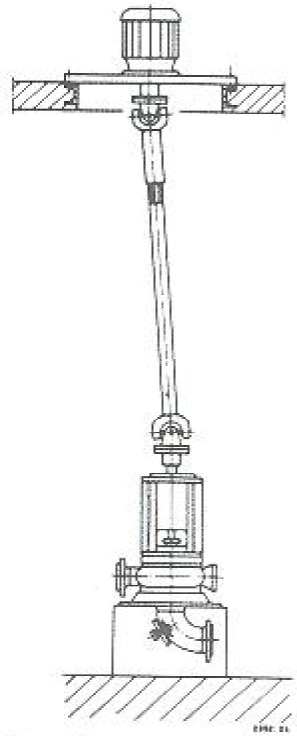


Fig. 4 Dry installation with cardan shaft

Dry Installation
With intermediate pipe (Fig. 3); installation in dry pit; the rotor can be pulled out upwards without disconnecting the suction and discharge piping. A suction elbow connects the pump to the horizontal suction line. The driver is located in the flood-proof motor and switchgear room situated above the pit.
Depending on the nominal size, the pump casing with sole-plate or with claw, is placed on a foundation.

Dry Installation
With cardan shaft (Fig. 4), for installation in dry pit.
Depending on the length of shaft the pump is equipped with one or more cardan shafts.

Underfloor Installation
The pump and driver (Fig. 5) are arranged together in a room adjoining the collection tank, in cases where a horizontal pump cannot be accommodated because of lack of space. It can however only be adopted if the room where the set is installed is dry, and there is no danger of flooding the electrical equipment. The pump is connected directly to the driver via a flexible coupling and its footplate is placed on a foundation.

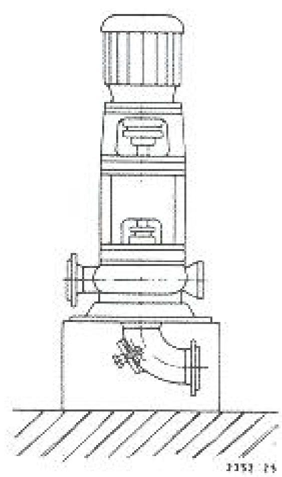


Fig. 5 Underfloor installation

Differences of Characteristics of Volute Pumps, Mixed Flow Pumps and Axial Flow Pumps

The pump characteristic changes considerably by the type of the pump. Therefore, when selecting a pump, it is essential to fully understand the characteristic of every type of pump beforehand. Fig. 1.7, Fig. 1.8 and Fig. 1.9 show the pump characteristics of a volute pump, mixed flow pump and axial flow pump, for which the difference in characteristics is the largest among various pump types, in percentage curves. (The percentage curves are to show the pump characteristic curves on the basis that every one of the total head, capacity, shaft horsepower and efficiency at the maximum efficiency is 100%).

(1) **Total Head Curve**

As shown in Fig. 1.7, Rising Character (i.e., the characteristic that the total head decreases as the capacity increases) becomes stronger in the order of the volute pumps, mixed flow pumps and axial flow pumps. The shut-off head (head at the point of 0 capacity) of the volute pump is about 120~140% of the head at the maximum efficiency. But, it is 140~200% for the mixed flow pump and it further increases to 200% and over for the axial flow pump.

(2) **Shaft Horsepower Curve and Efficiency Curve**

For the volute pump, the shaft horsepower curve drops as the capacity decreases as illustrated by Fig. 1.8. But, in case of the axial flow pump, the curve rises on the contrary. Therefore, in case of the volute pump, it is better to start it by fully closing the valve beforehand in order to minimize the starting torque. But, for the axial flow pump, shut-off operation is impossible because the shaft horsepower increases. When planning, it is necessary to take this fact into consideration. The shut-off horsepower (shaft horsepower at the point of 0 capacity) of the volute pump is about 30~50% of the shaft horsepower at the maximum efficiency. For the mixed flow pump, it is about 80~120%. However, for the axial flow pump, it increases to about 180~250%.

Of the efficiency curves, the volute pump has the most gentle curve with the largest radius of curvature. It suggests that the volute pump shows the smallest decrease of efficiency by change of the capacity. Besides, when compared with the maximum efficiency of the pumps of the same bore, the volute pumps show the most excellent value in general.

Fig. 1.7 Head -- Capacity Percentage Curves

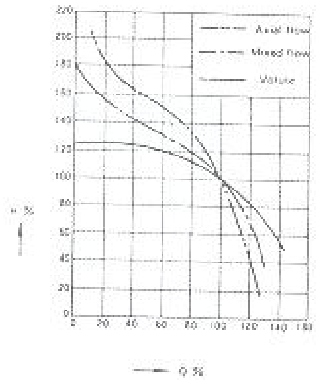


Fig. 1.8 Shaft Horse Power – Capacity Parcentage

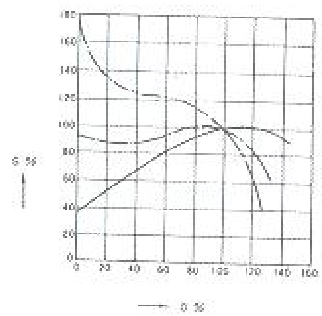
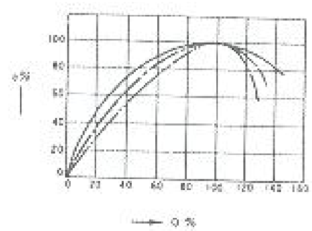


Fig. 1.9 Efficiency -- Capacity Percentage Curves



Selection among Volute, Mixed Flow and Axial Flow Pumps

Comparison of Pump Types regarding Total Head

Total Head	Suction Lift	Centrifugal	Mixed Flow	Axial Flow	Remarks
Less than 3 m	–	X	○	◎	◎ Used widely.
3 – 4 m	Less than 3m	△	○	◎	○ Used.
	More than 4m	△	◎	△	△ Not used frequently but can be used.
4 – 5 m	Less than 2m	△	◎	○	X Better to avoid. (or cannot be used.)
	More than 3m	△	◎	X	
5 – 8 m	Less than 4m	◎	◎	X	For those which are not in this range, consult with the manufacturer.
	More than 5m	◎	X	X	
More than 8 m	–	◎	X	X	

Comparison of Pumps Types regarding Fluctuation of Head

Permissible Fluctuation to Estimated Head	Centrifugal	Mixed Flow	Axial Flow	Remarks
+ 5 ~ –30 %	◎	◎	◎	◎ Suitable ○ Can be used
+10 ~ –30 %	○	◎	◎	△ Better to avoid. X Not suitable
+15 ~ –30 %	△	◎	◎	As for cavitation, study separately.
+20 ~ –30 %	X	○	◎	

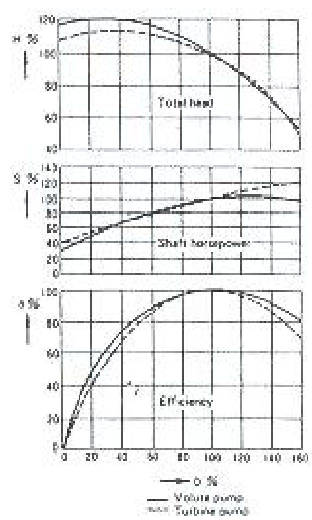
Comparison of Pump Types regarding Operation, etc.

Items	Centrifugal	Mixed Flow	Axial Flow	Vertical	Remarks
Operation and control	A	A	B	A	For every item, marks A, B and C are given from favourable one to unfavourable one in this order.
Maintenance	A	B	B	C	
Price	C	B	A	–	As for the speed, marks A, B and C are given from the quicker one to slower one.
Speed	B or C	B	A	–	
Efficiency	A	B	C	–	
Floor Space	B or C	B	B	A	

Differences of Characteristics of Volute Pumps and Turbine Pumps

In the paragraph *above* differences of characteristics of the centrigugal pumps, mixed flow pumps and axial flow pumps are described. Of centrifugal pumps, however, the performance of the volute type pumps differs from that of the turbine type pumps. Fig. 1.10 shows the difference between them by percentage curves. The turbine pumps tend to show a convex characteristic for the total head curve (total head curve for which the maximum value of the head is at a point of capacity other than the shut-off point) and the operation characteristic at the time of parallel running sometimes becomes unstable. Generally, the shut-off head of the volute pump is 120~140% of the head at the maximum efficiency point and that of the turbine pump is 110~120%.

Fig. 1.10



Specific Speed. If we give the following data of a → centrifugal pump: → capacity Q, → total head H and → rotational speed n, the s.s. of said centrifugal pump is the true rotational speed of a *model pump* (index q), similar in vane geometry and in velocity planes (→ velocity triangle), having the following performance data:

capacity $Q_q = 1\ m^3/s$,
total head $H_q = 1\ m$.

From the relationships of similitude mechanics (→ similarity conditions, → affinity law, → model laws) it follows:

$$\frac{Q}{Q_q} = \frac{D^3 n}{D_q^3 n_q};$$
$$\frac{H}{H_q} = \frac{D^2 n^2}{D_q^2 n_q^2}.$$

Solved for n_q we obtain:

$$n_q = n \cdot \frac{(Q/Q_q)^{1/2}}{(H/H_q)^{3/4}}$$

or, with $Q_q = 1\ m^3/s$ and $H_q = 1\ m$:

$$n_q = n\,\frac{Q^{1/2}}{H^{3/4}}$$

with
Q in m^3/s,
H in m,
n in min^{-1},
n_q in min^{-1}.

In centrifugal pump technology, it is usual to quote the s.s. in relation to the optimum values of capacity and total head (i.e. at the → operating point of optimum → efficiency η_{opt}), and in relation to the nominal (rated) rotational speed, so that we have:

$$n_q = n_N\,\frac{Q_{opt}^{\ 1/2}}{H_{opt}^{\ 3/4}}$$

with
n_q specific speed in min^{-1},
n_N nominal → rotational speed in min^{-1},
Q_{opt} optimum → capacity in m^3/s,
H_{opt} optimum → total head in m.

The s.s. n_q in the last-named version is a frequently used characteristic magnitude in centrifugal pump technology, and it is characteristic of the optimal → impeller shape required to achieve optimum efficiency:

radial impeller $n_q \approx 12$ to $35\ min^{-1}$,
mixed flow impeller $n_q \approx 35$ to $160\ min^{-1}$,
axial impeller $n_q \approx 160$ to $400\ min^{-1}$ and over.

Based on the dimensional magnitude n_q, a non-dimensional coefficient characterizing the type of construction has also been adopted in centrifugal pump technology, which, according to DIN 24260 is expressed as:

$$n_q' = 333\,n\,\frac{Q^{1/2}}{(g\,H)^{3/4}}$$

with
n → rotational speed,
Q → capacity,
g → gravitational constant,
H → total head,
} in coherent units

The numerical values of the magnitudes n_q and n_q' are the same. The conversion of the characteristic factor n_q' into the so-called "type number"

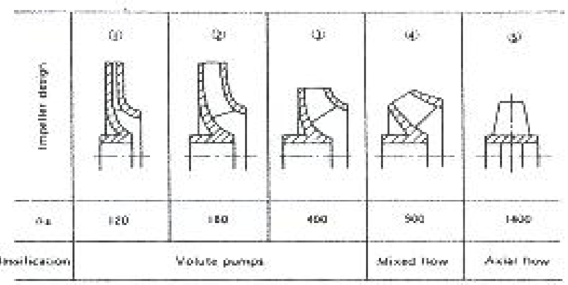
$$K = 2\pi \cdot n\,\frac{Q^{1/2}}{(g \cdot H)^{3/4}},$$

frequently used in English and American centrifugal pump literature (see also ISO 2540) is given by

$$K = \frac{1}{52{,}919} \cdot n_q'.$$

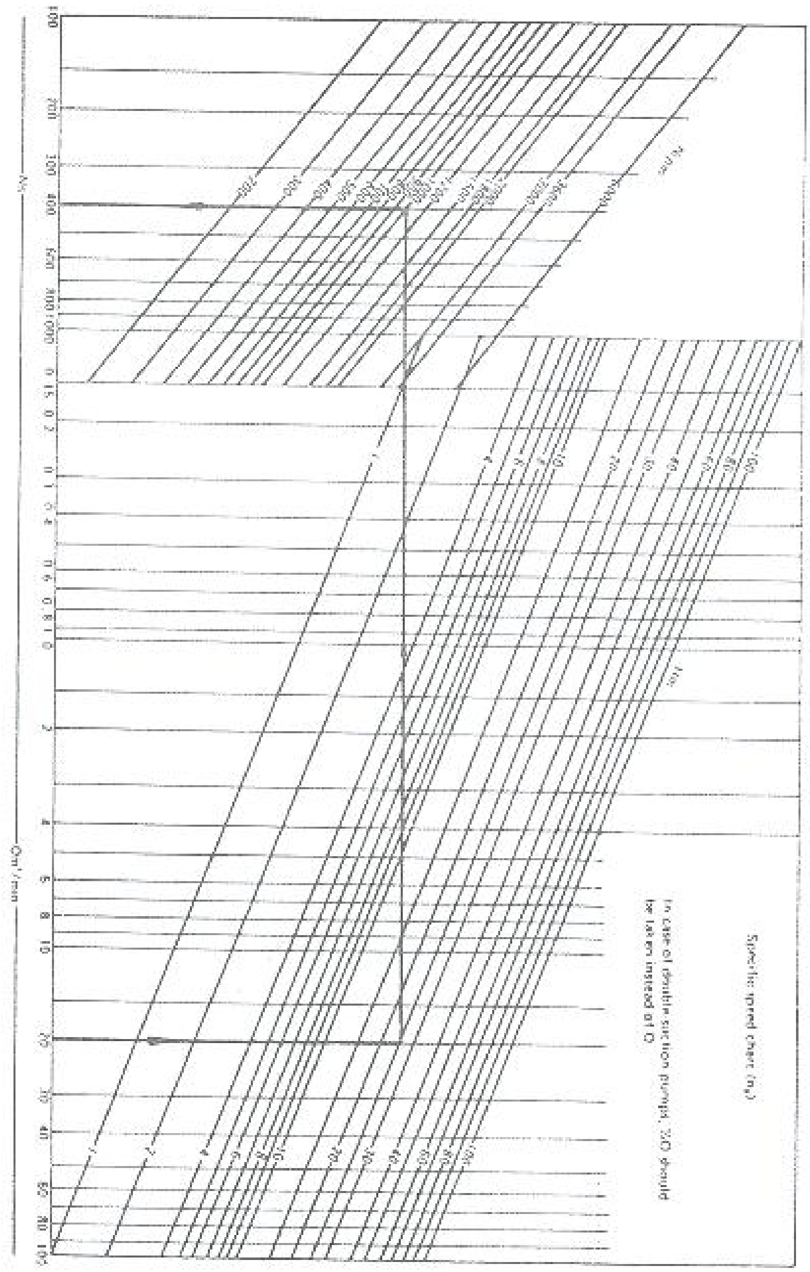
Fig. 1.3 is to illustrate the relation between the impeller design and n_s. As the value of n_s of the volute pump becomes larger, the ratio of the impeller blade width and

Fig. 1.3



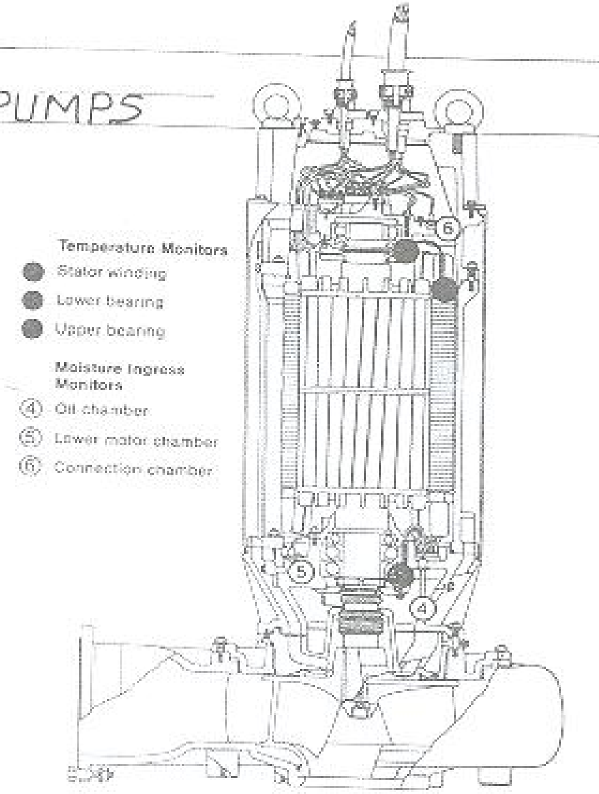
inner diameter to the outer dimension of the impeller becomes larger. As n_s increases, the pump type changes to the mixed flow type and then to the axial flow type.

Specific Speed Chart



SUBMERSIBLE PUMPS

SUBMERSIBLE PUMPS



Bearing Temperature Monitors.

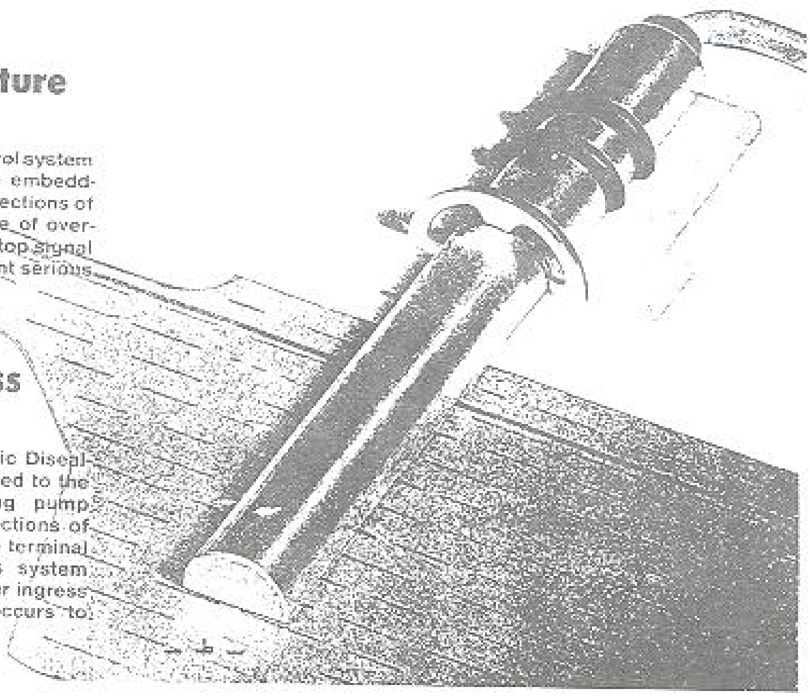
The temperature monitors fitted to the upper and lower ball-bearings give early indication if a critical temperature has been reached and switch off the unit automatically if a limiting value is exceeded.

Motor Temperature Monitors.

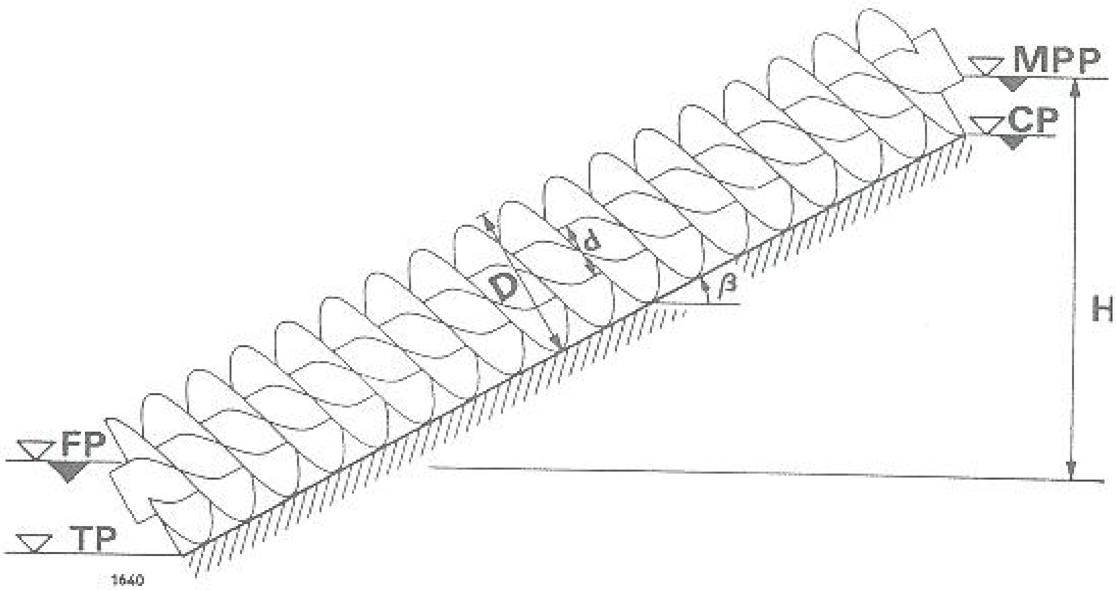
As part of the thermo-control system temperature monitors are embedded in the upper and lower sections of the stator winding. In case of overheating, a warning pump stop signal will be given prior to prevent serious damage occurring.

Moisture Ingress Monitors.

Electrodes of the electronic Dis-sealing monitor system are fitted to the seal oil chamber, cooling pump cavity, upper and lower sections of the motor housing and the terminal connection chamber. This system gives prior warning of water ingress before serious damage occurs to the unit.



2- Screw Pumps



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SELECTION OF INCLINATION			
Difference in level FP–CP	Screw capacity in l/s		
	20	100	500
to 3 m	30°	30°	30°
3–4 m	35°	35°	30°
4–6 m	—	38°	35°
6–8 m	—	—	38°
over 8 m	—	—	38°
Compact screw 35° only			

SELECTION OF SCREW DIAMETER WITH OPTIMUM NUMBER OF STARTS			
Screw diameter mm.	Capacity in l/s with inclination β		
	30°	35°	38°
400	25	20	15
500	35	30	25
600	60	45	40
700	85	65	60
800	120	95	80
900	160	120	100
1000	250	200	170
1200	380	300	250
1400	540	430	360
1600	750	580	500
1800	980	770	650
2000	1250	1000	900
2200	1550	1200	1000
2400	1900	1500	1300
2600	2300	1800	1500
2800	2700	2100	1800
3000	3200	2500	2200

CARACTERISTIC LEVELS AND DIMENSIONS

FP	= Filling point	– Screw capacity 100%
TP	= Touch point	– Screw capacity 0
CP	= Chute point	– Discharge level at the end of the trough.
MPP	= Maximum Pumping point	– Maximum water level in discharge chamber against which pump will operate.
H	= Lift	– Used for sizing and selectior of suitable drive unit.

REMARKS ON TABLES

1. The information on screw diameters and angles is given for guidance only. More detailed information is available on request.
2. Level difference FP to TP = approx. 0.75 D cos β.
3. Level difference CP to max. pumping point = 0.10 D — 0.30 D depending on number of spirals etc When screws are operating in parallel the chute point must be arranged to avoid water streaming back down the non-operating screw.
4. Minimum internal width of trough = D + 400 mm.
5. Maximum permissible angle of inclination = 38° degrees.

As the water level at inlet rises, the pump delivery increases from zero at T to the maximum capacity of the screw at F. The water level at outlet has no influence on the pump delivery, provided it does not exceed the level P. If the water inlet level is raised above F the pump delivery remains sensibly constant at its maximum value. C represents the maximum outlet level at which a screw pump should be run without a non-return valve. This prevents back flow through the clearance between screw and trough when the pump is shut off. If this back flow is allowed to take place there is a danger of the screw becoming choked by sediment or solid matter, making it difficult or impossible to restart. Level P is the outlet water level at which the pump will operate at maximum efficiency. At outlet levels greater than this, water is thrown back down the screw, with the result that the delivery and efficiency drop sharply, and the required driving power increases. If the pump is run at this condition it is possible to overload the motor, and it should therefore be avoided.

From these remarks it can be seen that careful specification of the relevant water levels is necessary when an enquiry for a screw pump is made. Once the screw is designed, alterations in the levels are not easily accommodated for two reasons:

(i) As the inclination α is generally between 30° and 40°, a fairly small increase in the head H has a larger effect on the bladed length L, as can be appreciated from Fig. 1. The length of the screw between bearing centres is an important parameter of the design, as its allowable value is fixed by the acceptable deflection of the screw. Hence an increase in H may necessitate the use of a central tube with greater wall thickness. Taken in conjunction with the additional length of both tube and blades, a marked increase in weight, and hence in cost, may result.

(ii) As the head H is normally not high for a screw pump, slight alterations to the water levels may imply a large percentage variation in its value. This may make it necessary to provide a larger motor, gear unit, and belt drive which, taken together, represent a large proportion of the cost of a screw pump installation.

Finally, it should be noted that of the four levels, T, F, C and P, only two can be specified. The other two are then fixed by the diameter of the screw and its inclination. Normally F is given and either C or P. If the top outlet water level is specified as C rather than P the expense of a reflux valve is avoided, but the screw itself will be rather longer and therefore more expensive. Furthermore it will operate at a rather lower efficiency.

Design of screw pumps

The capacity of a screw pump depends on the following parameters—

(i) The outside diameter of the blades (D).

(ii) The rotational speed (N).

(iii) The number of starts to the screw. (This term is used as an analogy with the terminology of multiple screw threads) (S).

(iv) The inclination of the screw axis to the horizontal (α).

(v) The outside diameter of the central tube (d).

(vi) The lead of the blades (λ).

(vii) The water level at inlet to the screw.

But note it is not dependent on the head H, except in so far as this varies with (vii) above, or on the bladed length L of the screw.

It can be shown that the capacity of a screw pump, like any other pump, varies according to the following law—

$$Q = q_s ND^3$$

where Q is the capacity of the pump, N and D have the meanings assigned above, and q_s is a dimensionless quantity called the specific capacity. This is constant for geometrically similar screw pumps, i.e. those for which S, α, d/D and λ/D are the same and which have sufficient immersion at inlet to produce maximum quantity from the screw. It is found that there are certain optimum values for d/D and λ/D, and these are adopted as standard. The speed is determined from an empirical formula giving the maximum speed which can be employed without excessive losses due to splashing; the larger the screw diameter the lower this maximum allowable speed.

Of direct interest to the customer is the manner in which the capacity varies with screw inclination. It is readily apparent that the steeper the inclination of the screw the shorter will be its length for a given head. However the capacity of a given diameter of screw decreases with inclination as shown in Fig. 2.

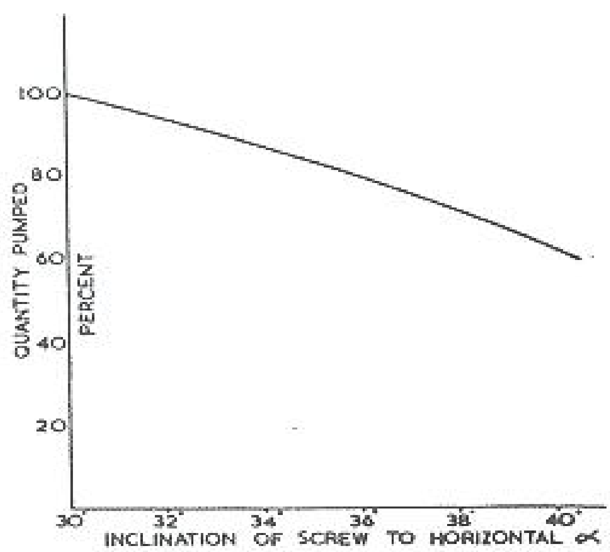


Fig. 2. The capacity at various angles based on the capacity at α = 30° as a datum

Although a screw for a given lift may be made shorter by increasing the inclination, to maintain the capacity it must be increased in diameter, which will also increase the width of the pumping installation. It should also be noted that the efficiency decreases with inclination. For these reasons it is found that the most economical range of values for α is 30° to 40°.

It can now be seen that the diameter of a screw

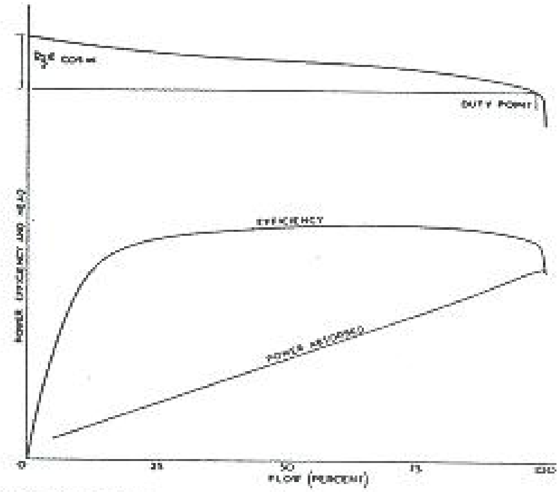


Fig. 3. Performance curves of a typical screw pump. The top curve shows the relationship between head and flow

depends on the capacity required, whereas the length depends mainly on the head. Hence if the quantity required is small but the head is large, a long thin screw results, which may not be mechanically feasible.

As can be envisaged, for a screw of given diameter, the greater the number of starts the greater the capacity of the pump. However, increasing the number of starts is subject to a law of diminishing returns. Three starts are more common, but there are occasions when the use of a screw with less than three starts is attractive.

Allen Gwynnes has a range of screw pumps of standard diameters, from which a required duty can be met by suitably adjusting the inclination and speed of one of the pumps to provide the most economical design. It is therefore better if the customer does not specify the inclination, as an attempt to do so can result in the cost of the screw being higher than would be the case if the manufacturer is free to optimise his design.

Screw pump performance

Fig. 3 shows the performance obtained from an Allen Gwynnes screw pump. The variations in head were obtained by altering the inlet water level only; the outlet water level was kept constant. The curves show the important properties of a screw pump, and the following points should be noted.

(i) It is important that the discharge specified with the enquiry is the maximum to be expected. Once a screw is submerged up to its 'filling point' (shown as the 'duty point' in Fig. 3) it cannot deliver a larger quantity if the inlet level rises any higher. This point is of considerable importance in the case of land drainage installations which may be subject to flood conditions.

(ii) The efficiency curve is very flat over a large range of flows. Therefore, as previously mentioned, it is perfectly economic to run a screw down to 25 per cent. to 30 per cent. of its maximum discharge.

(iii) The maximum power required from the motor occurs when the inlet level is at the 'filling point'. The motor is sized on this basis, and hence it is impossible to overload the motor under any operating condition, with the single exception mentioned earlier of allowing the outlet level to rise above the 'maximum pumping level' P.

In connection with efficiency, some explanation regarding the outlet water level is necessary.

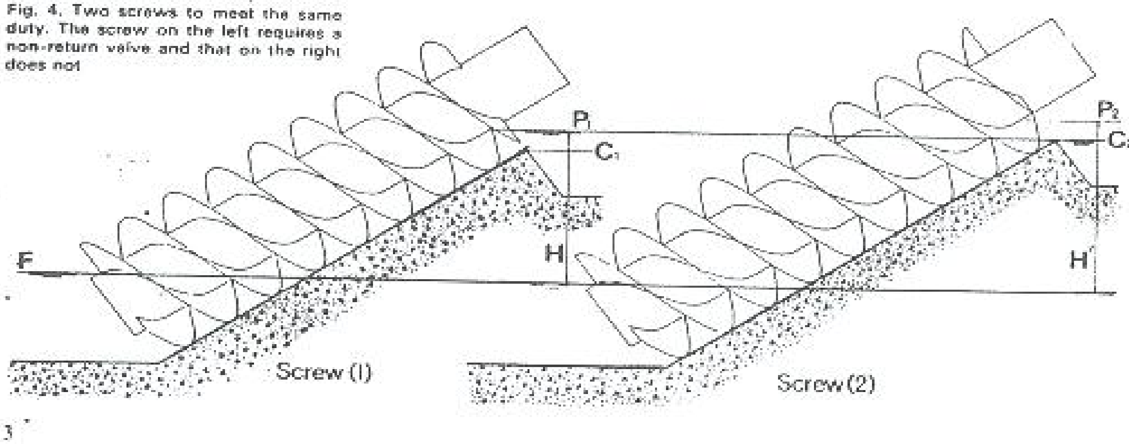
In Fig. 4 a screw is required to raise water through a height H. This can be done in two ways:

(i) A screw (1) with its 'filling point' at F and its 'maximum pumping level' at P_1, where $P_1 - F = H$. In this case a non-return valve must be provided.

(ii) A somewhat longer screw (2) with its 'chute point' C_2 at a height H above its 'filling point'. In this case no non-return valve is necessary. This screw however will lift water to its maximum pumping level, P_2, the effective head thus being $P_2 - F = H'$, and it is on this basis that the power consumed must be calculated.

Hence, when the term 'efficiency' is used for a screw pumping to some outlet level other than the 'maximum pumping level', it should be carefully stated to which outlet level it is related.

Fig. 4. Two screws to meet the same duty. The screw on the left requires a non-return valve and that on the right does not



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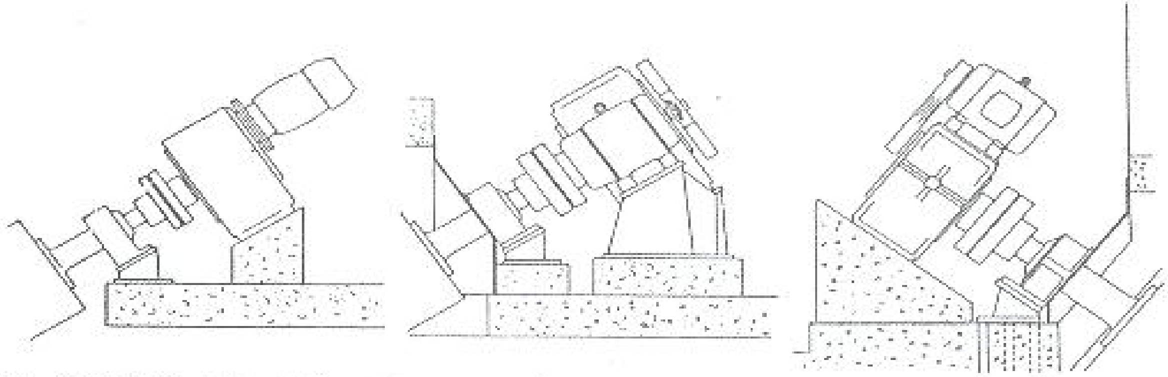


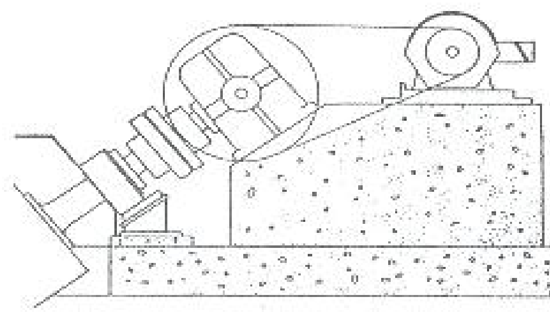


Fig. 5. Four of the various electric motor/screw pump drive arrangements are shown:

(*Top left*) Flange-mounted motor with parallel-shaft reduction gear

(*Top centre*) An electric motor mounted at the side of the parallel-shaft reduction gear with belt drive. This results in a rather wide arrangement which may be inconvenient if several screws are to be installed alongside each other

(*Top right*) An electric motor mounted on top of the parallel-shaft reduction gear with belt drive. This arrangement simplifies the foundations at the expense of an increase in the building height

(*Right*) An electric motor driving a right-angle reduction gear through belts. This produces a reasonably narrow unit which is convenient if several screws are installed in parallel, at the expense of an increased length of motor house

Drive arrangements (Fig. 5)

As the rotational speed of screw pumps is low, varying between approximately 20 and 90 rev/min for most applications generally, direct drive by electric motor is out of the question and some means of speed reduction must always be provided. It is therefore usual to employ 4-pole motors, as these are cheap and small in size. Whilst the required reduction in speed can be achieved by interposing a gear unit directly between the motor and the pump, it is usually more economical and convenient to connect the motor to the gear unit by means of a V-belt drive. In addition to enabling a gear unit with a smaller gear ratio to be used, the V-belt drive arrangement has the following advantages—

(i) The desired pump speed can be approached more closely than if the limited range of ratios available in proprietary gear units alone must be used.

(ii) If required, the capacity of the screw pump can be adjusted relatively simply and cheaply by altering the pulley ratio and hence the pump speed. The maximum flow required must of course be known at the design stage so that the screw has been sized for the maximum duty.

(iii) The physical arrangement of the motor and gear unit within the motor house is more flexible.

(iv) The coupling between motor and gear is eliminated, and a drive with good torsional flexibility substituted, with beneficial results, for example when starting up or when solids are being lifted.

The gear unit itself can have a parallel shaft layout or the high-speed shaft at right angles to the low-speed shaft. The latter arrangement is more expensive, but can have advantages in space-saving in the motor house if several pumps are installed in parallel.

Enquiry information

Although it is beyond the scope of this article to fully discuss all aspects of the design and selection of screw pumps, it is hoped that useful guidance has been given to their correct application. However, it has drawn attention to the need to include the following information with each enquiry for a screw pump:

type of application and fluid to be pumped;

number of pumps (i) duty pumps
(ii) stand-by pumps;

maximum flow per pump;

inlet level at which maximum flow is required;

minimum inlet level at which pumping is required, or alternatively minimum flow per pump;

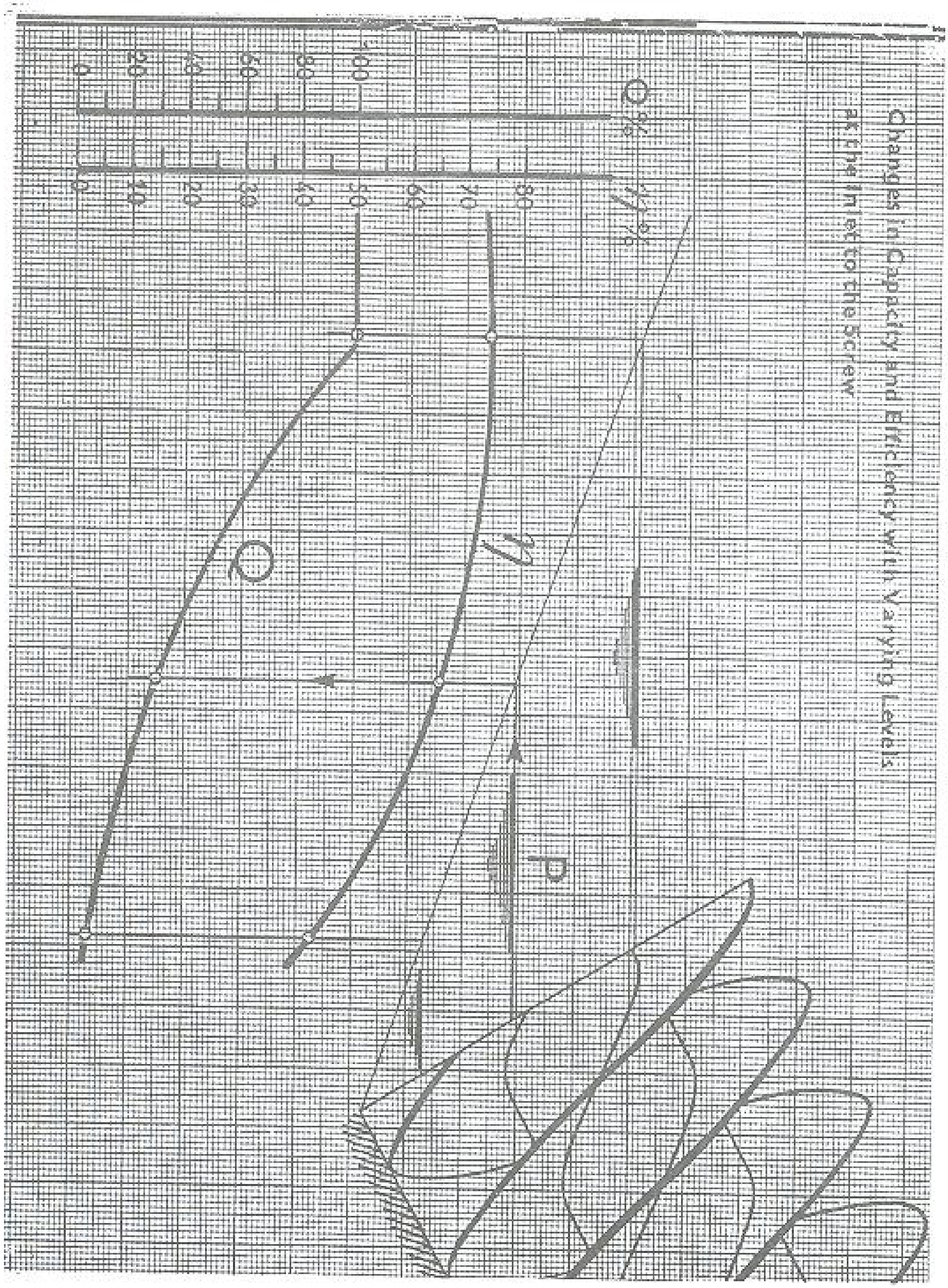
maximum outlet water levels, and whether this is to correspond to 'chute point' C or the 'maximum pumping level' P;

description, or drawing, of proposed installation;

details of available electrical supply, including any restriction on starting current.

Because of the characteristics of screw pumps it is important that this information, on which the design will be based, is final and accurate. Changes in flow or head figures, once the screw pump has been quoted, may make a complete redesign necessary. This could well alter both the price and the space occupied by the pumping plant, as even minor changes cannot be accommodated as easily as with an impeller pump.

It is generally known that Allen Gwynnes has long and specialised experience in the design and application of pumping installations, and is able to advise on pumping schemes to suit the particular requirements of any installation.


Changes in Capacity and Efficiency with Varying Levels
at the Inlet to the Screw
Q%
η%
Q
η
P

AIR LIFT PUMPS

AIR LIFT PUMP

DESCRIPTION

Air lift pump is a pneumatic device for lifting of liquids.

The mechanism is based on the decrease of the specific gravity of the liquid by injecting air into the bottom of the pump. Due to this the liquid-air mixture becomes lighter than the surrounding liquid and rises in the vertical pipe.

The air lift pump is mainly applied in settling tanks (grit collectors, primary and secondary clarifiers) for the purpose of lifting sand or sludge.

The air lift pump does not contain any movable parts. The cross-section of its straight vertical (lifting) pipe is the same along its complete length. This makes the pump insensitive to clogging or wear even when coarse-grained materials are being lifted. The design principle allows for a gentle conveyance of fluids which is of importance, for example, in handling activated sludge. When the pump becomes clogged, the bottom of the pump can be washed free by closing the quick-opening valve for a very short time.

ELEMENTS OF CONSTRUCTION

Air lift pump consists of the following elements:

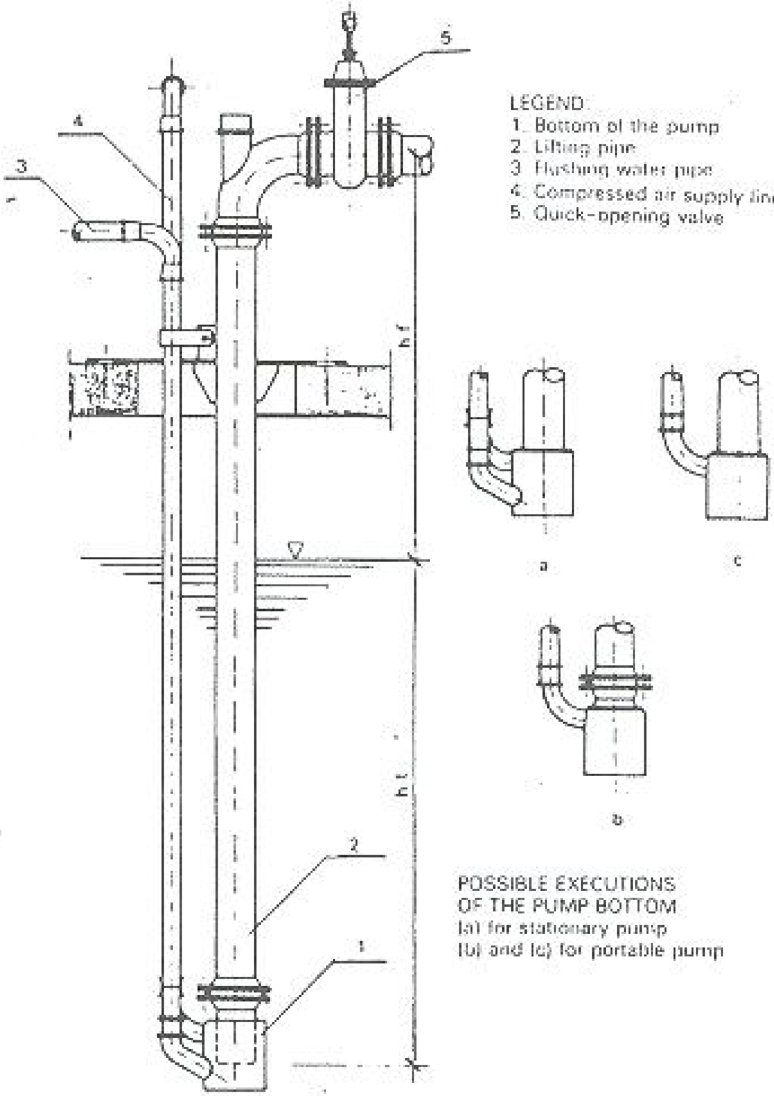
Bottom of the pump with connections for compressed air and, if required, for flushing water;
riser pipe for lifting grit-water or sludge-water mixture with air.

All parts are adequately protected against corrosion.

OPTIONAL ACCESSORIES AND EQUIPMENT

- Quick-opening valve for whirling up the liquid in the pump bottom, as a means against clogging of the pump inlet (e.g. when transporting grit). It acts by closing the vertical pipe for a very short period of time.
- Air compressor in normal execution, or, if requested by the customer, an air blower adapted to the air lift pump.

AIR LIFT PUMP TYPE MP



ORIENTATIONAL DATA ON CAPACITY

Type MP	ND 100	ND 125	ND 150	ND 200
Ratio hf/ht	0.2 1.2	0.2 1.2	0.2 1.2	0.2 and so on
Air volume used (Nm^3/h)	15 150	20 - 250	30 280	90 440
Lifting capacity (l/s)	6 14	10 24	15 35	23 58
Required water quant. (m^3/h)	18	18	22	30
Flushing water pressure (bar)	2	2	2	2
Air connection	ND40	ND65	ND65	ND 50 and ND 80
Flushing water connection	ND40	ND40	ND65	ND50

Required suction pressure $P_s = P_t + 0.02$ bar
P_t = pressure of the liquid column with the height ht expressed in bars

Annex 3: Protection degrees and temperature rise in electrical motors

Types of Enclosure
Protection of Persons Against Contact With Live or Moving Parts of Electrical Machines,
Protection of Machines Against Ingress of Solid Foreign Bodies and Water

DIN 40050 Part 2

Schutzarten; Berührungs-, Fremdkörper- und Wasserschutz, elektrische Maschinen

See Explanations for correlation with Publication 34-5, first edition 1958, issued by the International Electrotechnical Commission (IEC).

Contents

1. Scope

This Standard applies to rotating electrical machines as covered by VDE 0530 "Rules for Electrical Machines". The present Standard is concerned with the protection of machines by means of casings and covers and comprises the following:

1.1. Protection of persons against contact with live or moving components inside the casings, and protection of machines against ingress of solid foreign bodies (protection against accidental contact and protection against foreign bodies)[1];

1.2. Protection of machines against the ingress of water (protection against water);

1.3. Symbols for the internationally agreed types of enclosure and for the degrees of protection. Testing and inspections designed to verify that the machines conform with the requirements of the present Standard are laid down in DIN 40051 Part 1, DIN 40052 Part 1 and DIN 40053 Part 1 to Part 4. Any additional information required in the testings, will be found in this Standard.

With regard to flameproof and explosion proof machines, the special provisions of VDE 0170/0171 should be observed.

The testings are type testings carried out on batch-produced machines or models. They are performed on a new machine ready for service, fitted with all attachments and installed in the manner specified by the customer. If this is not practicable, the manner of testing shall be agreed between manufacturer and customer.

2. Composition of symbol

The types of enclosure are designated by a symbol consisting of the two code letters IP (which appear in this form in every symbol) followed by the two reference numbers designating the degree of protection.

Additional letters may be included, if necessary, as follows:

- R for pipe-ventilated machines,
- W for weather-proof machines,
- S for machines tested whilst stationary for protection against ingress of water,
- M for machines tested while running for protection against ingress of water.

The letters R and W are placed between IP and the two reference numbers; the letters S and M are placed behind the two reference numbers. The absence of the letters S or M means that testing for protection against ingress of water is carried out with the machine stationary and running.

The complete symbol (code letters, reference numbers and any extra letters used) is to be known as an enclosure code.

[1] As the protection against accidental contact and the protection against ingress of foreign bodies are closely related, a common reference number has been allotted to these two types of enclosure.

Continued on pages 2 to 6
Explanations on page 6

Code letters IP	Protection against accidental contact and against ingress of foreign bodies and of water
First reference number 0, 1, 2, 4 and 5 (see Section 3)	Degrees of protection against accidental contact and against ingress of foreign bodies
Second reference number 0 to 8 (see Section 4)	Degrees of protection against ingress of water

Examples of designation of a type of enclosure:

IP 4 4

Code letters — IP
First ref. no. — 4
Sec. ref. no. — 4

IP W 2 3 S

Code letters — IP
Additional letter — W
First ref. no. — 2
Sec. ref. no. — 3
Additional letter — S

If, in descriptions for example, only one reference number for the degree of protection appears after the code letters IP, a dash should be inserted in lieu of the missing reference number, e.g. IP – 4.

If the type of enclosure of one component of the machine, e.g. of the terminals, differs from the type of enclosure of the rest of the machine then the symbol for the type of enclosure of the component which differs shall be specified separately; in such cases, the type of enclosure giving the lower degree of protection shall be stated first. If the component that differs has a higher grade of enclosure this will not be stated, see VDE 0530 Part 1/1.69, § 48.1.

The type of enclosure should preferably be featured on the rating plate, and if this is not feasible, on the casing.

The indications relate to the "as-delivered condition" of the machine, and to its specified or usual mode of installation. The type of enclosure may alter as a result of a different type of installation or mounting or if the machine is operated under other conditions (e.g. by the closing of apertures).

3. Degrees of protection against accidental contact and ingress of foreign bodies

First reference number	Scope of protection: Denomination	Scope of protection: Explanation
0	No protection	No special protection of persons against accidental or inadvertent contact with live or moving components. No protection of the machine against the ingress of solid foreign bodies.
1	Protection against large foreign bodies	Protection against accidental or inadvertent large area contact with live or internal moving components, e.g. with the hand, but no protection against voluntary access to these components. Protection against the ingress of solid foreign bodies having a diameter in excess of 50 mm.
2	Protection against medium-sized foreign bodies	Protection against contact by the fingers with live or internal moving components[2][4]. Protection against the ingress of solid foreign bodies having a diameter in excess of 12 mm.
4	Protection against granular foreign bodies	Protection against contact with live or internal moving components by tools, wires or similar objects having a thickness in excess of 1 mm[2][5]. Protection against the ingress of solid foreign bodies having a diameter in excess of 1 mm; excluded from this are cooling air apertures (inlet and outlet openings of external fans) and condensate drain holes of totally enclosed machines which are allowed to have No. 2 degree of protection.
5	Protection against dust deposits[3]	Complete protection against contact with live or internal moving components[2]. Protection against injurious dust deposits. The ingress of dust is not completely prevented, but dust must not be able to penetrate in amounts large enough to adversely affect the operation of the machine.

For Footnotes see page 3

4. Protection against ingress of water

Second reference number	Scope of protection: Denomination	Scope of protection: Explanation
0	No protection	No special protection
1	Protection against vertically falling drip water	Water droplets falling vertically onto the machine must not adversely affect the operation.
2	Protection against drip water falling at a slant	Water droplets falling at any angle up to 15° from the vertical must not adversely affect the operation.
3	Protection against splash water	Water falling at any angle up to 60° from the vertical must not adversely affect the operation[4].
4	Protection against spray water	Water impinging as spray from all directions against the machine must not adversely affect its operation[4][5].
5	Protection against water jets	A water jet issuing from the nozzle of a hose aimed at the machine from any direction must not adversely affect its operation.
6	Protection against flooding	In the event of temporary flooding, e.g. in heavy seas, water must not penetrate into the machine in quantities liable to cause damage.
7	Protection against immersion	Water must not penetrate into the machine in quantities liable to cause damage when it is immersed in water under the specified pressure and time conditions.
8	Protection against submersion	Water must not penetrate into the machine in quantities liable to cause damage when it is submerged in water under a specified pressure for any length of time.

5. Types of preferred enclosure

The Table below contains the types of enclosure most commonly used in Germany for electrical machines; of these, the types most commonly used internationally are emphasized by bold type.

Protection against contact and ingress of foreign bodies — Code letters and first reference number	Protection against ingress of water — Second reference number: 0	1	2	3	4	5	6	7	8
IP 0	IP 00		IP 02						
IP 1		IP 11 S	IP 12 S	IP 13 S					
IP 2		IP 21 S	IP 22 S	IP 23 S					
IP 4					IP 44				
IP 5					IP 54	IP 55	IP 56		

2) Machines which are cooled by an external fan are to be protected against accidental contact with the fan by the fingers. Generally speaking this requirement is satisfied if contact with the vanes or blades of the fan by test finger 1 DIN 40051 is prevented. Motors driving agricultural appliances, small machines used by traders, and domestic appliances may require more extensive precautions against accidental contact.

3) The degree of protection specified in this Standard against dust and the testings for such protection conform to general practice. When the type of dust is stated (size of particles and their characteristics, e.g. fibrous particles) the test conditions are to be separately agreed between manufacturer and customer as necessary.

4) For further details regarding weather proof machines (additional letter W) see under Section 8.2

5) For further details regarding machines with pipe ventilation (additional letter R) see under Section 8.1

6. Testing for protection against contact and ingress of foreign bodies

The testings for all degrees of protection are to be carried out with the machine stationary.

First reference number	Testing
0	No testing
1	The testing is to be carried out with a ball with a diameter of 52.5 mm which is pressed against the casing with a force of 50 N ≈ 5 kp. The protection is deemed adequate if the ball does not penetrate into the casing and does not make contact with internal live or moving parts.
2	Testing performed with test finger 1 and interpreted according to DIN 40051 Part 1. For the purpose of the testing the rotor shall be turned slowly by hand. Shafts and similar smooth parts are excepted from the testing. When the machines have an external fan, footnote[2]) Section 3 shall be observed. In addition, a ball with a diameter of 12.5 mm must not penetrate into the casing.
4	The testing shall be carried out with a steel wire with a diameter of 1 mm. Excluded from the testing are cooling apertures (inlet and outlet of external fans) and condensate drain holes which are allowed to conform to No. 2 degree of protection. When the machines have an external fan footnote[2]) in Section 3 shall be observed. The protection is deemed adequate if the wire does not penetrate into the casing (e.g. at joints).
5	Testing is performed with the use of dust chamber 1 and is interpreted according to DIN 40052 Part 1. This testing is to be carried out only on machines with a shaft height up to 132 mm. In the case of machines with shaft heights greater than 132 mm the outcome of a testing carried out on a machine of comparable design but smaller shaft height, is regarded as adequate.

7. Testing for protection against ingress of water

7.1. General

For the No. 1, 2, 3 and 4 degrees of protection, scrutiny of the drawing is generally adequate. In border line cases the testing should be carried out on the lines indicated below.
For the No. 5, 6 and 7 degrees of protection, the testing should be carried out in accordance with the conditions stated for these levels of protection.
For No. 8 the conditions for acceptance and, where necessary, for testing shall be agreed between manufacturer and customer.
The testings for all degrees of protection are to be carried out with the machine stopped; for Nos. 4 to 6 they may also be carried out with the machine running.
All testings are to be carried out with fresh water unless stated or agreed to the contrary.

The values stated for the testings and concerning water pressure, quantity of water and test duration as well as the dimensions of the spray pipes have been specified as the outcome of thorough investigation. It should be noted that the quantity of water relates to a projected area of 1 m^2 parallel with the axis of the shaft; this area is sufficient for the majority of machines. If a machine has a projected area larger than 1 m^2 the same quantity of water and test duration is regarded as adequate if the testing is made at all the critical points, e.g. joints, seals, bearings.

For [2]), [4]) and [5]) see page 3

Mechanical testing for protection against ingress of water

Second reference number	Testing
0	No testing
1	Tested with the drip appliance A 1 DIN 40053
2	Tested with the drip appliance A 1 DIN 40053
3	Tested with the swivelling pipe B 1-... DIN 40053[4][6]
4	Tested with the swivelling pipe B 1-... DIN 40053[4][6]
5	Tested with the spray pipe D 1 DIN 40053[7]
6	Tested with the spray pipe D 1 DIN 40053[7]
7	For the purpose of the testing the machine is to be immersed in water in such a manner that the surface of the water is not less than 1 m above the fixing face of the machine and the top of the machine is not less than 15 cm below the water. The duration of the testing is 30 minutes. Subject to agreement between manufacturer and customer the above testing may be superseded by the following test method: The casing is tested with an internal air pressure of not less than 0.1 bar (≈ 0.1 kp/cm²). The duration of the testing is 1 minute. The protection afforded is deemed adequate if not air emerges during the testing. Emergence of air can be detected either by immersion, in which case the water must completely cover the machine, or by applying a soap solution to the machine.
8	The test conditions are to be agreed between manufacturer and customer.

A s s e s s m e n t

The protection afforded is deemed adequate if the following conditions are fulfilled after completion of the testings according to Section 7.2:
Any water that has penetrated must not interfere with the operation of the machine; windings and other live parts must not be wet and any accumulation of water inside the casing shall not reach such parts.
It is, however, permissible for the blades of fans inside the machine to be wet; ingress of water along the shaft is also acceptable provided that arrangements are made for draining such water.

Electrical testing

If the machine has been tested while stationary, it must be run for 15 minutes at no load and rated voltage and then subjected to a high voltage test. The test voltage is 50 % of the test voltage for a new machine and not less than 125 % of the rated voltage.
If the machine has been tested while running, only the high voltage test at the voltage stated above shall be carried out.

A s s e s s m e n t

The testing is deemed to be passed if there is no evidence of damage as defined in the testing for insulation in VDE 0530 and in IEC Publication 34-1.

Types of enclosure with additional letters

Machines with pipe ventilation (additional letter R)

The totally enclosed machine which has cooling air flowing through it, i.e. is internally cooled, has cooling air apertures which are connected to pipes, ducts or pits; the pipes are not in communication with the space where the machine is installed.
Example: IP R 44

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4) See page 3

6) Instead of the testing with the swivelling pipe B 1-...DIN 40053 a testing using the spray nozzle C 1 according to DIN 40053 Part 3 may also be agreed between manufacturer and customer.

7) For Nos. 5 and 6 the distance from the spray pipe D 1 DIN 40053 to the machine has been fixed at 3 m on the basis of experience acquired in actual practice; in order to allow the spray to be applied to the machine from all directions this distance may be reduced.

8.2. Weather proof machines (additional letter W)

The IP W types of enclosure are intended for internally cooled machines (degree of protection inferior to IP 44) with extra protective features for operating in the open under special climatic conditions. With regard to protection against contact and ingress of foreign bodies, these weather proof machines are subject to the particulars in Sections 3, 4, 6 and 7, which are supplemented by the undermentioned guide lines relating to design, and are further supplemented in the case of the IP W 24 enclosure by guide lines for additional testing. Where necessary, arrangements to provide protection against icing shall be made.

Enclosure IP W 23 S

Guide lines for design:
Before it contacts the components to be cooled, the cooling air drawn in through the cooling air apertures is so routed that it undergoes at least one deflection by not less than 90° and experiences velocity reduction.
Insulated windings must be able to withstand the effects produced by moisture when exposed to alternated climatic conditions according to DIN 50016.
Components made of iron and steel must be protected against rusting.
Bearing lubricants must be suited to the minimum and maximum outside temperature likely to occur at the place of installation. The penetration of fine sand and water into the bearings is made difficult by the fitting of covers or by appropriate design of the sealing arrangements

Terminal box design conforms at least to the IP 55 type of enclosure.

Enclosure IP W 24

Guide lines for design:
Before it comes into contact with the components to be cooled, the air drawn in and discharged through the ventilating openings is so routed that it undergoes at least three deflections through not less than 90° each time; this prevents the ingress through the ventilating openings of small solid foreign bodies, coarse dust particles, rain and snow driven by strong or gale-force winds. In addition, the inlet route for the cooling air must have a widened portion so that the velocity of the air at this point does not exceed 2.8 m/s, thus enabling any particles entrained in the air to settle.
Instead of this settling chamber, removable or otherwise easily cleaned filters may be provided.
Insulated windings must be able to withstand the effects produced by moisture when exposed to alternated climatic conditions according to DIN 50016.
Components made of iron and steel must be protected against rusting.
Bearing lubricants must be suited to the minimum and maximum outside temperature likely to occur at the place of installation. The penetration of fine sand and water into the bearings is prevented by the fitting of covers or by appropriate design of the sealing arrangements.
Terminal box design conforms at least to the IP 55 type of enclosure.

Guide lines for additional testing:
When fine sand is freely thrown at the machine no deleterious effects shall arise through ingress of sand.

For types of enclosure; protection of electrical apparatus against accidental contact by persons, against ingress of foreign bodies and against ingress of water, general, see DIN 40050 Part 1

Explanations

The contents of the present Standard conform to a large extent with IEC Publication 34-5, 1st Edition 1968 Rotating electrical machines, part 5: degrees of protection by enclosures for rotating machinery. The main points of difference are discussed below.

Under reference number 2. Publication 34-5 contains the expression "small foreign bodies". In conformity with the basic standard DIN 40050 Part 1 and with IEC Publication 144, 1st Edition 1963, however, this Standard refers to medium-sized foreign bodies.

In the Section dealing with preferred types of enclosure, IEC Publication 34-5 contains only 7 types. In this Standard five further types are identified as in common use.

The additional letter R for machines with pipe ventilation is not contained in the IEC Publication. With regard to weather proof machines, the IEC Publication does not state any guide lines for design and for additional testing. These have been taken over with only minor amendments from the former Extract Sheet.

The place and manner of installation as well as the question of access to the machine, and possibly, special operating conditions are the critical factors determining which type of enclosure according to this Standard is necessary.

In general, reference should be made to the Explanations in DIN 40050 Part 1.

The degrees of protection used with three-phase motors are designated by a symbol consisting of two letters and two numerals, some designations including an additional characteristic letter.

IP (International Protection)
Letters designating the degree of protection against contact with live or moving parts inside the enclosure and the ingress of solid foreign bodies and water.

0 to 6 The first characteristic numerals designate the degree of protection of persons against contact with live or moving parts inside the enclosure and the ingress of solid foreign bodies.

0 to 8 The second characteristic numeral designates the degree of protection against harmful ingress of water (no protection against oil).

W, S and M Supplementary code letters for special degrees of protection

Principal degrees of protection for electrical machines:

Motor	Degree of protection	1st numeral Protection against contact	Foreign bodies	2nd numeral Protection against water
Internally ventilated	IP 21	with the fingers	medium-size bodies with diameters greater than 12 mm	dripping water falling vertically
	IP 22			dripping water falling at an angle up to 15° from the vertical
	IP 23			water sprayed at an angle up to 60° from the vertical
surface-ventilated	IP 44	by tools or similar objects	small bodies with diameters greater than 1 mm	water splashed from any direction
	IP 54	complete protection	Protection against harmful deposits of dust	water splashed from any direction
	IP 55			water projected by a nozzle from any direction
	IP 56			water from temporary flooding [1] heavy stream
	IP 65	complete protection	protection against ingress of dust	water projected by a nozzle from any direction
	IP 67			motor submerged under fixed pressure and time conditions

[1] In the case of heavy seas (temporary flooding) only the non-ventilated motor type 1PB can be used.

Special degrees of protection

W for weatherproof machines:
The additional letter W is inserted between the letter symbol IP and the characteristic protection figures, e.g. IP W 23. The letter is applicable to machines "for use under specified weather conditions and with additional protective measures or equipment".

S and M for protection against water:
For special applications (e.g. open-type, open-circuit air-cooled machines on ship decks, where air inlet and outlet openings of the machines are closed during standstill) a letter can follow the characteristic figures indicating whether the protection against harmful water entry is certificated or tested with the machine at standstill (letter S) or running (letter M).

In this case the degree of protection for both operating states of the machine must be specified, e.g. IP 55 S/IP 23 M.

Where the additional letters are omitted, the stated degree of protection is complied with for both states, i.e. running and at standstill.

In line with international agreements, the additional letter R specified in the previous standards for pipe connected machines has been omitted in DIN IEC 34, Part 5.

3. **Protection of persons against contact with live or moving parts inside the enclosure and protection of equipment against ingress of solid foreign bodies**

Protection against contact with moving parts inside the enclosure is limited to contact with moving parts inside the enclosure which might cause danger to persons.

First characteristic numeral	Degree of protection
0	No protection of persons against contact with live or moving parts inside the enclosure. No protection of equipment against ingress of solid foreign bodies.
1	Protection against accidental or inadvertent contact with live or moving parts inside the enclosure by a large surface of the human body, for example, a hand, but not protection against deliberate access to such parts. Protection against ingress of large solid foreign bodies. See test Sub-clause 7.1.
2	Protection against contact with live or moving parts inside the enclosure by fingers. Protection against ingress of medium size solid foreign bodies. See test Sub-clause 7.2.
3	Protection against contact with live or moving parts inside the enclosure by tools, wires or such objects of thickness greater than 2.5 mm. Protection against ingress of small solid foreign bodies. See test Sub-clause 7.3.
4	Protection against contact with live or moving parts inside the enclosure by tools, wires or such objects of thickness greater than 1 mm. Protection against ingress of small solid foreign bodies. See test Sub-clause 7.4.
5	Complete protection against contact with live or moving parts inside the enclosure. Protection against harmful deposits of dust. The ingress of dust is not totally prevented, but dust cannot enter in an amount sufficient to interfere with satisfactory operation of the equipment enclosed. See test Sub-clause 7.5.
6	Complete protection against contact with live or moving parts inside the enclosure. Protection against ingress of dust. See test Sub-clause 7.6.

4. **Protection of equipment against ingress of liquid**

Second characteristic numeral	Degree of protection
0	No protection.
1	Protection against drops of condensed water: Drops of condensed water falling on the enclosure shall have no harmful effect. See test Sub-clause 8.1.
2	Protection against drops of liquid: Drops of falling liquid shall have no harmful effect when the enclosure is tilted at any angle up to 15° from the vertical. See test Sub-clause 8.2.
3	Protection against rain: Water falling in rain at an angle equal to or smaller than 60° with respect to the vertical shall have no harmful effect. See test Sub-clause 8.3.
4	Protection against splashing: Liquid splashed from any direction shall have no harmful effect. See test Sub-clause 8.4.
5	Protection against water-jets: Water projected by a nozzle from any direction under stated conditions shall have no harmful effect. See test Sub-clause 8.5.
6	Protection against conditions on ships' decks (deck watertight equipment): Water from heavy seas shall not enter the enclosures under prescribed conditions. See test Sub-clause 8.6.
7	Protection against immersion in water: It must not be possible for water to enter the enclosure under stated conditions of pressure and time. See test Sub-clause 8.7.
8	Protection against indefinite immersion in water under specified pressure: It must not be possible for water to enter the enclosure. See test Sub-clause 8.8.

IP $X_1 X_2$

IP PROTECTION DEGREES:

THE MARKINGS USED TO INDICATE THE DEGREE OF PROTECTION CONSIST OF THE LETTERS IP FOLLOWED BY TWO CHARACTERISTIC NUMERALS.

PROTECTION AGAINST INGRESS OF SOLID FOREIGN BODIES				PROTECTION AGAINST INGRESS OF LIQUID.			
X_1	TEST	PROTECTION AGAINST	CEE	X_2	TEST	PROTECTION AGAINST	CEE
0		No protection		0		No protection	
1		ingress of large solid foreign bodies (greater than 50 mm)		1		drops of falling liquid	
2		ingress of medium size solid foreign bodies (greater than 12 mm)		2		drops of falling liquid at any angle up to 15° from the vertical.	
3		ingress of small solid foreign bodies. (greater than 2,5 mm)		3		water falling in rain at any angle up to 60° from the vertical.	UTE
4		ingress of small solid foreign bodies (greater than 1 mm)		4		liquid splashed from any direction (360°)	
5		harmful deposits of dust		5	p1	water-jets from any direction (360°)	
6		ingress of dust		6	p2 p2>p1	conditions on ships' decks	
				7		immersion in water.	
				8		indefinite immersion in water under specified pressure.	

Standards :

DIN 40050 Bl 1: aug. 1970
IEC Publ. 144 : 1st ed. 1963

Marking : IP X_1 X_2

Table 1. Limits of Temperature Rise for Induction Machines (deg.)

Item	Parts of Induction Machin	Type* of enclosure	Class A insulation			Class E insulation			Class B insulation			Class F insulation			Class H insulation		
			T	R	D	T	R	D	T	R	D	T	R	D	T	R	D
1.	Stator winding	Open type	50	60	60	65	75	75	70	80	80	85	100	100	105	125	125
		Totally-enclosed type	55	60	60	70	75	75	75	80	80	90	100	100	110	125	125
2.	Insulated rotor winding	Open type	50	60		65	75		70	80		85	100		105	125	
		Totally-enclosed type	55	60		70	75		75	80		90	100		110	125	
3.	Uninsulated short-circuited winding		The temperature rise of these parts shall in no case reach such a value that there is a risk of injury to any insulating or other material on adjacent parts.														
4.	Iron cores and other mechanical parts, in contact with or adjacent to insulated winding	Open type	60			75			80			100			125		
		Totally-enclosed type	60			75			80			100			125		
5.	Commutators and collector rings		60			70			80			90			100		
6.	Brushes and brush holders		The temperature rise of these parts shall in no case reach such a value that there is a risk of injury to any insulating or other material on adjacent parts.														
7.	Bearings (Self-cooled)		40 degrees when measured on surface of metal 45 degrees when measured by thermometers embedded in metal. When water-cooled bearing or heat-resisting lubrication oil is used, aggreement shall be made between purchaser and manufacturer case by case.														

*In above Table, "T" represents thermometer method. "R." resistance method. "D." embedded temperature detector method.

Table 3.2 Limit of Temperature Rise of Rotary Machines

(unit deg)

Item	Part of rotary machine	Class A Insulation			Class E Insulation			Class B Insulation			Class F Insulation			Class H Insulation		
		(a)	(b)	(c)	(a)	(b)	(c)	(a)	(b)	(c)	(a)	(b)	(c)	(a)	(b)	(c)
1	Stator winding of AC machine	50*	60	60	65*	75	75	70*	80	80	85*	100	100	105*	125	125
2A	Winding of armature with commutator	50*	—	—	65*	—	—	70*	—	—	85*	—	—	105*	—	—
2B	Insulated rotor winding	50*	60	—	65*	75	—	70*	80	—	85*	100	—	105*	125	—
3A	Multiple layer field winding	50*	60	—	65*	75	—	70*	80	—	85*	100	—	105*	125	—
3B	Low resistance field winding and compensating winding	60	60	—	75	75	—	80	80	—	100	100	—	125	125	—
3C	Exposed single layer field winding	65	65	—	80	80	—	90	90	—	110	110	—	135	135	—
3D	Field winding of synchronous machine with massive cylindrical rotor (squirrel cage type rotor)	—	—	—	—	—	—	—	90	—	—	110	—	—	125	—
4	Core or other mechanical part adjacent to insulated winding	60	—	—	75	—	—	80	—	—	100	—	—	125	—	—
5	Short-circuit winding without insulation, core or other mechanical part not adjacent to insulated winding, brushes and brush holders	Temperature which does not cause mechanical hindrance and does not cause damage to insulators nearby.														
6	Commutator and slip ring	60	—	—	70	—	—	80	—	—	90	—	—	100	—	—
7	Bearing (self-cooled)	40 deg. C when measured at surface, 45 deg. C when measured by temperature detecting element embedded in bearing metal. When, however, a water-cooled bearing or heat-resisting lubricant is adopted, the temperature limit has to be agreed upon for every particular case between the purchaser and manufacturer.														

(Note) (a): Thermometer method (b): Resistance method (c): Embedded temperature detector method

(Remarks)

1. Every class of insulation given in this table means the class of the insulation of the part given in the column of the corresponding item. For example, the class B insulation for item 6 means that the insulation of the commutator of slip ring is class B and it does not mean that the insulation of the winding is class B.
2. For the totally enclosed type corresponding to 5.11 (2), establish the limit of temperature rise as 5 deg. C higher than figures marked by asterisks (*) in this table.
3. The number of the embedded temperature detecting elements shall be 3 or more and those elements shall be embedded at such positions at adequate distances in the circumferential direction and, in the axial direction, at those places where the temperature seems to be the highest.
4. Even when a high class insulation is adopted for the commutator of slip ring, the limit of temperature rise for the low class insulation shall be applied if the low class insulation is adopted to the winding which is very close to it. For example, even when the insulation of the commutator is class H, the limit of temperature rise of the commutator has to be 70 deg. C of the class E insulation if the class E insulation is adopted for the winding which is very close to it.
5. Of the windings of items 3B and 3C the resistance method is not suitable for those windings which have small number of turns and many connections.
6. The low resistance field winding in item 3B means a field winding with small number of layers and small resistance for which the whole circumference is insulated, for example, an interpole winding, series winding, etc.

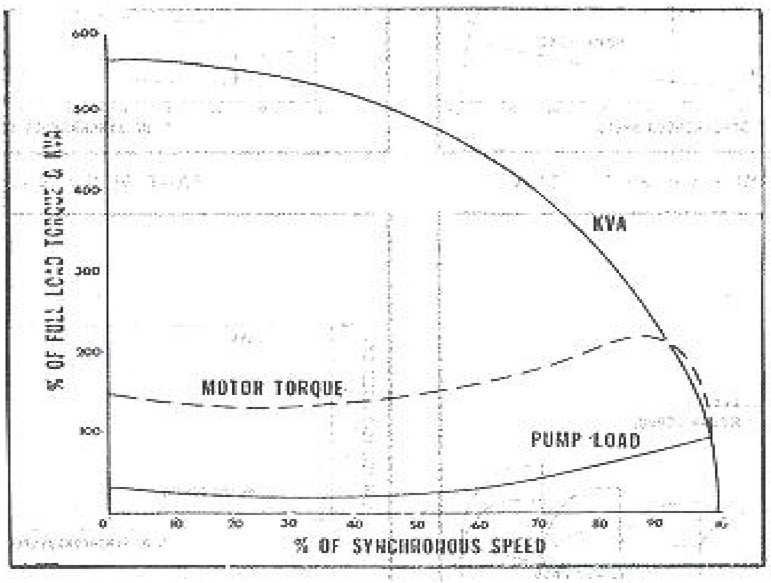
Tolerances of Induction Machines

Item	Kinds	Tolerances
1	a) Conventional efficiency (η)% (See 6.3, 6.12, 6.13.) b) Measured efficiency (η)%	$-0.1\times(100-\eta)$ % $-0.15\times(100-\eta)$ % Min. 0.7%
2	Losses (total losses of an asynchronous phase modifier)	$+1/10\times$(guaranteed value)
3	Power factor at the rated output (pf) %	$-1/6\,(100-\text{pf})$ % Min. 2%, Max. 7%
4	No-load current	$+3/10\times$(guaranteed value)
5	Slip	$+1/5\times$(guaranteed value)
6	Starting current	$+1/5\times$(guaranteed value)
7	Starting Torque	$-1/10\times$(guaranteed value)
8	Break-down torque	$-1/10\times$(guaranteed value)

Remark : Tolerances of Item 1 and Items 3 to 8 shall be applied to both the measured values and calculated values (circle diagram method, etc.).

Annex 4: Types of motor starting

When an AC induction motor is started across the line, the electrical current demanded by the motor instantaneously reaches a value of five to six times its normal full load running current; this is true whether the motor is fully loaded or unloaded. This instantaneous increase in current is called inrush.



igure 1. A.C. Motor across the line

Inrush occurs because the instant of starting the impedance of the motor winding is very low . As the motor starts to accelerate, the impedance increases , and therefore the current starts to diminish .

The above is true only because the voltage applied to the motor was held at a fixed value . therefore , it becomes obvious that if the voltage applied to the motor was reduced at start , the inrush current would be reduced . Or better yet , if we could gradually apply the voltage to the motor from zero on up , the inrush would be zero .

Over the years , many methods have been developed and used to reduce the inrush current , such as the autotransformer , part winding motor design , way – delta motor design and in more recent years the reduced voltage solid state starter . However, all of these merely reduce the level of inrush , they cannot eliminate the inrush .

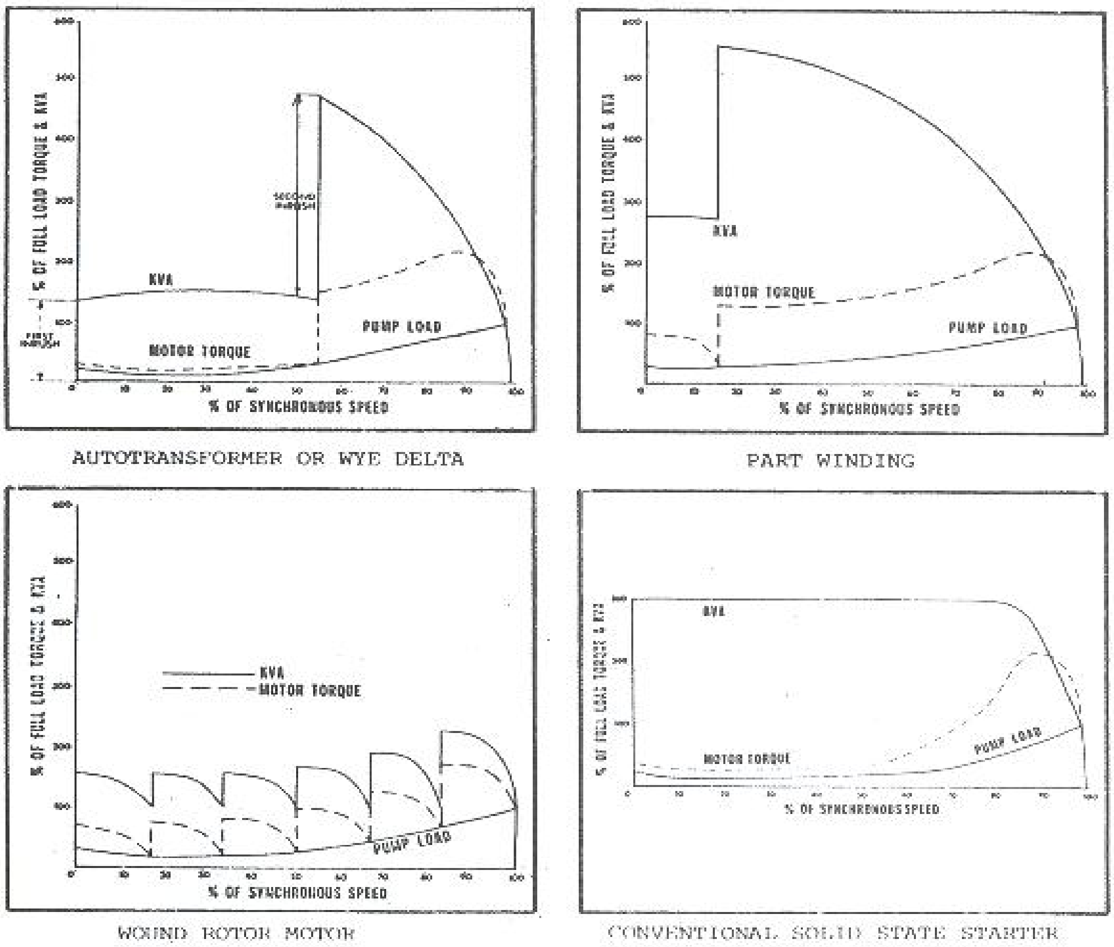


FIGURE 2 .

It is apparent from the curves in figure 2 that each has some degree of inrush. Three out of four have two steps of inrush , each of a slightly different magnitude . the fourth , the solid state starter , has one level of inrush and this level being adjustable must be set at a level high enough to not only provide the power to break the load away , but also to accelerate the load to full speed . This bring us to the real problem.

The problem is, the machine must be started and accelerated up to full speed and still stay within the power line and inrush limitations.

It is therefore apparent that only certain kinds of reduced voltage methods can be used with any given kind of loads .
For all practical purposes. There are only three types of loads .

For all practical purposes, there are only three types of loads.
(1) constant torque , (2) variable torque ,and (3) high inertia loads with which we have to be concerned .

Since the starting torque of an Ac induction motor varies as a square of the applied voltage, it becomes apparent that not all types of loads can be successfully started by fixed step functions. Obviously, the constant torque type of load cannot be started by the autotransformer the part winding or the wye – delta method. Not only is the accelerating torque constant for loads such as conveyors, but in most cases the breakaway torques (stiction) can be quite high.

In contrast to this, the variable torque type loads, such as centrifugal pumps, fans, etc., the torque required varies as a square of the speed.
It has a very low breakaway torque (15-35% of full load). Therefore, most any one of the four reduced voltage means can be successfully used to start this kind of load. Whether or not it would allow staying within what ever inrush limitations exist is another question. This can only be determined by the motor manufacturer and the kind of starting employed.
Keep in mind that motor design and characteristics vary not only between manufacturers but also from motor frame size to motor frame size within a given manufacturer. the only way to be sure that the motor will start and accelerate the load to full speed with any reduced voltage method is to put the full problem on the motor manufacturer and have him provide his recommendations . If the autotransformer method is to be employed. The motor manufacturer should know and sanction the voltage steps.

A completely new concept in motor starting is now available which solves the problem of starting most any type of load and still stay within any inrush limitations. The concept uses the conventional Ac induction motor in conjunction with a specially – designed solid state starter, the two matched to each other for the specific application. The end result is the assurance that the drive package will start the load and do it with zero inrush.

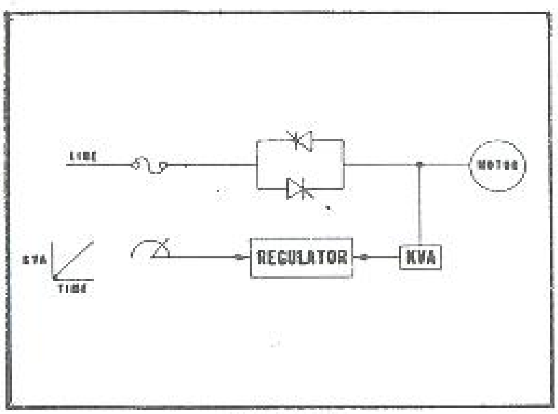


FIGURE 3
CONTROL SCHEMATIC

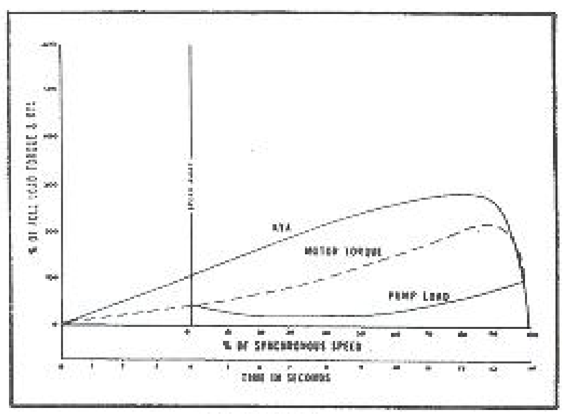


FIGURE 4
ULTRA TORQ START

The controller is made up of all solid state devices and the power section consists of six SCR's (two per phase) . A feedback loop measuring KVA

Controls the amount of power being supplied to the motor during the starting cycle (see figure 3). The control is such as to allow an ever increasing amount of KVA to flow to the motor on a time basis, thus providing a rate of change of KVA to the motor (see figure 4).

When the starter is first energized, the KVA output is zero. As the KVA increases to the motor , the motor starts to develop more and more torque at some point in time, the motor will have sufficient torque to break the load away . Since the KVA continues to increase, so does the motor's torque, thus applying acceleration torque to the load. When the motor is up to full speed, the KVA demand decreases to the running level and starter is full on. This is shown in figure 4 where a pump type load is used as an example. The level to which the KVA rises totally depends on motor design and the torque characteristics of the load .

It is now apparent , by properly selecting the right motor to match the load requirements and then match the starter to that motor , the motor will break the load away accelerate it to full speed and do it all with a zero inrush .

SELECTION OF REDUCED VOLTAGE STARTERS

To select a proper reduced voltage starter, consideration should be given to requirements of application which may be divided into the following three:

1. Limiting starting current throughout starting.

   Transition to full voltage needs to be delayed until just before the motor obtains full speed. Whether accelerating is large enough to accelerate the load should be considered.

2. Limiting the duration of flow of maximum current during starting.

   The main consideration should be reducing line disturbance by shortening maximum starting current interval rather than by restricting maximum starting current.

3. Providing cushioned starting.

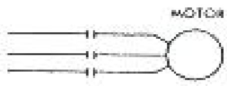
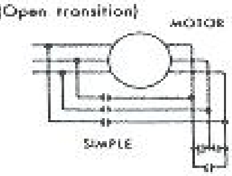
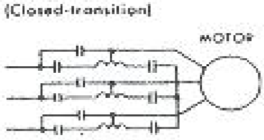
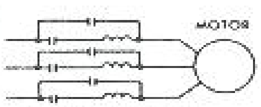
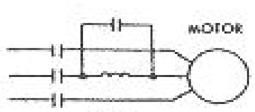
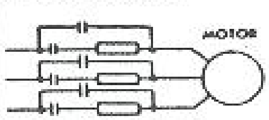
   Starting torque is first limited, then increased gradually with acceleration.

REDUCED VOLTAGE STARTER SELECTION TABLE

REQUIREMENT / TYPE OF LOAD	LIMITING STARTING CURRENT THROUGHOUT STARTING	LIMITING DURATION OF FLOW OF MAX. CURRENT DURING STARTING	PROVIDING CUSHIONED STARTING	APPLICATIONS
START AT NO LOAD	Wye-delta Korndorfer Reactor	—	—	Machine Tools Lathes, drilling machines, boring machines, spindle drives of milling machines, gear cutting machines, cutters of gear cutting machines, grinders, band saw machines, paper grinders, line shaft drives. Loading, Unloading and Transportation: Winches with clutch, capstans, crushers, unloaders. Spinning and Looming Machines. General Industrial Machines. Motor-driven Machines. MG Sets.
SQUARED OF TORQUE LOAD	Korndorfer Reactor	Korndorfer Reactor Wye-delta	—	Fluid Machines: Spiral pumps, turbine pumps, volute pumps, swash plate pumps, axial-flow pumps. Pneumatic Machines: Centrifugal-fans, -blowers and -compressors, axial-flow-fans, -blowers and -compressors.
GRAVITY LOAD	—	Korndorfer · Reactor	Kuza-Reactor Korndorfer	Lifting-Lowering Machines: Winches, tilted conveyors, elevators, escalators.
FRICTION LOAD	Korndorfer Reactor	Korndorfer Reactor	Kuza Korndorfer Reactor	Feed Drives: Horizontal conveyors, travelling trucks, machine tools. Crushers, Mixers, Feeders, Calenders. Electric Doors.
INERTIA LOAD	Wye-delta Korndorfer Reactor	Wye-delta Korndorfer Reactor	—	Centrifugal Separators, Hydro-extractors. Crank Presses (with small repulsion torque only).
START AT FULL LOAD	Korndorfer Reactor	Korndorfer Reactor	Kuza-Reactor Korndorfer	Reciprocating Pumps, Reciprocating Compressors. Roots-blowers, Extruders.
INTERMITTENT LOAD			Kuza-Reactor Korndorfer	Loom Machines, Winders, Pinch Rollers, Long Belt Conveyors, Chain Conveyors.

Note: Resistor starter can be used instead of reactor except where applications involve inertia load.

TYPES OF MOTOR STARTING

Starting methods and primary connections		Starting characteristics	Typical applications
Full voltage starting	 Very simple	.Both starting current and starting torque large, resulting in shortest starting time. Line disturbance and inrush current large. -Shock to connected inevitable at starting	General industry use .
	WYE-DELTA (Open transition)  SIMPLE	-Both starting current and starting torque small -Starting current not adjustable. Torque increase and maximum torque small. -Opening of circuit during transition to full voltage may cause line surge.	.Suitable for starting motors with no load or light load connected. -Machine tools .
	KORNDORFER (Closed-transition)  MOST COMPLICATED	.starting torque does not much decrease it starting current is reduced , starting current adjustable by autotransformer taps . Torque increase small but larger than with WYE-DELTA starting. . maximum torque small. . smooth acceleration.	-Suitable for use where reduction of starting current is of prime consideration. Pumps blowers
REDUCED VOLTAGE STARTING	REACTOR  A LITTLE COMPLICATED	. Reducing starting current sharply decreases starting torque. -starting current adjustable by reactor taps. -torque increase extremely large. -maximum torque largest among reduced voltage starters . -smooth acceleration .	.Suitable for use where WYE-DELTA starting does not provide adequate acceleration -used where cushioned starting is required pumps, blowers
	KUZA  SIMPLE	Only starting torque can be limited . Starting torque adjustable by reactor taps . . torque increase remarkably large . . smooth acceleration .	.Suitable for use in small motors where cushioned starting is desired.
	PRIMARY RESISTOR  A LITTLE COMPLICATED	Reducing starting current sharply reduces starting torque. . Starting current adjustable by resistor taps. . Torque increase and maximum torque pretty large. . Smooth acceleration.	Suitable for use where WYE-DELTA starting does not provide adequate acceleration. . used where it is desirable to eliminate shock to driven machines.

Annex 5: Loss of Head in Ductile Cast Iron

Diameter (m)	Coefficient $\frac{\lambda}{D}$ for roughness equal to:			
	k = 0·1 mm	k = 0·5 mm	k = 1·0 mm	k = 2·0 mm
0·030	1·02	1·54	2·00	2·71
0·040	0·700	1·04	1·34	1·80
0·050	0·528	0·78	0·985	1·30
0·070	0·35	0·500	0·615	0·80
0·080	0·290	0·413	0·512	0·660
0·100	0·222	0·310	0·380	0·490
0·125	0·168	0·232	0·284	0·360
0·150	0·133	0·182	0·223	0·280
0·175	0·110	0·150	0·180	0·229
0·200	0·0935	0·128	0·153	0·190
0·225	0·0813	0·110	0·129	0·162
0·250	0·0710	0·096	0·114	0·141
0·300	0·0573	0·076	0·090	0·110
0·350	0·0475	0·0625	0·0735	0·0900
0·400	0·0400	0·0530	0·0625	0·0758
0·450	0·0351	0·0460	0·0538	0·0650
0·500	0·0308	0·040	0·047	0·0566
0·600	0·0245	0·0322	0·0371	0·0477
0·700	0·0206	0·0266	0·0307	0·0368
0·800	0·0175	0·0225	0·0260	0·0310
0·900	0·0151	0·0194	0·0225	0·0267
1·000	0·0134	0·0170	0·0197	0·0234
1·250	0·0102	0·0130	0·0150	0·0177
1·500	0·00827	0·0104	0·0120	0·0140
1·750	0·00686	0·00857	0·0098	0·0116
2·000	0·00586	0·00735	0·0084	0·00980
2·500	0·00453	0·0056	0·0064	0·00745
Range of speeds with good approximation	1 to 3 m/s	1 to 3 m/s	$\geqslant$ 1 m/s	$\geqslant$ 0·5 m/s

3—Tables of values of the loss of head J.

In practice the roughness coefficients used most often are either 0·1 mm or 2 mm, or an intermediate value such that it is only necessary to take the arithmetic mean of the two values of J corresponding to each of these coefficients k (see page 991). The diameter of the metal pipes is standardized. The following tables give for current diameters the value of the loss of head through friction J under the least favourable assumption of water at a temperature near 0°C with the maximum viscosity.

TABLE *giving the* loss of head J in metres

as a function of the diameter of the pipe and the mean velocity :

(1) For new pipes (k = 0·1 mm) and (2) for existing pipes (k = 2 mm) (*the temperature of the water being at 0°C.*)

Mean velocity in metres/sec.	PIPE DIAMETER : 0·04 m. Pipe section : 0·0012566 m²			PIPE DIAMETER : 0·05 m. Pipe section : 0·0019635 m²		
	Head per metre of pipe length		Flow in litres/sec.	Head per metre of pipe length		Flow in litres/sec.
	New pipes	Existing pipes		New pipes	Existing pipes	
0·01			0·0125			0·0196
0·05			0·0628			0·0982
0·10			0·1256			0·1963
0·15			0·1884			0·2945
0·20	0·002115		0·2513	0·001590		0·3927
0·25	0·003138		0·3140	0·002358		0·4909
0·30	0·004329		0·3769	0·003248		0·5890
0·35	0·005694		0·4396	0·004281	0·008237	0·6872
0·40	0·007242		0·5024	0·005451	0·010690	0·7854
0·45	0·008966	0·018576	0·5652	0·006708	0·013468	0·8836
0·50	0·010861	0·022868	0·6280	0·008115	0·016587	0·9817
0·55	0·012895	0·027640	0·6908	0·009668	0·020046	1·0799
0·60	0·015116	0·032856	0·7538	0·011340	0·023826	1·1781
0·65	0·017493	0·038512	0·8164	0·013118	0·027924	1·2763
0·70	0·020072	0·044652	0·8792	0·015013	0·032374	1·3744
0·75	0·022793	0·051212	0·9420	0·017030	0·037128	1·4726
0·80	0·025647	0·058227	1·0048	0·019213	0·042210	1·5708
0·85	0·028681	0·065742	1·0676	0·021509	0·047658	1·6690
0·90	0·031845	0·073703	1·1304	0·023948	0·053429	1·7671
0·95	0·035190	0·082110	1·1932	0·026496	0·059524	1·8653
1·00	0·038546	0·090981	1·2566	0·029155	0·065955	1·9635
1·05	0·042143	0·100299	1·3194	0·031916	0·072710	2·0617
1·10	0·046021	0·110081	1·3822	0·034782	0·079801	2·1598
1·15	0·050052	0·120327	1·4451	0·037750	0·087229	2·2580
1·20	0·054224	0·131019	1·5079	0·040884	0·094980	2·3562
1·25	0·058535	0·142157	1·5707	0·044152	0·103054	2·4544
1·30	0·063011	0·153760	1·6335	0·047549	0·111465	2·5525
1·35	0·067647	0·165809	1·6963	0·051090	0·120200	2·6507
1·40	0·072428	0·178322	1·7592	0·054745	0·129271	2·7489
1·45	0·077423	0·191281	1·8220	0·058509	0·138665	2·8471
1·50	0·082570	0·204704	1·8846	0·062386	0·148396	2·9452
1·55	0·087865	0·218591	1·9474	0·066373	0·158463	3·0434
1·60	0·093293	0·232907	2·0105	0·070459	0·168841	3·1416
1·65	0·098874	0·247704	2·0733	0·074658	0·179568	3·2397
1·70	0·104657	0·262931	2·1362	0·978953	0·190606	3·3379
1·75	0·110597	0·278639	2·1990	0·083420	0·201993	3·4361
1·80	0·116671	0·294775	2·2608	0·088020	0·213691	3·5343
1·85	0·122893	0·311375	2·3236	0·092732	0·225725	3·6324
1·90	0·129260	0·328440	2·3864	0·097557	0·238096	3·7306
1·95	0·135764	0·345951	2·4499	0·102487	0·250790	3·8288
2·00	0·142410	0·363926	2·5132	0·107526	0·263821	3·9270
2·05	0·149244	0·382347	2·5760	0·112669	0·277175	4·0251
2·10	0·156222	0·401232	2·6388	0·117920	0·290865	4·1233
2·15	0·163337	0·420564	2·7016	0·123271	0·304879	4·2215
2·20	0·170586	0·440342	2·7645	0·128772	0·319217	4·3197
2·25	0·178048	0·460601	2·8273	0·134336	0·333904	4·4179
2·30	0·185708	0·481290	2·8888	0·140046	0·348901	4·5160
2·35	0·193518	0·502442	2·9516	0·145863	0·364235	4·6142
2·40	0·201476	0·524058	3·0158	0·151786	0·379905	4·7124
2·45	0·209576	0·546121	3·0786	0·157870	0·395899	4·8106
2·50	0·217815	0·568630	3·1412	0·164058	0·412217	4·9087
3·00	0·307923	0·818833	3·7698	0·133035	0·593597	5·8905
3·50	0·414432	1·114518	4·3981	0·312190	0·807948	6·8723
4·00	0·536204	1·455703	5·0264	0·404498	1·055283	7·8540

TABLE *giving the* **loss of head J in metres**

as a function of the diameter of the pipe and the mean velocity :

(1) For new pipes (k = 0·1 mm) and (2) for existing pipes (k = 2 mm) (*the temperature of the water being at 0°C.*)

Mean velocity in metres/sec.	PIPE DIAMETER : 0·06 m. Pipe section : 0·00282744 m²			PIPE DIAMETER : 0·08 m. Pipe section : 0·0050265 m²		
	Head per metre of pipe length		Flow in litres/sec.	Head per metre of pipe length		Flow in litres/sec.
	New pipes	Existing pipes		New pipes	Existing pipes	
0·01			0·0283			0·0503
0·05			0·1414			0·2513
0·10			0·2827	0·000256		0·5027
0·15	0·000753		0·4241	0·000520		0·7540
0·20	0·001249		0·5655	0·000863	0·001438	1·0053
0·25	0·001856		0·7069	0·001280	0·002213	1·2566
0·30	0·002557	0·004713	0·8482	0·001775	0·003154	1·5080
0·35	0·003364	0·006354	0·9896	0·002336	0·004263	1·7593
0·40	0·004277	0·008262	1·1310	0·002994	0·005539	2·0106
0·45	0·005289	0·010406	1·2723	0·003702	0·006969	2·2620
0·50	0·006412	0·012803	1·4137	0·004467	0·008568	2·5133
0·55	0·007633	0·015466	1·5551	0·005339	0·010347	2·7646
0·60	0·008961	0·018374	1·6965	0·006274	0·012290	3·0159
0·65	0·010388	0·021530	1·8378	0·007280	0·014396	3·2672
0·70	0·011907	0·024955	1·9792	0·008353	0·016680	3·5186
0·75	0·013523	0·028612	2·1206	0·009450	0·019120	3·7699
0·80	0·015223	0·032522	2·2619	0·010646	0·021733	4·0212
0·85	0·017034	0·036682	2·4033	0·011910	0·024515	4·2726
0·90	0·018959	0·041084	2·5447	0·013249	0·027458	4·5239
0·95	0·020968	0·045771	2·6861	0·014651	0·030590	4·7752
1·00	0·023064	0·050715	2·8274	0·016119	0·033895	5·0266
1·05	0·025257	0·055909	2·9688	0·017644	0·037367	5·2779
1·10	0·027556	0·061361	3·1102	0·019241	0·041011	5·5192
1·15	0·029941	0·067073	3·2516	0·020906	0·044828	5·7805
1·20	0·032418	0·073033	3·3929	0·022635	0·048811	6·0319
1·25	0·034975	0·079242	3·5343	0·024420	0·052961	6·2832
1·30	0·037615	0·085709	3·6757	0·026273	0·057283	6·5345
1·35	0·040392	0·092426	3·8170	0·028181	0·061772	6·7858
1·40	0·043257	0·099401	3·9584	0·030145	0·066434	7·0372
1·45	0·046204	0·106624	4·0998	0·032175	0·071261	7·2885
1·50	0·049255	0·114106	4·2412	0·034261	0·076262	7·5398
1·55	0·052392	0·121848	4·3825	0·036478	0·081436	7·7911
1·60	0·055606	0·129828	4·5239	0·038753	0·086769	8·0425
1·65	0·058908	0·138076	4·6653	0·041093	0·092283	8·2937
1·70	0·062308	0·146564	4·8066	0·043490	0·097955	8·5451
1·75	0·065796	0·155320	4·9480	0·045952	0·103807	8·7965
1·80	0·069359	0·164314	5·0894	0·048489	0·109818	9·0478
1·85	0·073003	0·173568	5·2368	0·051089	0·116003	9·2991
1·90	0·076759	0·183080	5·3721	0·053751	0·122360	9·5505
1·95	0·080625	0·192841	5·5135	0·056472	0·128884	9·8018
2·00	0·084576	0·202861	5·6549	0·059253	0·135580	10·0531
2·05	0·088607	0·213129	5·7963	0·062118	0·142443	10·3044
2·10	0·092722	0·223656	5·9376	0·065046	0·149479	10·5558
2·15	0·096914	0·234432	6·0790	0·068032	0·156680	10·8071
2·20	0·101266	0·245457	6·2204	0·071078	0·164049	11·0584
2·25	0·105710	0·256749	6·3617	0·074187	0·171597	11·3097
2·30	0·110234	0·268282	6·5031	0·077350	0·179304	11·5610
2·35	0·114844	0·280072	6·6445	0·080574	0·187184	11·8124
2·40	0·119540	0·292122	6·7859	0·083857	0·195238	12·0637
2·45	0·124318	0·304420	6·9272	0·087196	0·203457	12·3150
2·50	0·129176	0·316967	7·0686	0·090591	0·211842	12·5664
3·00	0·183110	0·456436	8·4823	0·128731	0·305056	15·0795
3·50	0·246110	0·621258	9·8960	0·172875	0·415213	17·5928
4·00	0·318732	0·811442	11·3098	0·224268	0·542321	20·1060

TABLE *giving the* **loss of head J in metres**

as a function of the diameter of the pipe and the mean velocity :

(1) For new pipes (k = 0·1 mm) and (2) for existing pipes (k = 2 mm) (*the temperature of the water being at* 0°C.)

Mean velocity in metres/sec.	PIPE DIAMETER : 0·10 m. Pipe section : 0·007854 m²			PIPE DIAMETER : 0·125 m. Pipe section : 0·012272 m²		
	Head per metre of pipe length		Flow in litres/sec.	Head per metre of pipe length		Flow in litres/sec.
	New pipes	Existing pipes		New pipes	Existing pipes	
0·01			0·0785			0·1227
0·05			0·3927			0·6136
0·10	0·000191		0·7854	0·000144	0·000207	1·2272
0·15	0·000388	0·000604	1·1781	0·000291	0·000449	1·8408
0·20	0·000643	0·001054	1·5708	0·000486	0·000783	2·4544
0·25	0·000956	0·001622	1·9635	0·000726	0·001204	3·0680
0·30	0·001335	0·002312	2·3562	0·001009	0·001712	3·6816
0·35	0·001763	0·003120	2·7489	0·001330	0·002311	4·2952
0·40	0·002248	0·004060	3·1416	0·001701	0·003004	4·9088
0·45	0·002786	0·005111	3·5343	0·002104	0·003785	5·5224
0·50	0·003370	0·006281	3·9270	0·002548	0·004656	6·1360
0·55	0·004009	0·007584	4·3197	0·003037	0·005618	6·7496
0·60	0·004707	0·009006	4·7124	0·003560	0·006568	7·3632
0·65	0·005447	0·010543	5·1051	0·004120	0·007804	7·9768
0·70	0·006245	0·012215	5·4978	0·004726	0·009037	8·5904
0·75	0·007090	0·014000	5·8905	0·005369	0·010356	9·2040
0·80	0·007985	0·015911	6·1830	0·006059	0·011769	9·8176
0·85	0·008931	0·017951	6·6759	0·006765	0·013279	10·4312
0·90	0·009930	0·020108	7·0686	0·007531	0·014878	11·0448
0·95	0·010980	0·022402	7·4613	0·008332	0·016567	11·6584
1·00	0·012080	0·024822	7·8540	0·009166	0·018349	12·2720
1·05	0·013233	0·027365	8·2467	0·010047	0·020228	12·8866
1·10	0·014431	0·030033	8·6394	0·010962	0·022201	13·4992
1·15	0·015673	0·032829	9·0321	0·011913	0·024268	14·1128
1·20	0·016955	0·035746	9·4248	0·012091	0·026424	14·7264
1·25	0·018301	0·038785	9·8175	0·013921	0·028670	15·8400
1·30	0·019692	0·041950	10·2102	0·014988	0·031010	15·9536
1·35	0·021142	0·045237	10·6029	0·016089	0·033440	16·5672
1·40	0·022637	0·048651	10·9956	0·017231	0·035964	17·1808
1·45	0·024197	0·052187	11·3883	0·018406	0·038578	17·7944
1·50	0·025803	0·055849	11·7810	0·019615	0·041285	18·4080
1·55	0·027456	0·059638	12·1737	0·020857	0·044086	19·0216
1·60	0·029149	0·063544	12·5664	0·022140	0·046973	19·6352
1·65	0·030890	0·067581	12·9591	0·023458	0·049957	20·2488
1·70	0·032671	0·071735	13·3518	0·024805	0·053028	20·8624
1·75	0·034514	0·076021	13·7445	0·026200	0·056196	21·4760
1·80	0·036397	0·080423	14·1372	0·027625	0·059450	22·0896
1·85	0·038324	0·084952	14·5293	0·029097	0·062798	22·7032
1·90	0·040296	0·089608	14·9226	0·030588	0·066240	23·3168
1·95	0·042347	0·094385	15·3153	0·032126	0·069772	23·9304
2·00	0·044446	0·099290	15·7081	0·033714	0·073397	24·5440
2·05	0·046589	0·104315	16·1007	0·035334	0·077112	25·1576
2·10	0·048777	0·109468	16·4934	0·036990	0·080921	25·7712
2·15	0·051010	0·114742	16·8861	0·038678	0·084820	26·3848
2·20	0·053285	0·120138	17·2788	0·040437	0·088809	26·9984
2·25	0·055608	0·125665	17·6715	0·042236	0·092894	27·6120
2·30	0·057970	0·131310	18·0642	0·044068	0·097067	28·2256
2·35	0·060377	0·137081	18·4569	0·045960	0·101333	28·8392
2·40	0·062828	0·142978	18·8496	0·047890	0·105692	29·4538
2·45	0·065320	0·148998	19·2423	0·049858	0·110142	30·0664
2·50	0·065853	0·155139	19·6350	0·051862	0·114682	30·6800
3·00	0·096333	0·223402	23·5620	0·073580	0·165143	36·816
3·50	0·129559	0·304073	27·4890	0·098802	0·224777	42·952
4·00	0·167589	0·397152	31·4160	0·128004	0·293587	49·088

TABLE *giving the* loss of head J in metres

as a function of the diameter of the pipe and the mean velocity :

(1) For new pipes (k = 0·1 mm) and (2) for existing pipes (k = 2 mm) (*the temperature of the water being at 0°C.*)

Mean velocity in metres/sec.	PIPE DIAMETER : 0·150 m. Pipe section : 0·0176725 m²			PIPE DIAMETER : 0·200 m. Pipe section : 0·031416 m²		
	Head per metre of pipe length		Flow in litres/sec.	Head per metre of pipe length		Flow in litres/sec.
	New pipes	Existing pipes		New pipes	Existing pipes	
0·01			0·1767			0·3142
0·05	0·000034		0·8836	0·000024	0·000030	1·5708
0·10	0·000114	0·000163	1·7671	0·000079	0·000110	3·1416
0·15	0·000232	0·000352	2·6507	0·000162	0·000238	4·7424
0·20	0·000387	0·000612	3·5343	0·000270	0·000413	6·2832
0·25	0·000578	0·000941	4·4179	0·000400	0·000636	7·8540
0·30	0·000801	0·001336	5·3014	0·000557	0·000903	9·4248
0·35	0·001059	0·001810	6·1850	0·000736	0·001217	10·9956
0·40	0·001351	0·002347	7·0686	0·000940	0·001581	12·5664
0·45	0·001674	0·002948	7·9522	0·001169	0·001989	14·1372
0·50	0·002031	0·003622	8·8357	0·001421	0·002445	15·7080
0·55	0·002421	0·004374	9·7193	0·001692	0·002945	17·2788
0·60	0·002842	0·005187	10·6029	0·001986	0·003491	18·8496
0·65	0·003293	0·006070	11·4865	0·002298	0·004080	20·4204
0·70	0·003777	0·007028	12·3700	0·002642	0·004734	21·9912
0·75	0·004289	0·008054	13·2536	0·002996	0·005433	23·5620
0·80	0·004834	0·009155	14·1372	0·003376	0·006181	25·1328
0·85	0·005411	0·010329	15·0208	0·003784	0·006979	26·7036
0·90	0·006017	0·011572	15·9043	0·004212	0·007824	28·2744
0·95	0·006652	0·012883	16·7879	0·004658	0·008717	29·8452
1·00	0·007316	0·014268	17·6715	0·005122	0·009659	31·4160
1·05	0·008009	0·015722	18·5550	0·005619	0·010648	32·9868
1·10	0·008732	0·017247	19·4386	0·006139	0·011686	34·5576
1·15	0·009487	0·018852	20·3222	0·006680	0·012774	36·1284
1·20	0·010271	0·020527	21·2058	0·007241	0·013909	37·6992
1·25	0·011086	0·022273	22·0893	0·007821	0·015092	39·2700
1·30	0·011933	0·024091	22·9729	0·008424	0·016324	40·8408
1·35	0·012813	0·025978	23·8565	0·009047	0·017603	42·4116
1·40	0·013726	0·027939	24·7401	0·009695	0·018931	43·9824
1·45	0·014667	0·029970	25·6237	0·010362	0·020307	45·5532
1·50	0·015642	0·032072	26·5072	0·011049	0·021737	47·1240
1·55	0·016646	0·034248	27·3908	0·011756	0·023206	48·6948
1·60	0·017684	0·036491	28·2744	0·012480	0·024726	50·2656
1·65	0·018752	0·038809	29·1580	0·013232	0·026297	51·8364
1·70	0·019846	0·041195	30·0415	0·014001	0·027913	53·4072
1·75	0·020970	0·043656	30·9251	0·014790	0·029581	54·9780
1·80	0·022129	0·046184	31·8087	0·015597	0·031294	56·5488
1·85	0·023317	0·048785	32·6922	0·016424	0·033056	58·1196
1·90	0·024533	0·051459	33·5758	0·017268	0·034868	59·6904
1·95	0·025777	0·054202	34·4594	0·018141	0·036727	61·2612
2·00	0·027062	0·057018	35·3430	0·019032	0·038635	62·8320
2·05	0·028374	0·059905	36·2265	0·019942	0·040591	64·4028
2·10	0·029716	0·062863	37·1101	0·020882	0·042596	65·9736
2·15	0·031085	0·065892	37·9937	0·021841	0·044548	67·5444
2·20	0·032497	0·068991	38·8772	0·022831	0·046748	69·1152
2·25	0·033941	0·072165	39·7608	0·023843	0·048899	70·6860
2·30	0·035411	0·075406	40·6444	0·024873	0·051095	72·2568
2·35	0·036911	0·078720	41·5279	0·025924	0·053340	73·8276
2·40	0·038441	0·082107	42·4115	0·026981	0·055635	75·3984
2·45	0·039998	0·085564	43·2951	0·028071	0·057978	76·9692
2·50	0·041583	0·089090	44·1787	0·029180	0·060367	78·5400
3·00	0·059023	0·128291	53·0145	0·041400	0·086929	94·2480
3·50	0·079296	0·174618	61·8503	0·055757	0·118320	109·956
4·00	0·102483	0·228073	70·6860	0·072051	0·154541	125·664

TABLE *giving the* loss of head J in metres

as a function of the diameter of the pipe and the mean velocity :

(1) For new pipes (k = 0·1 mm) and (2) for existing pipes (k = 2 mm) (*the temperature of the water being at* 0°C.)

Mean velocity in metres/sec.	PIPE DIAMETER : 0·250 m. Pipe section : 0·0490875 m²			PIPE DIAMETER : 0·300 m. Pipe section : 0·070686 m²		
	Head per metre of pipe length		Flow in litres/sec.	Head per metre of pipe length		Flow in litres/sec.
	New pipes	Existing pipes		New pipes	Existing pipes	
0·01			0·4909			0·7069
0·05	0·000017	0·000022	2·4544	0·000014	0·000018	3·5343
0·10	0·000060	0·000081	4·9087	0·000048	0·000064	7·0686
0·15	0·000122	0·000175	7·3631	0·000097	0·000139	10·6029
0·20	0·000204	0·000305	9·8175	0·000163	0·000241	14·1372
0·25	0·000303	0·000469	12·2719	0·000244	0·000370	17·6715
0·30	0·000424	0·000668	14·7262	0·000339	0·000527	21·2058
0·35	0·000563	0·000902	17·1806	0·000450	0·000711	24·7401
0·40	0·000720	0·001173	19·6350	0·000574	0·000925	28·2744
0·45	0·000890	0·001477	22·0894	0·000712	0·001164	31·8087
0·50	0·001080	0·001815	24·5437	0·000864	0·001431	35·3430
0·55	0·001286	0·002188	26·9981	0·001031	0·001725	38·8773
0·60	0·001512	0·002594	29·4525	0·001215	0·002046	42·4116
0·65	0·001753	0·003034	31·9069	0·001411	0·002393	45·9459
0·70	0·002013	0·003511	34·3612	0·001622	0·002769	49·4802
0·75	0·002294	0·004024	36·8156	0·001845	0·003170	53·0145
0·80	0·002586	0·004573	39·2700	0·002079	0·003603	56·5488
0·85	0·002896	0·005159	41·7244	0·002326	0·004064	60·0831
0·90	0·003226	0·005781	44·1787	0·002588	0·004556	63·6174
0·95	0·003571	0·006440	46·6331	0·002866	0·005076	67·1517
1·00	0·003935	0·007136	49·0875	0·003157	0·005624	70·6860
1·05	0·004315	0·007867	51·5418	0·003461	0·006200	74·2203
1·10	0·004712	0·008634	53·9962	0·003778	0·006804	77·7546
1·15	0·005123	0·009437	56·4506	0·004110	0·007438	81·2889
1·20	0·005555	0·010276	58·9050	0·004453	0·008099	84·8232
1·25	0·006002	0·011150	61·3593	0·004808	0·008787	88·3575
1·30	0·006464	0·012060	63·8137	0·005177	0·009504	91·8918
1·35	0·006944	0·013005	66·2681	0·005561	0·010249	95·4261
1·40	0·007441	0·013986	68·7225	0·005957	0·011022	98·9604
1·45	0·007956	0·015002	71·1769	0·006365	0·011823	102·4947
1·50	0·008486	0·016055	73·6312	0·006785	0·012653	106·0290
1·55	0·009033	0·017144	76·0856	0·007217	0·013511	109·5633
1·60	0·009593	0·018267	78·5400	0·007659	0·014397	113·0976
1·65	0·010169	0·019428	80·9944	0·008123	0·015311	116·6319
1·70	0·010759	0·020622	83·4487	0·008602	0·016252	120·1662
1·75	0·011364	0·021854	85·9031	0·009090	0·017223	123·7005
1·80	0·011989	0·023120	88·3575	0·009595	0·018221	127·2348
1·85	0·012629	0·024422	90·8118	0·010106	0·019247	130·7691
1·90	0·013285	0·025760	93·2662	0·010635	0·020302	134·3034
1·95	0·013954	0·027133	95·7206	0·011170	0·021384	137·8377
2·00	0·014639	0·028543	98·1750	0·011723	0·022495	141·3720
2·05	0·015345	0·029988	100·6293	0·012288	0·023633	144·9063
2·10	0·016067	0·031469	103·0837	0·012865	0·024801	148·4406
2·15	0·016804	0·032985	105·5381	0·013461	0·025996	151·9749
2·20	0·017564	0·034537	107·9924	0·014070	0·027218	155·5092
2·25	0·018341	0·036126	110·4468	0·014691	0·028470	159·0435
2·30	0·019133	0·037748	112·9012	0·015324	0·029749	162·5778
2·35	0·019940	0·039407	115·3555	0·015969	0·031057	166·1121
2·40	0·020763	0·041103	117·8099	0·016627	0·032393	169·6464
2·45	0·021600	0·042833	120·2643	0·017296	0·033756	173·1807
2·50	0·022465	0·044598	122·7187	0·017988	0·035148	176·7150
3·00	0·031873	0·064222	147·2625	0·025490	0·050613	212·058
3·50	0·042907	0·087413	171·8063	0·034341	0·068890	247·401
4·00	0·055455	0·114173	196·3500	0·044527	0·089979	282·744

TABLE *giving the* **loss of head J in metres**

as a function of the diameter of the pipe and the mean velocity :

(1) For new pipes (k = 0·1 mm) and (2) for existing pipes (k = 2 mm) (*the temperature of the water being at* 0°C.)

Mean velocity in metres/sec.	PIPE DIAMETER : 0·350 m. Pipe section : 0·0962115 m²			PIPE DIAMETER : 0·400 m. Pipe section : 0·125664 m²		
	Head per metre of pipe length		Flow in litres/sec.	Head per metre of pipe length		Flow in litres/sec.
	New pipes	Existing pipes		New pipes	Existing pipes	
0·01			0·0621			1·2566
0·05	0·000011	0·000014	4·8106	0·000010	0·000012	6·2832
0·10	0·000039	0·000052	9·6211	0·000033	0·000044	12·5664
0·15	0·000081	0·000112	14·4317	0·000068	0·000094	18·8496
0·20	0·000135	0·000195	19·2423	0·000115	0·000164	25·1328
0·25	0·000203	0·000298	24·0529	0·000172	0·000253	31·4160
0·30	0·000282	0·000425	28·8634	0·000239	0·000360	37·6992
0·35	0·000374	0·000574	33·6740	0·000317	0·000485	43·9824
0·40	0·000477	0·000747	38·4846	0·000406	0·000631	50·2656
0·45	0·000594	0·000941	43·2952	0·000506	0·000795	56·5488
0·50	0·000721	0·001157	48·1057	0·000615	0·000978	62·8320
0·55	0·000860	0·001396	52·9163	0·000732	0·001180	69·1152
0·60	0·001009	0·001657	57·7269	0·000858	0·001400	75·3984
0·65	0·001172	0·001942	62·5375	0·000996	0·001640	81·6816
0·70	0·001348	0·002252	67·3480	0·001146	0·001899	87·9648
0·75	0·001533	0·002584	72·1586	0·001305	0·002177	94·2480
0·80	0·001730	0·002940	76·9692	0·001472	0·002473	100·5312
0·85	0·001936	0·003320	81·7798	0·001648	0·002790	106·8144
0·90	0·002153	0·003722	86·5903	0·001832	0·003128	113·0976
0·95	0·002383	0·004147	91·4009	0·002026	0·003485	119·3808
1·00	0·002626	0·004595	96·2115	0·002233	0·003861	125·6640
1·05	0·002878	0·005065	101·0221	0·002447	0·004257	131·9472
1·10	0·003142	0·005559	105·8326	0·002672	0·004672	138·2304
1·15	0·003417	0·006077	110·6432	0·002905	0·005106	144·5136
1·20	0·003701	0·006616	115·4538	0·003147	0·005560	150·7968
1·25	0·003998	0·007179	120·2644	0·003399	0·006033	157·0800
1·30	0·004304	0·007765	125·0749	0·003659	0·006525	163·3632
1·35	0·004623	0·008373	129·8855	0·003929	0·007037	169·6464
1·40	0·004952	0·009005	134·6961	0·004208	0·007567	175·9296
1·45	0·005291	0·009660	139·5067	0·004498	0·008117	182·2128
1·50	0·005642	0·010338	144·3172	0·004796	0·008687	188·4960
1·55	0·006004	0·011039	149·1278	0·005107	0·009276	194·7792
1·60	0·006375	0·011762	153·9384	0·005425	0·009884	201·0624
1·65	0·006760	0·012509	158·7490	0·005752	0·010512	207·3456
1·70	0·007155	0·013278	163·5595	0·006087	0·011158	213·6288
1·75	0·007560	0·014071	168·3701	0·006431	0·011825	219·9120
1·80	0·007979	0·014886	173·1807	0·006783	0·012509	226·1952
1·85	0·008403	0·015725	177·9913	0·007143	0·013214	232·4784
1·90	0·008842	0·016586	182·8018	0·007516	0·013938	238·7616
1·95	0·009286	0·017470	187·6124	0·007898	0·014181	245·0448
2·00	0·009745	0·018378	192·4230	0·008288	0·015444	251·3280
2·05	0·010214	0·019309	197·2336	0·008686	0·016226	257·6112
2·10	0·010693	0·020262	202·0441	0·009092	0·017027	263·8944
2·15	0·011188	0·021239	206·8547	0·009513	0·017848	269·1776
2·20	0·011693	0·022237	211·6653	0·009942	0·018687	276·4608
2·25	0·012209	0·023261	216·4759	0·010380	0·019547	282·7440
2·30	0·012734	0·024305	221·2864	0·010826	0·020425	289·0272
2·35	0·013270	0·025373	226·0970	0·011280	0·021322	295·3104
2·40	0·013816	0·026465	230·9076	0·011744	0·022240	301·5936
2·45	0·014371	0·027579	235·7182	0·012215	0·023176	307·8768
2·50	0·014945	0·028716	240·5287	0·012695	0·024131	314·1600
3·00	0·021167	0·041351	288·6345	0·017971	0·034749	376·992
3·50	0·028543	0·056283	336·7403	0·024273	0·047297	439·824
4·00	0·036908	0·073513	384·8460	0·031296	0·061276	502·656

TABLE *giving the* **loss of head J in metres**

as a function of the diameter of the pipe and the mean velocity :

(1) For new pipes (k = 0·1 mm) and (2) for existing pipes (k = 2 mm) (*the temperature of the water being at* 0°C.)

Mean velocity in metres/sec.	PIPE DIAMETER : 0·450 m. Pipe section : 0·1590435 m²			PIPE DIAMETER : 0·500 m. Pipe section : 0·19635 m²		
	Head per metre of pipe length		Flow in litres/sec.	Head per metre of pipe length		Flow in litres/sec.
	New pipes	Existing pipes		New pipes	Existing pipes	
0·01			1·5904			1·9635
0·05	0·000008	0·000010	7·9522	0·000007	0·000009	5·8175
0·10	0·000029	0·000037	15·9043	0·000025	0·000033	19·6350
0·15	0·000059	0·000081	23·8565	0·000052	0·000070	29·4525
0·20	0·000099	0·000141	31·8087	0·000088	0·000123	39·2700
0·25	0·000149	0·000217	39·7609	0·000131	0·000189	49·0875
0·30	0·000207	0·000309	47·7130	0·000182	0·000270	58·9056
0·35	0·000275	0·000418	55·6652	0·000242	0·000365	68·7225
0·40	0·000352	0·000543	63·6174	0·000310	0·000474	78·5400
0·45	0·000438	0·000684	71·5696	0·000386	0·000597	88·3575
0·50	0·000533	0·000841	79·5217	0·000469	0·000735	98·1750
0·55	0·000636	0·001016	87·4739	0·000560	0·000887	107·9925
0·60	0·000746	0·001205	95·4261	0·000658	0·001053	117·8100
0·65	0·000865	0·001412	103·3783	0·000763	0·001233	127·6275
0·70	0·000994	0·001634	111·3304	0·000875	0·001427	137·4450
0·75	0·001131	0·001872	119·2826	0·000995	0·001635	147·2625
0·80	0·001276	0·002127	127·2348	0·001123	0·001856	157·0800
0·85	0·001429	0·002399	135·1870	0·001258	0·002093	166·8975
0·90	0·001589	0·002688	143·1391	0·001400	0·002343	176·7150
0·95	0·001757	0·002991	151·0913	0·001548	0·002606	186·5325
1·00	0·001936	0·003313	159·0435	0·001704	0·002885	196·3500
1·05	0·002122	0·003652	166·9957	0·001869	0·003180	206·1675
1·10	0·002316	0·004008	174·9478	0·002040	0·003491	215·9850
1·15	0·002520	0·004382	182·9000	0·002219	0·003815	225·8025
1·20	0·002730	0·004771	190·8522	0·002405	0·004154	235·6200
1·25	0·002948	0·005177	198·8044	0·002596	0·004508	245·4375
1·30	0·003174	0·005599	206·7565	0·002794	0·004876	255·2550
1·35	0·003408	0·006038	214·7087	0·003000	0·005258	265·0725
1·40	0·003650	0·006494	222·6609	0·003213	0·005654	274·8900
1·45	0·003901	0·006965	230·6131	0·003436	0·006065	284·7075
1·50	0·004162	0·007454	238·5652	0·003665	0·006491	294·5250
1·55	0·004430	0·007960	246·5174	0·003902	0·006931	304·3425
1·60	0·004706	0·008481	254·4696	0·004144	0·007385	314·1600
1·65	0·004990	0·009020	262·4218	0·004393	0·007854	323·9775
1·70	0·005280	0·009574	270·3739	0·004649	0·008337	333·7950
1·75	0·005578	0·010147	278·3261	0·004911	0·008835	343·6125
1·80	0·005883	0·010734	286·2783	0·005179	0·009347	353·4300
1·85	0·006194	0·011338	294·2305	0·005456	0·009873	363·2475
1·90	0·006518	0·011960	302·1826	0·005741	0·010414	373·0650
1·95	0·006848	0·012598	310·1348	0·006031	0·010970	382·8825
2·00	0·007186	0·013252	318·0870	0·006328	0·011540	392·7000
2·05	0·007530	0·013923	326·0392	0·006632	0·012124	402·5175
2·10	0·007887	0·014611	333·9913	0·006946	0·012723	412·3350
2·15	0·008252	0·015315	341·9435	0·007266	0·013336	422·1525
2·20	0·008623	0·016035	349·8957	0·007593	0·013963	431·9700
2·25	0·009003	0·016773	357·8479	0·007927	0·014605	441·7875
2·30	0·009389	0·017526	365·8000	0·008267	0·015261	451·6050
2·35	0·009783	0·018296	373·7522	0·008613	0·015932	461·4225
2·40	0·010184	0·019083	381·5044	0·008966	0·016517	471·2400
2·45	0·010593	0·019887	389·6566	0·009315	0·017317	481·0575
2·50	0·011008	0·020706	397·6087	0·009697	0·018030	490·8750
3·00	0·015607	0·029817	477·1305	0·013762	0·025964	589·05
3·50	0·021035	0·040585	556·6523	0·018519	0·035340	687·225
4·00	0·027034	0·053009	636·174	0·023976	0·046158	785·4

TABLE *giving the* **loss of head J in metres**

as a function of the diameter of the pipe and the mean velocity :

(1) For new pipes (k = 0·1 mm) and (2) for existing pipes (k = 2 mm) (*the temperature of the water being at 0°C.*)

Mean velocity in metres/sec.	PIPE DIAMETER : 0·600 m. Pipe section : 0·282744 m²			PIPE DIAMETER : 0·700 m. Pipe section : 0·384646 m²		
	Head per metre of pipe length		Flow in litres/sec.	Head per metre of pipe length		Flow in litres/sec.
	New pipes	Existing pipes		New pipes	Existing pipes	
0·01			2·8274			3·8484
0·05	0·000006	0·000007	14·1372	0·000005	0·000006	19·2423
0·10	0·000020	0·000026	28·2744	0·000017	0·000022	38·4846
0·15	0·000041	0·000056	42·4116	0·000034	0·000047	57·7269
0·20	0·000068	0·000095	56·5488	0·000057	0·000080	76·9692
0·25	0·000105	0·000149	70·6860	0·000087	0·000123	96·2115
0·30	0·000146	0·000212	84·8232	0·000121	0·000175	115·4538
0·35	0·000193	0·000287	98·9604	0·000160	0·000236	134·6961
0·40	0·000247	0·000372	113·0976	0·000205	0·000308	153·9384
0·45	0·000307	0·000469	127·2348	0·000255	0·000387	173·1807
0·50	0·000372	0·000577	141·3720	0·000309	0·000473	192·4230
0·55	0·000443	0·000697	155·5092	0·000368	0·000571	211·6653
0·60	0·000521	0·000827	169·6464	0·000433	0·000679	230·9076
0·65	0·000605	0·000969	183·7836	0·000502	0·000795	250·1499
0·70	0·000695	0·001122	197·9208	0·000576	0·000921	269·3922
0·75	0·000790	0·001287	212·0580	0·000655	0·001057	288·6345
0·80	0·000890	0·001463	226·1952	0·000738	0·001202	307·8768
0·85	0·000996	0·001651	240·3324	0·000826	0·001358	327·1191
0·90	0·001107	0·001849	254·4696	0·000917	0·001521	346·3614
0·95	0·001221	0·002059	268·6068	0·001015	0·001681	365·6037
1·00	0·001341	0·002279	282·7440	0·001117	0·001880	384·8460
1·05	0·001472	0·002513	296·8812	0·001224	0·002068	404·0883
1·10	0·001609	0·002758	311·0184	0·001338	0·002272	423·3306
1·15	0·001750	0·003014	325·1556	0·001454	0·002482	442·5729
1·20	0·001897	0·003282	339·2928	0·001562	0·002701	461·8152
1·25	0·002049	0·003561	353·4300	0·001688	0·002934	481·0575
1·30	0·002208	0·003852	367·5672	0·001817	0·003175	500·2998
1·35	0·002372	0·004154	381·7044	0·001946	0·003420	519·5421
1·40	0·002541	0·004467	395·8416	0·002084	0·003680	538·7844
1·45	0·002715	0·004792	409·9788	0·002225	0·003950	558·0267
1·50	0·002896	0·005128	424·1160	0·002376	0·004223	577·2690
1·55	0·003082	0·005476	438·2523	0·002528	0·004512	596·5113
1·60	0·003273	0·005835	452·3904	0·002681	0·004884	615·7536
1·65	0·003469	0·006205	466·5276	0·002843	0·005115	634·9959
1·70	0·003673	0·006587	480·6648	0·003012	0·005437	654·2382
1·75	0·003879	0·006980	494·8020	0·003181	0·005750	673·4805
1·80	0·004090	0·007384	508·9392	0·003356	0·006079	692·7228
1·85	0·004309	0·007800	523·0764	0·003530	0·006424	711·9651
1·90	0·004533	0·008228	537·2136	0·003714	0·006775	731·2074
1·95	0·004761	0·008666	551·3508	0·003901	0·007146	750·4497
2·00	0·004995	0·009117	565·4880	0·004088	0·007508	769·6920
2·05	0·005234	0·009578	579·6252	0·004286	0·007895	788·9343
2·10	0·005477	0·010051	593·7624	0·004484	0·008277	808·1766
2·15	0·005729	0·010536	607·8996	0·004686	0·008673	827·4189
2·20	0·005986	0·011031	622·0368	0·004889	0·009089	846·6612
2·25	0·006249	0·011539	636·1740	0·005103	0·009502	865·9035
2·30	0·006516	0·012057	650·3122	0·005322	0·009944	885·1458
2·35	0·006788	0·012587	664·4484	0·005547	0·010451	904·3881
2·40	0·007066	0·013128	678·5856	0·005773	0·010806	923·6304
2·45	0·007353	0·013681	692·7228	0·006010	0·011268	942·8727
2·50	0·007645	0·014245	706·8600	0·006248	0·011733	962·1150
3·00	0·010841	0·020513	848·232	0·008867	0·016901	1,154·5380
3·50	0·014610	0·027920	989·604	0·011925	0·022997	1,346·9610
4·00	0·018893	0·036476	1,130·967	0·015436	0·030410	1,539·3840

TABLE *giving the* **loss of head J in metres**

as a function of the diameter of the pipe and the mean velocity:

(1) For new pipes (k = 0·1 mm) and (2) for existing pipes (k = 2 mm) (*the temperature of the water being at* 0°C.)

Mean velocity in metres/sec.	PIPE DIAMETER : 0·800 m. Pipe section : 0·502656 m²			PIPE DIAMETER : 0·900 m. Pipe section : 0·636174 m²		
	Head per metre of pipe length		Flow in litres/sec.	Head per metre of pipe length		Flow in litres/sec.
	New pipes	Existing pipes		New pipes	Existing pipes	
0·01			5·0205			6·3617
0·05	0·000004	0·000005	25·1328	0·000004	0·000005	31·8087
0·10	0·000014	0·000018	50·2656	0·000012	0·000015	63·6174
0·15	0·000029	0·000039	75·3984	0·000025	0·000034	95·4261
0·20	0·000049	0·000067	100·5312	0·000043	0·000058	127·2348
0·25	0·000074	0·000103	125·6640	0·000064	0·000087	159·0435
0·30	0·000103	0·000147	150·7968	0·000089	0·000124	190·8522
0·35	0·000137	0·000198	175·9296	0·000118	0·000167	222·6609
0·40	0·000174	0·000258	201·0624	0·000150	0·000218	254·4696
0·45	0·000216	0·000324	251·1952	0·000186	0·000274	286·2783
0·50	0·000262	0·000398	251·3280	0·000225	0·000336	318·0870
0·55	0·000312	0·000481	275·4608	0·000268	0·000406	349·8957
0·60	0·000367	0·000572	301·5936	0·000316	0·000483	381·7044
0·65	0·000425	0·000670	326·7264	0·000367	0·000565	413·5131
0·70	0·000489	0·000776	351·8592	0·000421	0·000654	445·3218
0·75	0·000557	0·000890	376·9920	0·000479	0·000749	477·1305
0·80	0·000628	0·001012	402·1248	0·000540	0·000852	508·9392
0·85	0·000703	0·001142	427·2576	0·000605	0·000961	540·7479
0·90	0·000781	0·001279	452·3904	0·000671	0·001077	572·5566
0·95	0·000864	0·001425	477·5232	0·000743	0·001199	604·3653
1·00	0·000952	0·001579	502·6560	0·000817	0·001327	636·1740
1·05	0·001044	0·001741	527·7888	0·000896	0·001461	667·9827
1·10	0·001139	0·001910	552·9216	0·000980	0·001606	699·7914
1·15	0·001239	0·002088	578·0544	0·001065	0·001752	731·6001
1·20	0·001341	0·002274	603·1872	0·001144	0·001910	763·4088
1·25	0·001448	0·002467	628·3200	0·001237	0·002073	795·2175
1·30	0·001559	0·002668	653·4528	0·001332	0·002241	827·0262
1·35	0·001673	0·002877	678·5856	0·001428	0·002420	858·8349
1·40	0·001791	0·003095	703·7184	0·001529	0·002604	890·6436
1·45	0·001914	0·003319	728·8512	0·001632	0·002787	922·4523
1·50	0·002041	0·003552	753·9840	0·001741	0·002983	954·2610
1·55	0·002174	0·003793	779·1168	0·001857	0·003186	986·0697
1·60	0·002309	0·004042	804·2496	0·001968	0·003398	1,017·8784
1·65	0·002449	0·004298	829·3824	0·002086	0·003610	1,049·6871
1·70	0·002593	0·004563	854·5152	0·002208	0·003837	1,081·4958
1·75	0·002740	0·004835	879·6480	0·002337	0·004061	1,113·3045
1·80	0·002890	0·005115	904·7808	0·002461	0·004299	1,145·1132
1·85	0·003044	0·005403	929·9136	0·002594	0·004538	1,176·9219
1·90	0·003202	0·005699	955·0464	0·002726	0·004792	1,208·7306
1·95	0·003363	0·006003	980·1792	0·002862	0·005044	1,240·5393
2·00	0·003530	0·006315	1,005·3120	0·003001	0·005307	1,272·3480
2·05	0·003700	0·006635	1,030·4448	0·003144	0·005578	1,304·1567
2·10	0·003875	0·006963	1,055·5776	0·003296	0·005850	1,335·9654
2·15	0·004052	0·007298	1,080·7104	0·003445	0·006136	1,367·7741
2·20	0·004234	0·007641	1,105·8432	0·003598	0·006242	1,399·5828
2·25	0·004419	0·007993	1,130·9760	0·003757	0·006712	1,421·3915
2·30	0·004611	0·008352	1,156·1088	0·003915	0·007025	1,463·2002
2·35	0·004806	0·008719	1,181·2416	0·004074	0·007319	1,495·0089
2·40	0·005006	0·009094	1,206·3744	0·004240	0·007641	1,526·8176
2·45	0·005209	0·009477	1,231·5072	0·004419	0·007960	1,558·6263
2·50	0·005416	0·009867	1,256·6400	0·004590	0·008288	1,590·4350
3·00	0·007695	0·014209	1,507·968	0·006518	0·011923	1,908·5220
3·50	0·010357	0·019340	1,759·296	0·008782	0·016246	2,226·6090
4·00	0·013405	0·025261	2,010·624	0·011367	0·021204	2,544·6960

TABLE *giving the* **loss of head J in metres**

as a function of the diameter of the pipe and the mean velocity :

(1) For new pipes (k = 0·1 mm) and (2) for existing pipes (k = 2 mm) (*the temperature of the water being at 0°C.*)

Mean velocity in metres/sec.	PIPE DIAMETER : 1·000 m. Pipe section : 0·785398 m²			PIPE DIAMETER : 1·250 m. Pipe section : 1·22719 m²		
	Head per metre of pipe length		Flow in litres/sec.	Head per metre of pipe length		Flow in litres/sec.
	New pipes	Existing pipes		New pipes	Existing pipes	
0·01			7·8539			12·2715
0·05	0·000003	0·000004	39·2694	0·000002	0·000003	61·3575
0·10	0·000010	0·000013	78·5389	0·000008	0·000010	122·7150
0·15	0·000022	0·000029	117·8083	0·000017	0·000022	184·0725
0·20	0·000037	0·000051	157·0778	0·000028	0·000038	245·4300
0·25	0·000056	0·000078	196·3472	0·000043	0·000059	306·7875
0·30	0·000078	0·000111	235·6167	0·000060	0·000084	368·1450
0·35	0·000103	0·000150	274·8861	0·000079	0·000113	429·5025
0·40	0·000132	0·000195	314·1556	0·000101	0·000147	490·8600
0·45	0·000164	0·000246	353·4250	0·000125	0·000185	552·2175
0·50	0·000200	0·000302	392·6945	0·000152	0·000227	613·5755
0·55	0·000239	0·000365	431·9639	0·000182	0·000274	674·9325
0·60	0·000280	0·000433	471·2334	0·000213	0·000326	736·2900
0·65	0·000325	0·000507	510·5028	0·000248	0·000382	797·6475
0·70	0·000372	0·000587	549·7723	0·000285	0·000443	859·0050
0·75	0·000423	0·000673	589·0417	0·000324	0·000509	920·3625
0·80	0·000478	0·000765	628·3112	0·000366	0·000579	981·7200
0·85	0·000536	0·000863	667·5806	0·000409	0·000653	1,043·0775
0·90	0·000596	0·000966	706·8501	0·000456	0·000732	1,104·4350
0·95	0·000660	0·001076	746·1195	0·000505	0·000815	1,165·7925
1·00	0·000726	0·001193	785·3980	0·000556	0·000903	1,227·1500
1·05	0·000795	0·001315	824·6584	0·000609	0·000995	1,288·5075
1·10	0·000868	0·001443	863·9279	0·000665	0·001092	1,349·8650
1·15	0·000944	0·001577	903·1973	0·000723	0·001193	1,411·2215
1·20	0·001024	0·001718	942·4668	0·000783	0·001299	1,472·5800
1·25	0·001106	0·001864	971·7362	0·000846	0·001409	1,533·9375
1·30	0·001191	0·002016	1,021·0057	0·000911	0·001524	1,595·2950
1·35	0·001280	0·002174	1,050·2751	0·000979	0·001644	1,656·6525
1·40	0·001372	0·002338	1,099·5446	0·001049	0·001767	1,718·0100
1·45	0·001486	0·002508	1,138·8140	0·001121	0·001895	1,779·3675
1·50	0·001563	0·002684	1,178·0835	0·001196	0·002028	1,840·7250
1·55	0·001663	0·002866	1,217·3529	0·001274	0·002166	1,902·0825
1·60	0·001767	0·003053	1,256·6224	0·001353	0·002307	1,963·4400
1·65	0·001873	0·003247	1,295·8918	0·001434	0·002454	2,024·7975
1·70	0·001983	0·003447	1,335·1613	0·001518	0·002604	2,086·1550
1·75	0·002096	0·003653	1,374·4307	0·001603	0·002760	2,147·5125
1·80	0·002213	0·003864	1,413·7002	0·001691	0·002920	2,208·8700
1·85	0·002332	0·004082	1,452·9696	0·001782	0·003084	2,270·2275
1·90	0·002455	0·004306	1,492·2381	0·001875	0·003253	2,331·5850
1·95	0·002580	0·004535	1,531·5075	0·001971	0·003427	2,392·9425
2·00	0·002708	0·004771	1,570·7780	0·002068	0·003605	2,454·3000
2·05	0·002838	0·005012	1,610·0474	0·002168	0·003787	2,515·6575
2·10	0·002972	0·005260	1,649·3169	0·002269	0·003974	2,577·0150
2·15	0·003108	0·005513	1,688·5863	0·002375	0·004166	2,638·3725
2·20	0·003246	0·005773	1,727·8558	0·002483	0·004361	2,699·7300
2·25	0·003388	0·006038	1,767·1252	0·002593	0·004562	2,761·0875
2·30	0·003532	0·006309	1,806·3947	0·002705	0·004767	2,822·4450
2·35	0·003679	0·006587	1,845·6641	0·002819	0·004976	2,883·8025
2·40	0·003831	0·006870	1,884·9336	0·002936	0·005191	2,945·1600
2·45	0·003985	0·007159	1,924·2030	0·003055	0·005409	3,006·5175
2·50	0·004141	0·007454	1,963·4725	0·003178	0·005632	3,067·8750
3·00	0·005985	0·010734	2,356·194	0·004510	0·008110	3,681·57
3·50	0·007930	0·014610	2,748·893	0·006084	0·011039	4,295·165
4·00	0·010259	0·019083	3,141·592	0·007875	0·014418	4,908·76

TABLE *giving the* loss of head J in metres

as a function of the diameter of the pipe and the mean velocity :

(1) For new pipes (k = 0·1 mm) and (2) for existing pipes (k = 2 mm) (*the temperature of the water being at 0°C.*)

Mean velocity in metres/sec.	PIPE DIAMETER : 1·500 m. Pipe section : 1·76715 m²			PIPE DIAMETER : 1·750 m. Pipe section : 2·405281 m²		
	Head per metre of pipe length		Flow in litres/sec.	Head per metre of pipe length		Flow in litres/sec.
	New pipes	Existing pipes		New pipes	Existing pipes	
0·01			17·671			24·053
0·05	0·000002	0·000002	88·355	0·000002	0·000002	120·264
0·10	0·000006	0·000008	176·710	0·000005	0·000007	240·528
0·15	0·000013	0·000018	265·065	0·000011	0·000014	360·792
0·20	0·000023	0·000030	353·420	0·000019	0·000025	481·056
0·25	0·000034	0·000047	441·775	0·000028	0·000038	601·320
0·30	0·000048	0·000067	530·130	0·000040	0·000055	721·584
0·35	0·000063	0·000090	618·485	0·000053	0·000074	841·848
0·40	0·000081	0·000117	706·840	0·000068	0·000096	962·112
0·45	0·000101	0·000148	795·195	0·000084	0·000121	1,082·376
0·50	0·000122	0·000182	883·550	0·000102	0·000149	1,202·641
0·55	0·000146	0·000219	971·905	0·000122	0·000181	1,322·905
0·60	0·000172	0·000260	1,060·260	0·000144	0·000215	1,443·169
0·65	0·000200	0·000305	1,148·615	0·000167	0·000251	1,563·433
0·70	0·000230	0·000353	1,236·970	0·000191	0·000291	1,683·697
0·75	0·000261	0·000405	1,325·325	0·000217	0·000334	1,803·961
0·80	0·000295	0·000461	1,413·680	0·000246	0·000380	1,924·225
0·85	0·000330	0·000521	1,502·035	0·000276	0·000429	2,044·489
0·90	0·000368	0·000584	1,590·390	0·000306	0·000481	2,164·753
0·95	0·000406	0·000651	1,678·745	0·000339	0·000536	2,285·017
1·00	0·000447	0·000721	1,767·100	0·000373	0·000594	2,405·281
1·05	0·000490	0·000795	1,855·455	0·000409	0·000654	2,525·545
1·10	0·000535	0·000872	1,943·810	0·000447	0·000718	2,645·809
1·15	0·000582	0·000953	2,032·165	0·000486	0·000785	2,766·073
1·20	0·000631	0·001038	2,120·520	0·000527	0·000854	2,886·337
1·25	0·000682	0·001126	2,208·875	0·000570	0·000927	3,006·601
1·30	0·000735	0·001218	2,297·230	0·000614	0·001003	3,126·865
1·35	0·000789	0·001314	2,385·585	0·000659	0·001081	3,247·129
1·40	0·000845	0·001412	2,473·940	0·000706	0·001163	3,367·393
1·45	0·000903	0·001515	2,562·295	0·000754	0·001247	3,487·657
1·50	0·000963	0·001621	2,650·650	0·000805	0·001335	3,607·922
1·55	0·001025	0·001731	2,739·005	0·000857	0·001425	3,728·186
1·60	0·001089	0·001844	2,827·360	0·000911	0·001519	3,848·500
1·65	0·001155	0·001961	2,915·715	0·000966	0·001615	3,968·714
1·70	0·001223	0·002082	3,004·070	0·001023	0·001715	4,088·978
1·75	0·001292	0·002206	3,092·425	0·001080	0·001817	4,209·242
1·80	0·001363	0·002334	3,180·780	0·001140	0·001922	4,329·506
1·85	0·001436	0·002466	3,269·135	0·001201	0·002030	4,449·770
1·90	0·001512	0·002601	3,357·490	0·001264	0·002142	4,570·034
1·95	0·001589	0·002739	3,445·845	0·001329	0·002256	4,690·298
2·00	0·001669	0·002882	3,534·200	0·001396	0·002373	4,810·562
2·05	0·001749	0·003027	3,622·555	0·001463	0·002493	4,930·826
2·10	0·001833	0·003177	3,710·910	0·001531	0·002617	5,051·090
2·15	0·001916	0·003330	3,799·265	0·001602	0·002742	5,171·354
2·20	0·002003	0·003487	3,887·620	0·001675	0·002872	5,291·618
2·25	0·002092	0·003647	3,975·975	0·001749	0·003004	5,411·882
2·30	0·002182	0·003811	4,064·330	0·001824	0·003138	5,532·146
2·35	0·002274	0·003978	4,152·685	0·001901	0·003277	5,652·410
2·40	0·002378	0·004149	4,241·040	0·001980	0·003417	5,772·674
2·45	0·002462	0·004324	4,329·395	0·002058	0·003561	5,892·938
2·50	0·002557	0·004502	4,417·750	0·002139	0·003708	6,013·203
3·00	0·003633	0·006483	5,301·45	0·003035	0·005340	7,215·843
3·50	0·004891	0·008825	6,185·025	0·004092	0·007268	8,418·484
4·00	0·006350	0·011526	7,068·400	0·005303	0·009493	9,621·124

TABLE *giving the* loss of head J in metres

as a function of the diameter of the pipe and the mean velocity :

(1) For new pipes (k = 0·1 mm) and (2) for existing pipes (k = 2 mm) (*the temperature of the water being at* 0°C.)

Mean velocity in metres/sec.	PIPE DIAMETER : 2·000 m. Pipe section : 3·141592 m²			PIPE DIAMETER : 2·500 m. Pipe section : 4·908738 m²		
	Head per metre of pipe length		Flow in litres/sec.	Head per metre of pipe length		Flow in litres/sec.
	New pipes	Existing pipes		New pipes	Existing pipes	
0·01			31·416			49·087
0·05	0·000001	0·000002	157·080	0·000001	0·000001	245·437
0·10	0·000005	0·000006	314·159	0·000003	0·000004	490·874
0·15	0·000009	0·000012	471·239	0·000007	0·000009	736·311
0·20	0·000016	0·000021	628·318	0·000012	0·000016	981·748
0·25	0·000024	0·000032	785·398	0·000018	0·000025	1,227·185
0·30	0·000034	0·000046	942·478	0·000026	0·000035	1,472·621
0·35	0·000045	0·000062	1,099·557	0·000035	0·000048	1,718·058
0·40	0·000058	0·000081	1,256·637	0·000044	0·000062	1,963·495
0·45	0·000072	0·000102	1,413·716	0·000055	0·000078	1,208·932
0·50	0·000087	0·000126	1,570·796	0·000067	0·000096	2,454·369
0·55	0·000104	0·000152	1,727·876	0·000080	0·000116	2,699·806
0·60	0·000122	0·000181	1,884·955	0·000094	0·000138	2,945·243
0·65	0·000142	0·000212	2,042·035	0·000109	0·000161	3,190·680
0·70	0·000163	0·000246	2,199·114	0·000125	0·000187	3,436·117
0·75	0·000186	0·000282	2,356·194	0·000143	0·000214	3,681·554
0·80	0·000210	0·000321	2,513·274	0·000161	0·000244	3,926·990
0·85	0·000235	0·000363	2,670·353	0·000181	0·000275	4,172·427
0·90	0·000261	0·000406	2,827·433	0·000202	0·000308	4,417·864
0·95	0·000289	0·000452	2,984·512	0·000223	0·000343	4,663·301
1·00	0·000319	0·000501	3,141·592	0·000246	0·000380	4,908·738
1·05	0·000349	0·000552	3,298·672	0·000270	0·000419	5,154·175
1·10	0·000381	0·000605	3,455·751	0·000295	0·000459	5,399·612
1·15	0·000415	0·000662	3,612·831	0·000321	0·000502	5,645·049
1·20	0·000450	0·000720	3,769·910	0·000348	0·000546	5,890·486
1·25	0·000487	0·000782	3,926·990	0·000376	0·000593	6,135·923
1·30	0·000524	0·000845	4,084·070	0·000405	0·000641	6,381·359
1·35	0·000563	0·000912	4,241·149	0·000435	0·000691	6,626·796
1·40	0·000603	0·000981	4,398·229	0·000467	0·000743	6,872·233
1·45	0·000645	0·001052	4,555·308	0·000498	0·000797	7,117·670
1·50	0·000688	0·001126	4,712·388	0·000531	0·000853	7,363·107
1·55	0·000733	0·001202	4,869·468	0·000566	0·000911	7,608·544
1·60	0·000779	0·001281	5,026·547	0·000601	0·000971	7,853·981
1·65	0·000826	0·001362	5,183·627	0·000638	0·001032	8,099·418
1·70	0·000874	0·001446	5,340·706	0·000675	0·001096	8,344·855
1·75	0·000923	0·001532	5,497·786	0·000714	0·001161	8,590·292
1·80	0·000974	0·001621	5,654·866	0·000753	0·001229	8,835·728
1·85	0·001027	0·001712	5,811·945	0·000794	0·001298	9,081.165
1·90	0·001080	0·001806	5,969·025	0·000836	0·001369	9,326·602
1·95	0·001136	0·001902	6,126·104	0·000878	0·001442	9,572·039
2·00	0·001193	0·002001	6,283·184	0·000922	0·001517	9,817·476
2·05	0·001250	0·002102	6,440·264	0·000966	0·001594	10,062·913
2·10	0·001308	0·002206	6,597·343	0·001011	0·001672	10,308·350
2·15	0·001369	0·002313	6,754·423	0·001057	0·001753	10,553·787
2·20	0·001431	0·002421	6,911·502	0·001105	0·001835	10,799·224
2·25	0·001494	0·002533	7,068·582	0·001154	0·001920	11,044·661
2·30	0·001559	0·002647	7,225·662	0·001204	0·002006	11,290·097
2·35	0·001624	0·002763	7,382·741	0·001254	0·002094	11,535·534
2·40	0·001691	0·002882	7,539·821	0·001307	0·002184	11,780·971
2·45	0·001759	0·003003	7,696·900	0·001361	0·002276	12,026·408
2·50	0·001829	0·003127	7,853·980	0·001416	0·002370	12,271·845
3·00	0·002592	0·004503	9,424·776	0·002015	0·003413	14,726·214
3·50	0·003497	0·006128	10,995·572	0·002712	0·004645	17,180·583
4·00	0·004526	0·008004	12,566·368	0·003517	0·006068	19,634·952