Large Scale Field Physical Model Simulation of Roseires Dam-Break, Sudan

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***Abstract*-Physically based modeling approach has been widely developed in recent years for the simulation of dam failure process due to the lack of field data. This paper provides and describes a physically-based model depending on dimensional analysis and hydraulic simulation methods for estimating the maximum water level and the wave propagation time from breaching of field test dams. The field physical model has been constructed in Dabbah city to represent the collapse of the Roseires dam in Sudan. Five cases of a dam failure were studied to simulate water flood conditions by changing initial water height in the reservoir (0.8, 1.0, 1.2, 1.4 and 1.5 m respectively).The physical model working under five cases, case 5 had the greatest influence of the water wave movement in the canal downstream. The results showed the collapse of the dam and the sides of the canal due to the high water levels recorded 277.001, 277.084 and 277.161 m Above Mean Sea Level (AMSL) at section 13 in the canal. The wave vanishing time was 70 minutes from the beginning of the failure at a distance of 590 m downstream. The dam collapse leads to cover the sides of the canal completely, especially at the distance of 371 m.**

Keyword- Dam-Break; Physical Model Simulation; Roseires Dam.

I. INTRODUCTION

Dams are important infrastructures, providing flood control, water supply, irrigation, hydropower, navigation and recreation benefits. So, it is important to accurately predict the breach outflow hydrograph and its timing of evacuation efforts. Dam-break is the collapse of a dam due to the flood wave, piping, inefficient design and military attack; hence, it is useful to develop mathematical models to predict the effects of dam-break floods. Since field data for such cases are very difficult to obtain, experimental data to verify these mathematical models are required [1].

Cristofano [2] proposed the first physically based dam breach model using an equation that accounted for the shear strength of soil particles and the force of the flowing water. Fread and Smith [3] and Rajar [4] studied the physical model dam-break flow by using a physical model in a canal 95 m long and of a rectangular cross section. At first it was prismatic, the width being (0.4 m). Later various forms of expansions and contraction were built-in, so that the ratio of the width of two subsequent reaches of the canal varied from (α =0.5 up to 6) and Manning's roughness coefficient was (0.00965). The model of the dam was a vertical plate, which was lifted in approximate (0.1 sec) to simulate total and instantaneous collapse. Walton and Christenson [5] found the Manning roughness coefficient (n) for dam-break floods may be estimated to be (0.04-0.05) for a pasture land or cropland, (0.07) for a moderately wooded area, (0.10-0.15) for a heavily wooded area and recommended to use the higher value for effects caused by significant amounts of debris in the downstream valley.

Physical modeling approach has been widely developed in recent years for simulation of dam failure processes resulting from overtopping flow to help validate results and provide a higher level of confidence in extreme rain producing floods [6]. Fan et al., [7] presented a physically based simulation of the failure process of the Tangjiashan Quake Dam formed as a result of the ''May 12, 2008'' Wenchuan earthquake in China. The simulated flow hydrograph and breach progression process are in good agreement with the observed data. Unsteadiness and non-uniformity are found to be substantial characteristics of breach progression during the failure process of natural quake dams. The model significantly influences the flow peak discharge but has less influence on its occurrence time, also the velocity lag coefficient should be considered with bed-load transportation. Donald [8] found the Head-discharge equations which fitted to a set of physical models of dam breach, covering 378 different geometries. Joseph et al., [9] analyzed a simple, physically-based model of breach formation in natural and constructed earthen dams to elucidate the principal factors controlling the breach flood hydrograph. Theoretical predictions agree well with data from dam failures which could be estimated. The analysis provides a rapid, and in many cases, graphical ways to estimate plausible values of the peak flow at the breach. Kinori [10] found through experimental work reproduce that the observed flood should depart from Freudian scales and to operate the model with a discharge higher than that indicated by the scale relationship. The discharge scale for Freudian similarity can be calculated by many trials and errors that can be an indicator to the operating discharge scale.

Bogdan [11] studied the dynamic behavior of concrete dams by means of the physical model method. It is very useful to understand the failure mechanism of these structures to the action of strong earthquakes. Physical model method must be designed by a physical modeling process using the dynamic modeling theory. The result is a system of equations that permits the dimensioning of the physical model. Using physical models of large or medium dimensions as well as, its instrumentation creates great advantages, but this operation involves a large amount of financial, logistic resources and time. Zafer and Ali [12] obtained from the laboratory data model studies of an existing dam under, three different failure scenarios. Comparison of the measured and computed results indicates that both numerical models predict peak flood elevation with somewhat reasonable accuracy. Moreover, this is attributed to the high sensitivity of the numerical models to the bottom friction of the channel. Kjetil et al., [13] detailed the data on flow and formation processes of breaches through embankments/dams. Tayfur and Guney [14] investigated the flood propagation for a sudden partial collapse of a dam and the experimental results showed that the residential area is flooded in a matter of minutes, at depths reaching up to 2.5 meters. Morris, et al., [15] studied the embankment erosion where breach modeling had evaluated three physically based numerical models to be used to simulate embankment erosion. The three models were considered to be good candidates for further development and future integration into flood modeling software.

In this study a physical model was developed to simulate the collapse of Roseires dam on Nile River located in Dabbah city at a distance of 345 km north of Khartoum, Sudan. From this model, the impact of the vanishing line and time of vanishing are monitored for different operation conditions (five cases) of the model. The importance of this study may help to operate this dam especially at flood periods that may cause the collapse of Roseires dam which may affect the cities located downstream, as Ad Dawmah 15.652 km, Mangangan 21.294 km, Al Karori 29.12 km and Al Garef 33.02 km.

II. MATERIALS AND METHODS

A. Study Area Description

The field experimental work took place in northern Sudan in Dabbah district, about 345 km north of Khartoum at coordinates (1,983,607.8623),(275,085.7886) and (1,984,068.1485), (274,474.9925) in the King Valley site, with an estimated land area of 349,264 m^2 as shown in Fig. 1. Dabbah is a city on the river banks of the Nile, which is served by an Airport and has an estimated population of 52,000 capita. Its coordinates are 18°3'0" N and 30°57'0" E in DMS (degrees minutes seconds) or 18.05 and 30.95 (in decimal degrees). It's UTM (Universal Transverse Mercator) position is TE89 and Joint Operation Graphics reference is NE36-05.The nature of this region is considered a desert climate.

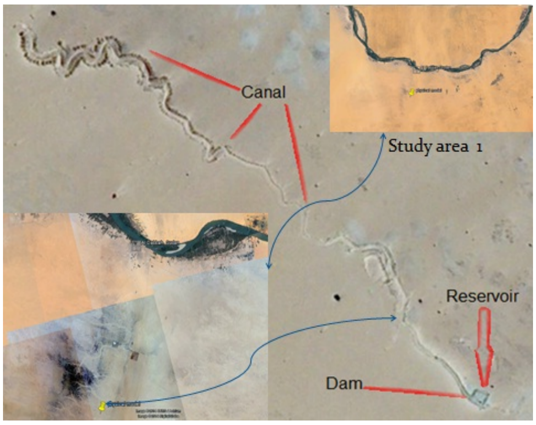

Fig. 1 Field experimental work site location and layout.

B. Description and Building a Physical Model

Models of hydraulic structures, such as dams, weirs and spillway, are often classified as physical models in which the length of the river modeled is short where the frictional forces may be neglected. This leads to operation requirements for Freudian similarity and the flow in the model is to be turbulent. Many attempts were performed to select the appropriate scale in the field work by using geometric, kinematic and dynamic hydraulic similarities to predict a physical model with the dimensions shown in Table 1.

TABLE 1 DIMENSIONS OF THE PHYSICAL MODEL.

Item	Length (m)	Width (m)	Height (m)
Reservoir	20	20	1.5
Dam	0.8	0.24	1.5
Canal	1000	Trapezoidal section	

The canal is of trapezoidal cross sections as shown in Fig. 2. The cross-section canal modeling specifications is the same as the natural sections of Nile River (Meandering) with bottom width 0.5 m, supreme 1.8 m; height 0.5 m and side slopes 1/1.3. Canal sections were created from natural soil in the area (clay); 34 sections constructed at different distances between each other as shown in Table 2 and Fig. 3. Approximately the total amount of cutting and filling in constructing the canal was about 7395 m^3 as shown in Fig. 4

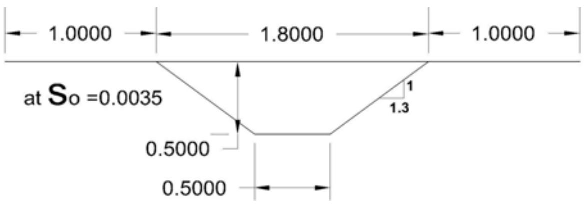

Fig. 2 Canal crosses section in the field experimental work.

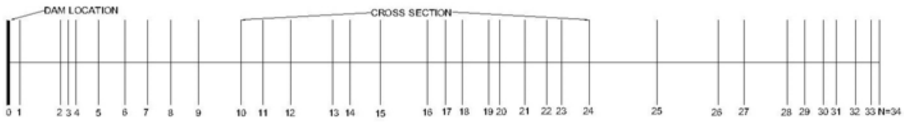

Fig. 3 Schematic of the canal's cross sections.

TABLE 2 CROSS SECTIONS DISTANCE ALONG THE CANAL IN THE EXPERIMENTAL WORK.

Section No.	Dam	1	2	3	4	5	6	7	8	9	10	11
Net Distance (m)	0	11	47	9	9	26	30	26	27	32	49	25
Section No.	12	13	14	15	16	17	18	19	20	21	22	23
Net Distance (m)	32	48	20	35	54	21	19	30	13	29	25	17
Section No.	24	25	26	27	28	29	30	31	32	33	34	T.L (m)
Net Distance (m)	32	78	70	30	50	20	21	15	22	18	10	1000

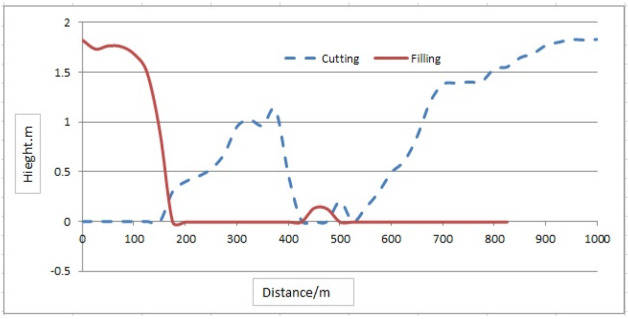

Fig. 4 Cutting and filling along the canal.

A well was dug at depth of 330 m with capacity of 450 m^3/hr to fill the reservoir with the required amount of water. The well is located at N Latitude 1982033.295, (17^o 5543' 70") and E Longitude 276659.295, (30^o 5235' 62") . The construction of the model and the digging processes of the dam and the canal as shown in Photo 1, was accomplished using the equipment and instruments shown in Table 3. The field test program instrumentation was by installing elevations at the 34 sections on the canal where the readings of the Global Positioning System (GPS) device were recorded by surveyors working group specializes in this area.

TABLE 3 EQUIPMENT AND INSTRUMENTS USED IN THE EXPERIMENTAL WORK.

Item	No	Item	No
Leica viva GPS	1	Bag loader	3
Level machine	1	Excavator	1
Digital camera	1	Bulldozer	1
Rig machine	1	Compacter	1
Compressor 40 bar	1	Bentonite bag	6
Water tanker	1	PVC Pipe 6inch in diameter	26
Grader	1	Loader	1

The location of the physical model was determined by choosing an area which has similar properties to the Roseires dam. Special calculations were made which included geometric, kinematic and dynamic similarities between the origin and the model to select the drawing scales from the normal size (prototype) to the experimental size (model). More than one model was made to test the appropriate drawing scale for the reservoir and canal. The most suitable scale was chosen to be (1/50), that depends on the flow of the Roseires dam 16000 m^3/s so, the amount of the flowing water from the model dam was 0.933 m^3/s with a flowing velocity of 0.686 m/s.

C. Dam Collapse Process and Data Measurement

The experimental facility and field test procedures are a complete set of data on a one-dimensional flood wave resulting from the dam-break (Roseires Dam). Different test conditions were performed by changing the depth of water in the reservoir model that simulates the flood conditions. The model dam collapse field experimental work began by filling the reservoir at different depths; through the constructed well using an air compressor under 40 bar pressure. The depth of water was measured by a ruler installed in the middle of the reservoir. The artificial failure process of the model dam was by opening the gate (steel plate dimensions 1.0 * 1.5 m) in the dam that leads to the flow of water strongly from the reservoir into the canal. Measurements of water level and distance at the center and on sides for each section in the canal, vanishing distance and travelling time were performed using a GPS instrument at each section along the canal. Five cases were performed using five different water depths in the reservoir: 0.8, 1.0, 1.2, 1.4, and 1.5 m respectively.

III. result and discussion

The constructed physical model is to represent the collapse of Roseires dam for any event of a flood. The experimental works were performed through five cases using different water depths in the reservoir representing the flood. Table 4 shows the experimental characteristics and operation conditions of the five cases including the required time to fill the reservoir and time to reach the final effect of the wave flow in the canal. The highest water levels of the attempts were recorded by the GPS with respect to mean sea level and for all cases appeared at section 13 which were 276.644, 276.754, 276.864, 276.974 and 277.084 m Above Mean Sea Level (AMSL) respectively as shown in Table 5.The worst case was recorded in case 5 as the maximum water levels recorded were 277.001, 277.084 and 277.161 m (AMSL) in left side, center, and right side of the canal, respectively. The wave arrival time recorded was 70 minutes from the beginning of the failure which leads to covering the sides of the canal completely, especially at the distance of 371 m (section 13). Table 5 shows the vanishing distances from the wave effect in the case 5 reached 590 m while it was 330 m in case 1. Case 5 is considered the most effective one which has more effects on both the center and the sides of the canal and the highest readings of the water flood. It also leads to the collapse of the canal sides completely at section No. 13.

TABLE 4 EXPERIMENTAL CHARACTERISTICS AND OPERATION CONDITIONS OF THE FIVE CASES.

Details	**Case 1**	**Case 2**	**Case 3**	**Case 4**	**Case 5**
Depth of water in the Reservoir (m)	0.8	1.0	1.2	1.4	1.5
Filling the reservoir					
Initial reading time	8:48	10:00	10:00	9:00	9:00
Final reading time	9:20	10:45	11:00	10:30	10:45
Filling time (min)	32	45	60	63	105
Flowing inside the canal					
Initial reading time	9:20	10:45	11:00	10:30	10:45
Final reading time	9:30	11:25	11:50	11:40	11:55
Time to reach the vanishing point (min)	10	40	50	70	70

TABLE 5 RESULTS OF THE EXPERIMENTAL WORK.

Recorded readings	**Case 1**	**Case 2**	**Case 3**	**Case 4**	**Case 5**
Left side of the canal					
Recoded max. water level (m) (AMSL)	276.862	276.826	276.871	276.916	277.001
Section no.	1	3	3	3	13
Distance downstream (m)	11	67	67	67	371
Center of the canal					
Recoded max. water level (m) (AMSL)	276.812	276.769	276. 784	276.974	277.084
Section no.	1	7	5	13	13
Distance downstream (m)	11	158	102	371	371
Right side of the canal					
Recoded max. water level (m) (AMSL)	276.855	276.771	276.901	276. 843	277.161
Section no.	2	13	13	4	13
Distance downstream (m)	58	371	371	76	371
Final effect of the flood wave					
Vanishing distance (m)	330	350	390	450	590

Figs. 5 to 9 show the recorded maximum water surface elevations, which were the readings by the GPS with respect to mean sea level at the center of the canal for all 34 sections for the five cases where no correlation could be obtained to represent the level readings with the section locations in the canal (as R^2 were low for all cases). A comparison between the water levels recorded along the canal for these cases is shown in Fig. 10.

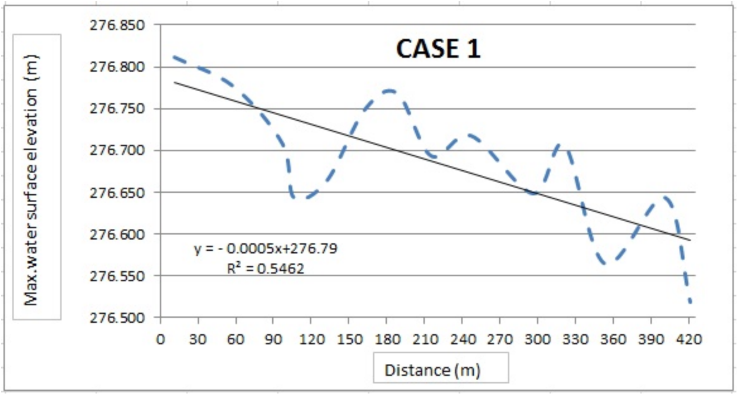

Fig. 5 Maximum water surface elevation along canal for case 1.

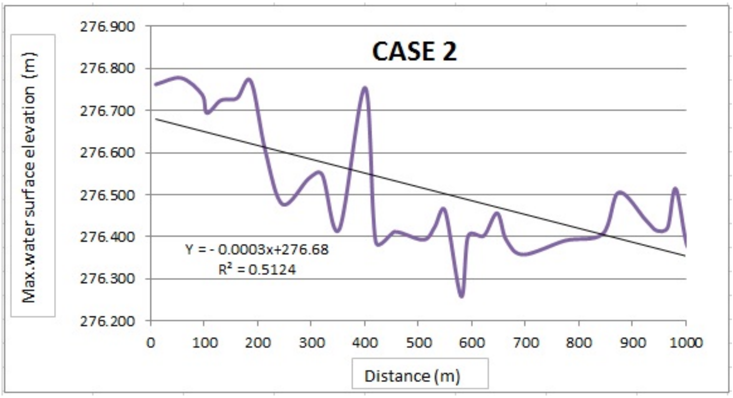

Fig. 6 Maximum water surface elevation along the canal for case 2.

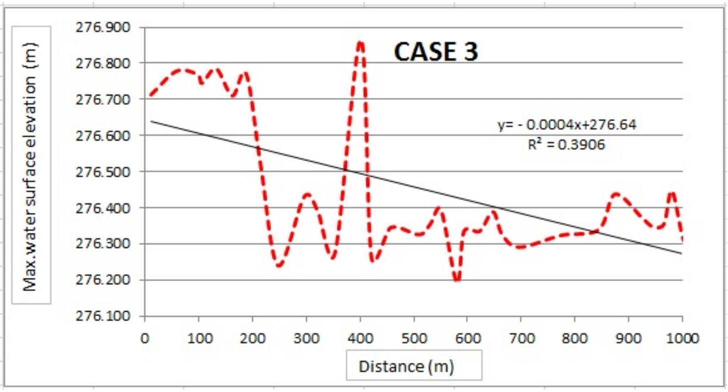

Fig. 7 Maximum water surface elevation along canal for case 3.

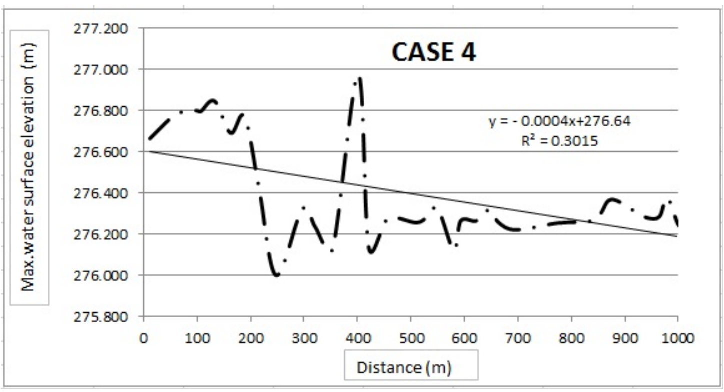

Fig. 8 Maximum water surface elevation along the canal for case 4.

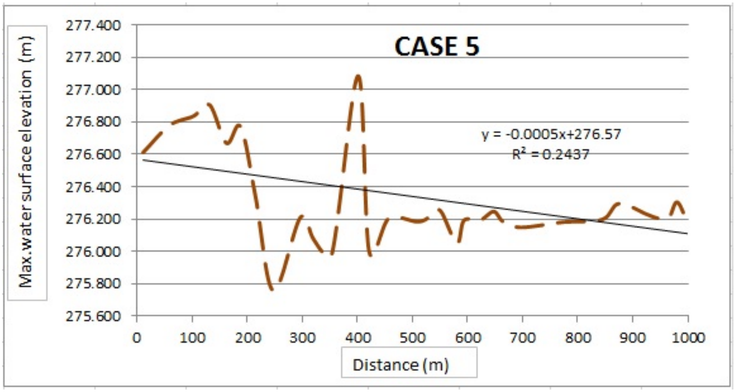

Fig. 9 Maximum water surface elevation along the canal for case 5.

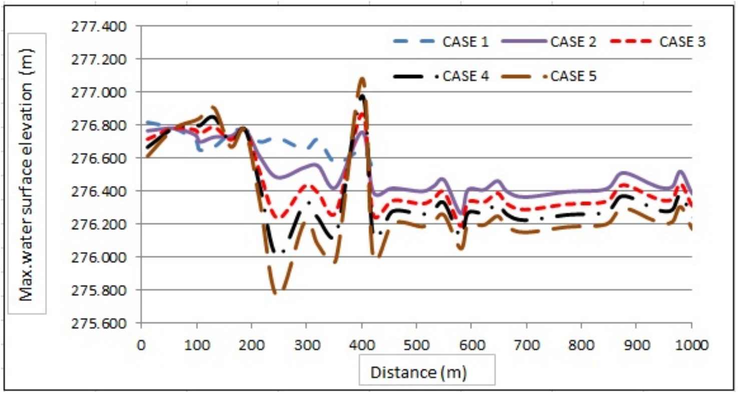

Fig.10 Maximum water surface elevation along canal for all cases.

Fig. 11 represents the water surface profile along the canal for case 5 after the failure of the model dam; it shows the water wave as it vanishes moving through the sections of the canal. Fig. 12 represents water surface cantor lines along and area surrounding the canal after the failure for case 5. The results showed the wave vanishing time was 70 minutes from the beginning of the failure at a distance of 590 m downstream. The model dam collapse leads to cover the sides of the canal completely, especially at the distance of 371 m (section 13).

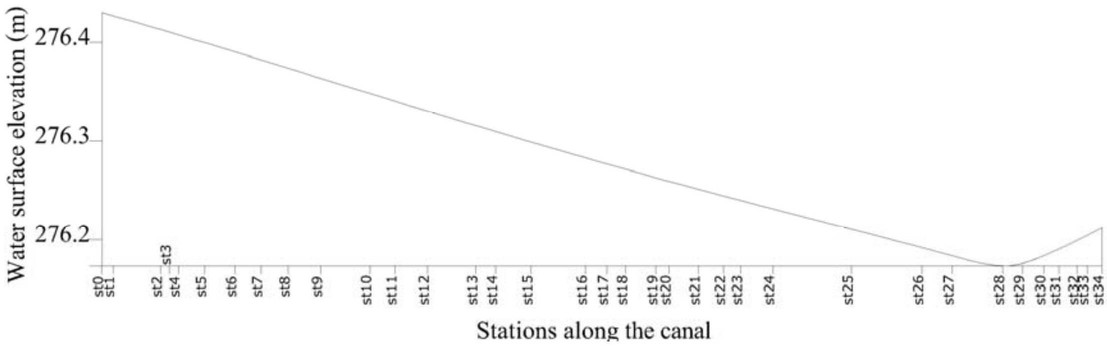

Fig. 11 Water surface profile along the canal sections for case 5.

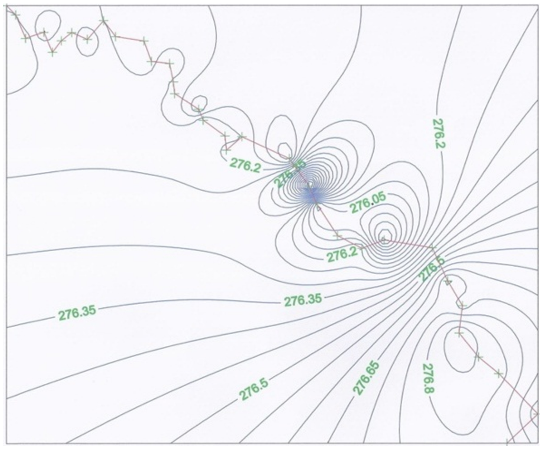

Fig. 12 Water surface cantor lines along and the area surrounding the canal for case 5.

While simulating the flood condition at Roseires dam (applying case 5) and taking into account the scale design (1/50), this model will describe the fact that the vanishing distance downstream may reach 30 km. For this case all the cities downstream may be out of the wave movement range caused from the flood. Many field measurements should be recorded from any flood events and fed to the physical model to monitor the wave movement and take the proper caution downstream to avoid any disaster.

IV. CONCLUSIONS

Field physical models with hydraulic similarity of an original prototype may represent the disposal of the flood wave in the canal downstream. Roseires dam collapse simulated by the physical model studied five cases for different flood conditions. Case 5 gave the highest water levels reaching 277.001, 277.084 and 277.161 (m) (AMSL) in the canal (left, center and right sides respectively). The moving wave vanished at a distance of 590 m after 70 minute in the canal.

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Photo 1 Construction and operating the physical model.

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