INCREASING LATERAL CAPACITY OF OLD BARRAGES INTRODUCING CABLES

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ABSTRACT

Barrages are hydraulic structures used to increase water level in their upstream and also to control water discharge in their downstream. Egypt has a large number of barrages which are considered as the backbone of the Egyptian Irrigation System. Most of the existing barrages are close to their service life span. Barrages consist of two abutments and series of arches carried by piers rested on raft foundation. For the purpose of development projects, increasing the head difference carried by a barrage in some cases may be considered as an essential requirement for upgrading. This requirement may lead to the total replacement of the old structure, which is very expensive. Also, most of the old barrages were designed for certain strength of the construction material. Because of material strength deterioration (as a matter of aging, loading pattern, environmental effects, etc.) survival of the present strength for these materials causes a serious problem facing the barrages. This problem may lead to the replacement of the barrage, decreasing the barrage loading or rehabilitate its structural elements. This research introduces a suggested methodology to increase the barrage head difference capacity or to strengthen the barrage. Also, the suggested solution enhances the structural seismic performance due to the new standard requirements. The suggested methodology uses cables joining all the barrage piers in a certain level. This cable scheme works as a lateral support that helps in resisting the lateral loads. The cable is fixed at the canal sides using dead weight or a group of piles. An example of a typical old barrage in Egypt was considered in this study. A finite element 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 increase the lateral loads without affecting the safety of the barrage or its hydraulic efficiency.

Keywords: Strengthening, Barrages, Cables, Seismic.

INTRODUCTION

The rapid change in the population results in high need for the increase in food production that forces to increase the irrigation needs. In Egypt, one of the methods of increasing water discharges is to increase the head differences carried by the regulators and barrages. This methodology may force the structure to withstand straining actions greater than it was designed for. Replacement of such structures is time consuming and is very expensive. Rehabilitation schemes may be considered in some instance an economic solution.

The seismic behavior of old existing structures is affected by their original structural inadequacies, material degradation due to time, and alterations carried out during operation over the years. The complete replacement of these structures will affect some social and human links in addition to the high cost demands. Therefore, seismic strengthening of existing damaged or undamaged structures could be a requirement in some members. Repair and/or strengthening of existing structures may become necessary due to

- Natural aging, inadequate design, poor quality of materials, faulty construction practices
- Severe environmental and accidental influences, e.g. overloads, strong earthquakes, etc.
- Changes in use e.g. load enhancement beyond the original design
- Increase safety requirements, due to modified standards.

Raising water levels was successfully attempted in Egypt several times. Esna, Assiut and Zefta Barrages were remodeled in the early 20-century for such purpose including their accompanying head regulators for the canals they serve. Extension of piers and raft and thickening the raft was the main and sole alternative implemented in such cases. However, this alternative became an expensive one to carry out. As an example of such procedure, problems of sliding occurred with the Old Delta Barrage that required extensive repairs and had to be totally replaced by the year 1937. Sliding is not a phenomenon restricted to regulators and barrages. In the Radiesiah Pump Station in Idfu, strapping the structure with steel wires to stable piles away was adopted to handle the excessive sliding. In some other cases, prestressing the upstream face of the structure was introduced for either raising water levels sustained by the structure or rehabilitating an old one.

The presented scheme in this research depends on wires, cables or bars installed in such a manner to serve as a method of increasing the overall stability or the efficiency of the structure.

PREVIOUS ATTEMPTS

Strengthening is an improvement of the original strength when the evaluation of the structure indicates that the strength is insufficient and restoration alone will not be adequate in future earthquakes. Strengthening procedures should aim at one or more of the following objectives:

- Increasing the lateral strength.
- Giving unity to the structure by providing a proper connection between its resisting elements.
- Eliminating features that are sources of weakness or that produce concentrations of stresses in some members.
- Avoiding the possibility of brittle modes of failure.

Previous works were carried out using several techniques to upgrade and increase the safety of the hydraulic structures [1]. Anchors were used for increasing stability in two dams in USA. The first was the Stewart Mountain dam, where anchors were used to restore monolithic action between construction joints which were weak points in the dam body. Also, anchors were used to enhance sliding resistance. The second dam was the Railroad Canyon dam. The dam needed an increase in its height to prevent overtopping during earthquake events. Anchors were used to connect the new concrete with the existing one.

The Maigrauge gravity dam in Germany is the oldest concrete dam in Europe [2]. 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.

One of the largest renewal and upgrading of old run-of-river Rhine power plants [3] in Switzerland first started operation in 1912, and equipped with Francis-turbines have been running for 78 years without modifications. The main purpose of the rehabilitation works was to replace Francis units by Straflo rim-generator propeller turbines. This work also included repair of the 213 m long gated barrage span across the river. The barrage did not meet the safety standards. The most important objective was to increase the safety of the structure against sliding. For this reason a total of 310 micro piles were installed on the bottom of the 10 slabs across the barrage. With the close contact of new concrete slabs to the existing piers, the piers were held from sliding. The advantage of this solution was that the large quantity of the piles used ensured that the load was dissipated and did not create high forces on the interface of the anchor connection and the old concrete structure and hence there was no need for grouting the old structures.

Other types of schemes may have been introduced that have not come to the attention of the authors.

SUGGESTED CABLES TECHNIQUES

The suggested methodology uses cables in two different patterns. In the first pattern cables were joined all the barrage piers in a certain level. This cable scheme works as a lateral support that helps in resisting the lateral loads. The cable is fixed at the canal sides using a dead weight or a group of piles. Figure 1 shows a schematic drawing for cable profile. In the second pattern each pier was anchored with two anchors. One is at the pier front and the last at the rear of the pier. The anchors drilled from the top of the pier into the soil foundation. Figure 2 displays a pier with anchors. This study uses a simple 2-D finite element model to determine the cable level used in first pattern. A 3-D finite element model was developed representing a typical old barrage in Egypt including the suggested solution. The effect of the suggested solution on the level of stresses including seismic loads (according to new standard demands) was compared to the original case as explained in the next sections.

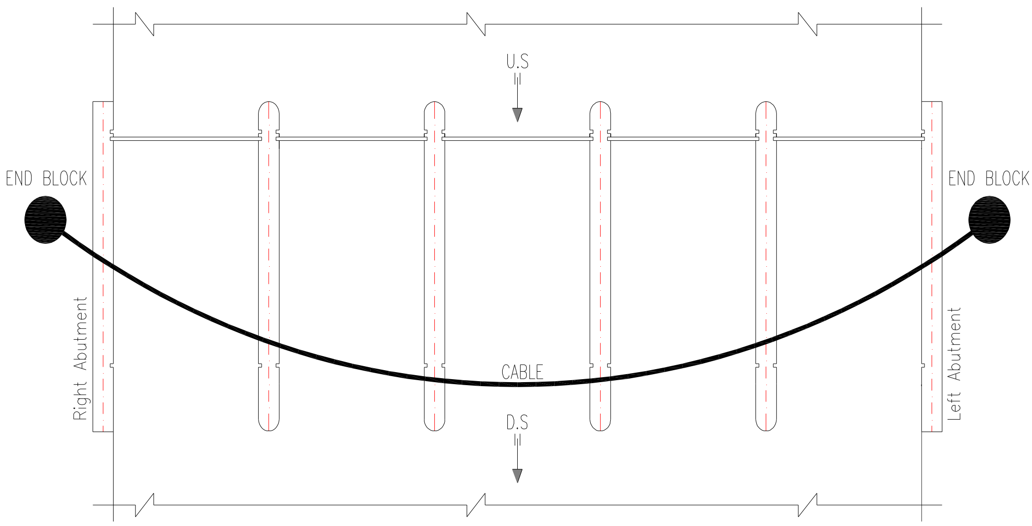


Fig. 1 Schematic Drawing for Cable Profile (Barrage Plan without Bridge Drawn)

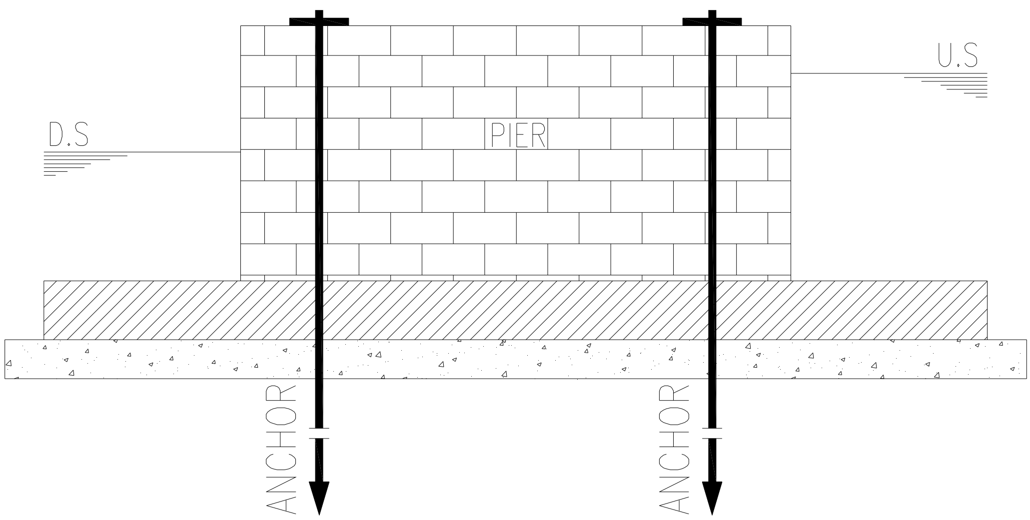
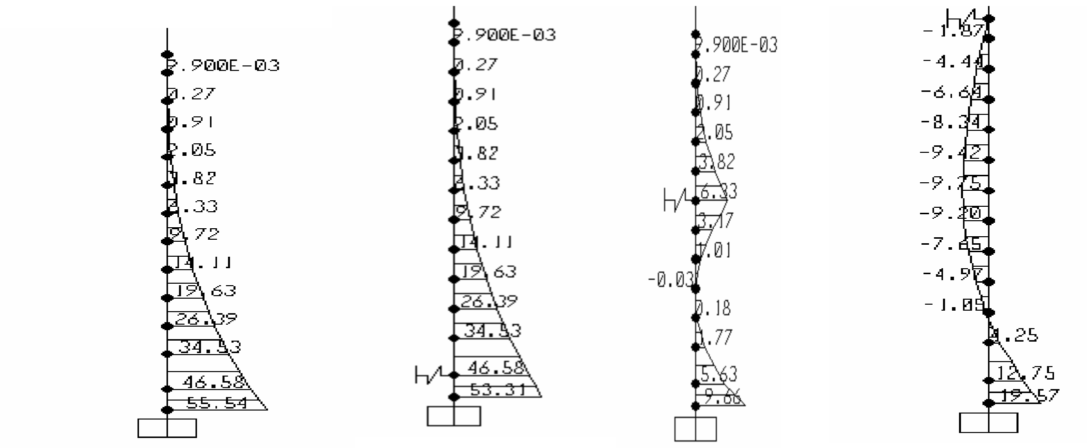


Fig. 2 Anchor Profile (Pier Side View without Bridge Drawn)

SIMPLE F.E.M.

A simple Finite Element Model for the pier was developed using SAP 2000 program [4] to determine the best location of the cable as shown in Figure 3. The pier was modeled using frame elements and the cable was modeled using a horizontal spring attached to the pier. The high water level is taken at a height 6.4 m from the base of the pier. Many cases were solved using different locations for the cable and one case for the pier without the cable figure 3(a).



(a) (b) (c) (d)

Fig. 3 Bending Moment diagrams for the Different Cases

1. Simple F.E.M. Results

Figure 3 shows the bending moment diagrams for some cases. In figure 3(b), (c) and (d), the cable is attached to the pier at height 0.5 m, 3.5 m and 6.5 m from the base of the pier, respectively.

The section at the base of the pier is the most important section in the design because it has the maximum moment (in case of no cable) so reducing this moment would be very useful for the design purposes. Table 1 summarizes the results of some cases with different cable locations.

Table 1 Results of Simple Finite Element Model

Case No.	H (m)	M_b (m.t)	F_c (t)	M_r %	V_r %
1	1.5	27.96	18.39	49.7	77
2	2.5	12.32	17.29	77.8	72.4
3	3.5	9.66	13.11	82.6	54.9
4	4.5	12.3	9.61	77.9	40.2
5	5.5	16.28	7.14	70.7	29.9
6	6.5	19.57	5.86	64.8	23.8

Where

H: Location height of cable — M_b: Moment at base — F_c: Force in cable

M_r: Moment reduction — V_r : Base shear reduction

2. Cable Location Effect

The selection of the suitable location for the fixation of the cable along the vertical cross section of the pier depends on two factors (extracted from simple models). The first factor is location of the cable with respect to the level of the water because it is easier to fix the cable above the water level and also to avoid the corrosion of the cable if it is constructed in the water. Also the cross section of the pier must be able to carry the internal forces induced from the cable.

The second factor is the additional forces which affect the barrage and cause the need for rehabilitation of the barrage (such as the forces due to the increase of the water head on the barrage or seismic forces). The cable could carry high percentage of these additional forces so that the stresses on the pier could be reduced. This reduction depends on the location of the cable in its vertical level. A high reduction of the stresses on the pier could be obtained as shown in case No. 3 (figure 3(c)). In this case the maximum moment (at the base of the pier) is 82.6 % less than that in the case of no cable (figure 3(a)) but in case No. 3 (the cable is constructed inside the water) the internal force in the cable is high (13.11 tons) which requires more massive block to fix the cable than that in case No. 6. In the latter case the base moment in the pier reduced by small amount (64.8 % only) and the internal forces in the cable is 5.86 tons (less than case No. 3) which requires smaller block. A balance should be obtained between the internal forces induced in the pier and the reduction in the moment which is needed to obtain.

TYPICAL BARRAGE 3-D F.E.M

3-D Finite Element Model was developed for a typical barrage. Figure 4 shows the 3-D finite element model for the barrage. The analysis includes two cases of cable profiles in the horizontal plan. One of them was straight line while the other was curved line to test the effect of cable profile in the analysis. Another model was developed to study the effect of using vertical anchors instead of horizontal cables. The effect of using cables was evaluated by comparing the stress level, the lateral drift and the sliding force under the worst load combination (structure own weight plus water pressure plus seismic force). The seismic force affecting the barrage was applied using a response spectrum dynamic analysis. The dynamic analysis was performed using the response spectrum curve according to Regulations for Earthquake Resistant Design of Buildings in Egypt (ESEE Regulations) [5] as shown in Figure 5. The peak ground acceleration was obtained from the seismic maps for Egypt [6] for such type of structures with 200 years exposure period and 90% non-exceeding probability (about 1.04 m/s^2). The results were obtained and discussed.

1. Model Description

The barrage consists of 4 vents with 7 m wide each. Two abutments and three piers resting on raft foundation are carrying the bridge girders. The bridge main girders have cross section 1.0 m depth and 0.35 m width. The bridge slab is 0.25 m thick. 10 cm of asphalt layer was considered in the analysis. The pier is 9.0 m height, 1.0 m width and 18.0 m length. The upstream water level is considered 6.50 m with no water in the down stream. The thickness of the raft foundation is 1.65 m. The piers and the raft foundation are modeled as shell elements. The soil structure interaction was modeled as vertical and horizontal springs. The values of the spring stiffness are based on soil sub-grade reaction and friction resistance at the interface between soil and foundation. The soil strata considered in the analysis was medium stiff clay with bearing capacity not exceeding 1.0 kg/cm^2. The vertical and the horizontal stiffness of springs is taken 800 t/m^3 200 t/m^3 for unit area respectively. Springs were assigned under each node in the shell elements of the raft foundation.

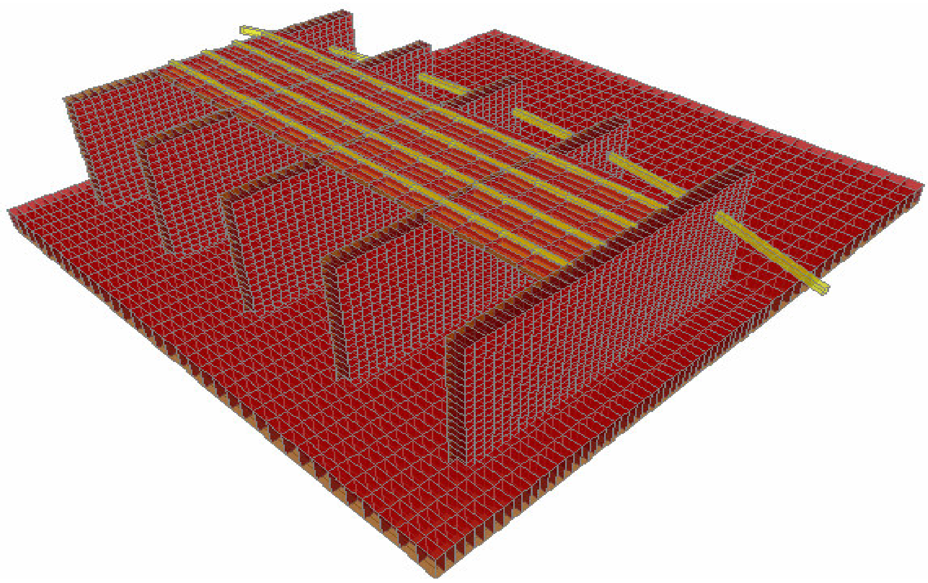


Fig. 4 The 3-D Finite Element Model of the Barrage

The cable was modeled as frame element with axial stiffness only. The deck of the bridge is modeled as shell elements and the four main girders of the bridge are modeled as frame elements. Two different materials were used to model the barrage. The assigned material characteristics were based on previous experiences in testing of such structures. One of the two materials was plain concrete (P.C) with compressive strength 150 kg/cm^2 and the other material was masonry brick with compressive strength 30 kg/cm^2.

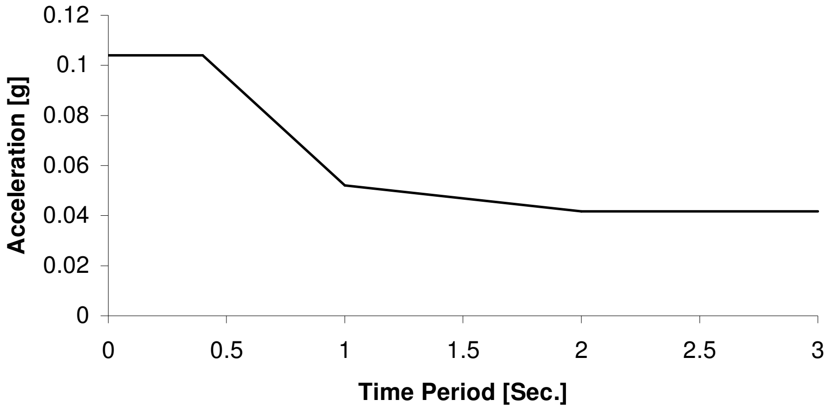


Fig. 5 Response Spectrum Curve

2. Results

Samples of the results of the plain concrete barrage (with and without cable) are presented in Table 2 and Table 3. These tables show the maximum stresses in the pier edges calculated just above the raft foundation. The calculated stresses were induced in two shell elements, one of them at the upstream side (U.S) while the other at the downstream side (D.S).

Table 2 Results of the P.C. Barrage without cable

Case	V (t/m^2)		H (t/m^2)		δ (mm)
	U.S	D.S	U.S	D.S	
W (water pressure)	13.2	-20.5	31.8	-49.1	2.5
S (seismic load)	10.3	-18.3	30.1	-51.8	3.5
D.L (own Wight)	-66.5	-75.8	-22.9	-254.4	0.0
Total (W+S+D.L)	-43.0	-114.6	161.0	-355.3	6.0

Where

V: Vertical normal stress H: Horizontal normal Stresses δ: Top lateral drift

Table 3 Results of the P.C. Barrage with cable

Case	V (t/m^2)		H (t/m^2)		δ (mm)
	U.S	D.S	U.S	D.S	
W (water Pressure)	11.6	-17.3	26.8	-39	2.2
S (seismic load)	8.0	-13.7	22.9	-36.9	3.1
Total (W+S+D.L)	-46.4	-106.8	-173.2	-330.3	5.3

For the plain concrete barrage, it can be concluded from the results that the percentage of the maximum reduction in the stress due to using cable in the case of water pressure, seismic load and total loads are 20.6%, 28.8% and 8.0%, respectively. Also the sum of the horizontal spring reactions due to the total loads was calculated in both cases (with and without cable). It was 593.2 tons and 1366.6 tons in case of using cable and in the normal case (without cable) respectively. It means that using cable increases the factor of safety against sliding by 2.3 times than the normal case (1366.6/593.2=2.3). The results of the brick masonry barrage are shown in Table 4 and Table 5.

Table 4 Results of the Brick Masonry Barrage without cable

Case	**V (t/m^2)**		**H (t/m^2)**		**δ**
	U.S	**D.S**	**U.S**	**D.S**	**(mm)**
W (water Pressure)	13.7	-17.7	33.5	-39.8	2.7
S (seismic load)	8.0	-11.0	23.2	-29.5	2.6
D.L (own Wight)	-35.7	-35.5	-119.5	-118.6	0.0
Total (W+S+D.L)	-14.0	-64.2	-62.8	-187.9	5.3

Table 5 Results of the Brick Masonry Barrage with cable

Case	**V (t/m^2)**		**H (t/m^2)**		**δ**
	U.S	**D.S**	**U.S**	**D.S**	**(mm)**
W (water Pressure)	11.8	-14.8	27.6	-31.1	2.4
S (seismic load)	6.2	-8.2	17.6	-21.2	2.2
Total (W+S+D.L)	-17.7	-58.5	-74.3	-171.1	4.4

For the brick masonry barrage, it can be concluded from the results that the percentage of the maximum reduction in the stress due to using cable in the case of water pressure, seismic load and total loads are 21.9%, 34.1% and 26.4%, respectively. From the comparison of the results in case of brick masonry barrage and plain concrete barrage it can be concluded that the effect of cable increases in the case of brick masonry barrage than that the case of plain concrete barrage. This also means that the use of cable is more effective in the barrages with lower stiffness.

The maximum axial force induced in the curved cable scheme was calculated to be 398.8 tons which allows a reasonable supporting system and cross section of cables. Also, the results show that the cable with curved profile is more effective than the cable with straight line profile.

For the case of pier strengthen with vertical anchors, there were an improvement in the stress level at the down stream side. This method of strengthen has some limitation at the upstream side because the vertical anchors required prestressing forces which increase the compression stress at the upstream side. These forces must be determined to keep the level of compression stress in all cases of loading to be not exceeding the allowable compressive strength.

CONCLUSIONS

From the analysis of the results it may be concluded that:

- For plain concrete barrage, the percentage of the maximum reduction in the stress due to using cable in the case of water pressure, seismic load and total loads are 20.6%, 28.8% and 8.0%, respectively.
- Using cable increases the factor of safety against sliding by considerable amount than the normal case (without cable).
- For the brick masonry barrage, the percentage of the maximum reduction in the stress due to using cable in the case of water pressure, seismic load and total loads are 21.9%, 34.1% and 26.4%, respectively.
- The effect of cable increases in the case of brick masonry barrage than that the case of plain concrete barrage or in other words, the use of cable is more effective in the barrages with lower stiffness.

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