JES, Vol. 51, No. 1, Jan 2023 DOI: 10.21608/JESAUN.2022.151656.1156 Part A: Civil Engineering

Journal of
Engineering Sciences
Faculty of Engineering
Assiut University

مجلة
العلوم الهندسية
كلية الهندسة
جامعة أسيوط

journal homepage: http://jesaun.journals.ekb.eg

Using Dynamic Tests to Evaluate Structural Status of Barrage Before and After Rehabilitation

Received 21 July 2022; Revised 26 October 2022; Accepted 27 October 2022

Yasser El-Hakem[1]
Dina A. Emarah[2]

Keywords
Egypt; River Nile; Barrage; Time Histories; Rehabilitation; Dynamic Tests.

Abstract

Many old barrages along the Nile River face different problems, such as increased discharge or/and differences in head, scour, and material aging. Therefore, the irrigation networks need to be enhanced by upgrading the main controlling water structure, especially on the Nile River. As a result of examining the structural integrity of the main Nile River barrages, the decision was made to replace many of the Nile river's defected barrages, with the exception of Zefta barrage, which was rehabilitated. The decision to rehabilitate Zefta barrage was chosen according to the structural status, affected area, and expected life after repair. Moreover, the decision was taken after comparing the cost of replacement and rehabilitation of the barrage. Heavy massive shear deformation stiffened structures are rarely tested by implementing such techniques contrary to elastic structures such as bridges. This study aims mainly to evaluate the structural status of Zefta barrage before and after recent rehabilitation using dynamic tests. This paper presents the collected structural data and test results of the Zefta barrage. The results indicate that the recent rehabilitation of the Zefta barrage significantly influences structural behaviour and barrage safety.

1. Introduction

Several existing hydraulic structures are sensitive and affected by dynamic loads [1-2]. In addition, many are over age and need to assess and provide recommendations and enhancement if required [3-4]. Hydraulic structures such as barrages, regulators, and pump stations are classified based on function into eleven types: flow control structures, flow measurement structures, and division structures [5-7]. Barrage is a type of control structure, which consists of many gates. Gates could be closed or opened to control the amount of

[1] Professor, Construction Research Institute, NWRC, Delta-Barrage, 13621, Egypt. yelhakem@yahoo.com
[2] Assoc. professor, Construction Research Institute, NWRC, Delta-Barrage, 13621, Egypt. dina_emarah@yahoo.com

https://doi.org/10.21608/JESAUN.2022.151656.1156

water that passes through. In addition, it contains other structural elements such as piers, arches, locks, abutments, and retaining walls. It is listed under the control structure category and is used to permit transportation over a water flow [8].

Due to water scarcity and the role played by hydraulic structures, the Ministry of Water Resources and Irrigation (MWRI) is undertaking a program to either rehabilitate or reconstruct the old main barrages and regulators along the Nile River. Most existing regulators evaluate the structural and hydraulic situation and determine which needs rehabilitation or replacement. Recently MWRI had technical evaluation reports of different regulators, for example, the technical reports issued in the last two years for Al- Bagoria, Danshal, and Bahr Hafeer Shehab Al-Deen [9-11]. Moreover, the said program includes the rehabilitation of Zefta barrage on the Damietta branch of the Nile River [5] and the neighboring hydraulic structures of Mansouria, Omar Bey, and Abassi regulators. Zefta barrage is in the Nile Delta some 88 Km downstream of the Damietta barrage. Zefta barrage was constructed between 1901 and 1903 but completely remodeled between 1952 and 1954 to increase upstream levels and discharges. Moreover, it required an increase in performance and strength of structure for new conditions of loads, water pressure, and traffic loads over the barrage, this needed to increase the lengths of piers, raft, and bridge width.

Monitoring and maintenance of the barrage were done in several stages from 1994 until 2014. In addition, a structural assessment was performed on the structure of the barrage from 1996 to 2013. The results were gathered and studied to assess the property and the quality of the constituting material. Moreover, loading tests on the barrages monitoring the horizontal and vertical movement were carried out. In addition, the piezometers were established in the barrage from 1994 to 1996. Finally, comprehensive maintenance of the barrage gates and cranes was done from 2003-2004. From 2003 to 2005, a Pre-feasibility study of barrages was established [12-13]. The study aims to evaluate the current structural situation of the barrages and calculate the expected risks to the survival of the situation. This is required to identify urgent work needed for rehabilitation or replacement and study the feasibility of raising water levels in front of barrages. The consultant recommended the rehabilitation option, where the barrage needs necessary maintenance and monitoring of the cracks depending on the permissible traffic load.

From 2011 to 2014 [14-15], a technical, environmental, and economic feasibility study was done. To perform this study, ten openings on the right side next to the new lock and detects cracks were dewatered. The barrage floor was examined, and piers showed no major defects, and these elements do their functions perfectly. The study provided some recommendations to rehabilitate the barrages by dewatering and detecting another 20 openings on the left side. The rehabilitation includes repair of the barrage body, piers injection, and maintenance of the electromechanical parts required for the gates.

The recent rehabilitation works of the barrage were divided into two stages, the first stage included drying, detection, and rehabilitation of the raft for 20 openings on the left side. The second stage involved strengthening and rehabilitation the number 30 openings on the right side and strengthening many hydraulic structures. Economically, according to the results of many studies, building a new barrage is very expensive so upgrading and enhancing Zefta barrage as old masonry hydraulic structures in Egypt is an extreme necessity. Some studies have produced different methods to upgrade, rehabilitation, and solution repairing hydraulic structures [16-17].

The dynamic tests were one of the methods used to evaluate the rehabilitated hydraulic structures. Several studies [18-19] have addressed the evaluation of dynamic characteristics, dynamic identification and condition assessment, strength assessment, and repair of old masonry structures. The dynamic behaviour of several structures was examined experimentally and numerically [20-21]. In addition, many researchers used dynamic tests to determine the dynamic properties such as natural frequencies and mode shapes, which mainly affect the dynamic response of the selected structure [22-23]. Such techniques are rarely used in hydraulic massive structures. Elwy et al. [24] estimated the real dynamic properties of the Old Rayah Menoufi barrage to find its behaviour under seismic loads. ANSYS FE Software was used to simulate the barrage in 3-dimensional finite element (FE) models. The dynamic properties of the barrage in terms of mode shapes, natural frequencies, and damping ratio were investigated experimentally and numerically. The results indicated that the dynamic test is a good tool to examine the structural status of the regulator. Also, when the structure consists of typically replicated bays, choosing an intermediate vent to be tested, can give an adequate, realistic indication of the structure's behavior. Moreover, for long monitoring of this kind of structure, the Experimental Modal Analysis (EMA) is an effective and less time-consuming tool that gives an indication of the real state of the structure. Where any change in the stiffness or the occurrence of any damage will be easily noticed and reversed based on the value of the natural frequencies. The natural frequency depends only on the mass and the stiffness of the structure.
This study is carried out to examine the efficiency of the recent rehabilitation scheme of Zefta barrage. The dynamic testing was done before and after rehabilitation. The paper presented testing procedure and equipment, test setup, data collection and analysis, initial testing stage, second testing stage, obtained frequencies and mode shapes from both tests as well as the results and main finding.

2. Zefta Barrage Description

Figures 1 and 2 show the photo and general layout of Zefta barrage, respectively. Zefta barrage consists of a disused ship lock on the left bank, and a new ship lock on the right bank. The barrage constitutes a set of 50 vents (all identical) between the two ship locks, each 5 m wide, constituting a total discharge width of 250 m. In addition, a weir was constructed in 1925, located 200 m downstream of the barrage, and built to limit the water head difference between the upstream and downstream faces of Zefta barrage that was induced by an increase of the upstream operation level.
The barrage is equipped with 50 double gates (i.e., one double gate per vent). Each double gate consists of an upper and a lower roller gate. Each gate is operated independently (but not simultaneously) by a gantry crane placed on the top of the barrage. Slots are provided upstream and downstream of the gates for each vent to allow for installing stop log elements. Gates, grooves, and gantry cranes were replaced by new equipment in 1954. The description of Zefta barrage is given in **Table 1**.

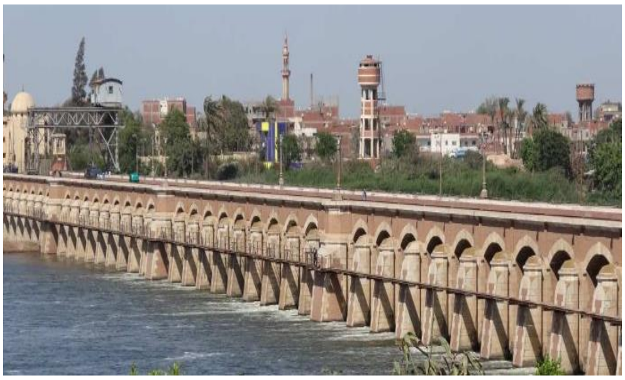


Fig. 1: Photo of Zefta barrage.

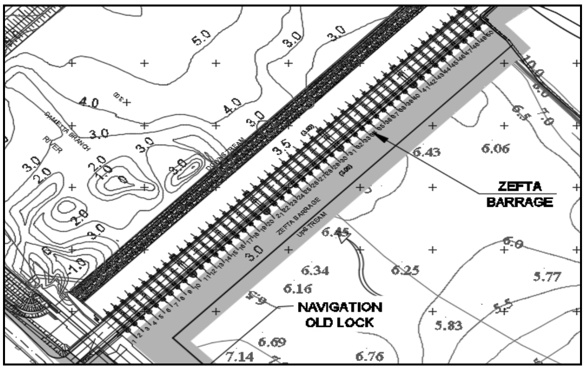


Fig. 2: General Layout of Zefta barrage.

Table 1: Structural parameters of Zefta barrage.

Structural Parameters	Values
Number of openings of the barrage	50
Width of vents of the barrage	5 m
Number of anchored gates	2
Width of the road above the barrage	9 m
Two sidewalks width (total)	3m
Number of overhead winches to lift all gantry gates	2
Navigation lock width	12 m
Navigation lock length (not used).	80 m
Width of first-class navigational lock	17 m

3. Zefta Barrage Rehabilitation

Different problems face old hydraulic structures, such as material deterioration and demand for increasing discharges [16, 25]. In addition, the assessment, upgrade, rehabilitation, and repair of old hydraulic masonry structures have been carried out through the years with the development in understanding their behavior and knowledge [26-29]. The traditional techniques for repairing or upgrading hydraulic structures were mainly increasing cross-section and/or adding a concrete jacket. However, the structure's hydraulic efficiency may affect by adding a concrete jacket. Therefore, the need for strengthening without any hydraulic side effects leads to replacing masonry with reinforced concrete or using steel jackets. Ezzeldin and Khalil [16] presented the upgrading and repairing techniques of major hydraulic structures in Egypt. These techniques were supporting the lock abutment with four different systems: strut system, increasing the raft's thickness by adding concrete blocks of 1.0 m depth, replacing the overstressed part of the raft with reinforced concrete, and developing an artificial crack for dissipating the over stresses.

Zefta barrage was rehabilitated twice. Once in 1952, where the raft was thickened and extended and the piers with the bridge were extended. However, the pier extension was carried out in plain concrete with brick facing rather than the original total brick. The second rehabilitation scheme was carried out over the last five years where reinforced micro–piles were introduced in the old part of the piers. The newer addition was considered sound and strong. In addition, the raft was thickened in between the piers with reinforced concrete [30-31].

4. Experimental Modal Analysis (EMA)

Modal testing has become a popular means of studying the dynamic response and defining the dynamic properties of structures. Recently, massive efforts have been made to combine and correlate modal testing with analytical methods in structural dynamics modeling. Since modal testing directly deals with the real structure, the models produced by modal testing are invariably used to identify analytical modeling problems and update analytical models. But because modal testing is becoming more popular and essential, it is time to take a strategic step to improve the quality of experimental methods. Experimental Modal Analysis (EMA) began in the 1940’s. However, since the development of the Fast Fourier Transform (FFT) and the digital minicomputers in the 1960’s, a new modern experimental modal analysis has started [24].

The dynamic testing of a lively full-scale Podgorica footbridge was described by Živanovi et al. [32]. The test was conducted using 14 measurement points to capture the identified mode shapes of the pre-finite element model. The study showed the correlation between experimental results and a very detailed finite element model. The bending stiffness of inclined columns and the stiffness of girder end supports in the longitudinal direction were identified as the modeling parameters. Haritos et al. [33] carried out dynamic testing for the skew bridge. The dynamic test was applied using the experimental dynamic testing system package of Melbourne University in its "shaker mode of operation. Two excitation points were selected for the dynamic testing to excite as many mode shapes as possible. These mode shapes were predicted to lie in the natural frequency range (0 to 50 Hz). EMA in cooperation with bridge inspection and traditional material tests can provide sufficiently accurate results. This technique enhances the fine-tuning of numerical models of civil engineering structures. Calcian et al. [34] performed ambient vibration tests on an arch dam. These tests were carried out under two different working conditions to evaluate the effect of the two different reservoir water levels on the dynamic properties of the dam. The experimental vibration analyses were carried out using a simple instrumental layout. The analyses showed a variation in the first two natural frequencies of the dam related to the effect of the impounded water in the artificial reservoir. Elwy et al. [24] determined the structure's response under dynamic testing by a group of sensors, located at various measurement points along the structure and concluded that the location of the sensors plays a potential role to capture the predicted response that matches the FE model.

5. Methodology and Equipment

For testing these types of structures, there is a need for a pre-finite element model to predict the results of the EW and control the factors that affect the accuracy of the results. According to preliminary finite element modeling done by CRI staff before dynamic tests, the number of these points is set to attain the spatial resolution necessary for accurately detecting the most important vibration mode shapes.

The sampling frequency is usually controlled by the characteristics of the equipment being used. However, to avoid errors, the sampling frequency should exceed at least two times the highest frequency captured by the sensors or the cutting frequency of analog low-pass filters that might be included in the measuring chain. The number of mode shapes that can be identified is limited according to the chosen sampling frequency. Therefore, only the modes with a frequency lower than one-half of the sampling frequency are observable. Finally, the last step is to choose the length of the time series collected in each setup. Moreover, in most cases, the adopted time length is conditioned by the time available to perform the test. Researchers with a lot of experience say that the length of the time windows that are collected should be one thousand to two thousand times the period of the structure's fundamental natural frequency [24].

Structure vibration can be measured in velocities, accelerations, displacements, or even strains, but accelerations are usually preferred. Even though many different types of acceleration sensors work in different ways and have the right properties to measure vibrations, force-balance accelerometers are the best sensors for testing vibrations in structures. In traditional measuring chains, the continuous electrical signal produced by each sensor is transmitted by electrical cables to a data acquisition system. A digital card controls the measuring process and converts analog signals to digital ones. Then, adopted cards transmit the digital data to a laptop computer for data storing and analyzing. The proceedings of data acquisition are shown in **Fig. 3**.

An accelerometer is the main equipment to measure the structural response regarding acceleration or velocity. Then it transmits the measured signal to be recorded on a computer. In the current study, adopted accelerometers were Piezo electronic accelerometers of type ICP, Model No. 393A03. These accelerometers have been calibrated to comply with ISO10012-1, and former MIL-STD-45662A and are traceable to NIST. **Table 2** shows the specifications of the adopted accelerometers. The accelerometer is connected to a cable of 0.05 mm^2. In addition, standard cables are used for connecting different types of elements. These cables are sorted into two types (white cable connects the sensor to the conditioner and black cable connects the conditioner with the PCD card).

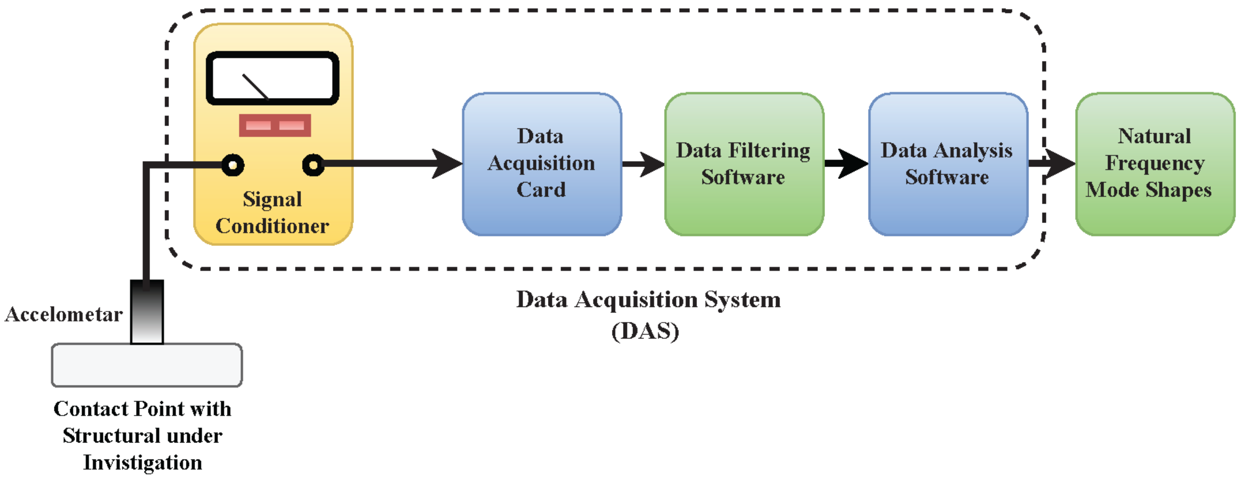


Fig. 3: Data Acquisition System (DAS) Configuration.

A data acquisition system involves selecting the types of sensors to be used, including the locations where the sensors should be placed, the required bandwidth and resolution, the number of sensors to be used, and the data acquisition/storage/transmittal hardware. In addition, economic considerations play a major role in deciding the type and extent of the data acquisition system that can be deployed. The components of a data acquisition system are signal conditioning, data acquisition cards, data acquisition software, and data analysis software. Signal conditioners are used to power ICP sensors with built-in electronics unless the capability already exists in the readout instrumentation. They provide a constant current excitation to Piezoelectric sensors. The signal conditioner specifications are listed in **Table 3**.

Table 2: Piezo electronic accelerometer specifications [24].

Specification	Value	Specification	Value
Frequency range (+ 5%)	0.5 to 2000 Hz	Temperature range	-65 to +250 0F
Frequency range (+ 10%)	0.3 to 4000 Hz	Amplitude linearity	+ 1%
Resonant frequency	> 10 KHz	Transverse sensitivity	< 5%
Amplitude range	5+ g pK	Excitation voltage	20 to 30 VDC
Voltage sensitivity	1000 Mv/g	Average mass	330 gm

Table 3: Signal conditioner specifications [24].

Specification	Value	Specification	Value
Supply voltage	27 Volt	Low-frequency response	0.05 Hz
Supply current	2 mA	High-frequency response	500 KHz
Battery life	100 Hours	--------	------

There are two types of data acquisition cards (PCD-320A and PCD-300A). The PCD-320A voltage meter card is used in combination with the PC and is capable of measuring voltage. The PCD-300A is a strain meter card. Results are obtained using the attached control software. Since a USB interface is used for connecting to the PC, the PCD-300/320A can be used by almost all PCs. This system can take measurements of 4 channels per PCD-300/320A and a maximum of 16 channels with 4 PCD-300/320A or any compatible cards, resulting in conducting measurements in a wide range from simple experiments to advanced measurements.

Control software PCD-300A is designed for collecting data from different types of sensors. The software could control the data-sampling rate, test duration, number of points, and number of channels The software can create a new file with the name of the current reading and save it on the hard disc of the used laptop. It can store the measurement record in a spreadsheet format for easy data analysis.

The PCD-300A is designed to control a maximum of four PCD-300A/320A sensors interface. It saves the measured data into a recording data file with an arbitrary name (Extension: KS1) on the PC by data recording. It can also save the preset measuring conditions to a measuring condition file with an arbitrary name (Extension: PRM). Furthermore, by reading the measuring condition file, the PCD-300A can reset the previously set measuring conditions once again.

A commercial frequency domain software called "ME'scope Visual Modal" is used for the filtering and analyzing process. This software can perform complementary analysis such as Fast Fourier Transformation (FFT) and obtain the modal parameters of the barrage. Then, consequently determining the dynamic behavior of the barrage, presented in its fundamental properties, also corresponding mode shapes. The connection of the whole equipment for the test setup is shown in **Fig. 4**. More details about the dynamic test, setup, steps, and procedure are available in [24].

In this work, the dynamic behavior of Zefta barrage is evaluated by measuring the natural frequencies and comparing mode shapes of the barrage before and after the rehabilitation process. Accelerometers were used to record the barrage acceleration response due to excitation. Eight accelerometers are distributed over the barrage surface; the generated signal by the accelerometers is transmitted to the data acquisition system throw coaxial cables. A digital card converts the measured analog signals to digital signals and transmits the digital data to a computer for analysis. The measured signal is manipulated and treated based on installed software "ME SCOPE". As mentioned above, **Fig. 3** shows the data acquisition system configuration sequences. A digital card converts the obtained signals from the accelerometers to digital signals. The data is filtered, the fundamental frequencies were determined, and the corresponding mode shapes were obtained. Eight accelerometers (CH1 to CH8) were mounted to the barrage. CH1, 2, 4, 5, 6, and 8 are horizontal channels while CH3 and CH7 are vertical channels, as shown in **Fig. 5**. The vibration of the barrage is recorded with a sample rate of 200 Hz. The suitable cut of frequency was chosen. At least, five records were selected to achieve acceptable accuracy.

6. Data Collection and Analysis

6.1. Testing before and after rehabilitation

A technique of excitation was applied to develop a lateral and vertical deformation/response of the barrage together. This technique was based on letting the truck move over the obstacle with an average speed of 60 km/h (vertical excitation), then instantly stopping the truck to apply braking force on the barrage. This braking force is responsible for allowing the lateral excitation of the barrage. This technique has mainly developed the required lateral and vertical mode shape.

After vertical excitation of the barrage, data is initially collected before rehabilitation for each channel (CH1 to CH8) as signal records in the acceleration - time response records sample. First, the collected data are processed and filtered for each record. Then, the records are subjected to digital signal processing such as filtering and averaging. The Fast Fourier Transformation (FFT) detected the fundamental first modes. FFT transforms the data from the acceleration - time domain to the acceleration-frequency domain.

In the second testing stage, the same testing procedure was conducted after the rehabilitation of the barrage. **Figures 6** and **7** show the acceleration time history for all channels before and after rehabilitation, respectively. **Figures 8** and **9** show the Fourier spectra fitted curves for all channels before and after rehabilitation. In addition, **Figures 10** and **11** plotted the shape of the fundamental modes in both dynamic tests before and after rehabilitation.

6.2. Effect of rehabilitation

Through three comparisons made between three mode shapes before and after rehabilitation, the structural status of Zefta barrage was evaluated. The concept of the comparison was based on selecting the matching mode shapes with the same deformed shape and comparing the values of its corresponding frequencies. **Table 4** concluded frequencies of three modes before and after rehabilitation in addition the variations between both tests are represented as percent ratio for testing before rehabilitation results.

Fig. 4: Equipment setup.

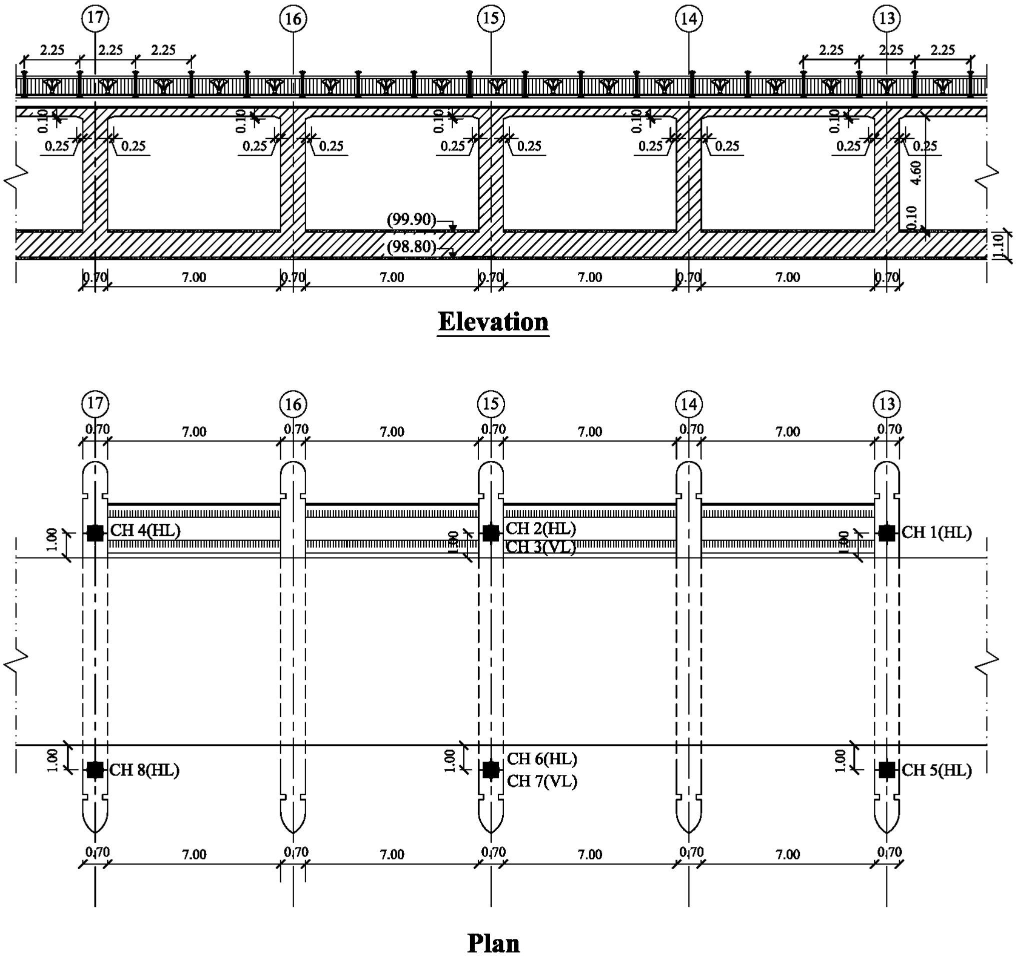


Fig. 5: Typical layout of accelerometers arrangements and orientation (CH1 to CH8)

Table 4: Obtained frequencies and the variations between both tests

Mode no.	Frequency (Hz)		Frequency (Hz)		Shape
	Before rehabilitation	Step	After rehabilitation	Step	
1	2.58	2	8.71	61	Combined
2	3.21	3	11.50	79	Combined
3	35.60	65	69.50	470	Combined

Mode 1, 2, and 3 occurred in the testing before rehabilitation (TBR) at a frequency of 2.58, 3.21, and 35.60 Hz, while the testing after rehabilitation (TAR) was at 8.71, 11.50, and 69.50 Hz, respectively. Due to the rigidity of such structures and their piers which have large frequencies, it wasn't easy to catch the same mode shapes to make the comparisons. Also, most of the modes were combined modes, so the enhancement percentage due to the barrage repair couldn't be calculated. Nevertheless, because of this research, it can be concluded that the frequencies generally increased after repair than before.
The increase in the value of frequencies after rehabilitation pointed to the large stiffness of the rehabilitated barrage. In addition, the results indicate that Zefta barrage was affected by rehabilitation and prolonged its service life.

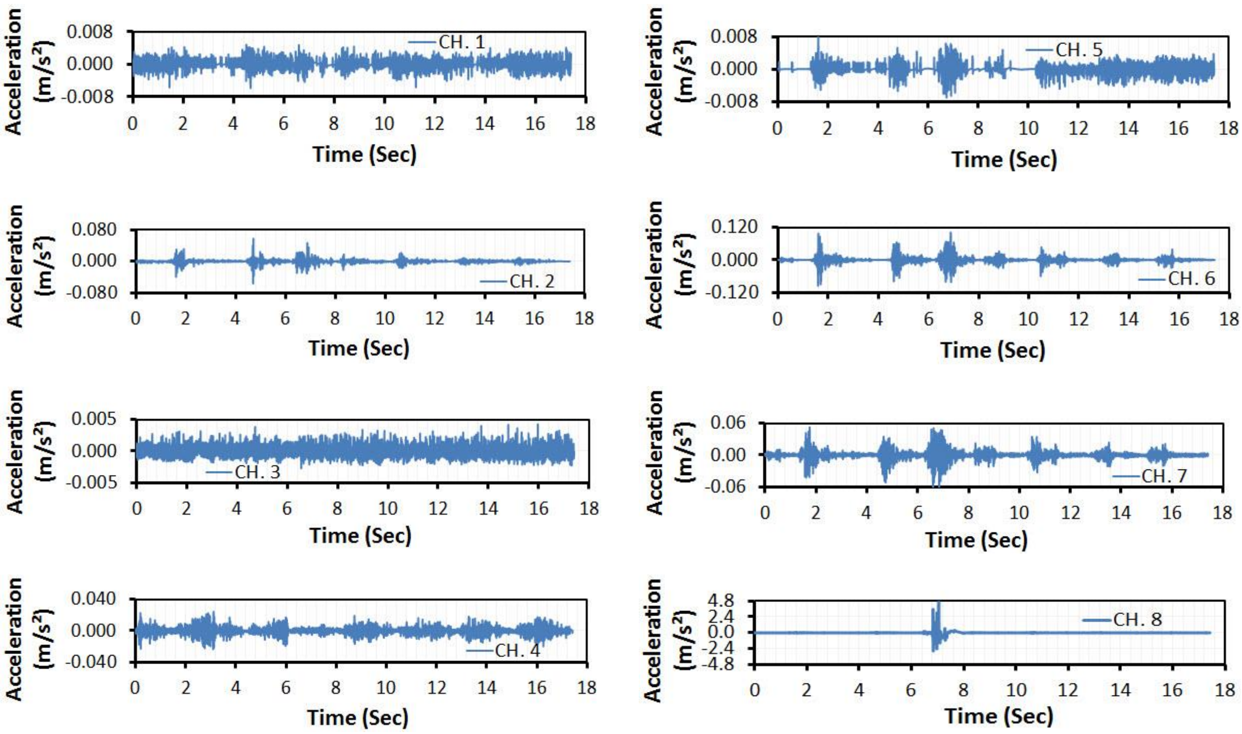


Fig.6: Time histories for the measured channels before rehabilitation.

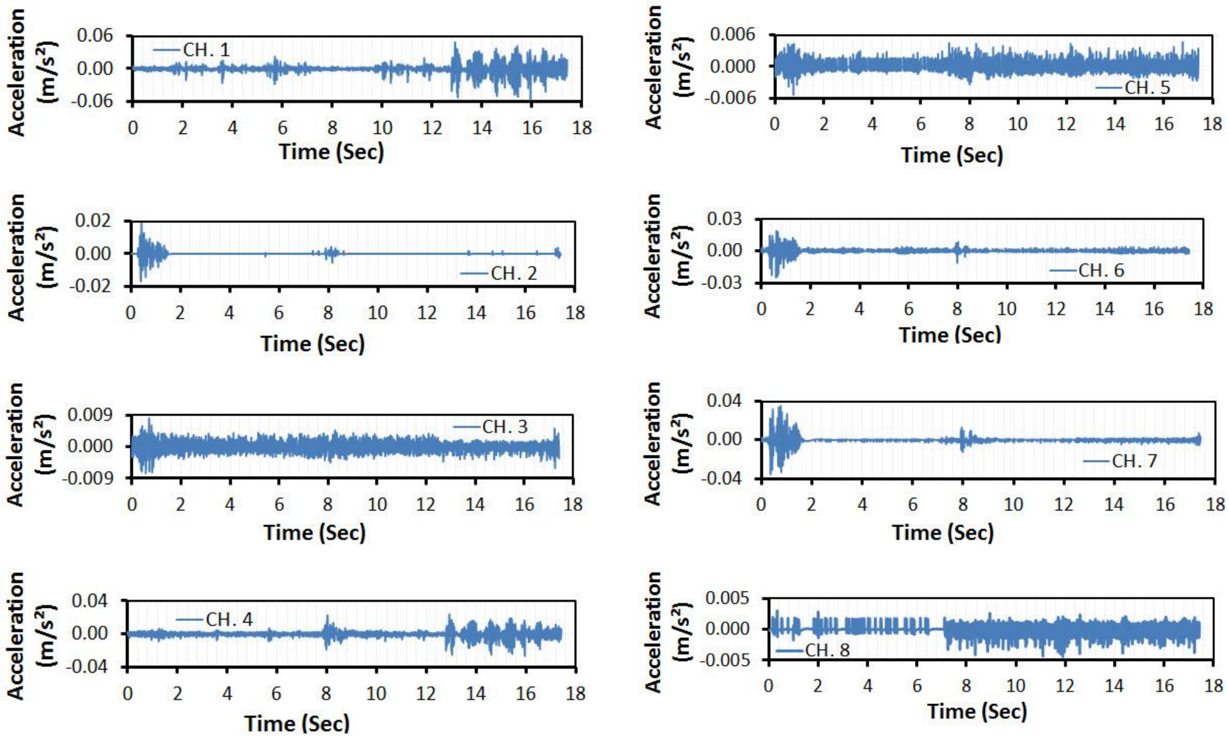


Fig. 7: Time histories for the measured channels after rehabilitation.

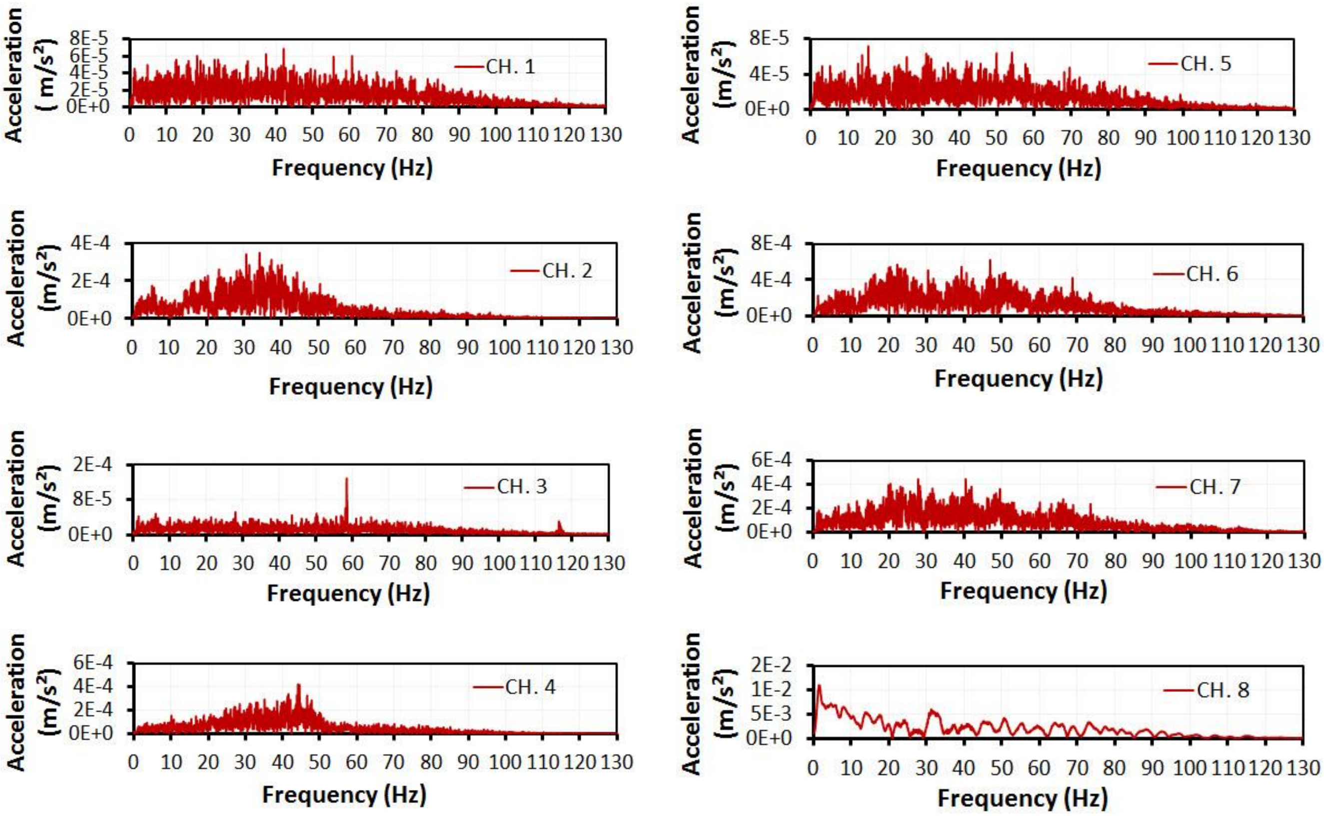


Fig. 8: Power spectrum for the measured channels before rehabilitation

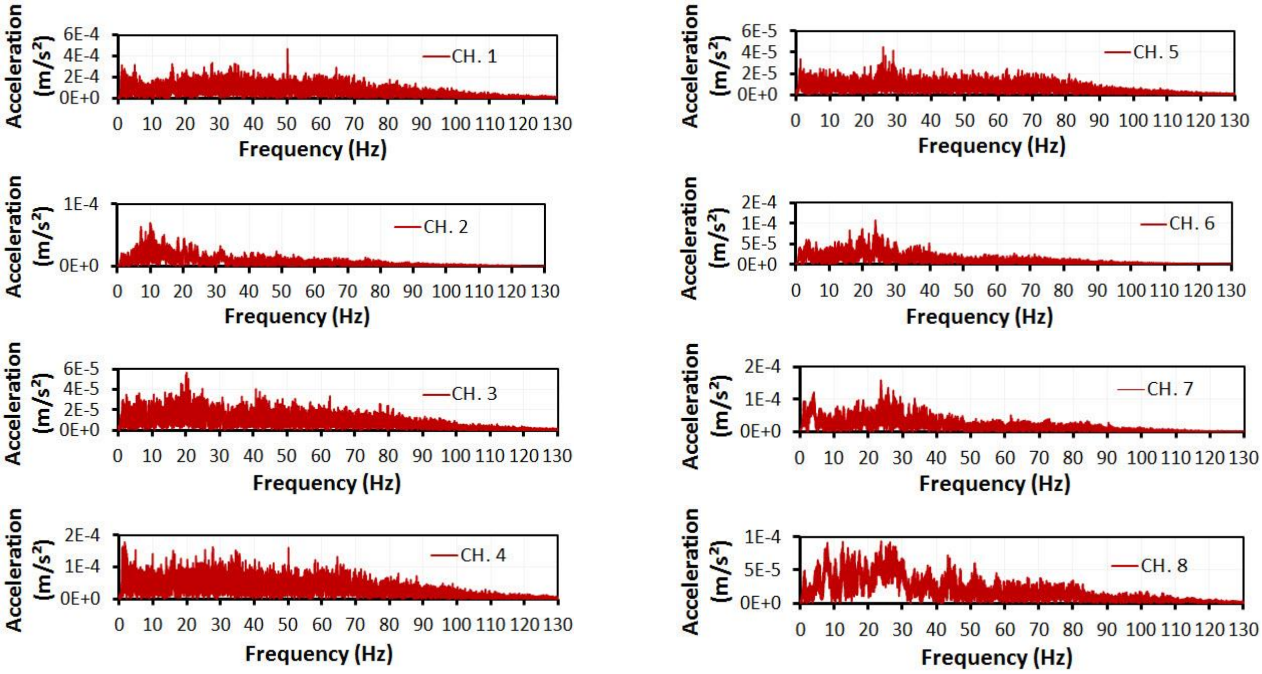
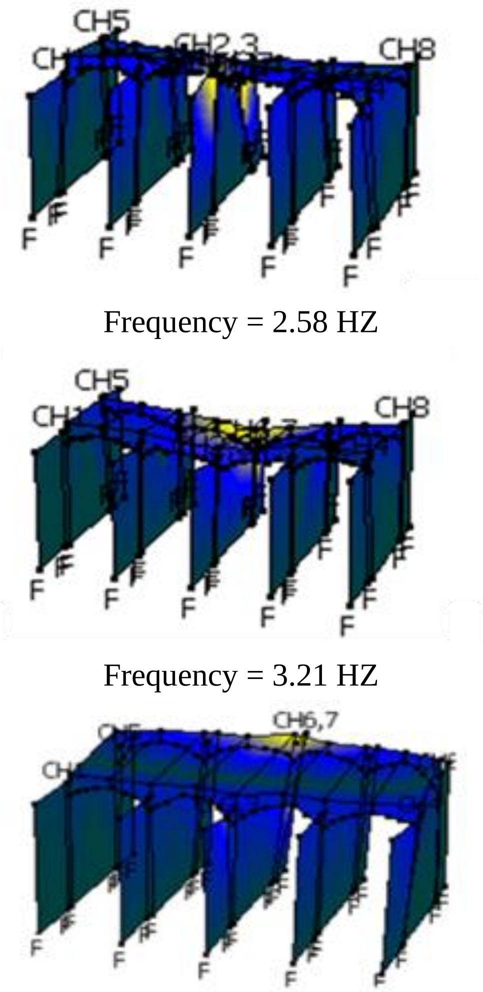


Fig. 9: Power spectrum for the measured channels after rehabilitation

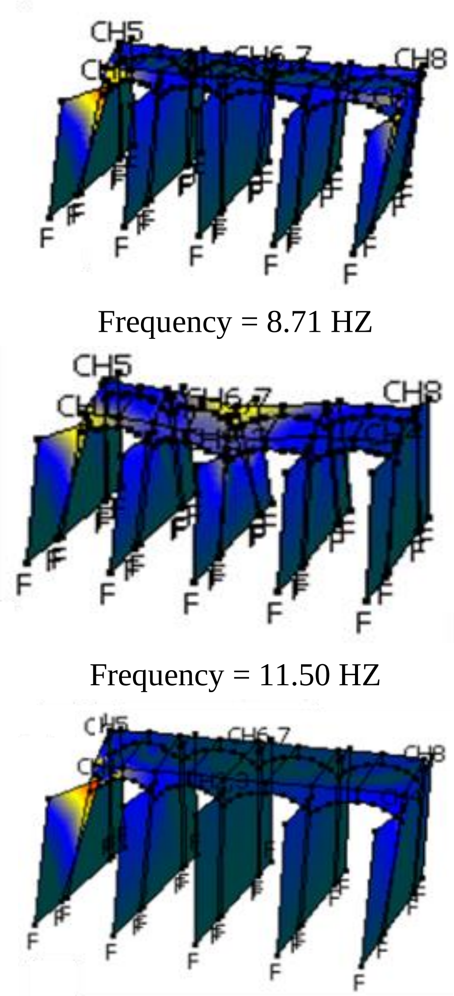


Frequency = 2.58 HZ

Frequency = 3.21 HZ

Frequency = 35.60 HZ

Fig. 10: Mode shapes of test before rehabilitation (TBR)



Frequency = 8.71 HZ

Frequency = 11.50 HZ

Frequency = 69.50 HZ

Fig. 11: Mode shapes of test after rehabilitation (TAR)

7. Conclusions

MWRI has undertaken a program to rehabilitate or replace the old main barrages and regulators along the Nile River. Zefta barrage is one of the major barrages included in the rehabilitation program. This study presents the influence of rehabilitation on the structural status of Zefta barrage by comparing the results of the dynamic tests before (TBR) and after (TAR) rehabilitation. It can be concluded that:

1. A significant variation in the results between TBR and TAR was found.
2. Zefta barrage was affected by rehabilitation and has an influence on structural behaviour and safety and prolonging its service life.
3. Due to the rigidity of such structures and their piers which have large frequencies, it wasn't easy to catch the same mode shapes to make the comparisons.
4. Most modes were combined modes, so the enhancement percentage due to the barrage repair couldn’t be calculated.
5. The frequencies generally increased after repair than before the repair.

Acknowledgment

The authors are grateful to the staff of Reservoirs and Grand Barrages Sector (RGBS), MWRI, for their kind assistance and support in preparing this work. In addition, the authors would like to thank the Construction Research Institute (CRI) staff for their help in conducting the dynamic tests.

References

[1] I. M. Shenouda, A. E. Fleifle, H. M. Awad, and N. A. Younan, “Simulation-optimization model for the hydraulic and structural design of barrages-regulators in Egypt,” Journal of Irrigation and Drainage Engineering, vol. 144, no. 04018034, 2018.

[2] B. Sun, S. Zhang, M. Deng, C. Wang, “Nonlinear dynamic analysis and damage evaluation of hydraulic arched tunnels under mainshock–aftershock ground motion sequences,” Tunnelling and Underground Space Technology, vol. 98, 2020.

[3] Z. El-Fakharany, A. Fekry, “Assessment of New Esna barrage impacts on groundwater and proposed measures,” Water Science Journal, vol. 28, no. 1, pp. 65–73, 2014.

[4] A. M. A. Sattar, Y. M. Raslan, “Predicting morphological changes DS New Naga-Hammadi Barrage for extreme Nile flood flows: A Monte Carlo analysis,” Journal of Advanced Research vol. 5, pp. 97–107, 2014.

[5] Coteba, Sogreah, “Feasibility Study for Rehabilitation/Reconstruction of The Zefta Barrage,” Tender Design – Draft, 6, 2013.

[6] Y. El-Hakem, A. Hashad, “Assessment of using reinforced and pre-stressed masonry to upgrade lateral load capacity of barrage pier,” The International Conference on Civil and Architecture Engineering vol. 9, no. 9, pp. 1–13, 2012.

[7] H. Nohutcu, E. Hökelekli, A. Demir, E. Ercan, G. Altıntaş, Sülün, Y. Ömer, “Evaluation of dynamic characteristics of historical masonry structures by operational modal analysis,” International Civil Engineering and Architecture Conference, 2019.

[8] M. Irini, Shenouda, E. Amr Fleifle, M. A. Haytham, and A. Y. Nazeih, “Simulation-

optimization model for the hydraulic and structural design of barrages- regulators in Egypt," Journal of Irrigation and Drainage Engineering, vol. 144, no. 12, 04018034, 2018.
[9] Construction Research Institute (CRI), "Geotechnical and structural investigation report Al-Bagoria head regulator," CRI, NWRC, Delta-Barrage 13621, Egypt, 2020.
[10] Construction Research Institute (CRI), "Geotechnical and structural investigation report Danshal regulator (old)," CRI, NWRC, Delta-Barrage 13621, Egypt, 2021.
[11] Construction Research Institute (CRI), "Geotechnical and structural investigation report Bahr Hafeer Shehab Al-Deen Head Regulator," CRI, NWRC, Delta-Barrage 13621, Egypt, 2022.
[12] Sogreah, P-à-lA, "Navigation lock repair by grouting," Notes, 2004.
[13] Sogreah, P-à-lA, "Zefta rehabilitation/reconstruction prefeasibility study," Final Report, 2005.
[14] Artelia, "Feasibility study for the rehabilitation/reconstruction of Zefta Barrage," Phase I - Literature Review and Presentation of Study Approach, 2011.
[15] Artelia, "Feasibility study for the rehabilitation/reconstruction of Zefta Barrage," Phase II - Data collection and analysis of option, 2012.
[16] E. K. Mohamed, E. A. B. Khalil, "Innovative solution for the repair of hydraulic structures (regulators)," Water Science Journal vol. 32, pp. 179–191, 2018.
[17] E. A. B. Khalil, "Upgrade and rehabilitation of irrigation regulators implementing structural steel," Journal of Engineering Research, pp. 121–132, 2012.
[18] F. Cakir, "Determination of dynamic parameters of double-layered brick arches," Journal of the Croatian Association of Civil Engineers, vol. 66, pp. 123–130, 2014.
[19] D. B. A. Pandey, P. Chakrabortty, P. Gupta, C. Jain, "Dynamic characteristics of a barrage at various stages of construction,"13th World Conference on Earthquake Engineering, vol. 1778, pp. 5–10, 2004.
[20] A. Cunha, E. Caetano, "Experimental modal analysis of civil engineering structures," Sound Vibration, vol. 1, pp. 12–20, 2006.
[21] C. G. E. Lai, M. G. Mulas, "Experimental and numerical serviceability assessment of a steel suspension footbridge," Journal of Constructional Steel Research, vol. 132, pp. 16–28, 2017.
[22] B. K. J. Charatpangoon, A. Furukawa, C. Hansapinyo, "Dynamic analysis of earth dam damaged by the 2011 off the pacific coast of Tohoku earthquake," Soil Dynamics and Earthquake Engineering, vol. 64, pp. 50–62, 2014.
[23] R. Sancibriana, E. G. Sarabiab, Y. Boffilla, H. Wonga, L. Villegasa, "Dynamic identification and condition assessment of an old masonry chimney by using modal testing," Procedia Engineering, X International conference on structural Dynamics, EURODYN 2017. vol. 199, pp. 3410–3415, 2017.
[24] A. E. Elwy, Y. El-Hakem, B. Eltaly, "Numerical and experimental modal analyses of real hydraulic structural elements," M.Sc. Menoufia University, 2017.
[25] G. Valadimir, P. Stanislaw, on rehabilitation of hydraulic structures subjected to alkali-aggregate reaction," In book: Numerical Models in Geomechanics, 2020.
[26] G. A. Rahman, T. S. Elsalakawy, M. Elmashad, R. M. Elwin, "Structural Analysis and Safety Assessment of a Historic Hydraulic Structure in Egypt," In book: Cities' Identity Through Architecture and Arts, 2021.
[27] J. C. Silva, C. Serra, "A Review on Cement-Based Materials and Practices for Rehabilitation, Retrofitting, and Strengthening of Hydraulic Structures," Practice Periodical on Structural Design and Construction, vol. 27, no. 3, 2022.
[28] J. C. Silva, Repair, "Rehabilitation and retrofitting of concrete dams with cement-based materials," Conference: Hydro 2020 - Strategies for future progress, 2020.
[29] A. Aprile, G. Monti, "Advanced methods for structural rehabilitation," Buildings, vol. 12, no. 1:79, 2022.

[30] Sogreah, Ca, “Feasibility Study for rehabilitation/reconstruction of the Zefta Barrage,” Tender Design – Draft 6, 2013.
[31] F. A. Hurley, “The Zefta barrage and subsidiary works,” Minutes of the Proceedings of the Institution of Civil Engineers, vol. 156, pp. 323–336, 1904.
[32] E. Caetano, Á. Cunha, and F. Magalhães, “Output-only dynamic testing of bridges and special structures,” Structural Concrete, Vol. 8, No. 2, pp. 67–85, 2007.
[33] B. Eltaly, G. Saudi, R. Ali, and K. Kandil, “Experimental and FE modal analysis for elevated steel water tanks,” International Journal of Engineering Research & Technology (IJERT), Vol. 3, No. 1, pp. 213–222, 2014.
[34] Cakir F., “Determination of dynamic parameters of double-layered brick arches,” Journal of the Croatian Association of Civil Engineers, Vol. 66, pp. 123–130, 2014.

استخدام الاختبارات الديناميكية لتقييم الحالة الإنشائية للقناطر قبل وبعد إعادة التأهيل

ملخص البحث:

هناك العديد من المنشآت المائية القديمة على طول نهر النيل ومن أهمها القناطر الكبرى والتي يتطلب الأمر زيادة التصرفات المارة منها وزيادة فرق التوازن عليها طبقاً لظروف التشغيل نظراً لطلب زيادة المساحة المزروعة أمامها. ونظراً لأن هناك حاجة دائمة لتحسين أداء شبكات الري، فقد قامت وزارة الموارد المائية والري المصرية بوضع خطة لتقييم الحالة الإنشائية للقناطر الرئيسية على نهر النيل. وبناءً على هذا التقييم وبعد عمل مقارنة بين تكلفة استبدال كل قنطرة وإعادة تأهيلها، تم اتخاذ قرار باستبدال بعض القناطر وتأهيل البعض الآخر. وقد جاءت قنطرة زفتى ضمن القناطر التي تم اتخاذ قرار بإعادة تأهيلها. تهدف هذه الدراسة بشكل أساسي إلى تقييم الحالة الإنشائية لقنطرة زفتى قبل وبعد إعادة التأهيل باستخدام الاختبارات الديناميكية. ومن ثم تم عرض جميع البيانات والنتائج الخاصة بتلك االدراسة مع إجراء مقارنة بينها. وقد أظهرت النتائج أن أعمال التأهيل التي أجريت على القنطرة لها تأثير إيجابي على الحالة الإنشائية للقنطرة وسلامتها مما يؤدي إلى زيادة مدة خدمة تلك القنطرة مما له الأثر الكبير من الناحية الفنية والاقتصادية.

الكلمات الدالة: مصر، نهر النيل، القناطر الكبرى، الحالة الإنشائية، قنطرة زفتى، التأهيل، الاختبارات الديناميكية.