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Description of the design and construction of a physical model of a dam for educational purposes

Descripción del diseño y construcción de un modelo físico de una presa con fines educativos

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Abstract

The objective of this document is to present the construction process of a physical model that resembles a dam, the use of which allows the reproduction of different hydrological and hydraulic phenomena, for example: flow, pump calculation, pipeline design, flow in open channels, among others. The built physical model has plan dimensions of 2.85 m wide by 11.50 m long, built with 15x20x40 concrete blocks and f'c=100 kg/cm^2, 150 kg/cm^2 and 200 kg/cm^2 resistance concrete, contains PVC pipes of 3” that contribute to the discharge of the flow; It will be part of the Hydraulics Laboratory facilities and impacts the academic development of the Civil Engineering and Administration, Energy Engineering and Mechanical Engineering programs of the Engineering Faculty of the Universidad Autónoma de Campeche.

Physical model, Hydraulic, Laboratory

Resumen

El objetivo del presente documento es presentar el proceso de construcción de un modelo físico que asemeje una presa, cuyo uso permita reproducir diferentes fenómenos hidrológicos e hidráulicos, por ejemplo: caudal, cálculo de bombas, diseño de tuberías, flujo en canales abiertos, entre otros. El modelo físico construido tiene dimensiones en planta de 2.85 m de ancho por 11.50 m de largo, construido con blocks de concreto de 15x20x40 y concreto de resistencia de f’c=100 kg/cm^2, 150 kg/cm^2 y 200 kg/cm^2, contiene tuberías de PVC de 3” que aportan a la descarga del flujo; formará parte de las instalaciones del Laboratorio de Hidráulica e impacta en el desarrollo académico de los programas de Ingeniería Civil y Administración, Ingeniero en Energía e Ingeniero Mecánico de la Facultad de Ingeniería de la Universidad Autónoma de Campeche.

Modelo físico, Hidráulica, Laboratorio

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Introduction

The development of physical models allows to evaluate at scale the behavior of structures or the development of phenomena that by their nature are difficult to measure. At the international level, different physical models have been developed that help to understand the behavior of hydraulic structures such as dams, canals, among others. For example, Leiva Llenera (2017) develops a model to evaluate the failures of earthen dams in the world and in Cuba; o Parcero López (2016) who studies the stability of dams considering the effects of earthquakes and seepage forces through a physical model; On the other hand, Gutiérrez Gómez (2015) builds a model to demonstrate the technical feasibility for water collection; likewise, Ortiz Quizhpi & Portilla Flores (2014) analyze the stability of dam slopes. Most physical models are developed in specialized laboratories belonging to institutions for research purposes.

Universities must have adequate and optimal infrastructure for the development of their academic activities, among which are the development of laboratory practices; however, due to the socioeconomic context in which the Universities of Mexico are located, sometimes the acquisition and equipment of the laboratories becomes complicated.

The Faculty of Engineering of the Universidad Autónoma de Campeche is not exempt from the above situation, so the Hydraulics Laboratory lacks equipment that allows the correct development of activities related to the practice and teaching of the hydraulics area.

That is why, as a contribution to academic development and the implementation of knowledge offered by the Civil Engineering area, the faculty has developed projects focused on the proposed reconditioning of areas (Ice Cream Parlot of the Faculty). and preventive and corrective diagnosis of the built infrastructure (Barrera-Lao *et al.*, 2017). Here we propose the design and construction of a physical model that allows the development of activities as a laboratory practice and that becomes part of the Hydraulics Laboratory equipment.

Allowing the development of practices concerning a wide variety of topics, among which stand out: flow, pump design, channel hydraulics, hydraulic jump, conduction, protection works, elements of a dam, power generation, among others.

Methodology

Once the objectives of the physical model and the hydraulic phenomena to be reproduced were defined, a pre-design was obtained in an assisted drawing software, later and after knowing the outdoor area where the model could be built, several calculations of the focused dimensions were carried out. in the speed, flow, and storage volume the final design was generated (Figure 1).

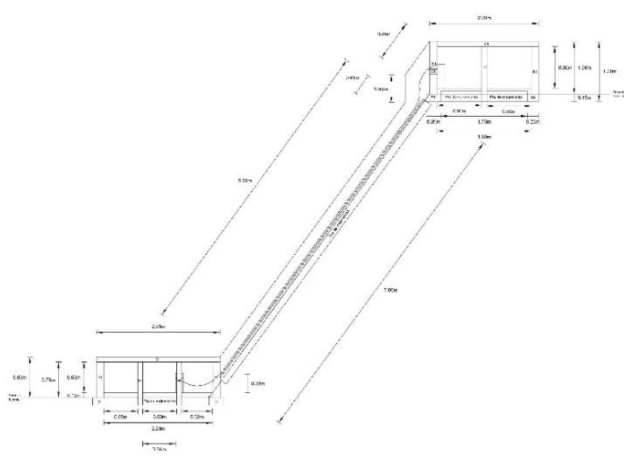

Figure 1 Schematic section of the physical model
Source: Own elaboration

It was decided to make a three-dimensional physical model, since the runoff occurs on a free surface, where the predominant force is gravity. As for the construction material, it was decided on concrete with fixed margins and initially with a fixed bottom. Likewise, within the design project, future modifications were contemplated in the configuration of the hydraulic jump and discharge.

Once the dimensions of the model, its elements and location were defined, the model was built, which can be divided into 3 stages:

1) Upper tank: Located in the highest part of the land, it includes 3 outlets with 3" pipes, which simulate intake work, diversion work and excess work. Likewise, there is a download area.

2) Lower tank: Located in the lower part of the land, it includes 3 entrances with 2" pipes, here the structure that allows the hydraulic jump and the buffer tank are located.

3) Screen: allows downloading and works as an open channel, the margins are fixed.

The construction of the model can also be defined in 7 general items derived from the construction process:

1) Preliminaries: This phase comprises all the initial activities before starting the actual construction. Includes work such as plotting and leveling the land.

2) Excavations: It consists of the process of removing earth or other materials to create the necessary space where it will be built.

3) Foundations: Refers to the base or structure that is placed to transmit and distribute loads to the ground in a safe and stable manner.

4) Structures: In this phase, the main parts of the physical model are built, such as castles, dice, enclosing chains, and slabs, which provide support and stability to the construction. Different materials such as concrete and steel are used to form the structure.

5) Masonry: This stage contemplates the placement of similar blocks (masonry) for the construction of the walls.

6) Finishes: This stage implies the completion and decoration of the construction. Includes activities such as coatings and painting.

7) Hydraulic installation: It is related to the network of pipes and systems for the supply and drainage of water within the model.

These stages had to be organized sequentially, although some were carried out in parallel. Each one of them was crucial for the success of the construction and required the collaboration of different specialists and work crews.

For the construction of the physical model, the plot and leveling of the land was carried out by means of manual tools to remove the undergrowth and obstacles that prevented locating and defining the axes indicated in the project plan (Figure 2).

Figure 2 Trace and leveling of the land
Source: Own elaboration

Results

Upper tank

From a structural point of view, the upper tank is made up of three parts:

1) Bottom slab.

2) Perimeter walls.

3) Crown beam.

It also includes secondary, but no less important elements that fulfill specific functions. Among the secondary elements, the following could be mentioned: the piers and the cimacio weir, which acts as a work of excess and is built with the purpose of giving way to the volumes of water that cannot be retained in the vessel of the physical model (Figure 3).

Constructive process:

1) Outline, leveling and cleaning of the land.

2) Excavation for foundation skirting board based on 15x20x40 block and trenches for pipes.

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3) Foundation skirting for piers, made of 15x20x40 hollow block filled with concrete f'c=150 kg/cm^2 with alternate reinforcement of 3/8" rods at the height of the first row of pile blocks.

4) 0.10m thick foundation slab for Upper Tank, concrete f'c=200 kg/cm^2 with reinforcing steel electro-welded mesh.

5) 15x20x40cm hollow block wall glued with a 1:6 cement-sand mixture for the Upper Tank, curtain and piers.

6) Concrete castle f'c=150 kg/cm^2 of 0.15x0.15m with armex for castle of 0.10x0.10.

7) 15x20x40cm hollow block drowned castle filled with f'c=150 kg/cm^2 concrete and 3/8" rod reinforcing steel for upper tank and buttresses.

8) Enclosure chain for piles with concrete of f'c=150 kg/cm^2 and armex reinforcing steel for half chain on ladder 0.10x0.075m

9) Chamfers in foundation slab joints based on concrete f'c=100 kg/cm^2.

10) Flattened (3 rich layers, patch, and putty) on perimeter walls and crown beam.

Figure 3 Bottom tank construction. a) Laying of electro-welded mesh, b) Construction of walls
Source: own elaboration

Lower tank

The lower tank also has a bottom slab, perimeter walls and crown beam and the structure (damping box) that allows the hydraulic jump and the pool (Figure 4).

Constructive process:

1) Outline, leveling and cleaning of the land.

2) Excavation for foundation skirting board based on 15x20x40 block and trenches for pipes.

3) Foundation skirting for piers, made of 15x20x40cm hollow block filled with concrete f'c=150 kg/cm^2 with alternate reinforcement of 3/8" rods at the height of the first row of pile blocks.

4) 0.10m thick foundation slab for the Lower Tank, concrete f'c=200 kg/cm^2 with reinforcing steel welded mesh.

5) 15x20x40cm hollow block wall glued with a 1:6 cement-sand mixture for the Lower Tank and Structure for the hydraulic jump.

6) Concrete castle f'c=150 kg/cm^2 of 0.15x0.15m with armex for castle of 0.10x0.10.

7) 15x20x40cm hollow block drowned castle filled with f'c=150 kg/cm^2 concrete and 3/8" rod reinforcing steel for upper tank and buttresses.

8) Enclosure chain for piles with concrete of f'c=150 kg/cm^2 and armex reinforcing steel for half chain on 0.10x0.075m ladder.

9) Chamfers in foundation slab joints based on concrete f'c=100 kg/cm^2.

10) Flattened (3 rich layers, patch, and putty) on perimeter walls and crown beam.

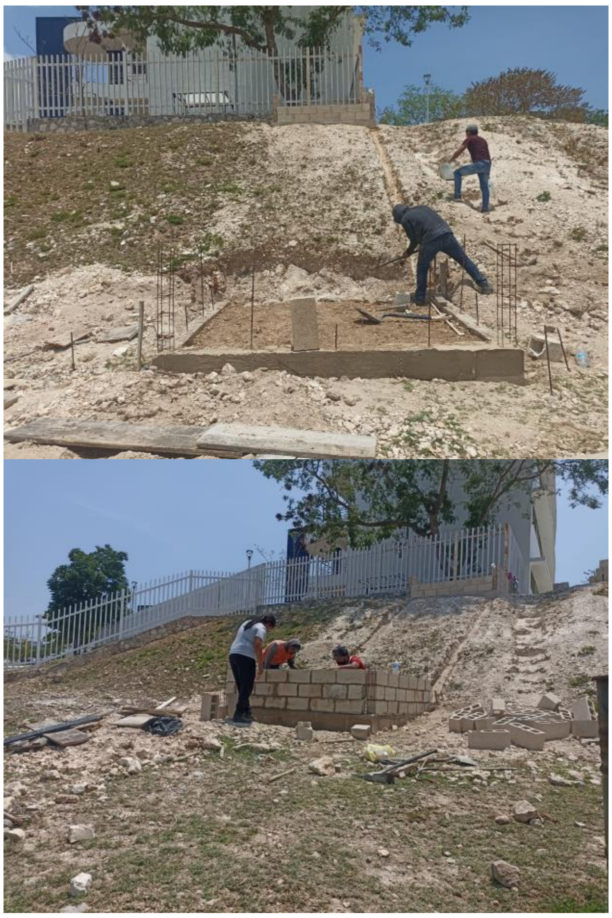

Figure 4 Bottom tank construction. a) Foundation, b) Construction of walls
Source: own elaboration

Screen:

The screen is the most important part in the physical model since this is the one that is in charge of joining the upper tank with the lower tank. The cimacio weir and the backwater box are the elements that intertwine with the screen. In addition, it works as a gravity channel (Figure 5).

Constructive process:

1) Outline, leveling and cleaning of the land.

2) Excavation for foundation skirting board based on 15x20x40 block and trenches for pipes.

3) Foundation skirting board for concrete cylinder base screen.

4) Installation of 3" pipes in the upper and lower tank outlets.

5) Filling and leveling the screen with fine and coarse aggregate to later place the electro-welded mesh.

6) Foundation slab 0.05m thick for the curtain, made of concrete f'c=100 kg/cm^2 with reinforcing steel electro-welded mesh.

7) Enclosure chain for piles of, f'c=150 kg/cm^2 and armex reinforcing steel for half chain on ladder 0.10x0.075m.

8) Elaboration of structure for hydraulic jump and cymacio.

9) Flattened (3 layers of riveting, patching and putty) on perimeter walls and crown beam.

10) Placement of intake, control, and excess works between the tanks.

11) Supply and placement of sealant and blue and white paint in the upper and lower tank and screen of the physical model.

Figure 5 Screen construction. a) Laying of electro-welded mesh, b) Casting
Source: own elaboration

In Figure 6, some of the details of the constructive elements used in the physical model are presented.

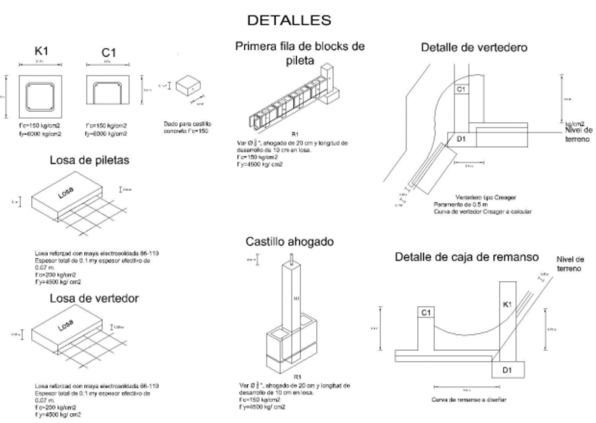

Figure 6 Constructive details
Source: Own elaboration

A three-dimensional physical model with plant dimensions of 2.85 m wide by 11.50 m long was obtained, the model has 2 storage tanks with a capacity of 3.3m^3 each that are linked through a screen (which simulates the curtain of a dam) with an effective length of 6.35 m that allows the discharge of water by means of gravity from the upper tank to the lower tank. In the upper tank, 3 3” PVC-type pipe outlets were placed, each simulating: intake work, diversion work and excess work. This pipe is connected to the lower tank, where the discharge produces a hydraulic jump and there is a damping box that reduces the speed of the flow and stores the fluid (Figure 7).

The upper tank has a Creager-type spillway, with a 0.5m facing; on the other hand, the curtain was made with a smooth finish in order to increase the discharge flow speed and the hydraulic jump to be generated; this zone is 0.62 m wide, while the buffer box is 1.53 m wide. The height in both tanks is 1.0 m, with 0.60 being the effective height. Likewise, two walls were built that simulate the buttresses, these with a rectangular section of 0.56 m high and 0.85 m long with 0.20 m thick.

Figure 7 physical model. a) Side view, b) Front view
Source: own elaboration

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Conclusions

The model is one of the projects that will bring the greatest impact to the Hydraulics Laboratory of the Faculty of Engineering of the Autonomous University of Campeche, since it will allow the reproduction of different phenomena related to Hydrology and Hydraulics. Among the phenomena, the following stand out: a) the hydraulic behavior of the different elements that make up the structure; b) scour phenomenon at the discharge foot, c) calculation of pumps, d) Calculation of flow in pipes and open channel, among others.

Additionally, a future improvement is proposed through the installation of elements that allow the generation of electrical energy such as solar panel and wind energy; It also gives rise to new projects such as the numerical simulation of phenomena in CFD.

The construction of this model makes it possible to considerably reduce the uncertainties offered by the different mathematical formulations used to assess the physical phenomena involved in hydraulics, in addition to being a model for educational purposes that directly impacts the educational programs offered at the Faculty of Engineering from the Autonomous University of Campeche: Civil Engineer and Administration, Energy Engineer, Mechatronics Engineer, as well as a Postgraduate Degree in Engineering.

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