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Efficiency of Post-Tensioning Method for Seismic Retrofitting of Pre-Cast Cylindrical Concrete Reservoirs

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Abstract**—**Cylindrical concrete reservoirs are appropriate choice for storing liquids as water, oil and etc. By using of the pre-cast concrete reservoirs instead of the in-situ constructed reservoirs, the speed and precision of the construction would considerably increase. In this construction method, wall and roof panels would make in factory with high quality materials and precise controlling. Then, pre-cast wall and roof panels would carry out to the construction site for assembling. This method has a few faults such as: the existing weeks in connection of wall panels together and wall panels to foundation. Therefore, these have to be resisted under applied loads such as seismic load. One of the innovative methods which was successfully applied for seismic retrofitting of numerous pre-cast cylindrical water reservoirs in New Zealand, using of the high tensile cables around the reservoirs and post-tensioning them. In this paper, analytical modeling of wall and roof panels and post-tensioned cables are carried out with finite element method and the effect of height to diameter ratio, post-tensioning force value, liquid level in reservoir, installing position of tendons on seismic response of reservoirs are investigated.

Keywords**—**Seismic Retrofit, Pre-Cast, Concrete Reservoir, Post-Tensioning.

I. Introduction

CIRCULAR reservoirs are appropriate choice for storing liquids as water, oil and etc. usually, their main materials are concrete or steel. In the recent years, using of the pre-cast concrete panels increased in many fields of civil engineering. Pre-cast concrete panels had been applying in constructing of the bridges, offshore and highway pavements from many years ago. But pre-cast concrete panels have been using in the construction of the storing reservoirs for recent decades. Constructed reservoirs by this method were in two shapes; rectangular and circular. Two of the well-known commercial companies in the construction of these reservoirs are Shay Murtagh and Stresscrete [1, 2]. Generally, using of the pre-cast concrete panels instead of the in-situ concrete would considerably increase the speed and precision of the construction. Many researches were performed in the field of concrete and steel reservoirs. In these studies the effects of various loadings such as static, dynamic and thermal loads were investigated [3-7]. Their results are shown in the reservoir construction building code and books [1-3]. about steel oil reservoirs the extended researches were carried out and effect of support bracing, level of oil in reservoir and height to radius ratio were investigated [6-8]. In the field of pre-cast or pre-stressed concrete, numerous researches and handbooks are existing [8]. But in the field of pre-cast concrete reservoirs a few number researches were carried out. One of their major ones was seismic retrofitting of numerous pre-cast rectangular and cylindrical reservoirs in New Zealand [9]. In this paper, analytical modeling of wall and roof panels and post-tensioned cables are carried out. The effect of the height to diameter ratio, post-tensioning force value, liquid level in reservoir, installing position of the tendons on seismic response of the reservoirs are also investigated.

II. Method Of Construction And Seismic Retrofit

A. Stages of Construction

-Preparing the bedding plane

In first step, the reservoir bedding plane is compacted until the foundation can be erected on it. The bedding is consisted of the grading and the soil compaction by machinery.

-Foundation erecting

In this stage, the strip footing with the suitable width and circular shape is established under the walls.

-Assembling the wall panels

In this stage, the wall panels are arranged together. For creating the Integration between the panels, the cables are installed around the wall panels before the latest panel is installed. Then, these cables are completely stretched by Special Jacks so that the stability of the reservoir is provided.

In the latest stage, the roof panels are installed if the reservoirs are be roofed. While, the spans are large, the beams are firstly constructed. Then, the roof panels are installed.

Roof panel assembling and Completed 20000 m^3 reservoir is shown in figures 1&2.

Fig. 1 Assembling roof panels.

Fig. 2 Completed 20000 m^3, pre-cast concrete reservoir.

B. Methods of Seismic Retrofitting

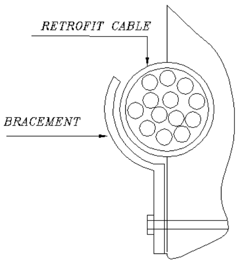
Passing the pre-stress cable around the reservoir and post-tensioning it which is one of the effective ways for seismic retrofitting of pre-cast concrete reservoirs. This method is reduced the panel edges opening under the hydrostatic and seismic loads. Consequently, the less water would leakage during the operation of the reservoir.

Advantages of this retrofitting method include:

1. It is fast and functional
2. It isn't necessary to reservoir be out of service, in retrofit process.
3. It is relatively cheap way. The estimates made by Taylor and Wright [9] indicated that this method costs about 8% of building a new reservoir.

Executive details of this method are shown in figure 3:

(a)



(b)

Fig. 3 (a) Retrofit post-tensioned cables, (b) Detail of post-tensioning cable saddles.

III. ANALYZES

A. Modeling

Modeling is done by SAP2000 software. The cables are modeled by cable element without the post-tensioned force. The wall and roof panels are modeled by the SHELL element which has a 30 cm thickness.

In the constructed reservoirs, using the expansion and contraction joint for preventing the cracking. This joint is filled by the elastic materials. Therefore, the small join is between the panels n the modeling so that these panels have no contact together. In this state, the momentum is not transported and the only force transportation way is cables.

For modeling the post-tensioned cable, the eccentricity with the value of 10 cm relative to panel sheets is determined so that by generating the tensile force at this situation, the Center-oriented radial force is created.

Quality of the cable modeling is shown in figure 1. For investigating the effect of the radius to height on wall edge opening, two models are presented in table 1.

According to increase the ring pull force at the cylindrical reservoir wall due to hydrostatic water pressure, by increasing the depth, the cabling distances decrease.

In the first model, the cable level from bottom is 0.5, 1, 1.5, 2.5, 4, 7 m and for second model is 0.5, 1, 1.5, 2.5, 4 m

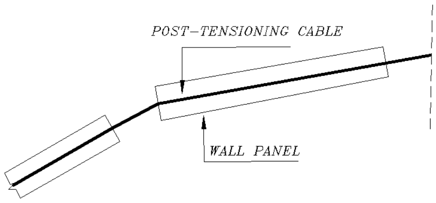
The cable materials are determined as Multi – Territory and based on the Dehdashti's study [10]. The value of the yield stress and ultimate stress is defined 1000 MPa 1600 MPa respectively. The loads and load combinations are as below:

Water pressure: hydrostatic water pressure on walls.

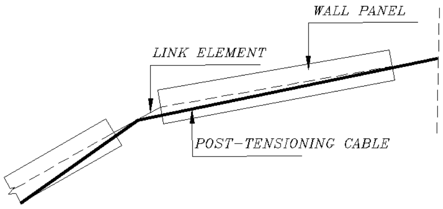
Earthquake: quake effect on wall and roof panels (because their mass)

Water wave: effect of water motions in quake (illustrated in 3.2 Sec.)

Combo: water pressure + earthquake + water wave.



(a)

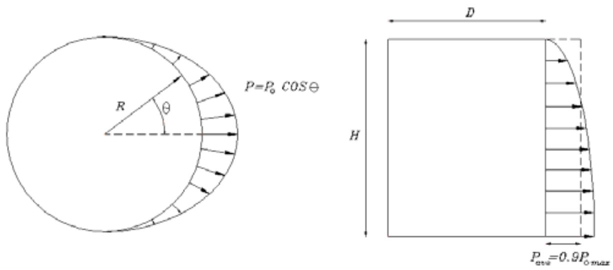


(b)

Fig. 4 Detail of (a) crossed post-tensioning cable from wall holes, (b) retrofit post-tensioning cable

B. Seismic Loading

For modeling the effect of seismic vibration of water in earthquake, relation and diagrams of 123 publication of design on ground reservoirs was used [4]. Calculations were carried out for two level of water in reservoir. Equivalent static method was used for modeling seismic water pressure. In this method water mass in seismic was divided to two parts (hard and waving masses). As 123 code [4], seismic effect of the water on walls should be applied as figure 5.a. For simplicity, the pressure was assumed to be uniform in height. For calculation of earthquake coefficient (C), the 2800 building code was used [11], assuming that the reservoir is be in high seismic zone and the soil conditions of III. The calculation results are shown in table 1.



(a) (b)

Fig. 5 Seismic pressure distribution (a) in plan, (b) in height as 123 code.

TABLE I
GEOMETRICAL PARAMETERS AND RESULTS OF SEISMIC CALCULATION OF MODELS

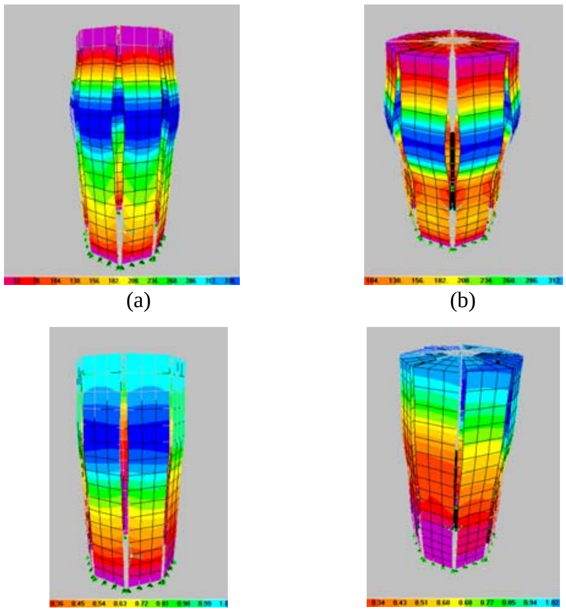
Model	H_{total}	R	Panel Num.	H_w	0.9 $P_{0,max}$ (kg/m^2)
No.1	8	1.9	8	8	763
				4	1498
No.2	5	2.6	12	5	866
				3	1550

IV. RESULTS AND DISCUSSIONS

For investigating the effect of the cable tensioning force, installing position level of cable, height of water in reservoir and height to diameter ratio (with constant volume of reservoir), the numerous analyzes are carried out. One of the important cases in operating the pre-cast concrete reservoirs is opening value of conjunction joints of wall panels. If the strength of elastic materials is exceeding from elastic limit, the water may leakage. Therefore, this problem is especially pointed out in analyzes and maximum displacement of panel edges is investigated (plus value show opening and minus value show closing wall joints). Analyzes carried out for two states: full and middle height of water level in reservoir.

A. Full height water level

In this case assumes that the reservoir be full of water. For investigating the effect of cable installing level, retrofit cables are modeled in two positions: First, top of reservoir (0.5 meter below roof level) and second about middle height (0.5 m below middle height). Analyzes are also carried out for two ratios of diameter to height as table 1. Deformation contours for water pressure, Combo loadings, two installing level of post tensioning cable and 5 ton post-tensioning force value of No.1 model are shown in figure 6. Panel edge displacements for water pressure, Combo loading, various cables installing positions and tensioning forces (5, 10 and 15 ton) in No.1 and No.2 are shown (Figs 7:10).



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

Fig. 6 Deformation contours for (a) water pressure and top level of post tensioning cable, (b) water pressure and middle level of post tensioning cable, (c) combo loading and top level of post tensioning cable, (d) combo loading and middle level of post tensioning cable.

● :Position of reftrofit post-tensioning cable.
● : Position of modeled cable elements in wall panel holes.

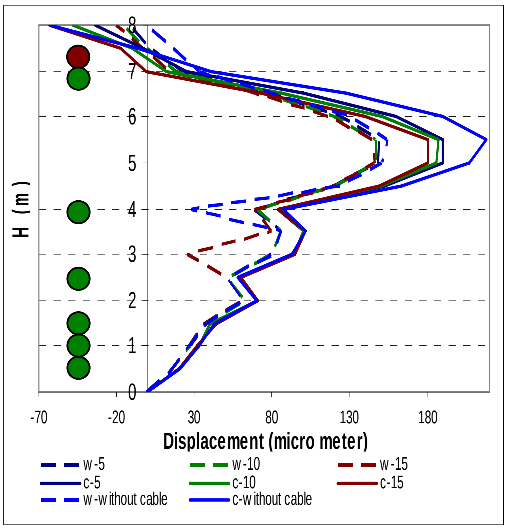


Fig. 7 Displacements of panel edges for 8m height reservoir in full water level and top height position of retrofit cable.

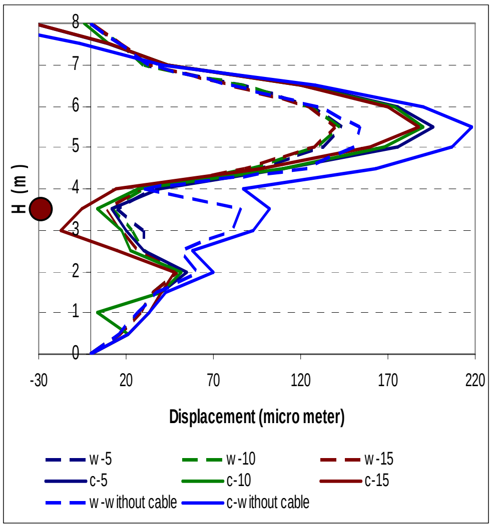


Fig. 8 Displacements of panel edge for 8m height reservoir in full water level and middle height position of retrofit cable.

B. Half full reservoir

In this case is assumed that reservoir be half full. Analyzes are carried out as well as the full reservoir and results are shown in figures 11:14.

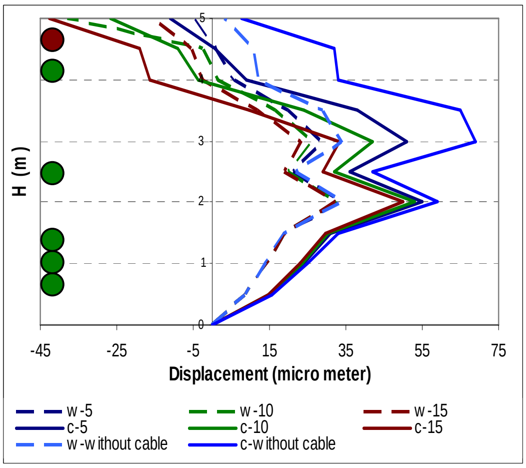


Fig. 9 Displacements of panel edges for 5m height reservoir in full water level and top height position of retrofit cable.

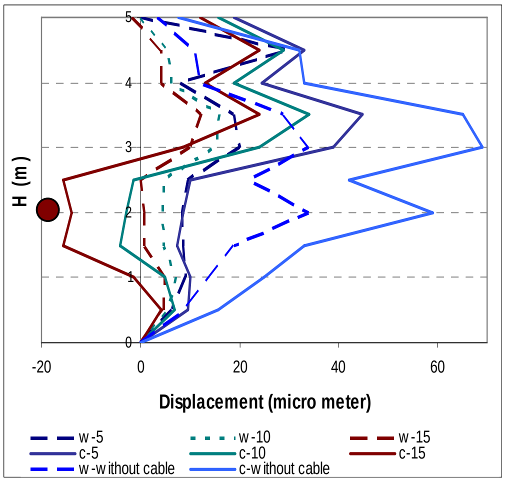


Fig. 10 Displacements of panel edge for 5m height reservoir in full water level and middle height position of retrofit cable.

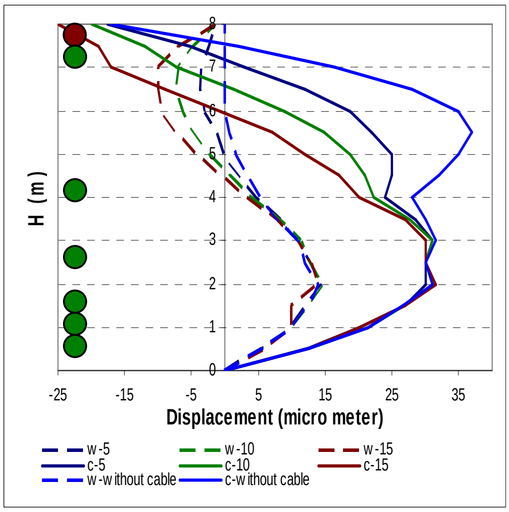


Fig. 11 Displacements of panel edges for 8m height reservoir in half water level and top height position of retrofit cable.

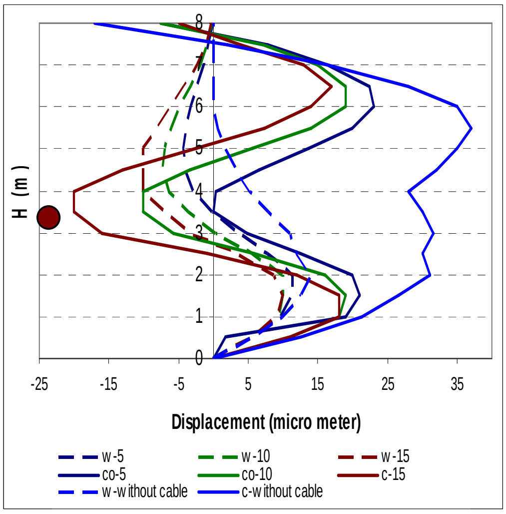


Fig. 12 Displacements of panel edge for 8m height reservoir in half water level and middle height position of retrofit cable.

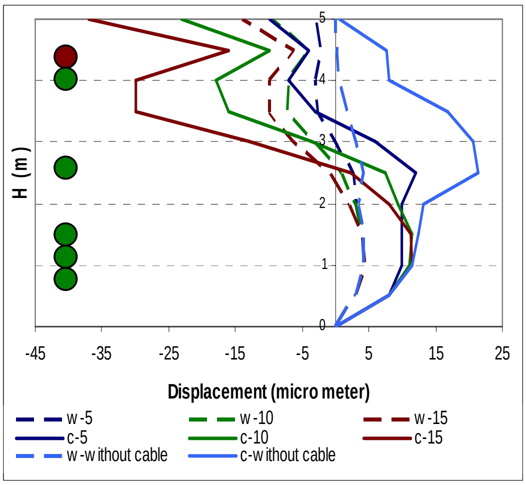


Fig. 13 Displacements of panel edges for 5m height reservoir in half water level and top height position of retrofit cable.

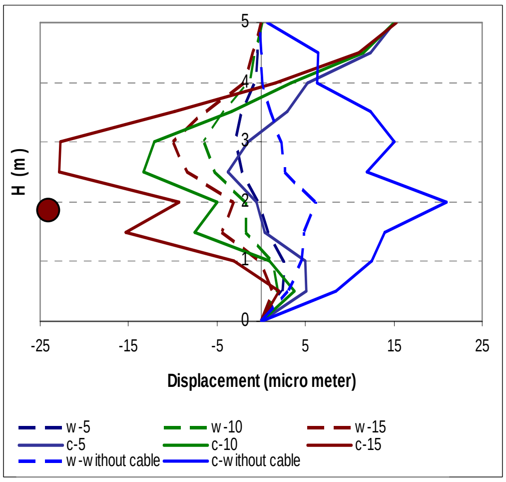


Fig. 14 Displacements of panel edge for 5m height reservoir in half water level and middle height position of retrofit cable.

The following results are obtained from comparing between 7 to14 diagrams;

1. For full water height state, installing position of cable (top or middle height) doesn't have significant effect on maximum opening value of wall joints. But, in half full state by decreasing the post-tensioning cable installing level, the value of the wall panel edge opening would decrease.
2. Effect of the Post-tensioning cable force value on wall panel joint opening for top position of cable is less than the middle height position.
3. By increasing the ratio of height to diameter (the volume of the reservoir to be constant), opening of wall panel edges to post-tensioning force value ratio would decrease.

V.CONCLUSION

The finite element modeling of pre-cast concrete reservoirs shows that adding the post-tensioning cable is efficient method for decreasing opening joints of wall panels in horizontal earthquake motions. It is also shown that the water level in reservoir, installing position and tensioning value of post-tensioning cable have a significant effect on seismic response of reservoirs.

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