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Numerical and Physical Simulation to Improve the Hydraulic Performance of Lined Channels Using Inflatable Dams

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Abstract

Predicting Stream flow forecasting is of great interest to engineers and hydrologists for the management and planning in designing water resources projects and for water resources for. Long-term and short-term stream flow forecasting can provide valuable information on the possibility of designing water projects. This paper aims to improve the hydraulic performance selected channel namely the Shatt al-Ibrahim channel by measuring the depth of flow, using an Inflatable dam and comparing it with the water depth before the dam was placed in operational discharge (2 m^3/sec). One-dimensional and two-dimensional numerical models are generated and analyzed using HEC-RSA software and then calibration with a physical model. The study results included a rise in water depth upstream of the inflatable dams compared to the natural case of almost 1.32 m in the dam region and 0.16 m at the beginning of the channel and backwater curve extends from 18 kilometers to zero kilometers and the velocity of water in downstream is not effect to the bed of channel and it doesn't happen to scour in concrete, The calibration results between the numerical model and the physical model by using the coefficient of determination R^2 (the acceptable value it is closer to 1).

Keywords: Design discharge, Rubber dams, Water surface elevation, Water depth.

1. INTRODUCTION

To control the flow of water in rivers, canals and streams, it is necessary to build hydraulic structures. Hydraulic structures are used for multiple purposes such as controlling water level. One of the economic structures used to organize the water level is the inflatable dam. An inflatable dam is a simple barrier made of a flexible membrane, which is controlled by inflating or deflating by injecting and discharging air or water., and fixed to a canal bed **(Alhamati, 2005)** rubber dams, also called inflatable dams, are made of rubberized, it was flexible cylindrical inflatable and dilatable structures attached to a rigid base at either one or two ends (single or double anchor) **(Moorthy et al., 1995; Liapis, 1999; Breukelen, 2013; Shirazi et al., 2014; Streeter et al., 2015)**

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(Imbertson, 1960) developed the first Inflatable dam. This dam was installed in the USA as part of a water supply project for the city of Los Angeles. **(Hitchand Narayanan, 1983; Chanson, 1998; Brunner, 2016; Kareem and AL-Thamiry, 2019; Shankar et al., 2001)** used the HEC-RAS (5.0.3) software to perform calculations A-. example of Galal-Badrah River on the Iraqi river - Iranian border, two hydrographs were used at the upstream side of the river, representing two leaks and producing three simulation models, and two water image scenarios, including maximum removal. The results showed that the speed exceeded the permissible sliding speed. Consequently, it is recommended that a flood barrier be built along the southern bank of the river, depending on the water level at each crossing. Therefore, a bank with a height of between 2.5 and 5.6 m.

(Daham and Abed, 2020) used the HEC-RAS software to study the hydrology of the Al-Gharraf River. Their research focused on the effects of industrial structures—such as aeration ponds—on water level and flow variability, researchers who used HEC-RAS to model a variety of conditions and it assessed the impact of these structures on river water dynamics to simulate various scenarios and provide important hydrological insights for management strategies. **(Jassam and Abed, 2021)** performed two-dimensional hydraulic simulations of the Lower Diyala River using HEC-RAS software. The study used a two-dimensional model to simulate different flood scenarios and evaluated the effects of water systems including inflatable dams on river discharge and elevation Their study provided recommendations to understand river behavior under different conditions, to improve flood control and dam construction Provides valuable technical recommendations for water supply they will be reduced and handled responsibly **(Chu et al., 2021).**

A combination of large eddy simulation (LES) and volume of fluid (VOF) method was used to model free surface flow on rubber dams. Different types of dams were examined, including circular, oval and tear-shaped Coefficients of discharge and comparison with experimenting work. The results showed that the drag coefficient of tear-shaped dams was slightly higher than that of circular dams, while changes in aquifer depth affected drag coefficients more than lift Research of the findings contribute valuable information for improving rubber dam design for water management efficiency **(Ren et al., 2021).**

The effects of sedimentation and vegetation conditions on flow velocity in open water were investigated. Analyzes using 3D numerical models showed that vegetation diameter has a significant effect on flow structure, while vegetation height influences the location of vertical velocity inflexion point. The results provide important insights into water control of flow dynamics in open channels with vegetation, especially for applications in flood control and materials an environmental restoration **(Zhang et al., 2022).** The researchers laterally analyzed flows in open channels with low density vegetation and investigated how vegetation size, distribution and connectivity patterns affect flow velocity and turbulence development The findings can inform water identification with vegetation design and management to help improve drainage and reduce flood risk. Numerical simulations and experimental data provide the basis for future studies of open water with vegetation. **(Dehrashid et al., 2023)** examined the effects of precipitation, vegetation structure, and density on flow velocity in water plants in two layers. Factors such as geometry greatly influence flow dynamics and resistance and the results are useful for the design and management of flow channels and flood banks. The study provides a practical application to develop robust, sustainable designs. **(Alaa and Al-Sulttani, 2023)** proposed water distribution solutions by computing the minimum instream flow (MIF) of the Shatt al-Hillah River of the compulsory irrigation system in Iraq. The river is important for industry, tourism and agriculture. It is controlled by the Shat Al-Hillah head regulator and maintains a design discharge of 350 m^3/s. Recently, regular assessment of water availability has become important due to climate change and upstream water depletion to meet agricultural, manufacturing and urban demands water flows were reconstructed conditions and developed a one-dimensional fluid, HEC-RAS version 5.0.7, was used for research. Field measurements considered in the study. Three cases were set to estimate the minimum possible stream flow, the third recommended 83 m^3/s under two days per week of irrigation preparation. **(Huang et al., 2023)** used an explicit mesh-free method to simulate open water flow, such as weir flow and water jump. The simulated velocity distributions and flows were used against experimental data, showing good agreement. Studies show that the open channel flow capture method works well, and provides water engineers gain valuable tools for designing and conducting flow system analysis **(Gao et al., 2023)** and carried out to evaluate the performance of air-water separation double rubber dams, lower dam inflated by water and the upper dam inflated by air. Large-scale physical hydraulic model tests are carried out to investigate the influence of the inflated air and water pressures, anchoring distances, external water levels, and cross-sectional perimeter ratios on the static response of the proposed structure. The study showed that the total material costs of the air- and water-inflated double rubber dams are only 11.5%–24.2% of the traditional rubber dam. **(Hazim et al., 2023; Ali and Al-Thamiry, 2021)** used an inflatable rubber dam and verified for its feasibility and suitability on the Shatt Al-Arab River, Southern Iraq to reducing the salt front resulting from the seawater of the Arabian/Persian Gulf. Also, the other types of hydraulic structures were feasibly compared with inflatable rubber dams. The results showed the employed inflatable rubber dam to control the salt front is more economical and efficient than other hydraulic structures.

The aim of this research is to raise the water level in the Shatt al-Ibrahim channel within the study area at operational discharge (2 m^3/sec) while the design discharge (5 m^3/sec) by the construction of the inflatable dam to raise the water depth upstream the dam to reach the design water depth. The lower construction and simple of operation, ease and maintenance costs, easy and simple and prevent flooding quickly in upstream, therefore inflatable dams are the best solution for maintaining the required water depths.

2. METHODOLOGY

This section includes a description of the steps required to create two models, the first a numerical model using a program and the second a physical model in a laboratory. The steps are as shown in the steps below.

2.1 Data Collecting

The hydrology data of discharges at the intakes of Shatt Al Ibrahim channel (design discharge and scarce discharge) and the surveying data of the cross sections along the channel for the period from 1-10-2021 to 1-10-2023.

2.2 Change the Geometry

For the purpose of stabilizing the dam and increasing the efficiency, the channel section of dam region was changed from trapezoidal to rectangular with dimensions 2 m width and 3.75 m height (control section) with contraction length L_c= 10 and length of expansion L_e=50 m **(Daher and Ameen, 2024)**.

2.3 Numerical Models

The HEC-RAS (V.6.3.1) software was used to simulate water flow in open channels. The model can perform different calculations for the flow regime subcritical, supercritical, and hydraulic jumps in the flow calculations model and including one-dimension and two-dimensions flow for simulating the hydraulic characteristics (surface water elevations, water depth and velocities), with the use of the gathered data of scarcity discharge **(Alrammahi and Ahmed Hamdan, 2024; Asaad and Abed, 2020; Alhamdi and Al Thamiry, 2023)**

2.4 Laboratory Model

A laboratory model is developed to simulate the hydraulic characteristics (water depth, velocities) and calibrate the results with a Numerical model.

3. DESCRIPTION OF SITUATION

Shatt al-Ibrahim channel is located in the south of Iraq. It is a trapezoidal and lined channel. The length of channel 36500 m with a designed discharge of 5 m^3/sec which is pumped by a head regulator at 0+000 Km and also pumped water to the channel from the Al-Sallhiya channel at 20+000 Km with a design capacity of 2 m^3/s, the channel operates at discharge 2 m^3/sec instead of 5 m^3/sec. So, the problem of low water level appears to span from 13 kilometer to 18 kilometer in a special condition and along 23 kilometer of the channel, Therefore, suggesting installing an inflatable dam at kilometer 18 from the intake of Shatt al-Ibrahim channel to raise the water level upstream the dam to provide water to meet agricultural needs and irrigation agricultural lands. Choose the study area from 13 to 23 kilometer, see **Figs. 1 and 2 (Daher and Ameen, 2024).**

Figure 1. Aerial photo of Shatt Al-Ibrahim

Figure 2. photo of Shatt Al-Ibrahim

4. HYDRAULIC MODELING

The HEC-RAS (V.6.3.1) program was used to simulate and analyze the unsteady and steady flow in artificial open channels and natural as well as sediment transport and water quality **(Azzubaidi, 2020).** The model can perform different calculations for the flow regime subcritical, supercritical, and hydraulic jump, in the flow calculations model whether it is steady or unsteady **(Alsaadi and AL-Thamiry, 2022).** The software HEC-RAS version (6.3.1), is software used to analyze river systems. For the present study, the software is used to develop hydraulic models for the flow in 1D and 2D **(U.S. Army Corps of Engineers, 2016; Hashim and Azzubaidi, 2023; Razzaq et al.,2024)**

4.1 Boundary Conditions For 2D Unsteady Flow Model

The two-dimensional boundary conditions contain five types, which are used to simulate the unsteady two-dimensional flow (stage hydrograph, flow hydrograph, rating curve, normal depth, and precipitation) **(Daham and Abed, 2020)**. The boundary conditions were taken from unsteady flow for one dimension and chose a stage hydrograph including water surface elevation upstream and downstream of the dam (**Al-Zaidy and AL-Thamiry, 2020; Ghali and Azzubaidi, 2021)** as follows:

4.1.1 Nature Case

Upstream of the dam, the maximum water surface elevation is from 0+000 km to 13+000 km, in downstream of the dam chosen maximum water surface elevation at 23+000 km.

4.1.2 Case of the dam (1.5 m diameter of the dam)

In the upstream of the dam chosen maximum water surface elevation is from 13+000 km to 18+000 km. Downstream of the dam chosen maximum water surface elevation from 18+000 km to 23+000 km, and all boundary conditions were presented in the **Table. 1**.

Table 1. Boundary two-dimensional flow data

Boundary two-dimensional flow data			
case	**discharge**	**W.S.E. max.**	**W.S.E. max.**
		up stream	**down stream**
Natural	2	5.73	3.29
1.5 m dam	2	5.6	5.59

5. PHYSICAL MODEL (LABORATORY MODEL)

Experiments were conducted at the Hydraulic Laboratory of the Center of Engineering Studies and Design of the Iraqi Ministry of Water Resource. The testing included diameters of the dam was chosen for the purpose of study 1.5 m. Here are the details of all instrumentation and equipment used during the period of the experiments described.

5.1 Flume

Experiments were carried out in a glass channel of length of 12.5 m with a cross-section 0.3m wide and 0.45m deep. The floor was stainless steel with walls of toughened glass. A separate freestanding electrical console is supplied that houses the digital flow meter readout and control for the water pump shown in **Fig. 3.**

Figure 3. The flume that was used in the experiments

5.2 Flow meter

By using a manually adjusted valve, the flow of water into the channel is regulated by using an electromagnetic flow meter and its rate is measured. The percentage of maximum flow rate available is 38 liters /second, see **Fig. 4.**

Figure 4. The electromagnetic flow meter

5.3 Propeller Velocity Flowmeter

The Propeller Velocity Flow meter is used to measure very low point –velocities in water and other conductive fluids, The fine diameter of the sensing head enables the meter to be used in small ducts and channels with an ability to measure fluid velocities as low as 25 mm/sec, see **Fig. 5.**

Figure 5. Propeller Velocity Flow meter

5.4 Point gauge

A point gauge is used to measure the depth of water and it is based on the metal base mounted on the upper part of the walls of the channel and can move in three directions along the flume and in the transverse direction and the vertical directions, see **Fig. 6.**

Figure 6. Point gauge

5.5 Inflatable Dam models

The Inflatable dam models installed in the physical model were manufactured from Plastic material with a cylindrical shape. In this study dam model with a width of 30 cm and a diameter (15 cm) is fixed by using silicone, see **Fig. 7.**

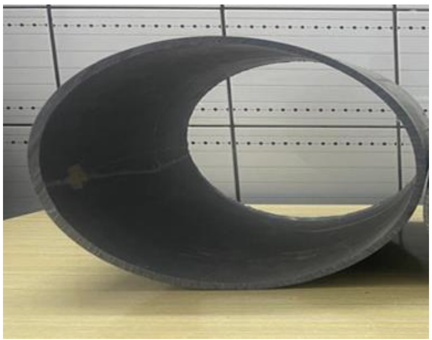

Figure 7. Plastic models of dam

6. SIMULATION OF LAB MODEL

Preparations before starting work in the laboratory, see **Table. 2.**

Table 2. Inflatable Dam dimensions and discharge used in the lab

Dimensions of the dam in prototype (m)	**Dimensions of the dam in the laboratory model(cm)**
1.5	22.5
Discharge in prototype (m^3/sec)	Discharge in the laboratory model (m^3/sec)
2	0.017

7. EXPERIMENTAL WORK PROCEDURE

1. Identify action points; three basic points have been identified for work: the first at the front of the channel (upstream), the second in the middle of the channel (dam position), and the third at the end of the channel (downstream). The distance between one point and another is 6m then the dam was installed in the middle of the flume.

2. Measured the water depth, discharge pumping is 2 m^3/sec, then after opening the discharge required in the flume by a flowmeter, measured the water depth in three positions (upstream, downstream and dam position) by a Point gauge.
3. Measured water velocity, water velocity is measured upstream, downstream and above the weir at a depth of 0.6 m of water depth at the three points that were fixed (Mean velocity) by using a velocity current meter (**Mays, 2010)**; see **Fig. 8.**

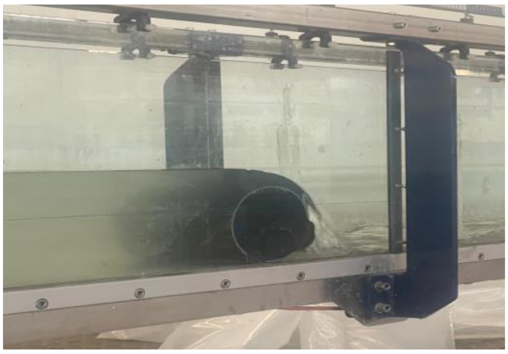

Figure 8. Cross-section with bed material (dam 15 cm diameter)

8. RESULTS AND ANALYSIS

8.1 Results and Analysis of Numerical Model (HEC-RAS software)

The range of water depths is between 1 to 2 m along the middle of the channel but on the sides of the channel less than 0.33 m. The range of velocity is between (0.33 and 1.67) m/s in the middle of the channel and higher than in the sides of the channel. see **Figs. 9** and **10.**

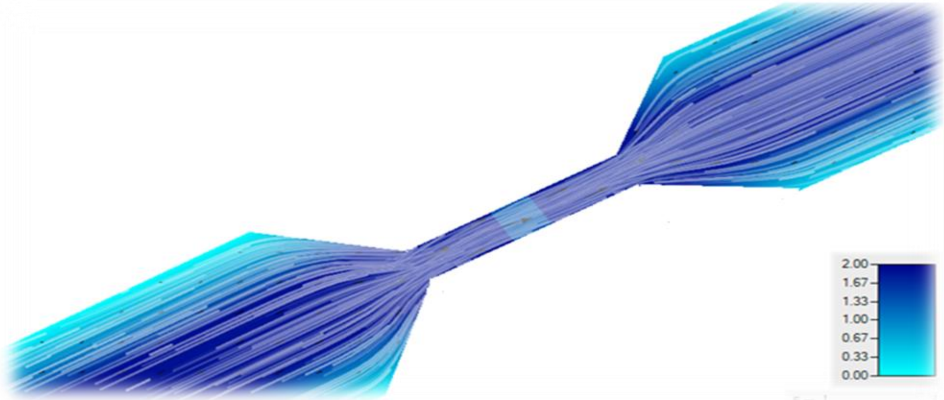

Figure 9. Water depth distribution in natural case

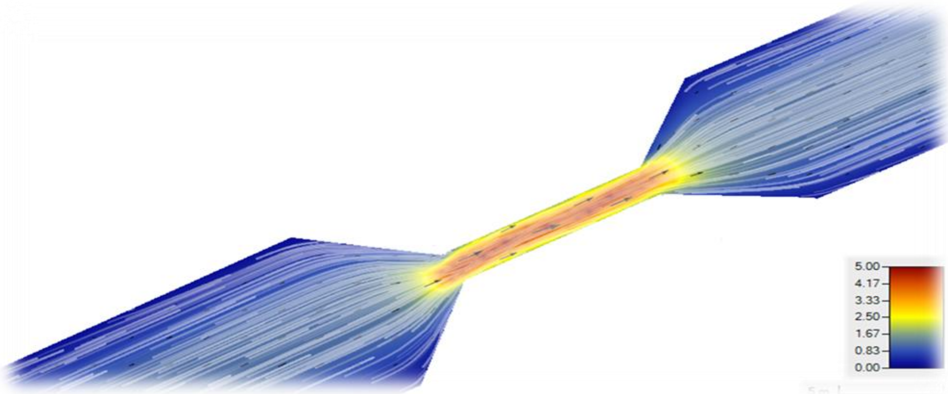

Figure 10. Velocity distribution in natural case.

8.2 Flow Condition using a 1.5 m Diameter Inflatable Dam

The range of water depths is between 1.17 to 2.22 m along the middle of the channel but on the sides of the channel less than 1.17 m. The range of velocity is between (0.83 and 1.67) m/s in the middle of the channel and higher than on the sides of the channel, see **Figs. 11 and 12.**

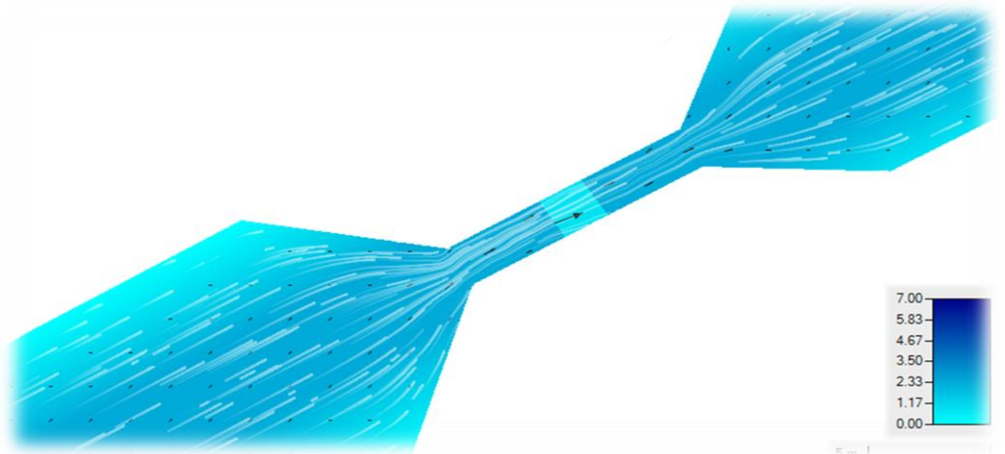

Figure 11. Water depth distribution with using 1.5 m diameter inflatable dam

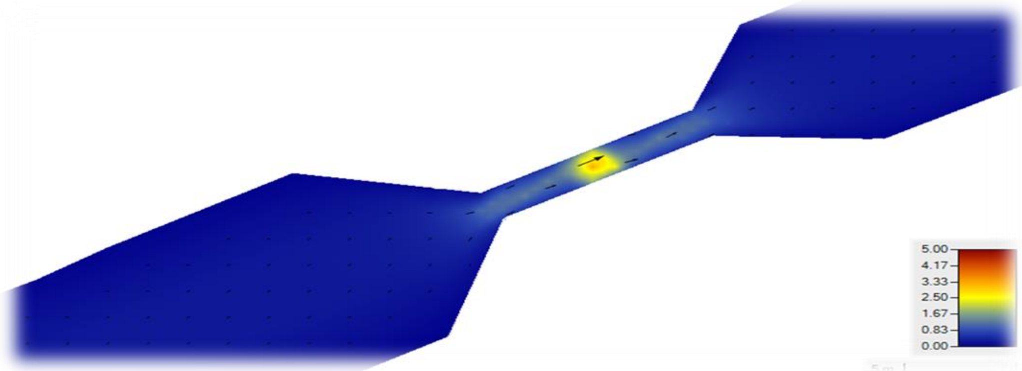

Figure 12. Velocity distribution using 1.5 m diameter inflatable dam

8.3 Results and Analysis Physical Model (laboratory model)

8.3.1 Natural case

The hydraulic performance of the Shatt al-Ibrahim channel is represented by the water depth of 0.16 m in the model and 1.1 m in the prototype, and a velocity of 0.02 m/sec m in the model and 0.49 m in the prototype along the channel in the natural channel as listed in the **Table 3**

Table 3. Hydraulic performance of the channel in the natural case

For model			For prototype		
Q(m^3/s)	**water depth (m)**	**v(m/sec)**	**Q(m^3/s)**	**water depth (m)**	**v(m/sec)**
0.017	0.14	0.02	2	1.1	0.49

8.3.2 Using an inflatable dam with a 1.5 m diameter

Hydraulic performance of the channel for flow condition using 1.5 m inflatable dam represented by the water depth upstream, above the dam and downstream were 0.14, 0.09 and 0.105 m respectively in the model while in the prototype were 2.1, 0.65 and 0.7m respectively and velocity in upstream, above the dam and downstream were 0.076, 0.227 and 0.19 m/sec respectively in the model while in the prototype were 0.4,1.2 and 1.05 m/sec respectively as listed see **Table 4.**

Table 4. Hydraulic performance of the channel using 1.5 m dam height.

upstream					
For model			**For prototype**		
Q(m^3/s)	**water depth (m)**	**velocity (m/sec)**	**Q(m^3/s)**	**water depth (m)**	**velocity (m/sec)**
0.017	0.16	0.076	2	2.1	0.4
downstream					
0.017	0.09	0.227	2	0.65	1.2
Above the dam					
0.017	0.105	0.19	2	0.7	1.05

8.4 Verification of Numerical Model with Physical Model

Water depths and velocity's for the flow conditions of the present study were simulated by using HEC-RAS software, and the results were compared with the measured values. The accuracy of the measurements was tested using the coefficient of determination R^2.

8.4.1 Flow Condition Using 1.5 m Dam Height

When the discharge is equal to 2 m^3/sec, R^2 is equal to 0.9994 m (water depth) as shown in **Fig. 13** and equal to 0.9717 (velocity) as shown in **Fig. 14.** It reflects the accuracy of the prediction since it is closer to 1.

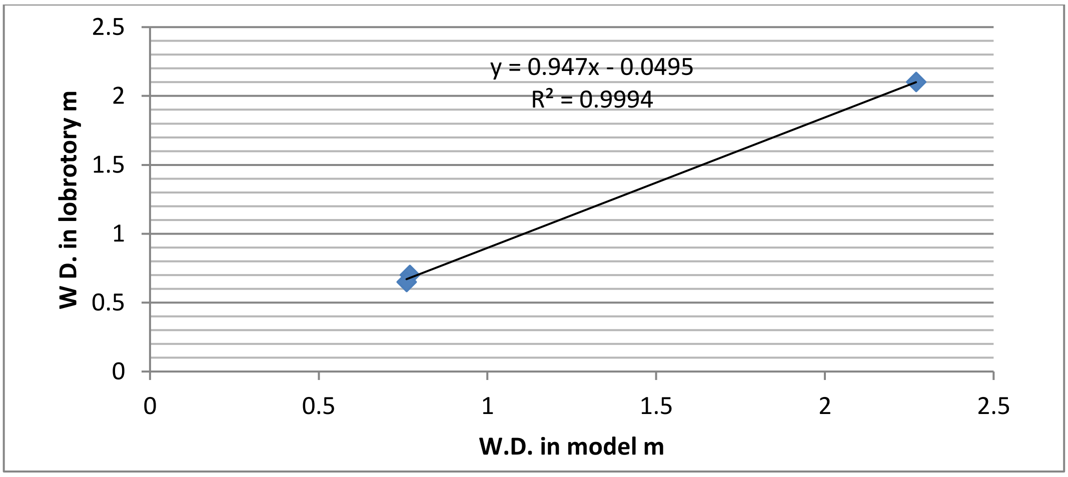

Figure 13. The relationship between the value of measured depth and the simulated value of depth

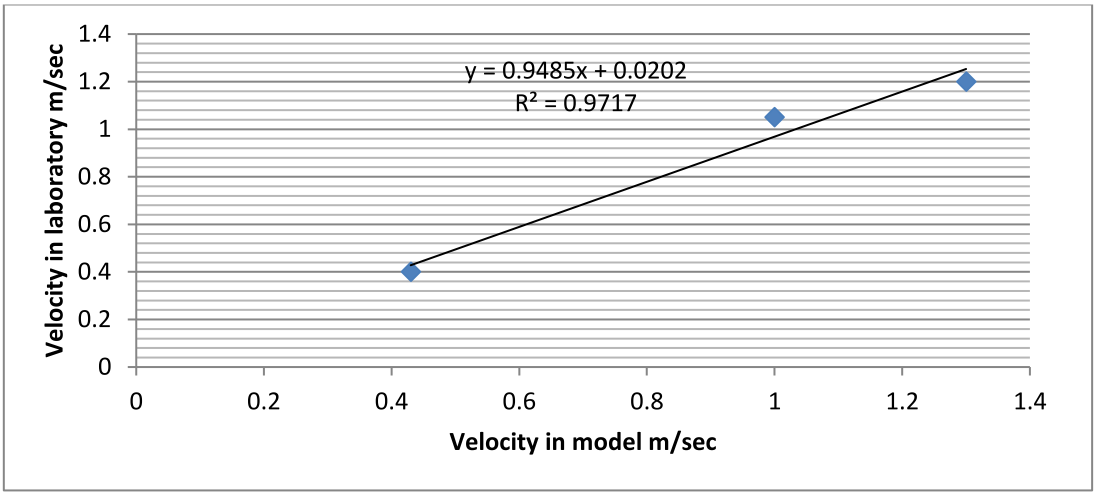

Figure 14. The relationship between the value of measured velocity and the simulated value of velocity

8.4.2 Backwater Curve

Fig. 15 and **Table 5** show that in natural case (without dam), the water surface elevation is found in 18+000 km almost 4.06 (a.m.s.l.) and the curve over distance 18+000 Km that mean return to 0+000 Km (the beginning of the channel) with water surface elevation almost 5.83 (a.m.s.l.) - When the height of the dam equal to 1.5 m, find the water surface elevation in the dam region almost 5.38 (a.m.s.l.). and the curve over distance 18+000 Km that mean return to 0+000 Km (the beginning of the channel) with water surface elevation almost 5.99 (a.m.s.l.) when compared the natural case with the dam 1.5 m (raise water surface elevation 1.32 m in dam region and 0.16 m at the begging of the channel).

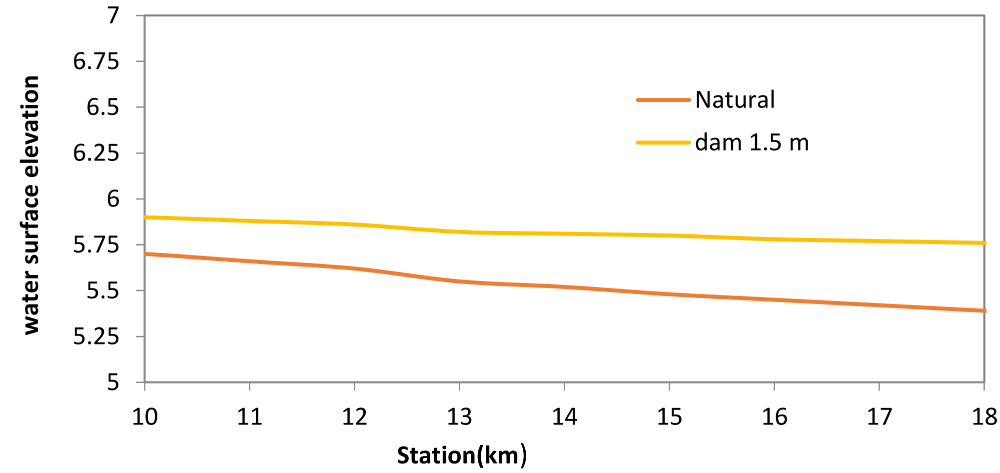

Figure 15. Backwater curve at discharge 2 m³/sec.

Table 5. Summary of back water curve at discharge 2 m³/sec

Summary of back water curve at discharge 2 m³/sec				
case	In dam region (18+000 Km)		In the beginning of the channel (0+000 Km)	
	Water surface elevation (a.m.s.l.)	Raise the W.S.EL. to Natural case	Water surface elevation (a.m.s.l.)	Raise the W.S.EL. to Natural case
Natural	4.06		5.83	
Dam 1.5m	5.38	1.32	5.99	0.16

8.4.3 Effect of the Inflatable Dam on Channel Safety

In inclined channels such as channels concrete, if the water is not carrying large concentrations of flow sediment, the velocity of 12 m/sec has been found to be compatible with concrete channels **(Chaudhry, 2008),** therefore the results showed that the high velocity downstream not effect to the concretes (safely against scouring). When discharge is between 1.5 to 85 m^3/sec, the free board of the channel is 0.75 **(Chaudhry, 2008).** The results showed that at discharge 2 m^3/sec when using a 1.5 m diameter of the dam, the free bore of the channel was almost 1.47. Therefore, the presence of the dam is considered safe.

9. CONCLUSIONS

According to the results of the study of the construction of an inflatable dam at a site 18 km of Shatt Ibrahim Canal, the conclusions were listed below.

1. The percentage rise in water depth to the natural case 85% upstream of the dam, with back backwater curve extending from 18 kilometer to zero kilometer(beginning the channel) to provide water to meet agricultural needs and irrigation agricultural lands.
2. Construction inflatable dam for 18 kilometer, the Range of velocity is between (0.83 and 1.67) m/s; therefore, the presence of the dam is considered safe.

Credit Authorship Contribution Statement

Saba Abdul Razzak Daher: Writing – original draft, Validation, Software, Methodology.
Ameen Mohammed Salih Ameen: Writing – review & editing, Methodology.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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محاكاة عددية وفيزيائية لتحسين الأداء الهيدروليكي للقنوات المبطنة باستخدام السدود القابلة للنفخ

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الخلاصة

عُد التنبؤ بتدفق المياه احد الاهتمامات المهمة لعماء المياه والمهندسين لتخطيط وادارة موارد المياه وتصميم مشاريع موارد المياه .يمكن ان يوفر التنبؤ بتدفق المياه على المدى الطويل والقصير معلومات قيمة حول امكانية تصميم مشروع المياه .السدود المطاطية وتسمى ايضا السدود القابلة للنفخ تكون مصنوعة من هياكل مطاطية اسطوانية مرنة قابلة للنفخ والتمدد متصلة بقاعدة صلبة اما في احد الطرفين او من كلا الطرفين (مرساه واحدة او مزدوجة) ويتم نفخها بالهواء او الماء او مزيج من كليهما . تهدف هذه الورقة الى تحسين الاداء الهيدروليكي لقناة شط ال ابراهيم من خلال قياس عمق التدفق باستخدام السد القابل للنفخ ومقارنة بعمق الماء قبل وضع السد عند تصريف الندرة (2 م^3/ثانية) . تم انشاء نموذج رقمي احادية– ثنائية الابعاد وتحليلها باستخدام برنامج HEC-RAS ,ومعايرته مع النموذج الفيزيائي .اظهرت نتائج الدراسة الى زيادة ارتفاع سطح الماء خلال القناة بعد وضع السد القابل للنفخ مقارنة بالظروف الاعتيادية (عدم وجود السد) بنحو 1.32 م في منطقة السد و 0.16 م عند بداية القناه مع امتداد منحني المياه من 18 كم الى بداية القناة عند صفر كم في حين ان السرعة في مؤخر السد لا تؤثر على ارضية القناة ولا يحدث تأكل في كونكريت ارضية القناة .وان نتائج معايرة النموذج العددي مع النموذج الفيزيائي أظهرت نتائج مقبولة (تقريبا واحد) باستخدام طريقة الجذر التربيعي .

الكلمات المفتاحية: السدود القابلة للنفخ, مستوى سطح الماء، عمق الجريان، التصريف التصميمي.