

STRENGTHENING AND REHABILITATION TECHNIQUES FOR MASONRY HYDRULIC STRUCTURES - A CASE STUDY (PART I- ASSESSMENT)

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ABSTRACT

Barrages are considered one of the most important water structures in Egypt. It is very important to keep them working in good condition to assure water management in good manner. Most of these barrages have been built many decades ago using burned clay bricks and still in service till now. The construction cost of new barrages is very expensive, so, maintaining, repairing and strengthening these structures are an economical option that cannot be ignored. Many reasons cause defects in masonry hydraulic structures. These defects affect the structure capacity and performance. The causes of defects should be understood to be treated in optimum way. Structure assessment is the basic step to restore the structural capacity and to assign the suitable repairing technique. The aim of this paper is to present guidelines for the assessment of the masonry barrages when repairing, strengthening or upgrading is required. This could be achieved through reviewing the international experience in that field beside the gained experience from the many barrages upgrading projects. The paper displays a case study for assessment process for a typical masonry barrage type in Egypt. This study provides a solid basis for integrating all the monitored/output data into practical assessment of barrage system performance. The results of this study can also help to develop the current design codes.

Keywords: Masonry Structures, Hydraulic Structures, Structural Assessment, Deterioration

1 INTRODUCTION

Most of the masonry barrages in Egypt are relevant to heritage buildings. Several advantages could be achieved by maintaining and continual using of these facilities such that, Preserving their distinctive architectural character, environmental, social and economic value. Old masonry structures in Egypt were designed based on experience, without explicit structural calculation. Working with masonry design Codes began after the fifties in the last century. The early published documents were based on allowable-stress and empirical design and seismic design requirements were not included. The current Egyptian specification for design of masonry structures is strength-based design provisions (ECP 203, 2005) and there is a separate specification for design loads values applied on structures and their combinations (ECP 203, 2012). The assessment process is the effort that must be done to answer this simple question: "Is the building in conformity with the requirements of the current construction codes?". And it will be useful in order to get your answer to this question to be sure from the beginning that this building was in valid conditions with the specifications in the period when the structure was designed.

In general, the assessment procedure was carried out by specialized engineers with intensive practical experience (Holický, M. et al., 2013). The assessment process starts with visual inspection to obtain a good feel for actual situation and state of the structure. Visual inspection of the assessed structure should be made whenever possible. The main principal in visual inspection is to avoid negligence of any structural condition that may affect actual reliability of a given structure. The assessment process in general consists of two stages as follows:

Initial assessment step which includes

Preliminary inspection, Study of available documentation, Preliminary checks, Recommendation for an immediate actions and Detailed assessment.

Final assessment step which includes

Assign specification of the assessment scenarios related to structural conditions and actions, Detailed inspection, Detailed structural analysis, Full validation of original documents, Verifying the objectives required by the client authority.

When the preliminary assessment indicates that the structure is reliable for its intended use over the remaining life a detailed assessment may not be required. Conversely if the structure seems to be in dangerous or uncertain condition immediate interventions and detailed assessment may be necessary. The evaluation of structural reliability is a basic step of assessment process and be done through applying a verification technique carried out by structural analysis using: actual characteristics of structural materials those were determined through material testing process, structure properties to determine forces and its actions, as built geometric data and structure conditions, and check results taking into consideration structural behavior.

2 BACKGROUND

Most of the Egyptian barrages are constructed using masonry/brick as a construction material and a structural system consists of arches carried by piers rested on mattress/raft foundation. The aim of the assessment is to establish the safe load carrying capacity of the masonry barrage. Assessments should not be extremely conservative, resulting in unnecessary remedial action, or so lax that they impose an unacceptable risk to the public. The basic requirement in the assessment process is to get a good balance between safety and economy. The strength assessment or evaluation of an existing barrage becomes necessary for the following reasons:

- The structure has seriously deteriorated or suffered substantial damage resulting in a decrease in strength.
- There has been a change in design codes which may mean a reduction in acceptable safety levels.
- Raising water levels.
- It is required to carry higher traffic loads than it was designed for, due to general increase in traffic weights, increase in traffic densities or due to the passage of an abnormal vehicle load.

If the assessment process concluded that barrage is a structurally deficient it means that the barrage is in relatively poor condition or has insufficient load-carrying capacity. The main reasons for the overall structural inadequacies or degradation of the masonry hydraulic structures are the original design, overloading, seismic loading, differential settlement, overstresses induced by operation conditions or due to material deterioration because of aging, corrosion, ingress of moisture, temperature changes or harsh environmental exposure.

The existing shape of the old barrages is considered one of the Egyptian cultural and historic landmarks, so it is very important to preserve such kinds of structures. Strengthening is an improvement or upgrading the original strength and aims at one or more of the following objectives:

- (1) Eliminating sources of weakness.
- (2) Decreasing any load or operation cases that produce stress concentrations in some locations.
- (3) Avoiding the possibility of brittle modes of failure.
- (4) Giving unity to the structure by providing a proper connection among its resisting elements.
- (5) Increasing the overall capacity to satisfy the risk requirements.

A lot of researchers studied the assessment process for brick arch bridges and evaluated the rehabilitation solutions. Fotis P., & Costas, A., (2011) were developed a simple mechanics model for the nonlinear load–deformation relationship of the stabilized piers which was accurate enough for design purposes. The vulnerability and the overall seismic behavior of masonry building were

investigated. Determination of loading capacity of arch bridges is a sophisticated problem because of many factors, the behavior of the construction materials, and the effect of fill material in load resistance. Many researchers studied the different methods to determine the arch loading capacity as done by Brencich et al., (2002). The study presents some aspects of the assessment approach of masonry arch bridges was developed by the Italian National Railway Authority (RFI) and the University of Genoa. Brookes C., and Mullett P., (2004) carried out a series of service load tests have been undertaken on a typically deteriorated bridge. Test results have shown that the strengthening reduces intrados strains and helps to control pre-existing crack movement. Frunzio et al., (2001) were performed a numerical analysis by means of a nonlinear F.E.M. algorithm, showed that the results can be useful, in case of restoration of a masonry arch. Studies were also carried out to increase the capacity loading of masonry arches using different methods. Mullett et al., (2006) performed a study to describe the features of the Archtec system with particular relevance to strengthening bridges. It is concluded that the method has significant environmental benefits and reduced cost compared with some alternatives. Hashad et al., (2007) displayed an evaluation process for one of the old barrages in Egypt. The evaluation process was aimed to evaluate the strength of the construction materials and the state of the different structural elements. The research introduced a method for increasing traffic loading capacity for barrage by using a continuous reinforced or prestressed slab rested on its piers.

The problems related to soil problems or using foundation techniques to upgrade the barrage overall capacity were studied in a lot of researches, El-Kasaby A., (2001) discussed the barrage foundation problems in terms of bearing capacity problem or sliding problem can be solved by using micro-piles technique. the strengthening of Historic Buildings by the methodology of Micro-piles. DYWIDAG systems used anchors to increase the stability in two dams in USA. Anchors were used to restore monolithic action between construction joints which were weak points in the Stewart Mountain dam body and to enhance its sliding resistance. The second dam was the Railroad Canyon dam where the Anchors were used to connect the new concrete added to increase the dam height with the existing one. Mivelaz et al., (2006) evaluated the masonry gravity dam in Germany which is considered the oldest concrete dam in Europe. Dam safety assessment has led to the conclusion that the dam was deficient in meeting stability and strength criteria under severe flood and earthquake loadings. In order to adapt the dam to modern standards, strengthening measures became necessary. Different alternatives for the rehabilitation were analyzed and compared with regard to technical, economical and environmental aspects. The final design consisted of the installation of 52 inclined pre-stressed anchors drilled from the dam crest into the rock foundation. Hashad et al., (2012) suggested a technique to increase the ability of the hydraulic structures to resist seismic loads. The suggested technique depends on using soil improvement methods to improve the most stressed soil bulb zone under the structure. The effect of seismic site soil factor will be decreased by improving this soil part.

The main problem of the masonry structures is their low resistance of lateral load especially in the out of plane direction which causes over stress in the barrage piers during earthquakes. Many researchers studied the upgrading of lateral capacity of masonry structures. Hernan and, et al., (2004) tested masonry panels reinforced with externally bonded carbon fiber reinforced polymer (CFRP) laminates and sheets subjected to in-plane shear load. Panels with two configurations of the reinforcement were subjected to monotonic and cyclic loading. They reported the results of the tests in terms of strength, and mechanism of failure. Hashad et al. (2007) introduced a methodology to increase the barrage head difference capacity or to strengthen the barrage. The suggested methodology uses cables joining all the barrage piers in a certain level. The solution enhances the structural seismic performance and considered an economic solution. Asli, A., (2008) developed a methodology for seismic design and evaluation of the response of the masonry structure. 4-storey masonry residential buildings instead of multi-story reinforced concrete were proposed. They verified that it is possible to construct a four-story residential building with masonry bearing walls instead of reinforced concrete skeleton system without changing its architectural characteristics. El-Hakem Y., and Hashad A., (2012) investigated the effect of using reinforcement and pre-stressing techniques for strengthening masonry piers to increase the the out of plane seismic load capacity of barrage piers.

The final selection of a suitable and most effective method generally depends on simplicity, speed of application, structural performance, practically and total cost. A study conducted by Arduni et al.,(1997) found that the failure modes for repaired structures may change from ductile to brittle. Durgesh C.,and Subhash C., (2007) concluded that the undesirable compressive mode of failure of stabilized rocking piers at large drifts can be eliminated by the use of yielding energy dissipation device to limit the forces in verticals and thereby the compression force in rocking piers. They developed a simple mechanics model for the nonlinear load–deformation relationship of the stabilized piers which was accurate enough for design purposes. Abu-Khashaba M.I., Hashad A., (2013) studied the effects of different repair techniques on the dynamic structural response of masonry barrage piers. These techniques had been selected for their potential to either increase the structural capacity of members or to restore the original capacity of the repaired masonry cracked piers. Efficiency of repair works was evaluated by testing the repaired structures under seismic loads. Crack repair methods may have a positive effect, but result in changing the pattern of collapse of structure which requires to be considered when assessing these methods. Crack repair methods may also contribute to improve structure integrity which making it with multiple advantages, (Robet, G. et al., 1999).

3 CASE STUDY

3.1 General Description

The ninth barrage located at kilometer 36.00 on Moyes Sea within the city of Zagazig and track Barrage public administration Irrigation eastern east. The due date of the barrage establishment was 1923 and made up of a number of barrage (7) openings with aperture width (2.35 m) and piers display (3.00) and lock navigation width (8.00 m). A weir behind the barrage to raise the water level was also constructed. Barrage and all its different parts (shoulders, piers and opening arches) were constructed as stone buildings. Barrage has been amended in 2000 to convert the lock room to the two holes each opening (2.35 m) and strengthen the winch with a layer of reinforced concrete and pour the barrage higher lock opening reinforced concrete (beams and slab concrete) and making front and background parapets of stone bound with pink brick and Tlsanh of Dstoor stone and changing the operating gates system through a metal truss on all openings. The available data do not explain the dimensions of the barrage raft or its type, (Hikal, A., 2015). Figs 1-2 show both site description and photo of the barrage.

3.2 Purpose

The main goal is to conduct study of evaluating the structural safety status of the barrage. It aims to review the barrage current state and assess its stress state to determine its structural integrity case or providing the necessary recommendations measures to ensure its safety in light of the current state of operational loads where still barrage operate an origin to hold the water in addition to the exposure to high traffic loads on the nature of its presence on a main axes of internal roads in Zagazig city.



Figure 1. Site description of the ninth barrage



Figure 2. Photo of the ninth barrage

3.3 Case Study Axes

A project plan was developed to include a number of complementary studies to be inferred on the current condition of the barrage by the results of the structural analysis of its mathematical model which is configured including the availability of data and information during the study period, which lasted more than for the whole year, as a result of the operating conditions of the barrage bridge as hub traffic area and the difficulty of prevent the highest traffic on the barrage deck for applying a loading test experiment, and in light of the results of all the studies that has been carried out on the barrage body and on the soil under the barrage foundations, each study has included a detailed program as will be seen later through the axes of each study. The following studies were carried out:

1. Making a virtual preview to find out the status of barrage and a questionnaire study requirements.
2. Conducting a structural survey to monitor and document the state of the cracks and defects.
3. Conducting raise surveyors for the barrage's structural body and completing the missing dimensional data and making as built drawings for the barrage.
4. Conducting geotechnical study of the barrage site to determine the nature of the soil.
5. Carrying out the necessary tests for conducting a study to evaluate the properties of the constituent materials of the barrage.
6. Carrying out the loading test on the barrage.
7. Conducting a structural analysis to determine the current stress levels on the foundations of barrage and its body as a result of the current operating loads.

3.1.3 Visual inspection works

It should be stated that with a case study, resechersare much more of an observer than an experimenter. A technical committee from the Construction Research Institute has formed to inspect the site and the body of barrage and well acquainted with the surrounding site conditions in coordination with the representative engineers for General El-sharquia irrigation administration to discuss the nature of the barrage operating conditions, its maintenance/repair history and the results of the periodic inspection of the barrage body.

3.2.3 Monitoring and documenting the defects and cracks case works

The study aims to document everything that can be accessed from a virtual defects and cracks in the body of barrage, to ensure documented case of barrage before proceeding to its loading test, as well as one of requirements essential to record the status of barrage on the date for the implementation of documentation study even could be used as a reference to follow updates to the arch of the manifestations defects or cracks. That study included the work of photo'ing documenting each defect or crack to include its description, the defect place and to make a preliminary assessment of the cause of occurrence. Some field observations can be summarized as follows:

1. The fall of cover edges of the concrete slab barrage and the emergence of rebar as shown in Fig. 3. Moreover, loss of the concrete cover and reveal rebar own slab and beams of the barrage lock bridge as shown in Fig. 4.
2. Poor façade condition and the loss of some parts of brick buildings as well as the disintegration of some dostoor stones of the taban of higher fence as shown in Figs. 5-6.
3. Lack of clarity of the ends of the wall supporter with an accumulation of amounts of debris into the waterway and not pitching the lock inlet and rubble falling as shown in Figs. 7-8.
4. Removal of pier stones from the front and that of shoulder at the top of the lock as shown in Figs. 9-10.
5. Erosion of some of stones of the barrage back wall as a result of weathering conditions as shown in Fig. 11.
6. Crack occurs along the stone wall side supporter as shown in Fig. 12.
7. Block opening No. (1) entirely from the front by building a full brick wall from front side as shown in Fig. 13.

8. Loss of some mortar parts carnivores stone and the disintegration of some of them as shown in Figs. 14-16 for barrage openings No. (2-3& 5).
9. Erosion of the stones that have been cased the barrage opening No. (4) as shown in Fig. 17.



Figure 3. Fall of the concrete cover of the barrage slab



Figure 4. Loss of the concrete cover from slabs and beams of the barrage lock bridge



Figure 5. Poor state of façade and loss of some wall bricks



Figure 6. Falling of some of the building bricks/stones as well as disintegration of taban fence



Figure 7. Accumulation of amounts of debris into the waterway



Figure 8. Not pitching the lock inlet and falling rubble debris into the waterway



Figure 9. Pier stones take off from the front



Figure 10. Removal of stones from shoulder lock that contains a marble



Figure 11. Erosion of stones of the barrage back wall as a result of weathering conditions

3.3.3 Surveying and structural works

Since there is no complete set of structural engineering drawings for the barrage, therefore it was required to do surveyors and structural scanning works for site and the body of barrage in order to confirm the completion of the original available drawings/data as well as the issuance of structural drawings to show the general location of barrage and its structural system followed in the barrage construction. The output drawings/data is used in the formation of the mathematical model used in the analysis of the barrage structural work and can also be exploited in future when needed/dealing with such kinds of engineering barrages. Surveying works was implemented using a Total Station device as well as the traditional measurement tools in the places that could not use the device to identify critical

information needed to complete the rest of the arch studies. It should be noted that it was also a review of the special drawings/data available to barrage and determine what is in conformity with the current situation after barrage renovation. As built drawings were achieved such as layout of the barrage and its surrounding area, barrage x-secs and longitudinal secs, the barrage main façade and different detailed drawings.



Figure 12. Crack occurs in the lateral stone wall supporter



Figure 13. Block opening No. (1) entirely from the front by wall building



Figure 14. Loss of some mortar parts for stones and disintegration of some of them for opening No. (2)



Figure 15. Loss of some mortar parts for stones and disintegration of some of them for opening No. (2)



Figure 16. Loss of some mortar parts for stones and disintegration of some of them for opening No. (3)



Figure 17. Stone disintegration for opening No. (4)

3.4.3 Geotechnical work

The aim of this study was to determine the soil base parameters that used as a key input into the mathematical model, which will be configured to the structural study of barrage integrity. Therefore, it was necessary to carry out the borings needed to determine the nature of the soil beneath the foundations of barrage. The CRI acts exploratory borings and analysis of samples and conducting laboratory tests needed for them, and determine the soil layers relay site. The institute implemented borings using its own machines for perforating borings, and conducted laboratory tests by its laboratory facilities at El-Kanater-Elkharia city.

BORING WORK PROGRAM

A total of (4) borings named as BH(1), BH(2), BH(3) and BH(4) of the site was carried out mentioned a total boring depth of 25.00 m where it starts from the top arch bridge and continue in piers till to the end and then piers penetrates deeply barrage mattress with length 10.00 meters, then the boring persist in the soil down mattress with a depth of 15.00 meters in a way mechanical rotary drilling to explore the nature of the soil at the site, and Fig. 18 illustrates sketch of those borings places. Moreover, Table 1 shows some soil test results (unconfined compression tests).

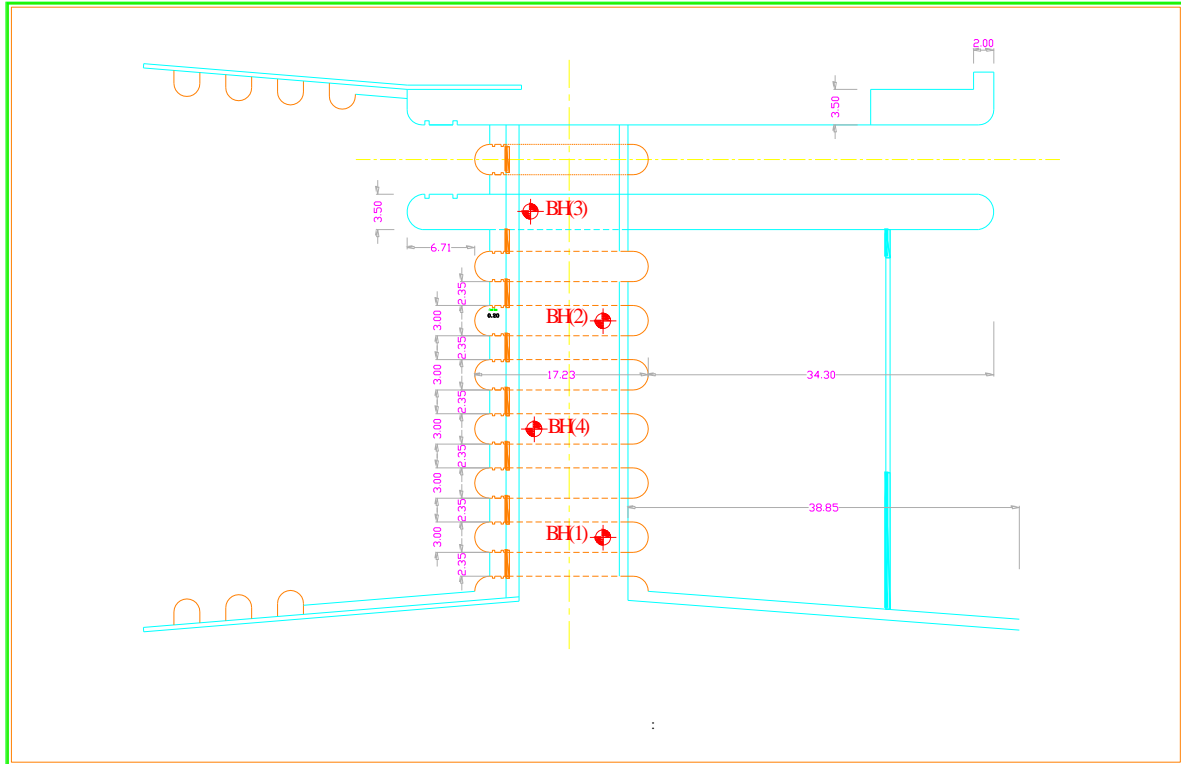


Figure 18. Barrage ketch shows boring places

Table 1. Results of unconfined compression soil tests

Location	Depth (m)	γ bulk (t/m ³)	γ dry (t/m ³)	W _c (%)	q _{un} (kg/cm ²)	C (kg/cm ²)
BH(1)	10.00 – 11.00	1.91	1.35	41.62	1.76	0.88
	12.00 – 12.50	--	--	--	1.78	0.89
BH(3)	10.50 – 11.00	2.37	1.78	32.67	1.40	0.70
	11.00 – 12.50	--	--	--	1.10	0.55
BH(4)	11.50 – 12.50	2.24	1.72	30.42	0.92	0.46

STRATIFICATION OF THE SOIL

According to the sectors of borings turns out that the nature of the stratification of the soil down mattress barrage is divided into the following layers:

A layer of Silty clay appeared in most of the borings with thickness of 2.50 m from a depth of 10.00 meters to a depth of 12.50 m. The values of liquid limit ranging between from 56.5% to 74.0%, the plastic limit values ranging from 15.9% to 27.9%, while the plasticity index values ranging from 32.5% to 47.0% for this layer. The results of chemical analysis shows that the ratio of total soluble salts ranging from 231 to 327 ppm, and that calcium carbonate ratio ranging from the traces to 6% while the chlorides ratio was ranging from 55 to 67 ppm, the sulfates ratio ranges from zero to 30 ppm, and the proportion of organic materials ranging from 0.65% to 1.4%.

A layer of sand appeared in most of the borings of the depth of 12.50 m to a depth of 25.00 m, and the results of chemical analysis shows that the ratio of total soluble salts ranging from 240 to 337 ppm, and that of calcium carbonate ratio ranging from traces to 6%, and chlorides ratio ranging from 52 to 68 ppm, and the sulfate ratio ranging from zero to 25 ppm, and the proportion of organic materials ranging from zero to 0.65%.

3.5.3 Assessing the properties of materials of barrage

To assess on an object barrage construction materials, some cores were extracted from the barrage body, as to be representative of all barrage elements. It has been identified compressive and tensile strength properties of the barrage elements. Samples were taken from a total number of (4) boring excavations that were all taken in the barrage body from bridge deck and continue along the whole barrage pier to explore the nature of its structural composition (layers) boring excavations, as previously shown in Fig. (18), the following includes laboratory program, which has been made on these selected samples:

1. Conduct the visual descriptions of extracted samples and take notes for all boring samples.
2. Conducting mechanical tests to determine the compressive and tensile strength of the different layers to help determine the barrage ability to withstand the exposed loads.
3. Conducting physical tests (specific weight, volumetric weight and absorption) in order to determine the ability of the used materials to carry the load with time.
4. Conducting chemical tests to determine the percentage of total salts and chlorides and sulfates and influence on barrage piers to prevent their bad effect and the damage to barrage.

VISUAL EXAMINATION OF THE CONCRETE CORES

The visual inspection procedure of cylindrical core samples extracted from the site was conducted to measure the actual dimensions of the samples and note the presence of cracks or nesting if found. It was found the occurrence of fragmentation in some cores during the extraction process which has been observed to be impossible to conduct compression/tension tests for them. It has been observed that most of the structural composition is a mixture of limestone and pieces of the bricks and limestone and cement mortar. Figs. (19) describes the samples extracted photos of barrage piers in some borings.



Figure 19. Core samples extracted from boring No. (1)

LOGS OF BARRAGE PIERS LAYERS

Based on tests carried out for selected samples of (4) borings sectors in barrage piers, the nature of the stratification of the barrage piers is divided into the following classes:

A layer of **asphalt** appeared in all borings starting from boring surface and with a thickness of 10 cm.

A layer of **reinforced concrete** with a thickness of 35 cm, and its compression resistances to this class ranges between 4.41 N/mm² and 6.81 N/mm².

A layer of **ordinary concrete** with a thickness of in the range (40-70) cm.

Layer of **limestone** of thickness ranges between (20-30) cm, and its compression resistances range to this class from 2.18 N/mm^2 to 9.78 N/mm^2 , while its tensile strength ranges from 0.25 N/mm^2 to 4.28 N/mm^2 .

Layer of **limestone mortar** with thickness in the range (80-100) cm. Splitting resistance for this layer ranges from 0.70 N/mm^2 to 1.61 N/mm^2 .

Core layer of the barrage piers consists of **breaking brick pieces and mortar break lime stone pieces** with a thickness in the range (5.05-7.80) m. The compression resistance to this class ranges from 0.30 N/mm^2 to 4.11 N/mm^2 . Splitting resistance for this class ranges between 0.16 N/mm^2 and 1.64 N/mm^2 .

The results of physical tests showed that the specific weight of the hearts of the tested range between 2.14 and 2.63 and unit weight of the samples extracted between 1.44 and 2.35 t/m^3 and saturation coefficient for these samples are different depending on the nature of the components of the heart, which ranges between 0.34 and 0.90.

3.4 Loading test on the barrage body

To maintain the structural integrity of the barrage body, this study aims to conclude the its structural behavior under the influence of appropriate traffic load which could be allowed to pass. Moreover, the study was conducted in order to obtain field data that reflect the normal behavior of the barrage under the influence of load characteristics case similar to the standard loading test case. Through this behavior and using a mathematical model representative of the barrage body, the barrage behavior under the influence of the value benchmark and equivalent traffic load shape could be expected and derived, which will be allowed to pass on the barrage. This study includes a description of test loading mechanism, as well as to review the results of this test that has been conducted over 6 hours at night in the attending of the representative engineers of Ninth Barrage Administration as well as Reservoirs and Grand Barrages Sector.

A loading method was followed based on measuring the displacement from the top of barrage, where not prevent the passage of cars on the barrage and to access to avoid the impact the loading test was conducted during the night, at dawn on Friday, where less volume of traffic accessible as possible to get the highest possible accuracy test results. The loading test was conducted using Plate Loading device by using truck weighing 12 ton as a framework for the reaction so car wheels stand at the top of the pier carrying the tested arch to not cause a noticeable impact resulting from the car weight. Fig.20 shows a photo of the used car on the barrage deck during the test of one of the barrage openings and Fig. 21 shows plate loading device provided with three counters to read the occurred displacement, the value of carrying load is also determined by reading the pump pressure for the hydraulic compressor counter. The test was conducted at the middle of the span to the number of two openings spread over the entire length of the barrage so that there is a tested opening in the first and middle third of the barrage, those openings were selected after finishing work preview of all the openings from both sides (front and back), and the opening was chosen as of a virtual case most embarrassment compared to its neighboring holes.

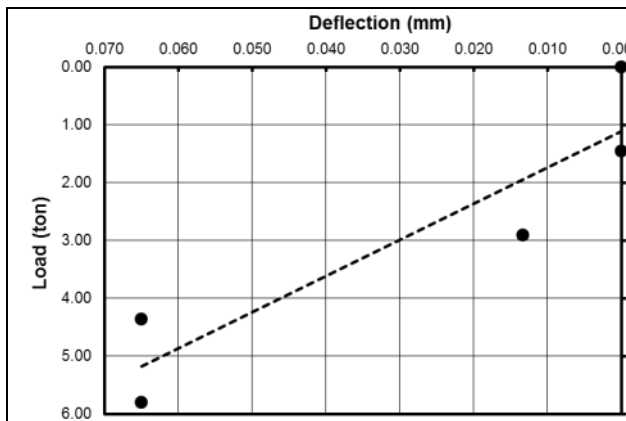
In light of the results of tests carried out as well as the virtual preview after the experiment, which showed that there is no manifestation of damage or collapse of origin novel may have undergone under the influence of test load and that the same condition before the test load has been inferred, the load displacement curves could be derived by using the maximum displacement readings. Test results has been clarified that the relationship between load and displacement during loading is found a linear relationship as shown in Fig. 22 using the best curve fitting for the test readings. Something that reflects the lack of flexibility limits for construction materials exceeded under the influence of a standard load, which indicates the existence of this applied load in safe term resistance of the constituent materials of the barrage body.



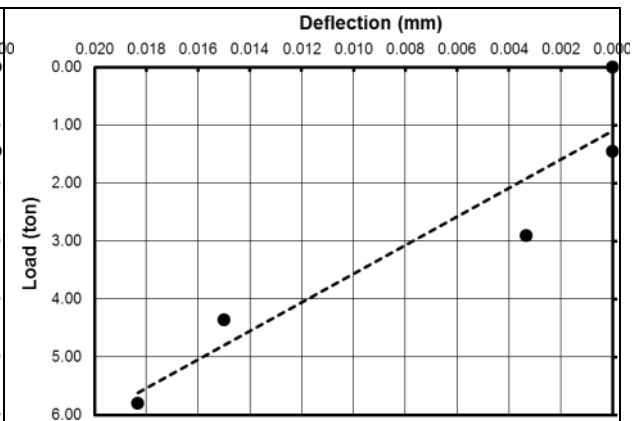
Figure 20. The used truck as a reaction frame on the top of one of the tested openings



Figure 21. The used plate loading device during the test



a. Loading test results of the tested openings No. 2



b. Loading test results of the tested openings No. 5

Figure 22. Load-deflection relationship during loading test

3.1.4 Structural analysis for the barrage

This study includes an assessment of the stresses within the barrage body as a result of a number of several load conditions taking into account the appropriate traffic load placed on which to base a conclusion safe load that does not cause the occurrence of the higher stresses exceed the allowed stresses on the construction materials for the barrage, which was calculated from the tests results of material current status for samples extracted from the body of barrage for its all structural elements. The model was prepared for the barrage using the Finite Element Method. It was performed numerical study and structural analysis for all barrage elements to determine their ability to withstand the applied loads according to the current specification (Egyptian Code for loads - 2012), as well as the study of general equilibrium of the barrage, through building a three-dimensional mathematical model of the barrage as shown in Fig. 23, it has been defined mechanical properties of materials involved in the formation of barrage using the available materials results and the remaining material properties, which were not covered by the tests were estimated if needed from the past experiences with generally accepted ways of estimating these characteristics. The structural shell elements have been used to represent the various structural elements of the barrage beginning of the arches, piers and even foundations. The study of the level of stress under the influence of various operating loads to determine stresses values on the different structural elements of the barrage body, which can determine the ability of these elements to withstand the stresses resulting from loads operating requirements or approve the loads running suit the results of the case study material.

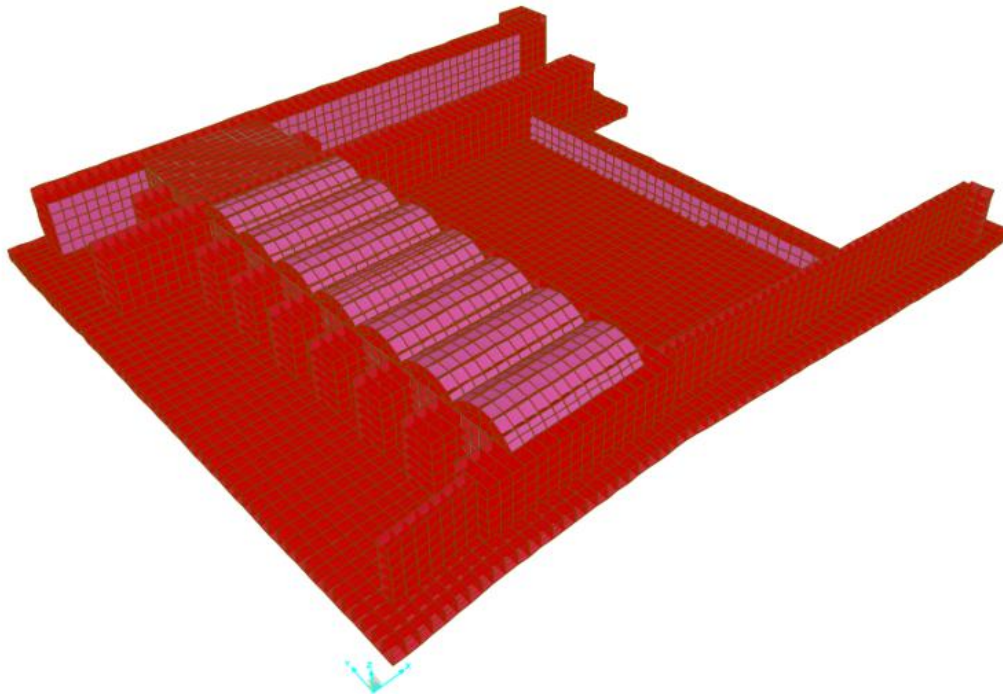


Figure 23. Mathematical model Representative ninth barrage

Structural study aims to contribute to determining the maximum load of the barrage to become acquainted with the stress levels within its various structural elements as well as the stresses concentration and most critical areas through loading barrage with several different scenarios corresponding to the maximum load cases on the barrage. It has been taking into account all the vertical loads acting on the barrage resulting from barrage self-weight loads and weight of the layers of backfill and pavement were also taking into account, the traffic load was approximately uniformly distributed on the entire width of the road so as to not exceed the total load of the bridge for 60 ton as high traffic load limits set on the main lane (according to the Egyptian code of loads). Several cases of loads were studied combine both dead loads and traffic loads (cars was put once on the arch and on the induced bridge once again) as well as the scenarios for balancing the barrage was done (It has been imposed real balance difference and is 1.15 m as well as the imposition of the lack of balance difference). The car load of 30 ton as a maximum load on the barrage was also studied, scenario was the work of the critical situation in the case of a barrage crack width. Figs. 24-25 describe some of these cases, traffic loads and loads of water pressure.

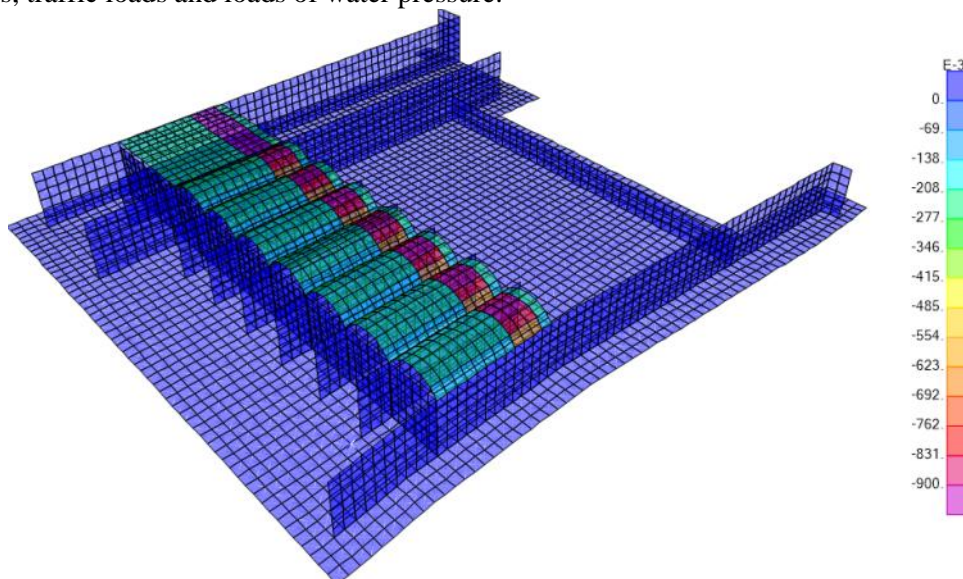


Figure 24. Distribution of traffic load on the bridge

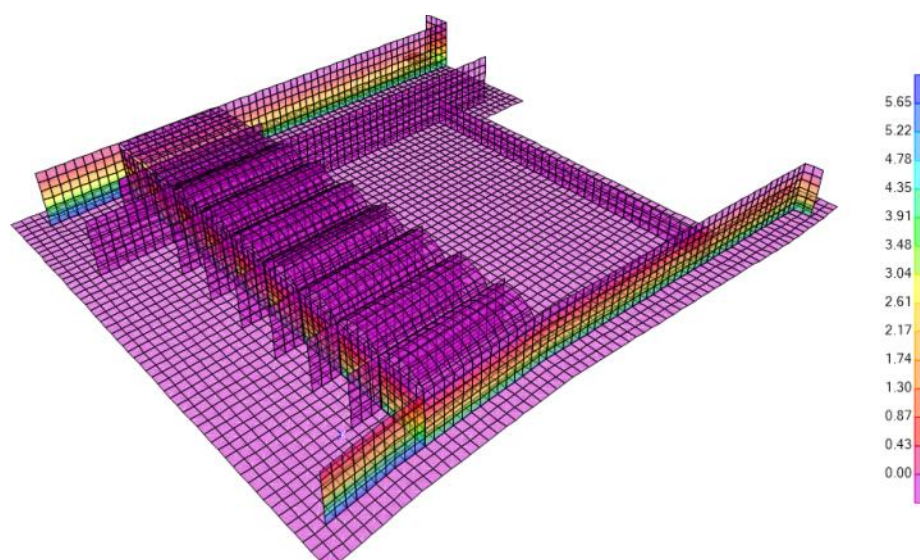


Figure 25. The static water pressure on the barrage

MATHEMATICAL MODEL INPUT DATA

The soil foundation was considered as flexible foundations consists of springs of vertical resistance as main direction with the development of spring resistance in the two horizontal directions, the first resistance is to represent the horizontal movement as a result of friction between the loading surface area and soil foundation, as well as the second resistance represents the lateral resistance forces activated over the entire thickness of the foundations from the two sides. The material properties for each structural element were defined depending on the area it was existed inside the barrage body in accordance with the nature of the used materials in the construction or composition of the barrage body in this region. The properties of these materials were determined through the results of field and laboratory tests and previous experience after reviewing the assessing study of the properties of the constituent materials of the barrage body. The values of material properties that are defined in the mathematical model can be summarize as shown in Table 2.

Table 2. Properties of the materials used in the mathematical model values

Element	Type	γ_c	F_c	F_t	E_c
		(t/m^3)	(Kg/cm^2)	(Kg/cm^2)	(Kg/cm^2)
Arched slabs	Plain Concrete	2.20	50	5	99,000
R.C. Bridge	R. Concrete	2.45	60	6	109,000
Piers and Lock	Lime Stone Concrete	2.00	70	10	117,000
Raft	Lime Stone + Mortar	2.20	75	8	121,000

Table 3. Summary of critical stress values on the different barrage sectors considering crack in raft (maximum load of 30 ton)

Element	Obtained Stresses		Allowable stresses	
	F_c (Kg/cm^2)	F_t (Kg/cm^2)	F_c (Kg/cm^2)	F_t (Kg/cm^2)
Arched slabs	-8.6	1.0	-50	5
R.C. Bridge	-52	7	-60	6
Piers and Lock	-2.9	1.3	-70	10
Raft	-7.6	6.2	-75	8

SUMMARY OF SUTRUCURAL ANALYSIS RESULTS

It is clear that the level of generated stress is higher than the operational boundaries of the barrage for a load of 60 ton and in particular on the piers and mattress. Also, those stresses may be increased when calculating the dynamic strength of barrage. Therefore, the load on the barrage should not exceed the design load which were confirmed by the loading test experiment of 30 ton as a maximum load for the barrage. Table 3-4 summarize the most critical obtained stresses values that have been calculated on the various barrage elements for comparison with the allowed stresses.

Table 4. Summary of critical stress values on the different barrage sectors considering crack in raft (maximum load of 60 ton)

Element	Obtained Stresses		Allowable stresses	
	F_c (Kg/cm ²)	F_t (Kg/cm ²)	F_c (Kg/cm ²)	F_t (Kg/cm ²)
Arched slabs	-9.60	5.7*	-50	5
R.C. Bridge	-115*	19.5**	-60	6
Piers and Lock	-3.5	1.5	-70	10
Raft	-7.5	7.4	-75	8

*Load of 60 tons cause stresses higher than allowed
 **Supposed to bear the rebar stresses high tensile values

4 CONCLUSIONS

The results of the current study lead to the following conclusions:

- The knowledge of the structure behavior and its global performance through a long period of time span (almost its life time) under its full operation conditions, is a powerful tool when developing the current codes.
- The analysis of actual characteristics of structural material under the application of the real service loads with their actions, the site boundaries and harsh surrounding environmental conditions may lead to valuable decisions in assigning projects specifications.
- For the current masonry barrage case study, the barrage capacity load was determined and should not exceed the design load that verified by the loading test experiment of 30 ton as a maximum load for the barrage. The concluded safe load does not cause stresses exceed the allowable stresses on the construction materials of the barrage. However, it must remember that, even in a multi-subject case, for a case study, each case must be treated individually and then cross case conclusions can be drawn.

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