SUGGESTED SOLUTION FOR OLD BARRAGE BRIDGE REHABILITATION

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ABSTRACT

Barrages are considered the backbone of the Egyptian irrigation system. Egypt has a large number of barrages; most of them are close to their service life span. Barrages are used as hydraulic structures which mainly control water discharges and also are used as bridges. The typical bridge consists of a series of arches carried by piers rested on raft foundation. The total replacement of the old structure is expensive. Most of old barrages were designed for small vehicle loads, which causes a serious problem facing the application of new live loads standard. This research displays an evaluation process for one of the old barrages located about 25 km north of Cairo on one of the river Nile branches. The evaluation process was aimed to evaluate the strength of the construction materials and the state of the different structural elements. A proof load test for a specific desired load was carried out to check the barrage's capacity. Also, a suggested methodology for the increased traffic loading capacity of barrage depends only on the existing piers excluding arches was introduced in this research. The suggested methodology is to use a continuous reinforced or prestressed slab rested on beams above the piers. The piers may or may not need to be strengthened using micro piles or soil grouting techniques. A prototype numerical model for the barrage and the suggested solution was developed. As a result of the analysis, the suggested method may be considered as an economic solution to gain traffic loads, without adversely affecting the barrage's safety or its hydraulic efficiency.

Keywords : Arch, Masonry, Strengthening, Bridges

INTRODUCTION

The aim of the assessment is to establish the safe load carrying capacity of the barrage bridge. The strength assessment or evaluation of an existing barrage bridge becomes necessary for three main reasons:

- It is required to carry greater 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.
- 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.

When the barrage bridge is “structurally deficient” it means that the barrage is in relatively poor condition or has insufficient load-carrying capacity, which would be due to the original design or due to deterioration. When the barrage bridge is “functionally obsolete” it means that the bridge is narrow, has insufficient load-carrying capacity, or no longer adequately service modern traffic.

The basic requirement in the assessment process to get good value for money is by maintaining a good balance between safety and economy. Assessments should not be extremely conservative, resulting in unnecessary remedial action, or so lax that they impose an unacceptable risk to the public.

The replacement of the existing barrages would result in a significant impact on the visual environment. The existing shape of the old barrages is considered to be a cultural and historic landmark in Egypt.

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 raft foundation. One of the main reasons for the degradation of the masonry/brick work is due to the ingress of moisture. Evaluation of barrage bridge (arch type) is required to determine the safe loading capacity. A lot of researches studied the assessment process for brick arch bridges and evaluated the rehabilitation solutions. In one of these studies [3], a series of service load tests have been undertaken on a typically deteriorated bridge. Tests undertaken before and after strengthening were carried out using two ballasted vehicles. The bridge is built typical of many arches from brick and masonry. These tests were designed to better understand Archtec strengthened bridge behavior at the serviceability limit state and to show that there are no detrimental effects. The tests were instrumented to measure intrados strains, crack widths and anchor strains. In parallel with the experimental work, strain and displacement predictions have been made using numerical simulation based on the Finite/Discrete Element technique. Test results have shown that the strengthening reduces intrados strains and helps to control pre-existing crack movement.

Another study [5] was performed 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

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 researches studied the different methods to determine the arch loading capacity as in [4]. This study presents some aspects of the approach to the assessment of masonry arch bridges developed by the Italian National

Railway Authority (RFI) and the University of Genoa. No Tensile Resistance approach, with limited inelastic compressive strains, has been formulated to allow an incremental non linear analysis of the bridge up to collapse in the frame of simplified 2-D geometry. This study concluded that the 2-D and 3-D models gave coherent results in terms of stresses and limit loads and seismic vulnerability and this topic is still an open issue that deserves further research. Also, a numerical analysis performed by means of a nonlinear F.E.M. algorithm, showed that the results can be useful, in case of restoration of a masonry arch [6].

The barrage foundation problems in terms of bearing capacity problem or sliding problem can be solved by using micro-piles technique. The study in [7] discusses the strengthening of Historic Buildings by the methodology of Micro-piles. Micro-piles are small diameter piles 10-25 cm having a capacity range of 15-60 tones. Their length may reach 40 m and resists loads vertically or inclined. Micro-piles are constructed by small machines that can be used inside buildings and in small areas. Micro-piles have been used already to strengthen Egyptian historic buildings.

BARRAGE REHABILITATION PROJECT

Irrigation structures are subjected to periodic visual inspection as a continuous process aims to keep this structure in good conditions. The considered barrage Photo 1 was constructed on the Monphie branch at a site located at 25 km from Cairo. The visual inspection that carried out on this barrage showed that this barrage needs some repair works and as a result the barrage bridge was closed for traffic. This barrage is located near a domestic region and the barrage bridge linked this region with one of the main roads. The closing of the barrage bridge created a major traffic problem for the bridge users. The original barrage was designed for a vehicle load not exceeding 20.0 ton. After estimating the most suitable vehicle loads, it was decided to study the ability of the barrage bridge to carry a vehicle with 5.0 ton weight. In other words, there is a need to make a proof load test for the barrage bridge. Figure 1 shows the barrage plan. Assessment process was carried out to propose the best repair / rehabilitation technique. Material studies were carried out [8] to define material factors required for determining the actual brick characteristic strengths for the different structural elements of the barrage. Table 1 displays some of the results of compressive strength and density tests. The compressive strengths varied from 12.7 kg/cm^2 to 39.8 kg/cm^2, while the dry density ranged from 1.23 gm/cm^3 to 1.74 gm/cm^3. The results of wet density tests showed variation between 1.35 gm/cm^3 to 1.74 gm/cm^3.

Piers integrity was tested using Packer permeability test [8]. Table 2 shows some of the results of Packer tests. Piers number P1, P2 and P3 failed in Packer test because of their high leakage during test which may indicate the existence of caves, cracks or holes. The assessment process recommended a fast repair works for the arches using shotcrete technique and doing some injection works in some piers. Photo 2 shows the process of dowels planting which are used to fix the main reinforcement mesh before shocrete process.

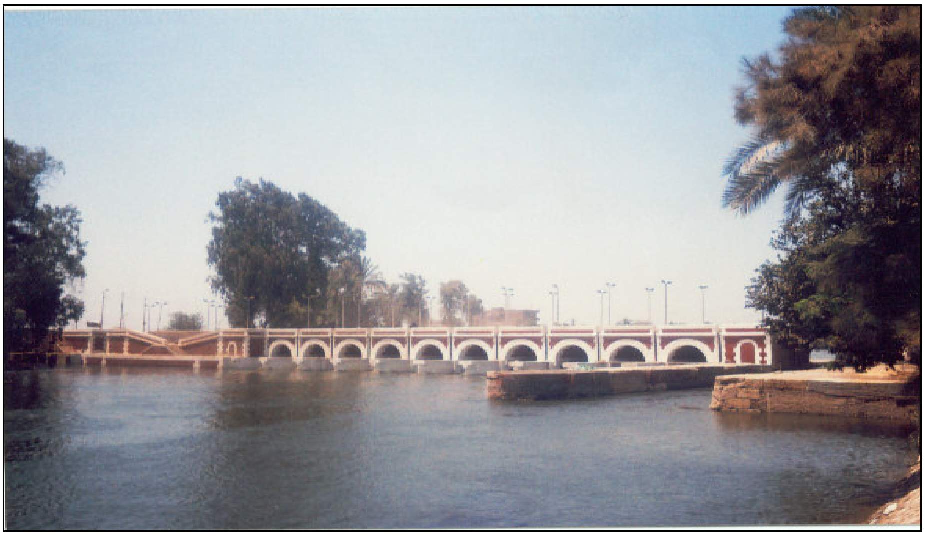

Photo 1 General View for the Barrage

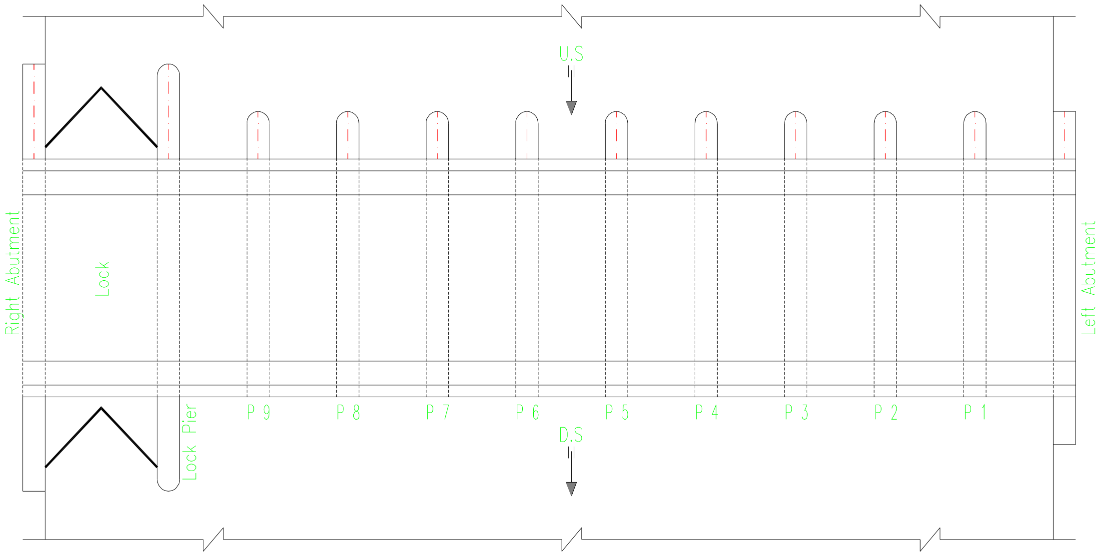

Figure 1 Barrage Plan

Table 1 Results of Compressive Strength and Density Tests [8]

Sample No.	Pier no.	Borehole no.	Sample data			Density gm/cm³		Comp. Strength kg/cm²
			Depth m	Length cm	Diam. cm	Wet	Dry	
1	1	1	8	4.5	3	1.74	1.6	38.07
2		2	10	7.5	3.8	1.38	1.27	19.19
3		3	5	6	3	1.7	1.62	39.8
4	2	1	6	5	3	1.37	1.23	13.85
5		2	7	12.5	3.8	1.35	1.24	15.74
6		3	6	6.5	3	1.42	1.32	22.3
7	3	1	8	5	3	1.48	1.3	20.12
8		2	4	6.5	3	1.6	1.74	30.61
9		3	8	3	3	1.6	1.33	23.05
10	4	1	8	7	3	1.6	1.42	29.51

Table 2 Results of Packer Permeability Test [8]

Pier	Borehole	depth	h cm		Q	T	q=Q/T	K
			Gravity	Pressure	liter	Sec.	cm^3/sec.	cm/sec
4	1	7.0-10.0	600	400	5.12	300	17.06	4.559E05
		4.0-7.0	550	200	3.42	300	11.47	4.089E-05
	2	7.0-10.0	600	400	5.23	300	17.44	4.662E-05
		4.0-7.0	550	200	3.51	300	11.71	4.175E-05
	3	7.0-10.0	600	400	5.42	300	18.07	4.831E-05
		4.0-7.0	550	200	3.63	300	12.09	4.31E-05
5	1	7.0-10.0	600	400	5.24	300	17.47	4.669E-05
		4.0-7.0	550	200	3.71	300	12.37	4.41E-05
	2	7.0-10.0	600	400	5.05	300	16.83	4.5E-05
		4.0-7.0	550	200	3.11	300	10.37	3.695E-05
	3	7.0-10.0	600	400	5.32	300	17.74	4.742E-05
		4.0-7.0	550	200	3.45	300	11.48	4.093E-05
6	1	7.0-10.0	600	400	5.32	300	17.75	4.744E-05
		4.0-7.0	550	200	3.19	300	10.62	3.784E-05
	2	7.0-10.0	600	400	5.22	300	17.41	4.655E-05
		4.0-7.0	550	200	3.53	300	11.75	4.188E-05
	3	7.0-10.0	600	400	5.42	300	18.07	4.829E-05
		4.0-7.0	550	200	3.52	300	11.73	4.182E-05

G.W.L= 6 m - L (length) cm= 280 - R (radius) cm = 2.54

where

h: Head Q: Discharge T: Time k: Permeability coefficient

Photo 2 Dowels Planting Process in one of the Arches

1. Proof Load Test

A complete structural analysis using the determined data was done to the bridge with all its structural elements for predicting the safe traffic capacity for the bridge. The results of the numerical model were used as a guide during proof load test to ensure that the test is well controlled. The proof test was carried out on one of the barrage vents. The tested vent was selected according to arches visual inspection and piers evaluation tests. The selected vent is the worst in condition of the barrage bridge. The test was carried out using two small lorries with gross weight 4.00 ton each. The desired load was 5.0 ton while the test was conducted using load with 8.0 ton to take into consideration long term effect, overloading vehicles and the impact effect. The relation between load and deflection at a point in the critical section was plotted using numerical model. Figure 2 shows isometric view for the numerical model. The model was built for the upper part only and uses real hinge supports instead of piers. This load deflection plot was used as guide and safety indicator during the real test. Figure 3 shows the relation between the truck loads and the deflection only at the location of maximum deflection. Two strain gauges were fixed at bottom fibers of the arch. The reading of strain gauges was recorded at a sampling rate 20 sample/ sec continuously using data logger. Also a gauge with sensitivity 0.001 mm was used to record the deflection manually. There were four loading stages starting from 0.25 maximum load to the full load. Each stage takes 15 min during this period the strains and the deflection were recorded. Moving load with velocity 40 km/hr obstructed with 10 cm height sudden riser was also tested using one of the two vehicles. Figure 4 displays part of one of the strain gauge record. The results of the readings showing that there were no significant strains or deflection recorded. It is easy to notice that the strains are too small with respect to the noise generated in the used equipments. (there is no trend for data in spite of loading process), this is because the tested load is small regarding to the barrage stiffness which agrees with the results of the numerical model. Barrage bridge rating process was calculated also.

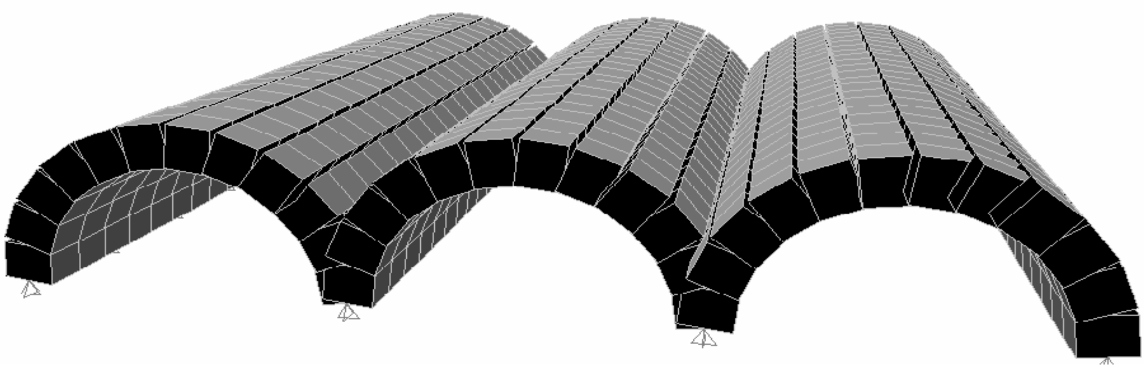

Fig. 2 Barrage Numerical Model

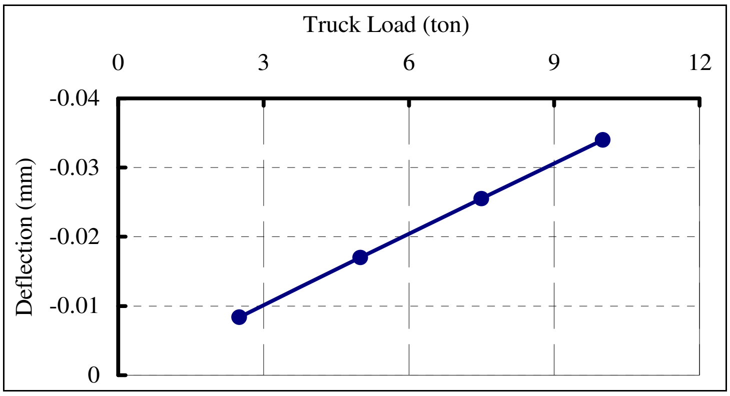

Fig. 3 Load Deflection Curve at Maximum Deflection Point

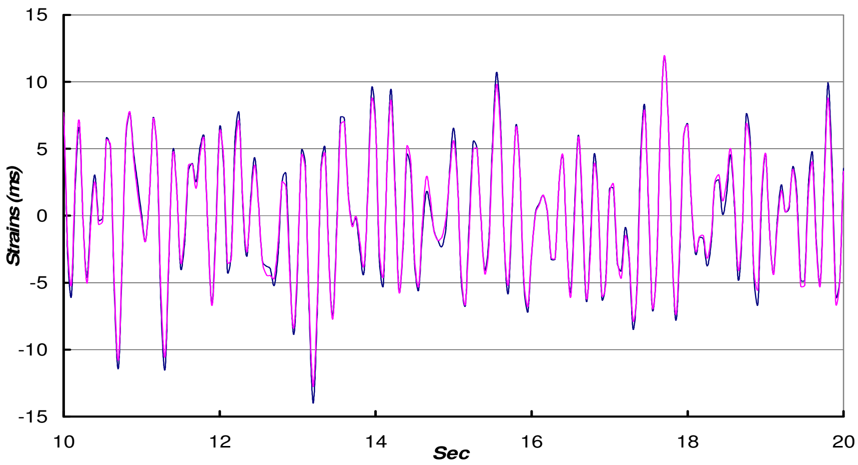

Fig. 4 Strain Gauges Readings

2. Bridge Rating

The rehabilitation and conservation have shown in recent years that there is a need of reliable methods for assessing masonry arch bridges. It is important not only to maintain ancient structures in good condition, but also, when necessary, to be able to estimate their safety factor as accurate as possible. The assessment of a particular bridge [1] is defined by a Rating Factor (R_f) described by:

R_f = Total Load carrying capacity/Applied Loads
$R_f = R/(Q + G)$

Where:

R_f : is the rating factor
R : is the maximum carrying capacity (based on actual material strength)
G : is the actual applied dead loads
Q : is the actual applied live loads

In either case if $R_f \geq 1.0$ then the bridge is safe and no action need to be taken. If $R_f < 1.0$ then action is necessary.

Since the rating factor is proportional to structural safety, greater priority is implied for lower rating factors.

The barrage bridge rating factor was calculated based on the measured brick strengths (maximum carrying capacity stresses) and maximum calculated stresses due to all applied loads (dead load and required vehicle load). The barrage bridge R_f was approximately 2.5 but there was no information about the state of the foundations so the barrage bridge was approved to pass the desired load after checking the foundation conditions.

UPGRADING TECHNIQUES

The presented solution is based on constructing a continuous slab rested on beams carried by the barrage piers. The suggested technique aimed to increase the barrage bridge capacity in an economic way without affecting the hydrological usage and the safety of the barrage. The suggested solution uses the following techniques:

1- Continuous slab supported by piers as a bridge deck.
2- Modified supports.
3- Micro piles in case of soil bearing problem and/or piers deterioration.
4- Grouting in case of piers strength problem.

1. Barrage Super Structure Failure Pattern

Before dealing with the barrage bridge upgrading techniques there is a need to differentiate between barrage failure as a hydraulic structure and barrage failure as a bridge. The barrage modes of failure as hydraulic structure happens due to damage or disrupted of gates, occurrence of piping problems, overturning and sliding problems,…etc. while the modes of failure as bridge structure happens when arches are damaged or in case of over bearing capacity in piers. The suggested techniques take into consideration barrage modes of failure as a bridge.

2. Continuous Slab Deck

This method makes all loads translated to piers only which means the arches capacity can not control the load capacity of the bridge. The continuous slab type can reduce the dead loads of old filling material over arches (by removing it), which decreases the stresses on soil and piers. Arches will be isolated from continues slabs and the only usage of arches will be the lateral supporting of piers. If there is a need to increase the total width of the bridge, the use of continuous slab as bridge deck allows the increase in the bridge width by reducing the side walks and changing the classical parapet with new steel barrier which can be easily fixed in the new deck. Figure 5, shows a comparison between the original barrage bridge cross section and the modified one.

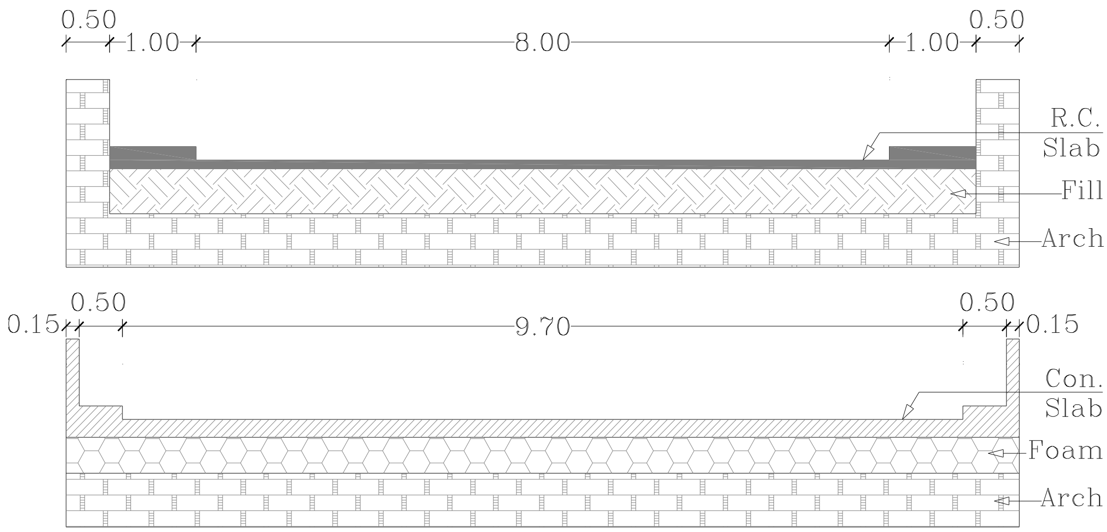

Fig. 5 Comparison between Original and Modified Barrage Bridge

3. Modified Supports

The lateral stiffness of piers around the minor principle axis may govern the design of pier cross section or may control the bridge capacity because of the effect of the eccentric loads on the piers. Using small modification in roller supports may lead to eliminate the eccentricities on piers. Figure 6 shows the suggested roller support which can be used with the continuous slab. Also for expansion joints the intermediate roller can be used as shown in Figure 7.

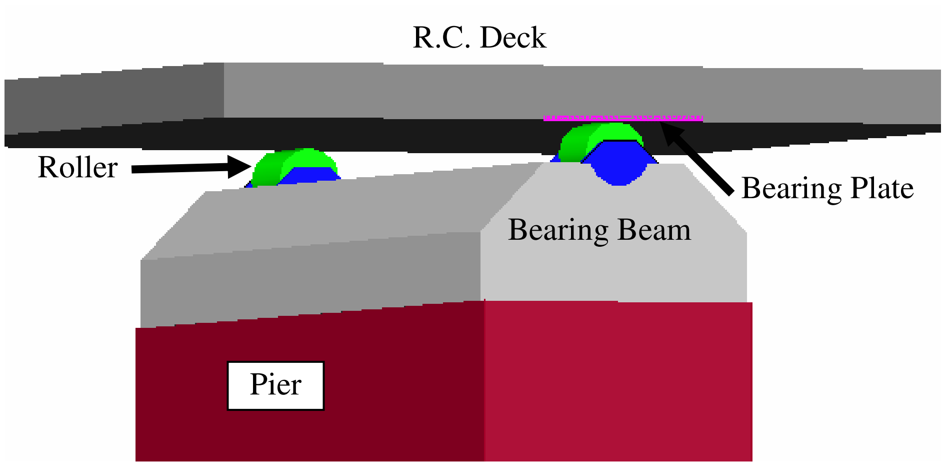

Fig. 6 Schematic Drawing for Continuous R.C. Deck Moves Over Roller Support Fixed at Top of the Pier

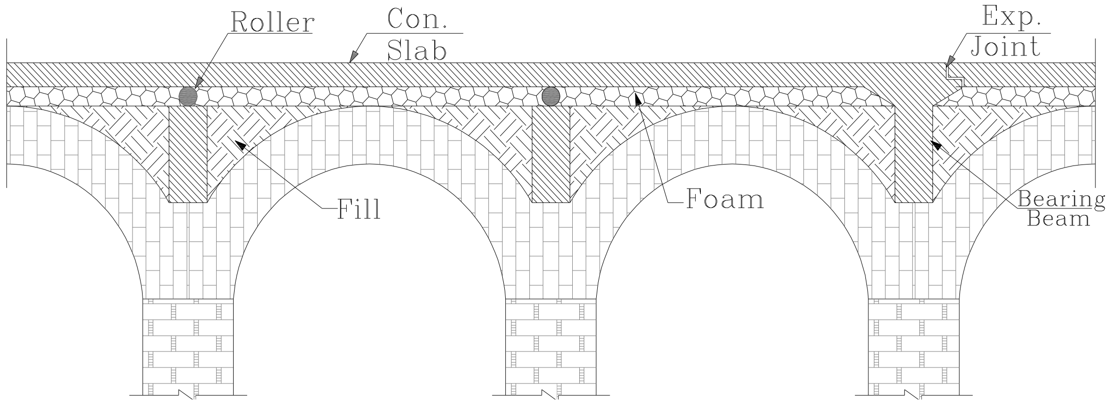

Fig. 7 Suggested Technique For Upgrading

4. Piers Grouting

The piers should be able to resist the loads coming from the bearing beam. Grouting is the ideal solution in case of piers with insufficient bearing capacity or caves problems. Using grouting leads to ensure piers integrity and to keep piers with the required bearing capacity or even to upgrade the piers bearing capacity. Grouting process is a traditional carried out work and is executed from the top level of piers.

5. Micro-Piles

In case of foundation problems such as limited bearing capacity of the soil due to the bridge upgrading, micro-piles can be used to carry the extra loads because it can penetrate the soil to the sufficient depth. Micro-piles can also transfer the bridge loads to soil without loading the piers if required. The execution of micro-piles will enhance also the behavior of barrage in resisting sliding.

EXAMPLE

The finite element model for the tested barrage was modified to evaluate the suggested technique as shown in Figure 8. The continuous slab which formed the bridge deck was represented by shell elements while frame elements were used to model the bearing beams. Rigid links were used to join the bearing beams with the piers. The continuous slab was elevated above the arches to represent the isolation between the slab and the arches. The finite element is developed for the upper part of the barrage and hinges supports was used to represent the effect of piers. The finite element model was solved for the case of maximum moment in the direction of the water current. Two trucks (60-30) ton was shifted as maximum as possible in the road right side. The middle axis of the trucks was just above one of the intermediate piers. Impact effect was considered according to the Egyptian code. The reactions of the bridge were calculated and reversed on the piers as shown in Figure 9. Also the effect of water pressure and the pier own weight were considered. The suggested solution does not change any other original barrage designed cases. The maximum allowed compressive strength will be taken 8.0 kg/cm^2 (according to minimum compressive strength test results divided by 1.5 as a material reduction safety factor). The considered pier dimensions were 1.0 m wide and 12.0 m long.

1. Result Analysis

$\sum N$ = 338 (top part load) + 115.2 = 453.2 ton Total Normal Forces

m_y = (45-20)×5.25+(64-35)×3.75+(56-35)×2.25+(45-38)×0.75+32×4/3 = 335 m.t

$e = m_y / \sum N$ = 0.74 m < 12/6 so, there are no tension stresses

f_{min} = (-453.2/12) + 335×6 /144 = -23.8 t/m^2

f_{max} = (-453.2/12) - 335×6 /144 = -51.73 t/m^2 = 5.173 kg/cm^2 < 8.0 kg/cm^2

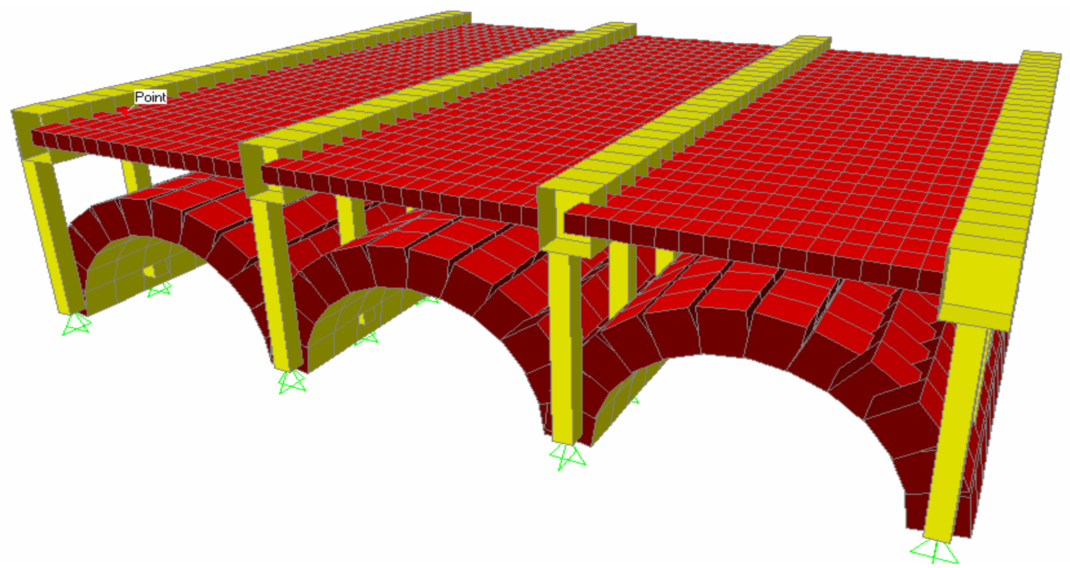

Fig. 8 Modified Model Representing the Suggested Solution

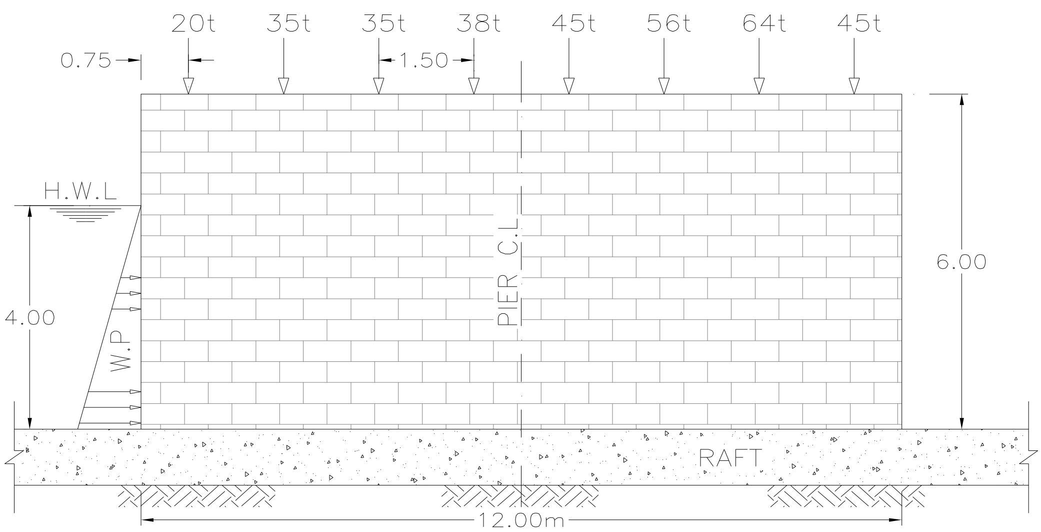

Fig. 9 Case of Maximum Moment about Pier Longitudinal Direction

CONCLUSIONS

1- Loading tests for structures like barrages have limited results whenever it reaches to high loads stage. This stage may be considered unsafe when dealing with such structures with old age and high priority.
2- Prototype models for structures like barrages are necessary for understanding the structure behavior and good estimation for load carrying capacity.
3- The suggested solution keeps the original structure shape which is considered as a cultural and historic landmark in Egypt.
4- The Suggested technique is applicable and can increase a barrage bridge capacity.

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