Research Article

Hazim AlKhafaji*, Wisam R. Muttashar, and Walaa M. Al-Mosawi

Proposing an inflatable rubber dam on the Tidal Shatt Al-Arab River, Southern Iraq

https://doi.org/10.1515/jmbm-2022-0201
received April 16, 2022; accepted April 30, 2022

Abstract: Increasing salinity in the Shatt Al-Arab River (SAR), south of Iraq, causes a serious issue with its water quality. In the current work, the proposed inflatable rubber dam was tested and verified for its feasibility and suitability on the SAR, Southern Iraq. The proposed rubber dam investigated its performance in reducing the salt front resulting from the seawater of the Arabian/Persian Gulf. Also, the inflatable rubber dam was feasibly compared with other types of hydraulic structure regulators and discussed the probable effect and benefits for each. Results of performance evaluation on the water quality were expressed in three groups: hydraulic, geotechnical, and economic performance. Results of the analyses of hydraulic indicators showed that the tide phenomenon has a significant impact on the water quality of the SAR. The geotechnical performance was assessed in terms of soil layers and was satisfactory. Analysis of the economic performance indicators showed that the inflatable rubber dam was feasible for the SAR problem compared with other types. Finally, a proposed design indicates the viability of inflatable rubber dam technology in controlling the salt front and improving the quality of the Shatt Al-Arab River water by reducing the salinity.

Keywords: hydraulic level, regulator, rubber dam, salt front, tidal phenomenon

*** Corresponding author: Hazim AlKhafaji,** Department of Building and Construction Engineering Techniques, Al-Mustafa University College, Baghdad, Iraq, e-mail: hazim-bcet@almustafauniversity.edu.iq
Wisam R. Muttashar: Marine Geology Department, Marine Science Center, The University of Basrah, Basrah, Iraq, e-mail: wisam.muttashar@uobasrah.edu.iq
Walaa M. Al-Mosawi: Marine Geology Department, Marine Science Center, The University of Basrah, Basrah, Iraq, e-mail: walaa.khudher@uobasrah.edu.iq

1 Introduction

A rubber dam is an inflatable and deflatable hydraulic structure that can be operated as a regulator on rivers [1]. Indicated advantages and uses of the rubber dam, such as their ease of installation, low cost, and ease of inflating and deflating, rapidly make it very practical in controlling the tidal phenomena and the flood damage [2]. New guidelines for the optimum design of rubber dam deflectors were provided by [3], where other researchers later recommended that the frequent rubber dam sediment cleaning by partial deflation allows fewer overflows [4]. It is not practical to deflate the rubber dam completely, since it needs a long period for the water to reach the required level, especially during low seasons. Comparison of the effectiveness of inflatable rubber dams having a metal gate with other rubber dams is crucial for evaluating the economic aspects. The inflatable rubber dam with a metal gate reveals more economical with an increase in the length proportional to its span(s) than others. The rubber dams are easy to operate and maintain with low cost-effect [5].

The technology of the inflatable rubber dam has been developed by using a rubber dam with a metal gate to be more feasible than other traditional technologies. This modern one allows an increase in the capital cost by approximately (8%) compared with a traditional rubber dam. Also, it is suitable in small and medium river projects for both tidal and non-tidal channel locations [6]. For example, the inflatable rubber dam has been very useful to disallow saltwater from the Caspian Sea during the tide conditions at the tidal Babol river [7]. A number of studies and investigations have been carried out by, in particular, Marine Science Center (MSC) – the University of Basrah, and other research councils to evaluate the environmental impacts of increasing the salt intrusion at the Shatt Al-Arab River (SAR) from the gulf since 2001. As the problems prompted, the Iraqi government has demanded to investigate its causes, risks, and challenges, and to urgently provide various solutions, which contribute to preserving the environment and restoring its biological balance. Thus, due to this serious issue of salt front entering the SAR from the Arabian/Persian Gulf, a hydraulic barrage structure on the SAR south of Iraq has been proposed to install for controlling the salt front and reducing the salinization of the river freshwater [8].

The current study, however, proposes an inflatable rubber dam on the Shatt Al-Arab River, south of Iraq. To do so, the suitability and performance of this modern type of dam to reduce the salt front from the Arabian/Persian Gulf were studied, evaluated, and compared with other hydraulic structures, such as the barrage dams.

2 Shatt Al-Arab River

The SAR is formed by a confluence of the Tigris and Euphrates rivers in Qurna city, north of the Basra, consisting of five main locations, Qurna, Basrah, North Abu Flous Port (NAFP), Seeba, and Faw as shown in Figure 1. The SAR runs for approximately 200 km to pour into the northwestern Arabian/Persian Gulf, south of the Faw city. The average width of the river is about 400 m, and its depths range from 6 to 20 m. The SAR is a tidal river in which tidal energy is basically generated from the Arabian/Persian Gulf. The river, therefore, is characterized by a semi-diurnal (mixed) tidal system (two floods and ebbs per day with a difference in amplitudes). The flood currents are usually higher than the ebb currents but less speed [9].

2.1 Salt front

The water of the SAR suffers from severe salinity as a result of the presence of chloride (CL) salts recorded (2,893–26,127 mg/L). The percentage, which exceeds 50% of the salts in the SAR water (SO4), comes from the Gulf water and their concentrations are being higher toward the mouth of the river, and it is called the salt front. The lack of freshwater imports in the Tigris and Euphrates rivers, as a result of the construction of many dams in the source countries, and has affected the incoming discharges to the SAR. They were 1,189 m^3/s in September 1991, while these discharges decreased to less than 20 m^3/s in August 2018. This decrease led to an increase in the total concentrations

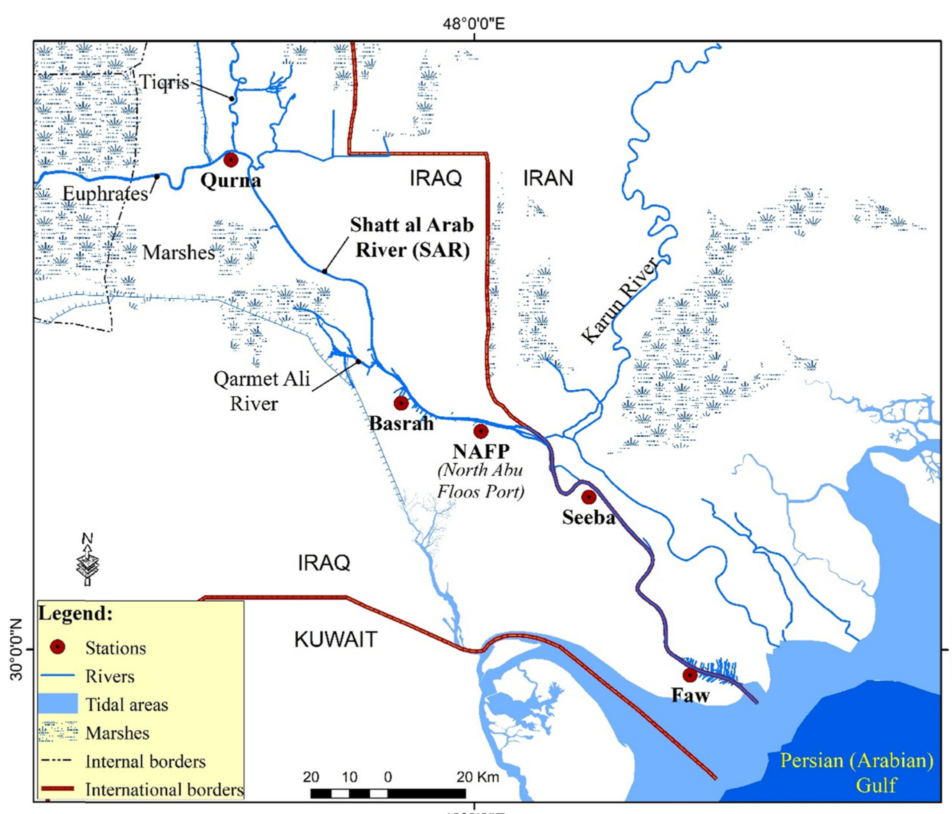

Figure 1: SAR site, 48°1′57.25″E and 30°27′28.67″N (mapped by authors).

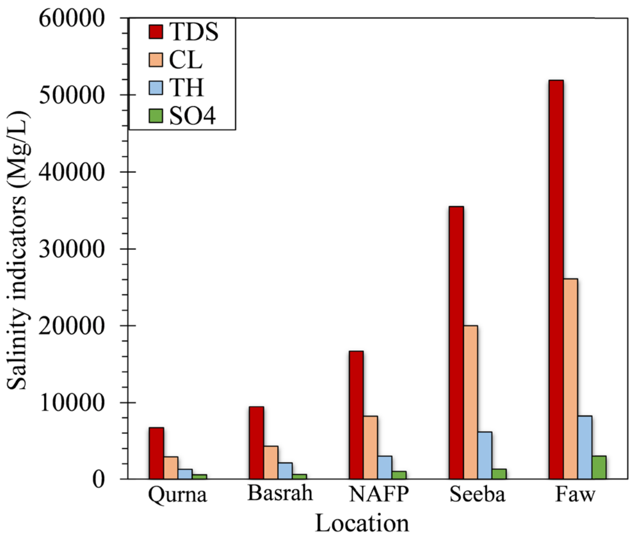

Figure 2: TDS, CL, TH, and sulfur salts (SO_4) of the water of the SAR for different locations recorded in August 2018 [10].

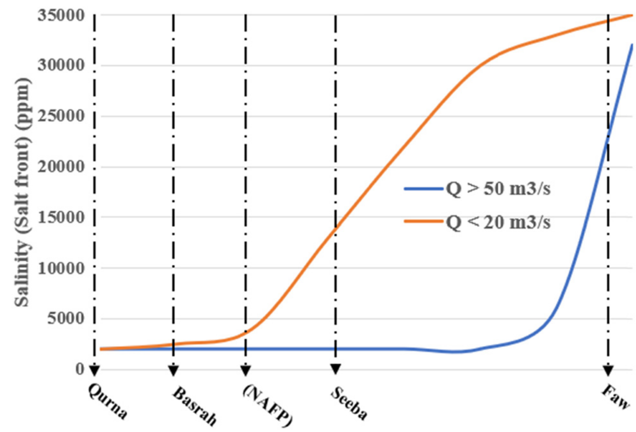

Figure 3: Effect of the salt front from the Arabian/Persian Gulf with incoming discharge in SAR (delineated by authors based on the literature).

of dissolved solid salts (TDS) and salinity to very large levels. The TDS values were recorded between 6,693 and 51,860 mg/L in different locations of SAR, and the total hardness (TH) values were 1,267–8,064 mg/L [10]. Figure 2 presents the salinity in form of TDS, CL, TH, and sulfur salts (SO4) for five different locations in SAR. This phenomenon negatively affected the biological diversity in the area and led to the disturbance of the natural ecosystems and deterioration of the quality of the freshwater.

The HEC-RAS (Hydrologic Engineering Center-River Analysis System) program was employed to study the salt front effect in SAR. The different simulation models showed at the low incoming flow, less than 20 m^3/s in SAR, and the salt front has an effect starting from the NAFP location, where its effects (salt front) can be prevented by increasing the incoming freshwater discharges in SAR by more than 50 m^3/s, as shown in Figure 3. However, the current water policy of the upstream countries imposes restrictions on the volume of water releases, and increased discharges have become difficult according to the current conditions and need other solutions to prevent the freshwater deterioration of the Shatt Al-Arab River. Among the proposed solution is a construction of a hydraulic structure regulator, such as weir, barrage, or rubber dam, to control the salt front at the time of the sea tide.

Choosing the suitable hydraulic structure regulator and its location to control the Shatt Al-Arab River problem requires studying the hydraulic characteristics, geotechnical considerations, and sediments profiles of SAR.

2.2 Hydraulic characterization

Table 1 presents the hydraulic properties of SAR at five sites, including Qurna and Basra city representing near upstream, and downstream of NAFP, Seeba, and Faw, respectively [11]. Figure 4 shows the various water depths in SAR for different locations starting from Qurna and ending at Faw.

2.3 Geotechnical consideration

The soil layers are mainly composed of soft clay and silt to the depth of 20 m. After this depth, the stiffness of the layers increases and reaches the highest standard penetration test values (>50) at 23 m of depth and greater (Figure 5). This deep layer presents hard and/or very dense sandy layers that are necessary, as a high bearing capacity layer, for deep foundations of the high load constructions.

2.4 Sediment profiles

SAR sediment profile is a part of the Tigris–Euphrates river sedimentary system. Most sediments of the system are fine-grained (mud). The large discharges of SAR in the past carry huge sediment loads deposited mostly at the mouth of the river. It is worth noting that there has been a remarkable contribution of the freshwater and sediment loads coming from the Iranian Karun river meeting SAR at a distance of 127 km (Figure 1). Karun river significantly increases the sediment loads deposited

Table 1: SAR hydraulic property parameters (MSC 2018)

Hydraulic properties	Qurna	Basrah	NAFP	Seeba	Faw
Width (m)	202	370	400	404	650
Depth (m)	5.7	10	6	11.8	10
Max velocity (m/s)	0.6	0.5	0.5	0.61	0.95
High water level (m)	0.15	1.8	0.45	1.30	2.1
Low water level (m)	0.1	0.6	−0.40	−0.25	−0.7
Average tidal range (m)	0.25	1.2	0.85	1.55	2.80
Measured ebb discharge (m^3/s)	104	835	—	344	820
Measured flood discharge (m^3/s)	99	690	—	258	635
Area (m^2)	873	3300	4347	2958	3779
Hydraulic radius (m)		7.36	5.12	—	5.02
Roughness of the bed	0.025	0.037	0.035	0.026	0.017
Conveyance (m^3/s)		—	25694	—	—
Wet perimeter (m)		476	607	363	761
d_{90} (mm)	0.0016	0.0014	0.0034	—	0.0035
d_{50} (mm)	0.025	0.016		—	0.027
Mean sea level (m)	—	1.92	—	—	1.70

in the southern part and mouth of SAR yet positively impacts the SAR freshwater. The riverbed sediments are mostly fine-grained (mud) sediments and become finer as heading toward the mouth of the river. This is ascribed to the widening of the channel cross section to the south and the low longitudinal slope of the river channel (1 cm/km) as well. Slowing down the velocity of the river currents stimulates the fines (mud) to deposit. Contents of the clay, silt, and sand range between 40–48, 50–59, and 0.4 and 1.0, respectively, at the Abu Flous port location [12,13] (Table 2).

It is evident that NAFP location will be a suitable selected location for constructing the hydraulic structure regulator in SAR to control the tidal effects and prevent the salt front.

3 Hydraulic structure regulators

The proposed hydraulic structure regulators must conserve freshwater on the upstream side and avoid interfering with the inflow of the saline tidal water. Several studies presented the advantage and disadvantages of using weirs, barrages, and rubber dams as regulators in the tide river [14–23]. Table 3 summarizes the comparison

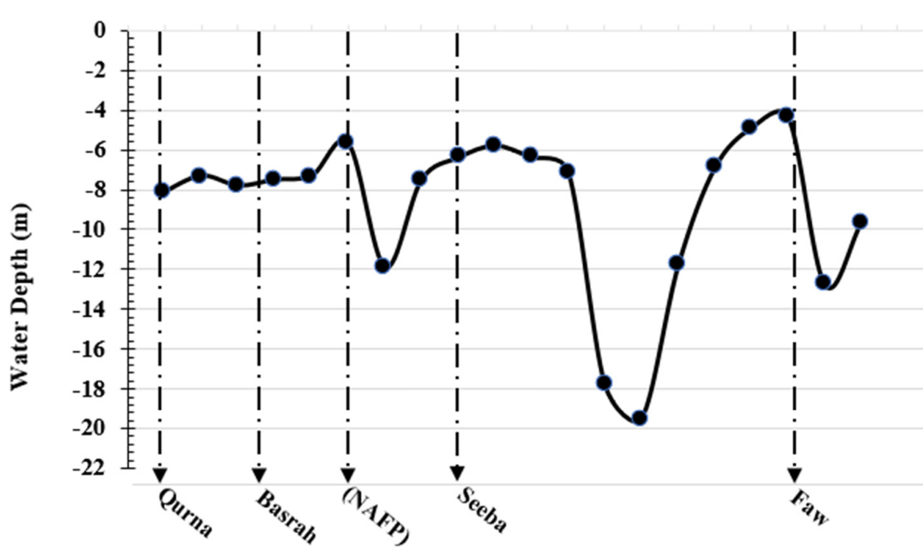

Figure 4: SAR water depth profile, modified after [11].

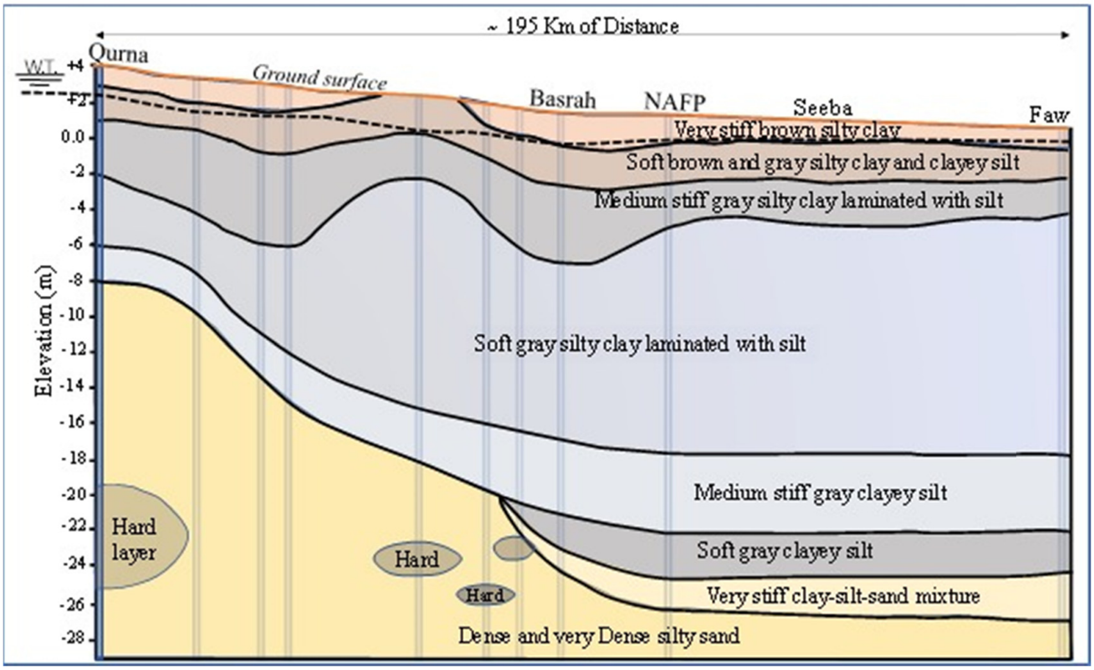

Figure 5: SAR soil profile, modified after [24].

Table 2: Sediment types for selected sites on SAR

Site	Sand (%)	Silt (%)	Clay (%)	Sediment class
Qurna	4–8	50–62	30–38	Clayey Silt with few sand
Basrah	2–11	43–55	40–34	Clay-Silt with few sand
NAFP	0.4–1.0	59–50	41–48	Clayey Silt
Seeba	2–10	43–50	35–45	Clayey Silt
Faw	5–10	70–75	20–25	Clayey Silt with few sand

between three proposed hydraulic structures regulators (weir, barrage, and inflatable rubber dam) tested in SAR. The comparison showed that the barrage and the inflatable rubber dam are feasible choices. Since the salt front only affects the river water during flood conditions, there is no effect during the ebb conditions. The inflatable rubber dam will be more feasible than the barrage structure; furthermore, the NAFP site, which has a total water depth of less than 8 m, will be a suitable location for the inflatable rubber dam.

3.1 Inflatable rubber dam

The traditional inflatable rubber dam consists of a rubber air bladder made from ethylene propylene diene monomer rubber, which can be both inflated and deflated as required. A concrete leveling pad is required to install the rubber dam to the river bed and ensure that the dam has the appropriate structural capacity to resist hydrostatic pressures. The inflatable rubber dam is vulnerable to damage and punctured due to sharp objects carried by river water, which is one of the major disadvantages. However, using the inflatable rubber dam with a metal gate substantially provides high protection from vandalism and

Table 3: Proposed hydraulic structure regulator comparison

Regulator type	Control				
	Salt front	Groundwater level (U/S)	Sediment accumulated	Traffic river navigation	River water depth with a height ≥ 8 m
Weir	Efficient	Not efficient	Not efficient	Not efficient	Not efficient
Barrage	Efficient	Efficient	Restricted efficient	Efficient	Efficient
Rubber dam	Efficient	Efficient	Efficient	Efficient	Not efficient

Figure 6: Proposed inflatable rubber dam with a metal gate in SAR-NAFP location (plotted by authors using Google Earth Image).

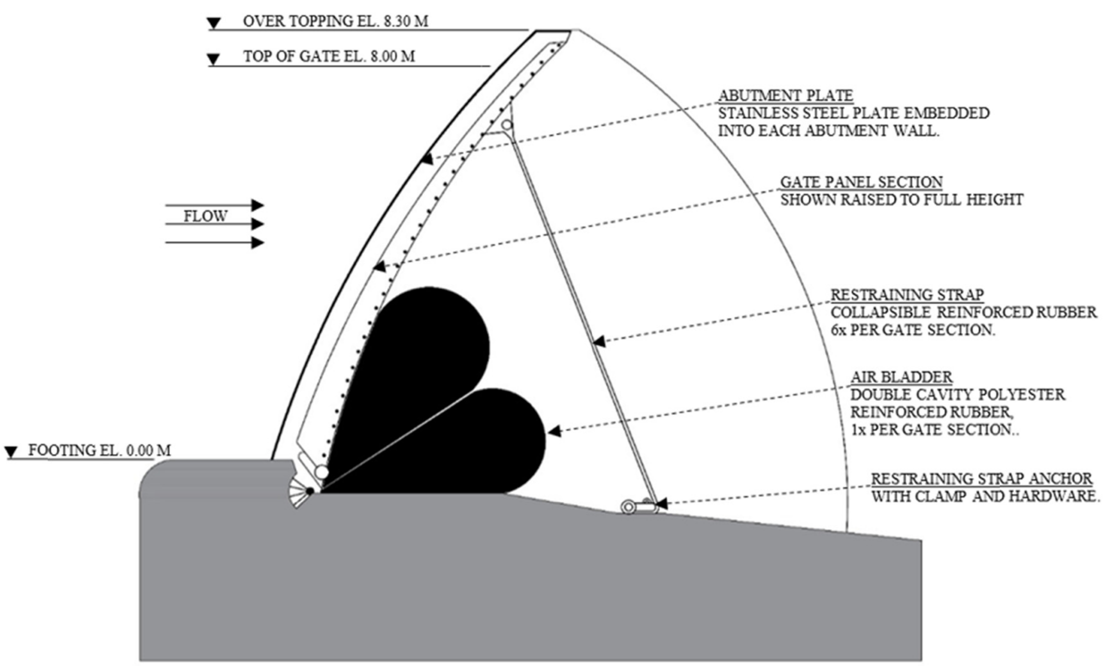

Figure 7: Proved design of the proposed inflatable rubber dam with a metal gate in SAR.

increases the integrity of the rubber dam installation compared to the traditional rubber dam. The metal gate consists of a series of metal sheets connected together through watertight inter panel seals that install longitudinally along the rubber dam width. The gates are raised using the rubber air bladder inflated to reach the required dam height specified for the project. The rubber dam with a metal gate provides approximately 30% greater discharge compared to the traditional rubber dam. The inflatable rubber dam with a metal gate in the NAFP site, a tidal environment not far from the sea, and separates downstream saline water as it impounds upstream freshwater flow in the SAR.

Table 4: Inflatable rubber dam with metal gate design parameters

Parameters	Value
Length of rubber bag (m)	67
Height of the rubber bag (m)	6
Thickness of rubber bag (mm)	8
Lifetime of the bag (years)	30–40
Duration of air filling in the bag (min)	40–50
Rubber dam coefficient (provided by Obermeyer Hydro, Inc.)	3.3
Pump capacity (m^3/s)	120
Metal gate height (m)	8

The main mechanism of using the rubber dam in the tidal river is to conserve freshwater on the upstream side and prevent the inflow of the saline tidal water from the downstream.

3.1.1 Proposed design

The suitable hydraulic property parameters for the selected regulator location must not affect the river navigation traffic in SAR. It was determined that six 8 m-high by 67 m-wide inflatable rubber dam with metal gates a total length of 402 m spaced about 1,600 m apart from the upstream Abo Flous port would provide the most economical and best technical solution, as shown in Figure 6.

The proposed design of inflatable rubber dams with a metal gate (Figure 7) was checked and proved by one of the biggest and pioneer companies in the design and supply the inflatable rubber dams, namely, the Obermeyer hydro company (http://www.obermeyerhydro.com) and its partner Dyrhoff Company (http://www.dyrhoff.co.uk). The company has rechecked the suitability of the proposed design parameters for the dams to comply with the hydraulic characteristics parameters of the Shatt Al-Arab River at the NAFP location as depicted in Figure 6. The concrete footing for the rubber dam with the gate can be recessed to allow the full extent of the gate to be placed below the channel bottom when deflated. This promotes an undisturbed flow regime over the top of the dam location during a severe storm event when the dams are subsequently deflated. Table 4 introduces the design parameters for an inflatable rubber dam with a metal gate in the NAFP location.

4 Conclusion

The inflatable rubber dam was investigated in this study to reduce the salt front from the Arabian/Persian Gulf. The study concluded that:

- Using an inflatable rubber dam with a metal gate to prevent the vandalism against sharp objects carried out by river water.
- According to SAR problem conditions, the employed inflatable rubber dam to control the salt front is more economical and efficient than other hydraulic structures.
- Based on the manufacturing product limitations, the inflatable rubber dam technology is feasible in small and medium rivers with a water depth less than 8 m. Otherwise, using other technologies will be more economical.
- The rubber dam with a metal gate provides approximately 30% greater discharge compared to the traditional rubber dam.
- The NAFP location will be a suitable location for constructing the hydraulic structure regulators.

Funding information: No funding involved.

Author contributions: All authors accepted responsibility for the entire content of this manuscript and approved its submission.

Conflict of interest: No conflict of interest.

References

[1] Tam PWM. Use of rubber dams for flood mitigation in Hong Kong. J Irrig Drain Eng. 1997;123(2):73–8.
[2] Novak P. Hydraulic structures. J Hydraulic Res. 2008;46:715.
[3] Chanson H. Use of rubber dams for flood mitigation in Hong Kong – Discussion. J Irrig Drain Eng-Asce. 1997;124:181–2.
[4] Tam PWM, Zhang XQ. Management of rubber dams in Hong Kong. Can J Civ Eng. 1999;26(2):123–34.
[5] Zhang XQ, Tam PWM, Zheng W. Construction, operation, and maintenance of rubber dams. Can J Civ Eng. 2002;29(3):409–20.
[6] Hasan S, Kabir I. Feasibility of natore rubber dam on Mahanonda river in Bangladesh and its performance on irrigation. Am J Eng Res. 2014;03(01):27–34.
[7] Parish Y. Evaluating the design, construction and use of rubber dams. Int J Adv Biotechnol Res. 2016;7(1):976–2612. http://www.bipublication.com.
[8] Hamdan ANA, Abbas AA, Najm AT. Flood hazard analysis of proposed regulator on Shatt Al-Arab River. Hydrology. 2019;6(3):80.
[9] Al-Badran BN. Delta of river Shatt Al Arab south Iraq. Mar Mesopotamica. 2004;19(2):311–22.
[10] Hamdan ANA, Al-Mahdi AAJ, Mahmood AB. Modeling the effect of sea water intrusion into Shatt Al-Arab River (Iraq). J Univ Babylon Eng Sci. 2020;28(28):210–24.
[11] MSC, Marine Science Center. Environmental impact Study of Dams proposed on Shatt al Arab River, southern Iraq. Internal Report; 2018.

[12] Al-Mulla S. Geomorphological study of the Shatt al Arab Basin using remote sensing techniques [dissertation]. Basra: Fine College, the University of Basrah; 2005.
[13] Muttashar WR, Bryson LS, Al-Humaidan ZA. The use of particle size distribution integrated with consistency limits for experimentally simulating fine-grained sedimentary units. Arab J Geosci. 2021;14:2436. doi: 10.1007/s12517-021-08812-7.
[14] Tam PWM. Application of inflatable dam technology–problems and countermeasures. Can J Civ Eng. Apr 1998;25(2):383–8.
[15] Indian Standard. Hydraulic design of Barrages and Weirs, Guidelines. New Delhi: Bureau of Indian Standards; 1989.
[16] Maatooq J, Alwash H, Al-Khafaji H. Analysis seepage and uplift pressure for Al-Shamiya Barrage south of Iraq. Eng Tech J. 2015 December;33:838–44.
[17] AlKhafaji H, Imani M, Fahimifar A. Three-dimensional bearing capacity analysis of rock foundations subjected to complicated loadings, case study: Shafaroud dam. AUT J Civ Eng. 2020;5:257–68. https://ajce.aut.ac.ir/article_3965.html%0Ahttps://ajce.aut.ac.ir/article_3965_2569add08fabb6bf6690762217ce6f1b.pdf.
[18] Alkhafaji H, Imani M, Fahimifar A. Determining the stress-settlement distribution of a gravity dam foundation considering different water levels using finite element method. Lect Notes Civ Eng. 2021;112:217–27.
[19] Karkush MO, Sabaa MR, Salman AD, Al-Rumaithi A. Prediction of bearing capacity of driven piles for Basrah governatore using SPT and MATLAB. J Mech Behav Mater. 2022 Jan 1;31(1):39–51.
[20] Karkush MO, Ahmed MD, Sheikha AA, Al-Rumaithi A. Thematic maps for the variation of bearing capacity of soil using SPTs and MATLAB. Geosciences. 2020 Sep;10(9):329.
[21] Hekmatzadeh AA, Zarei F, Johari A, Torabi, Haghighi A. Reliability analysis of stability against piping and sliding in diversion dams, considering four cutoff wall configurations. Comput Geotech. 2018;98:217–31.
[22] Alkhafaji H, Meysam I. Numerical simulation of driven piles under static axial compressive load testing using finite element model. In: Karkush MO, Choudhury D, editors. Geotechnical Engineering and Sustainable Construction. Singapore: Springer; 2021. p. 305–31. doi: 10.1007/978-981-16-6277-5_24.
[23] Johari A, Heydari A. Reliability analysis of seepage using an applicable procedure based on stochastic scaled boundary finite element method. Eng Anal Bound Elem. 2018;94:44–59. doi: 10.1016/j.enganabound.2018.05.015.
[24] Al-Badran BN, Mahmood RA. Geotechnical properties and aerial distribution of bearing strata along the Shatt Al-Arab Riverbank from Qurna to Faw. Mesopotamian J Mar Sci. 2006;21(1):45–56.