Military Technical College
Kobry El-Kobbah,
Cairo, Egypt

9th International Conference
on Civil and Architecture
Engineering
ICCAE-9-2012

ASSESSMENT OF USING REINFORCED AND PRE-STRESSED MASONRY TO UPGRADE LATERAL LOAD CAPACITY OF BARRAGE PIER

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ABSTRACT

Masonry barrages are considered one of the most important water structures in Egypt. They control water levels in the River Nile and its branches and canals. It is very important to keep them working in good condition to assure good water management and distribution process. Most of barrages in Egypt have been built many years ago using masonry bricks without steel reinforcement. Due to their importance it is essential to protect these structures from the risk of earthquakes. Also some of these masonry barrages have been belt hundreds years ago and still working till now. The new barrages in Egypt were built using reinforced concrete. The cost of reinforced concrete structures is much higher than masonry structures. The main problem of the masonry structures is their low resistance to lateral load especially in the out of plane direction which causes over stress in the barrage piers during earthquakes.

This research was performed to investigate the effect of using reinforcement masonry and pre-stressed masonry to increase the seismic load capacity of barrage piers in the out of plane direction. These two techniques could be used in new structures or in existing structures.

Three masonry piers were built on a shaking table using ordinary masonry, reinforced masonry, and pre-stressed masonry. These piers were exposed to cyclic loads with different frequencies to model the earthquake. Finite element model was developed for the tested piers. Dynamic analyses were performed using the same input motion of the shaking table. The results of the experimental and the numerical models were compared to adjust the numerical model. Another finite element models were developed for typical masonry barrage using ordinary and reinforced masonry. Time history dynamic analyses were performed to investigate the effect of earthquakes on their responses. Guidelines for the assessment of the use of reinforced and pre-stressed techniques in construction and strengthening of masonry barrages were suggested.

Keywords: Reinforced, pre-stressed masonry, barrages, dynamic test, and seismic design.

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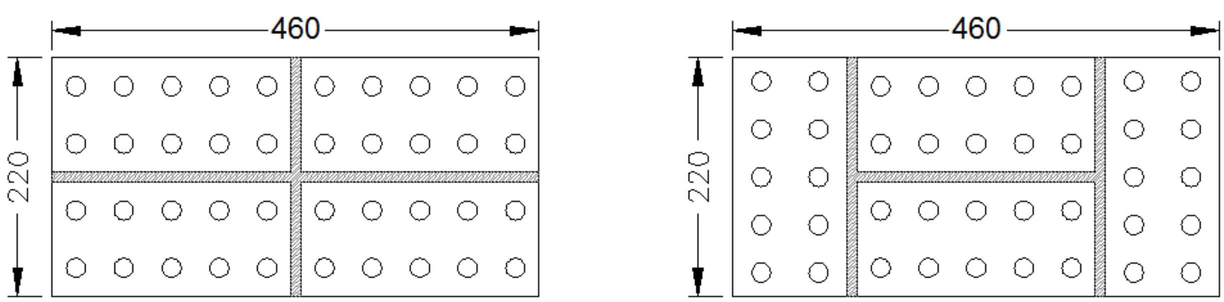
1. INTRODUCTION

Most of barrages in Egypt have been built many years ago using masonry bricks without steel reinforcement. Due to their importance it is essential to protect these structures from the risk of earthquakes. Also some of these masonry barrages have been belt hundreds years ago and still working till now. The cost construction of reinforced concrete barrages is much higher than masonry barrages. 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 walls to resist in-plane moment in the longitudinal direction due to earthquakes. Hernan and, et al., [1] 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. Durgesh, and et al., [2] 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. Fotis, and et al., [3] investigated the vulnerability and the overall seismic behavior of masonry building. They developed a methodology for seismic design and evaluation of the response of the masonry construction. Asli, A., and et al., [4] proposed 4-storey masonry residential buildings instead of multi-story reinforced concrete. They verified that it is possible to construct a four-story residential building with masonry bearing walls instead of reinforced concrete beam and column skeleton system without changing its architectural characteristics.
The problem of the barrage piers is that they are exposed to out of plane loads due to earthquakes or due to other load case considered in the design. This research investigates the effect of using some methods for increasing barrage pier resistance to out of plane loads.

2. EXPERIMENTAL WORK

Three masonry piers were built on a shaking table using commercial clay hollow bricks to model the barrage pier. The brick was arranged as shown in Fig.1. The length, breadth, and height of each wall were 46cm, 23cm, and 125cm, respectively. The masonry piers were built on a foundation layer consists of plain concrete with thickness = 7cm. Figure 2, display the tested piers built on the shaking table.

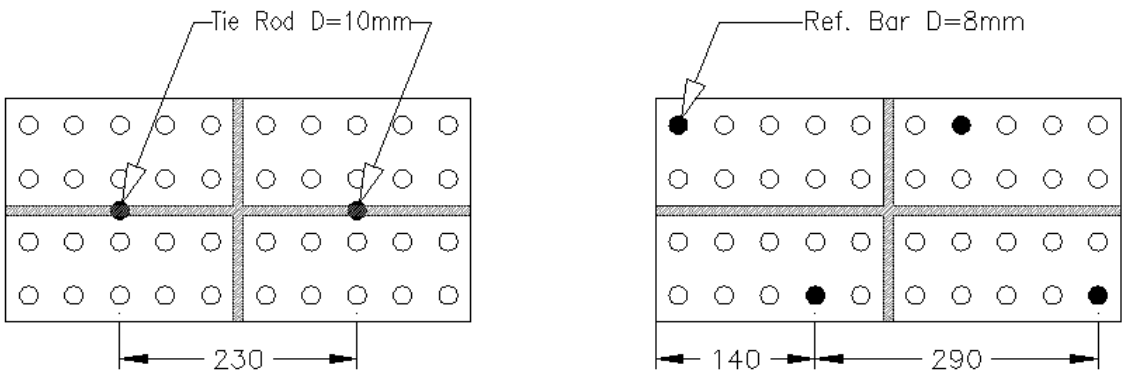


a) Course No. 1 b) Course No. 2

Figure1. Brick arrangement used in piers construction

Figure2. Masonry piers on shaking table

The first pier was built using ordinary techniques for masonry buildings. The second pier was strengthened by using steel bars as used in buildings with reinforced masonry wal ls techniques. The steel bars used in the reinforcement were four mild steel bars with 8mm diameter fixed in a staggered arrangement. The third pier was built as first pier but prepared for applying pre - stressing force =1 ton by using two tie rods of high grade steel with 10mm diameter. Figure 3 shows the configuration of reinforcement and pre -stressed techniques.



a) Prestress Configuration b) Reinforcement Configuration

Figure3. Strengthen techniques used in testing piers

The steel bars were fixed inside the brick holes. These holes were filled with mortar. The tie rods were put in a plastic pipe during the construction of the pier to apply the pre -stressing force after completion of the pier and gain its stress resistance . Figure 4-a shows the tie rods inside plastic pipes and Figure 4-b shows the steel bars inside the brick holes.

a)

Prestressed Pier

b) Reinforcement Pier

Figure4. Tested models during construction

The responses of the piers were measured using accelerometer sensors. Three accelerometers were used to measure each pier acceleration response. The accelerometers were fixed at the top of each pier where maximum response was expected. Two LVDT devices were used to measure the displacements response. One of them was fixed at the top of the pier of ordinary masonry building technique. The other LVDT device was fixed at the top of the pier with pre-stressing building technique. Figure5. Displays the instrumentation devices used in the tests and its mounted location on tested piers.

a)

LVDT & accelerometers sensors

b) accelerometers sensors

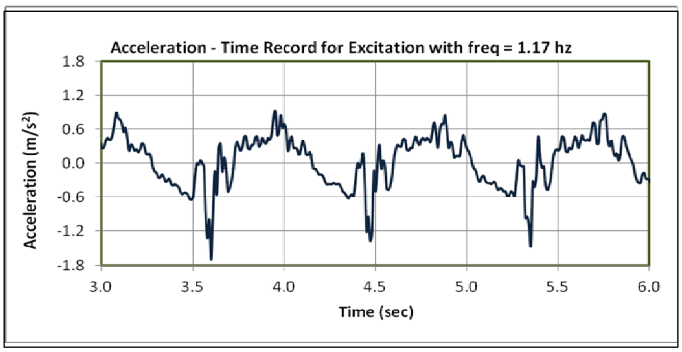
Figure5. Instrumentations mounting tested masonry piers

All the piers were built at the same time with the same brick and mortar type and with the same labors. Three specimens were prepared (using 5 bricks for each specimen) during the construction of piers to be tested with the compression test to determine the compressive strength of the masonry piers. The average compression strength for the three specimens was 34.9 Kg/cm^2. Figure 6 shows the specimen during the compression test.

a) Sample No. 1 b) Sample No. 2 c) Sample No. 3

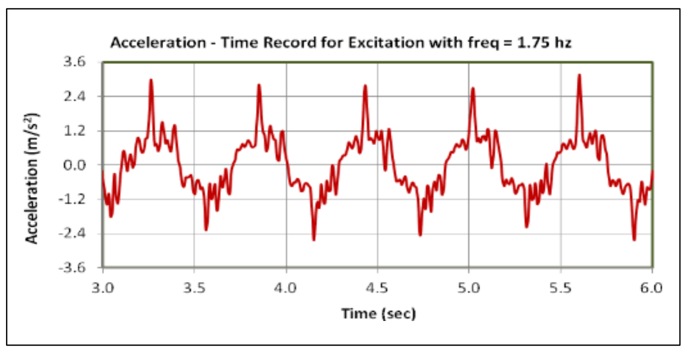
Figure6. Tested samples under compression test

The acceleration responses during shaking the three piers were measured. The displacement responses were also measured for pre-stressed pier and ordinary pier only. The piers were subjected to three input motions with three different frequencies. The frequencies of the applied motions were 1.17, 1.75, and 2.20 hz., respectively. Figure 7 displays the different input motion. The accelerometer sensors send the measured signals to a conditioner unit which in turn sends the conditioned signal to a data acquisition card through connecting cables. The acquisition card passes the digital data to a laptop computer for the purpose of data storage and analysis.



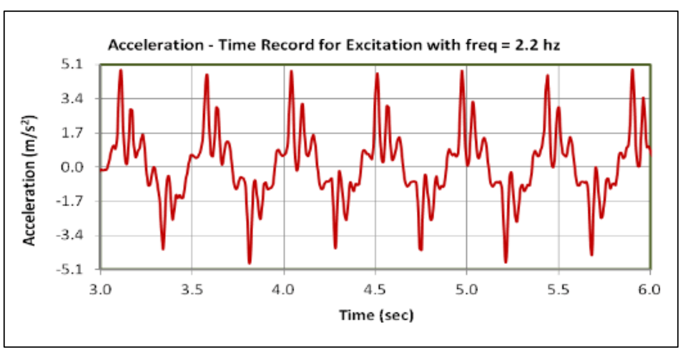
a) Input Motion with freq = 1.17 hz..

Noting that:-
Max. Acceleration = 1.83 m/sec^2
(Ground acceleration)



b) Input Motion with freq = 1.75 hz..

Noting that:-
Max. Acceleration = 3.15 m/sec^2
(Ground acceleration)



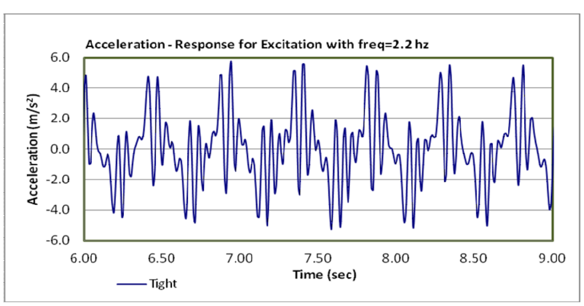
c) Input Motion with freq = 2.20 hz..
Noting that:-
Max. Acceleration = 5.41 m/sec^2
(Ground acceleration)

Figure7. Input motions applied on the tested piers

The logging software controls the measuring process and converts analog signals to digital ones. The data is filtered and analyzed using the signal processing techniques. These techniques were applied on the measured acceleration time record. These techniques such as Cut-off frequency technique filter are used to remove noises to get acceptable signal-to-noise ratio.
The type of the data acquisition cards is PCD-320A. The software produced by KYOWA is used to control and filter the measurements. The data analysis software used is Seismosignal.
The time lengths of input harmonic excitations were 10 sec., and 20 sec. The input motions were applied in two groups. The first group with time length =10 sec. starts with motion with frequency = 1.17 hz. then motion with frequency = 1.75 hz, and the last motion with frequency = 2.20 hz.
The second group was as the same as the first group except that the time length was 20 sec. the pier which was built using ordinary technique was totally failed during applying the last motion in group 2. Figure 8 displays the failed pier.

Figure8. Ordinary pier failure during test

Pre-stressed force was applied on one of the three piers then subjected to group 1 of input motions. The pre-stressing force was released then the pier was subjected to group 2 of input motion. Comparison between acceleration responses of pier with and without pre-stressing force is shown in Fig. 9.



a) Acceleration Response for Prestressed Case
b) Acceleration Response for Released Case

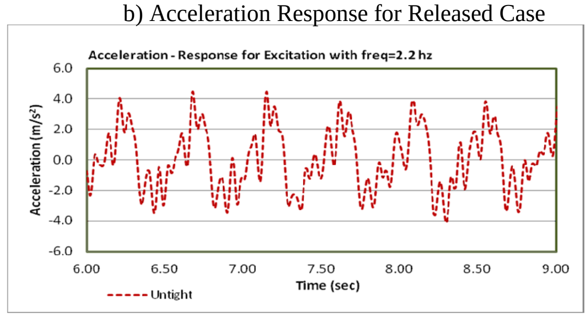
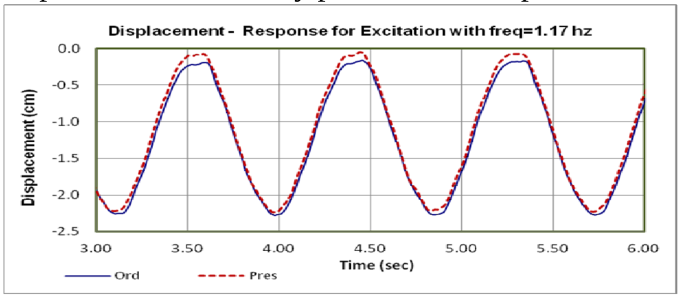


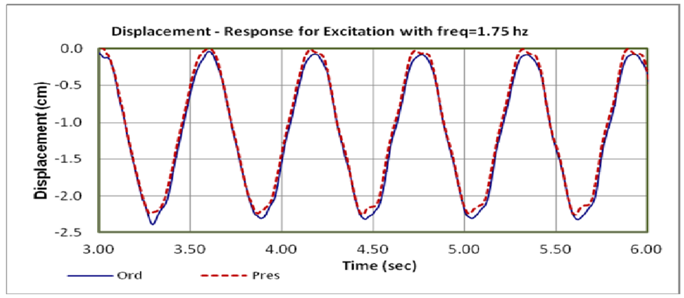
Figure9. Comparison bet. acceleration responses of pre-stressed and released cases

Also, the displacement responses measured during the three applied motions are displayed as a comparison between the displacement response of the pre-stressed pier and the displacement response of the ordinary pier. These comparisons are shown in Figure 10.



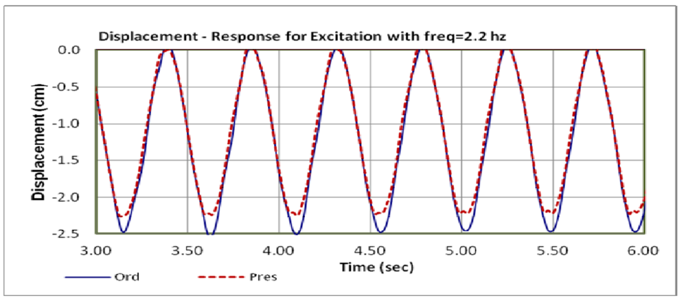
a) **Comparison between displacement response for two cases at excitation motion with frequency = 1.17 hz.**

Noting that:-
The increase in displacement in case of ordinary brick was 2.2% more than the that of pre-stressing brick case.



b) **Comparison between displacement response for two cases at excitation motion with frequency = 1.75 hz.**

Noting that:-
The increase in displacement in case of ordinary brick was 5.0% more than that of pre-stressing brick case.



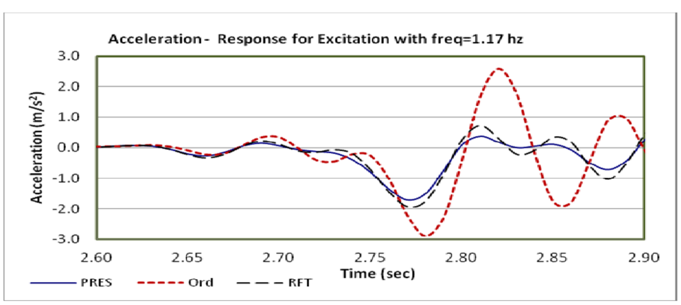
c) **Comparison between displacement response for two cases at excitation motion with frequency = 2.2 hz.**

Noting that:-
The increase in displacement in case of ordinary brick was 18 % more than that of pre-stressing brick case.

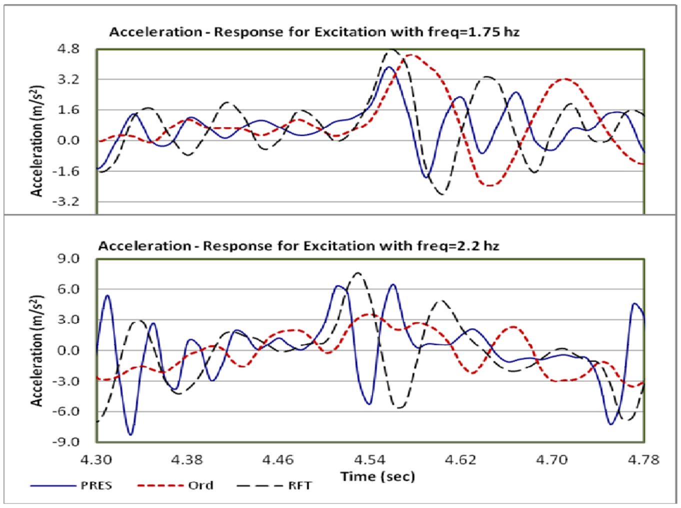
Figure10. Comparison between displacement response of ordinary masonry pier , and pre-stressing masonry pier

The acceleration responses for the three piers under the three input motions are displayed as a comparison between the acceleration response results of the tested piers under the three applied tested motions. These comparisons are shown in Figure 11. It is noted that for the three applied motions there is no clear trend for the acceleration response for each pier. For example; the acceleration response of ordinary masonry pier has the maximum peak acceleration under applied input motion with 1.17 hz., while it has the minimum peak acceleration under applied input motions with 2.20 hz..

The acceleration response of reinforcement masonry pier has the maximum peak acceleration under applied input motion with 1.75 hz., while the acceleration response of pre-stressed masonry pier has the maximum peak acceleration under applied input motions with 2.20 hz.



a) **Comparison between acceleration response for different cases at excitation motion with frequency = 1.17 hz.**
Noting that:-
The case of ordinary brick has maximum peak acceleration while the case of pre-stressed brick has the minimum peak acceleration.



b) **Comparison between acceleration response for different cases at excitation motion with frequency = 1.75 hz.**

Noting that:-

The case of reinforcement brick has maximum peak acceleration while the case of pre-stressed brick has the minimum peak acceleration.

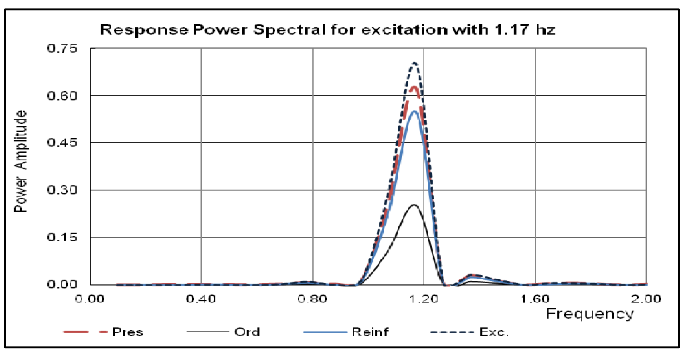
c) **Comparison between acceleration response for different cases at excitation motion with frequency = 2.20 hz.**

Noting that:-

The case of pre-stressed brick has maximum peak acceleration while the case of ordinary brick has the minimum peak acceleration.

Figure11. Acceleration responses for different cases at different excitation frequencies

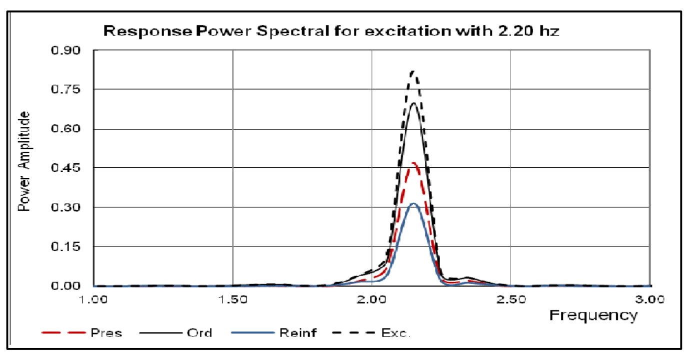
To understand these behaviors the power spectral acceleration response was calculated for all cases under all the applied motions. Figure 12-a., and 12-b, display comparisons between all power spectral acceleration responses and the acceleration power spectral of the input motion (excitation) under applying the input motion with frequency 1.17 hz., and 2.20 hz., respectively. To study the effect of the pre-stressing force on the dynamic response of masonry pier, comparisons between the power spectral acceleration response for case of applying pre -stressing force and case when pre-stressing force was released were performed as shown in Fig 12-c. Figure 12-a, and Fig. 12-b, show that the pre-stressed masonry pier has the lowest damping effect. Also when the pre-stressed force was released the damping effect increased as shown in Fig. 12-c. The reinforced masonry pier has damping effect higher than that of pre-stressed pier in all cases.



a) **Comparison between power spectral for different cases with respect to the excitation motion**

Noting that:-

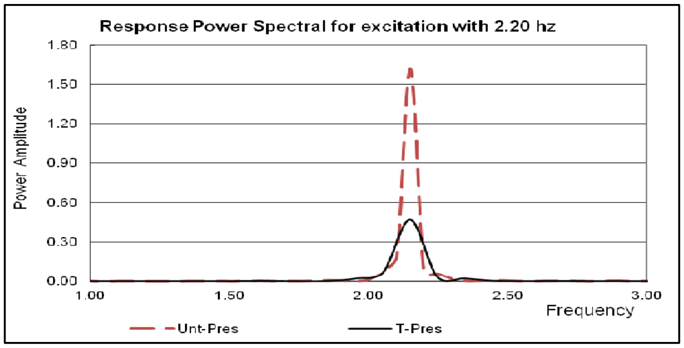
The case of ordinary brick has the lowest amplitude while the case of pre-stressing has the nearest amplitude to the excitation force.



b) **Comparison between power spectral for different cases with respect to the excitation motion**

Noting that:-

The case of reinforcement brick has the lowest amplitude while the case of ordinary brick has the nearest amplitude to the excitation force.



c) **Comparison between case of applying pre-stress force and case with released the pre-stress force**

Noting that:-
The amplitude of power spectra has a significant drop when the pre-stress force was released.

Figure12. Power spectral acceleration responses for different cases

The ratios of the increasing in the acceleration response in case of reinforced and pre-stressed masonry to the acceleration response in case of ordinary masonry were calculated. Figure 13 show the relation between the increasing in acceleration response and the frequency of the input motion for case of reinforced masonry and pre-stressed masonry. This figure shows that for case of reinforced masonry the relation between the increasing in acceleration response and the frequency of input motion was almost linear relation. The increase in acceleration response increased when the frequency of input motion increased. This relation criterion is matched with pre-stressed masonry but with nonlinear relation.

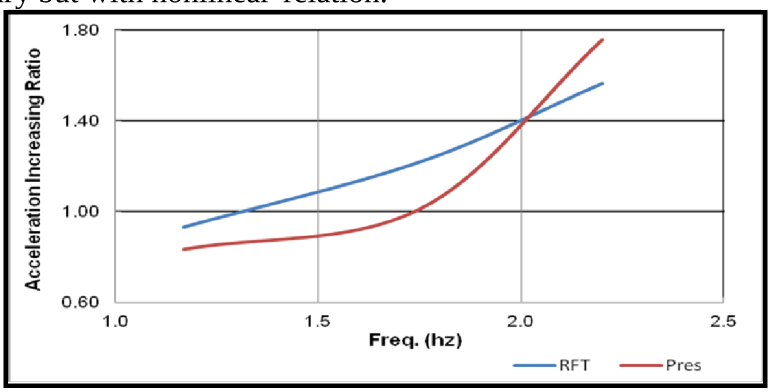


Figure13. Relation between acceleration increasing ratio, and frequency of input motion for reinforced and pre-stressed masonry.

3. NUMERICAL ANALYSIS

The experimental results show that the reinforcement masonry technique is more suitable for the construction of the new structures than the pre-stressed technique since it has higher damping effect than the pre-stressed technique so that the reinforced and ordinary masonry were considered in the numerical analysis.

3.1 Finite element model for the tested piers

Before developing a finite element model for a typical barrage, a numerical model was developed for the tested ordinary and reinforced piers using SAP2000 program [5] (as shown in Fig. 14) to adjust and validate the numerical model. The model was exposed to the same input motion used in the experimental work with frequency =1.17 hz., and maximum acceleration =1.83

m/s^2. The masonry walls and the steel bars were modeled using solid elements and frame elements, respectively.

Young's modulus of the clay bricks was taken about 580 times the compressive strength as specified in [6]. Young's modulus, Poisson's ratio, and density of the bricks were taken 200000 t/m^2, 0.2, and 1.60 t/m^3, respectively. Young's modulus, Poisson's ratio, and density of the steel bars were taken 2.1x10^{7}t/m^2, 0.3 , and 7.85 t/m^3, respectively.

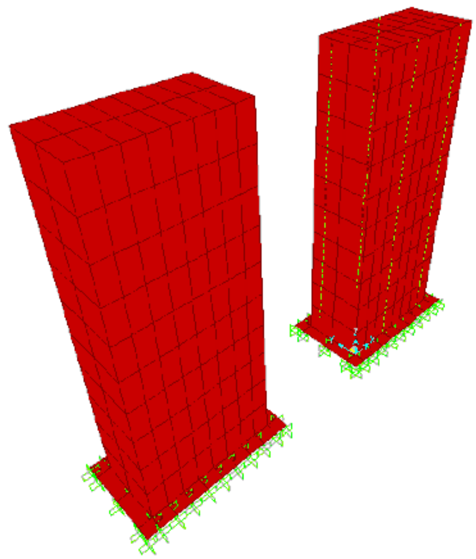


Figure 14. Finite element model for the piers.

The maximum acceleration obtained from the numerical model and occurred in the ordinary and reinforced masonry were 1.8 m/s^2, and 2.1 m/s^2 , respectively. These results are matched with results obtained from the experimental work (shown in Fig. 11-a).

3.1 Finite element model for a typical barrage

Then a Finite element model was developed for a typical barrage as shown in Fig.15. The model was exposed to El-Centro earthquake acceleration time history. The peak acceleration of this earthquake was scaled down to 1.0 m/s^2 to be suitable for the expected earthquakes in Egypt. The typical barrage consists of two masonry piers and 2 abutments at its sides carrying an arch bridge with thickness= 0.50m. The piers and the abutments are rested on a concrete raft foundation with thickness=2.0m. The breadth and the height of the pier and the abutment are 2.1m, and 4.75m, respectively. The length of the pier and the abutment are 35.0m, and 15.0m, respectively. The spacing between the centerline of the piers is 5.25m. The masses were obtained from the own weights and dead loads of the barrage and the arch bridge. The same properties of the bricks and the steel bars used in the modeling of the experimental work were used. Nonlinear link elements were added to model the soil structure interaction (SSI) between the foundation and the soil. The value of the spring stiffness (K_s) was taken as 1800 t/m^3. The spring stiffness of the nonlinear link element is assigned to this value multiplied by the area of the spring when the element is in compression to model the SSI. When a tensile force is developed in the element, the spring stiffness is assigned to zero to allow separation between foundation and the soil during the time history analysis.

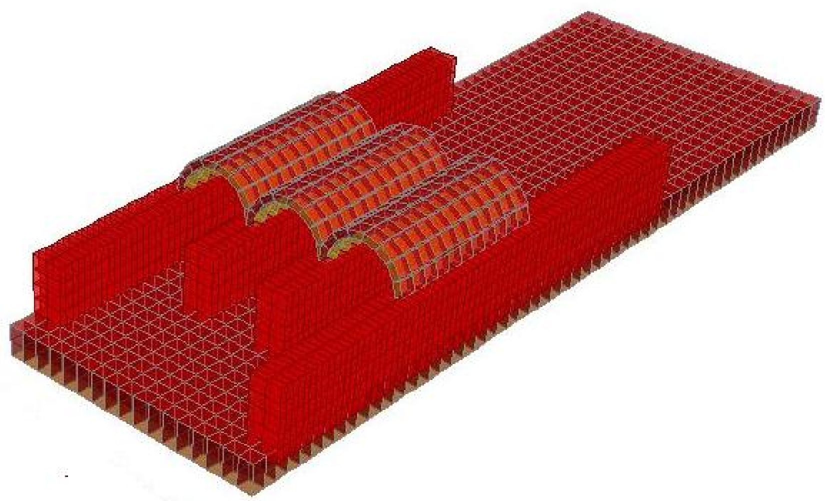


Figure .15 Finite element model for the barrage.

Another Finite element model was developed for the barrage using reinforced brick walls for the piers and the abutments. The area of the steel was taken 0.08% of the cross sectional area of the bricks. This reinforcement was distributed along each side of the pier and abutment as steel bars with diameter 22mm every 46 cm.

4. RESULTS

The results obtained from the finite element model of the barrage with and without reinforcement were compared to investigate the effect of the reinforcement.

Sample of the results is shown in Fig. 16 which show the maximum vertical compression stress induced in the pier with reinforcement during the earthquake.

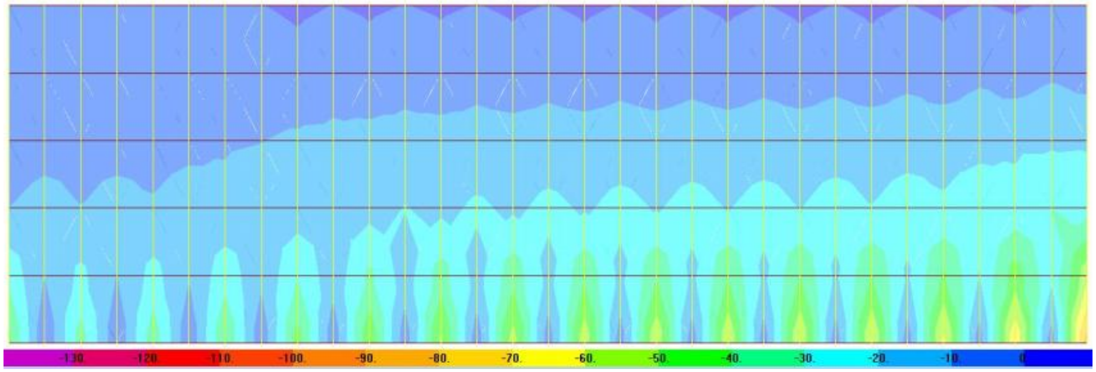


Figure 16. Max. Vl. comp. stress induced in the reinforced pier.

The maximum tensile stresses occurred in the pier with and without reinforcement were 12.5 t/m^2, and 16.5 t/m^2, respectively. The maximum compression stresses occurred in the pier with and without reinforcement were 36.6 t/m^2, and 44 t/m^2, respectively. These results mean that the use of reinforcement decreased the tensile and compressive stress by 24.2%, and 16.8%, respectively. Also, the tensile stress occurred in the pier without reinforcement can't be resisted by the ordinary masonry according to the Egyptian Code for masonry buildings [7] (allowable tensile stress specified in the Code=16t/m^2) while the tensile stress occurred in the pier with reinforcement can be resisted easily by the steel reinforcement with tension force in the steel bar =3.7 tons.

5. CONCLUSIONS

This study leads to the following conclusions:

- The use of pre-stressed and reinforced masonry could prevent the brittle failure occurred in the ordinary masonry pier during the experimental work.

- The reinforced masonry has damping effect higher than that of pre-stressed masonry so it can be used in new structures.

- The pre-stressed technique can be used in the strengthening of existing structures because of the difficulty of making many holes in existing pier in the case of using reinforced masonry technique. Also, the use of pre-stressed masonry could decrease the displacement than the case of ordinary masonry by about 18 % during the experiment.

- Using reinforced masonry technique could decrease the tensile and compressive stress induced in the barrage pier due to earthquake by 24.2%, and 16.8%, respectively.

- The tensile stress occurred in the pier without reinforcement can't be resisted by the ordinary masonry according to the Egyptian Code, while the tensile stress occurred in the pier with reinforcement can be resisted by the steel reinforcement.

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