ISSN:1813-1786 (Print) 2313-7770 (Online)

Effect of Different Column Arrangements on Structural Behavior of Square Overhead Water Tank by Response Spectrum Analysis

W. A. Adil[1], M. A. Baluch[2], Z. Ullah[3], M. A. Adil[4], M. U. Rashid[5]

[1]*Faisalabad Industrial Estate Development & Management Company, Faisalabad*
[2]*Chief Operating Officer, Punjab Higher Commission (PHEC), Lahore, Pakistan*
[3,5] *Civil Engineering Department, University of Engineering and Technology Taxila, Pakistan*
[4]*Civil Engineering Department, The University of Faisalabad, Faisalabad*

wajidaliadil@gmail.com

Abstract- Overhead water tanks are involved in the important structures of any industrial areas and societies etc. Water tanks should remain in the functional condition during and after an earthquake or in any other emergency. The intension of researchers is very limited to structural analysis and design of overhead water tanks whereas tanks are very important structures. A number of investigations had been conducted on the failure and damage of overhead water tanks during the earthquake in the past. Many researchers in the field of structural engineering investigated the structural behavior of overhead water tanks in terms of base shear, overturning moment, displacement and time period, etc. in different structural design software's with different water conditions in the container. Some researchers investigated the structural behavior of overhead water tanks by considering different seismic zones, soil profiles, staging elevations, and bracing systems in frame staging. In this study, the author investigated the effect of different column arrangements on the structural behavior of square overhead water tank in terms of Base Shear, Time Period, Axial Force, and Main Column Moment according to the seismic zone 2A of Building Code of Pakistan by Response Spectrum Analysis using SAP2000.

Keywords- Base Shear; Time Period; Axial Force; Response Spectrum Analysis; SAP2000

Symbols and Notations- *according to Building code of Pakistan (BCP)*

S_D	*Stiff Soil Profile, as set forth in Table 4.1 of BCP.*
C_a	*Seismic coefficient, as set forth in Table 5.16 of BCP.*
C_v	*Seismic coefficient, as set forth in Table 5.17 of BCP.*
C_v	*Seismic coefficient, as set forth in Table 5.17 of BCP.*
IMRF	*Intermediate moment-resisting frame, as set forth in Table 5.13 of BCP.*

I. Introduction

Water is a fundamental requirement of the public in daily life. Adequate water supply depends on the water tank design. The principal purpose of an overhead water tank is to store water at a required height according to design to achieve the required water pressure for efficient working of the water supply system. Water storage tanks are constructed in housing societies, educational institutes, hospitals, commercial areas, and industrial areas, etc. for safe water supply with adequate water pressure. There are different structural systems to store the liquids according to structural shape, capacity, material, and purpose of use. The importance of tanks is increasing day by day as continuously increase in construction of tanks for different purposes.

Overhead water tank becomes critical structural system due to heavy water mass at top of staging system during an earthquake. The poor structural performance of inverted pendulum-type structure during major earthquakes is reported many times [1-4]. Experimental and numerical techniques were used to investigate the seismic response of steel and concrete tanks [5-8]. Different factors such as size of tank [9], the soil-structure interaction [10], and fluid-structure interaction [11] are involved to effect the seismic response of tank. Finite element methods were utilized for the design of steel tanks on overheads towers [12] as well as for rectangular reinforced concrete tanks [13]. Most of the ways available in publications/literature were not appropriate to be applied in real life structures [14]. Ample research was carried out about meta-heuristics adopted for optimization of structural system such as meta-threshold and meta-simulated annealing [15], harmony search [16-18], swarm

intelligence techniques [19-20] and biogeography-based optimization [21], amongst others.
Overhead water tanks should remain in the functional condition during and after an earthquake to control any emergency. The structural design of an overhead water tank is critical as compared to the simple building due to the seismic effect on the tank and hydrodynamic effect on the tank wall.

A. Design Codes

Overhead water tanks are being designed by different structural design codes. ACI371R-08 describes the complete design process of steel and reinforced composite overhead water tower. ACI 350.3-06 [22]. ACI 350.3-06 describes the complete process of seismic design for liquid retaining structures [23]. ASCE 7-16 also provides complete design process of overhead water tanks [24]. ACI 318-14 is used for the design of concrete overhead water tanks [25. UBC 97 is developed in 1997 and chapter of this code is used for the design of water tanks [26]. The Building Code of Pakistan seismic is used for water tank design in Pakistan. [27].

Due to the lack of knowledge of structural behavior of overhead water tank against seismic load, hydrodynamic effect, and an inadequate number of columns in staging system, etc. water tanks were collapsed.

II. LITERATURE REVIEW

[28] Performed the design of circular overhead water tank for various Height/Diameter proportion in various seismic zones. In this investigation, the structural behavior of overhead water tank under seismic loading was executed by response spectrum analysis using ETABS according to IS 1893:2002. The comparison between required steel percentage and cost of overhead water tank in various seismic zones was prepared and economical section was observed in design.
[29] Performed analysis and design of circular and rectangular overhead water tanks by dynamic analysis using ETABS. The dead, live, wind and earthquake loads were applied according to IS codes. The structural behavior of both tanks was studied in terms of storey drift, storey shear, base shear, deflection, displacement, stiffness, hoop tension and area of steel and then results comparison was prepared between rectangular and circular overhead water tank. On the basis of results, it was observed that circular overhead water tank is suitable for larger volume of liquid and rectangular overhead water tank is suitable for less volume of liquid as well as rectangular overhead water tank is uneconomical for larger volume of liquid.
[30] Scrutinized the structural behavior of rectangular and circular water tank considering seismic effect. The capacity of water was one lakh liters for each for circular and rectangular overhead water tanks with different staging heights. Static and dynamic methods were used for analysis of both tanks. On the basis of results, it was observed that the displacement of overhead water tank was directly proportional to structural height. The performance of rectangular overhead water tank was good against seismic effect whereas performance of circular overhead water tank was good against wind effect.
[31] Executed analysis and design of circular overhead water tank by ETABS as well as manually using limit state method according to IS:3370(2009) and IS 456:2000. On the basis of results, it was observed that the analysis and design of circular overhead water tank on ETABS required 15 tons of steel whereas 19 tons of steel was required according to manual calculation. The analysis and design of tank on ETABS are economical and stable as compared to manual calculation.
[32] Studied the behavior of elevated water tanks in Bhuj Earthquake on 26-01-2001 with 7.7 magnitudes. Many overhead water tanks were damaged and fail due to Bhuj earthquake and these water tanks were investigated to understand the failure mechanism.
[33] Modeled overhead water tank with empty, half full, and full water conditions in the container and investigated model participation mass ratio, time period, overturning moment, base shear, and sloshing displacement.
[34] Scrutinized the performance of the overhead water tank during the earthquake of Chile 1960. The capacity of the tank as 4000 m^3 and tank was empty during the earthquake. The vertical cracks were observed along with the height of pedestals and in between the fins of the tank as shown in Figure-1.

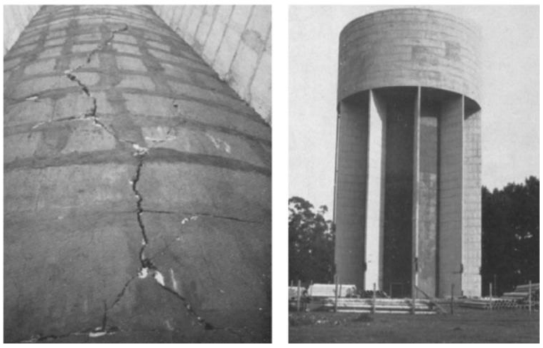

Fig. 1: Vertical Cracks in Tank

[35] Scrutinized the structural behavior of two concrete overhead water tanks during the Manjil-Roudbar earthquake 1990. They observed that the structural design of tanks was according to applicable codes at the time of construction but magnitude of considered design loads was five times less as compared to magnitude of design loads according to latest design codes. The capacity of the overhead water tank was 1500 m^3 which was

collapsed during this earthquake as shown in Figure 2.

Fig. 2: Collapse of tank

Furthermore, two overhead water tanks with 2500 m^3 capacity were also investigated. These tanks were empty at the time of the earthquake and minor cracks appeared at the bottom of pedestal above openings as shown in Figure 3.

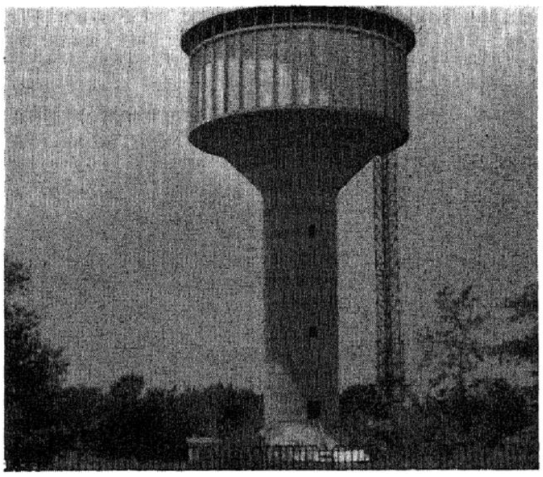

Fig. 3: Minor cracks in Pedestal of tank

[36] Analyzed overhead water tank by Time History Analysis using SAP2000.
[37] Performed Time History Analysis of the overhead water tank with different acceleration records of the earthquake by using SAP2000.

III. Problem Statement/ Research Gap

Many researchers in the field of structural engineering investigated the structural behavior of overhead water tanks in terms of base shear, overturning moment, displacement and time period etc. with different structural design software and with different water conditions in the container. Some researchers investigated the structural behavior of overhead water tanks by considering different seismic zones, soil profiles, staging elevations, and bracing systems in frame staging. A number of researchers compared the structural behavior of circular and rectangular overhead water tanks. In this study, the author is interested to investigate the effect of different column arrangements on the structural behavior of square overhead water tank according to seismic zone 2A of Building Code of Pakistan by Response Spectrum Analysis using SAP2000. The author believes, if the number of columns in frame staging system of the square overhead water tank are increased from four columns to eight columns in the symmetrical way then what will be the comparison of the structural response of both square overhead water tanks in terms of Base Shear, Time Period, Axial Force and Main Column Moment.

IV. Research Significance

Based on the comparison of the structural behavior of square overhead water tank with four and eight numbers of columns in the frame staging system, economical structural system for the construction of square overhead water tank can be selected. The overall effect of different column arrangements on structural stability, dimensions of structural members, and a clear picture of the structural response of both tanks after the design phase can be seen.

V. Objectives

The prime objective of this investigation is to compare the structural behavior of square overhead water tank with four and eight numbers of columns in the frame staging system respectively. Following are the secondary objectives:

- To execute dynamic analysis of both square overhead water tanks with different column arrangements according to the Building Code of Pakistan by Response Spectrum Analysis using SAP2000.
- To calculate the base shear, time period, axial force, and main column moment of the square overhead water tank with two different column arrangements by CSI SAP2000 Software.
- To compare the different structural parameters of both square overhead water tanks.

VI. Project Description

In this research, a square overhead water tank has a capacity of 67,158 imperial gallons is considered with two-column arrangement options namely option-I and option-II. In option-I, four columns are planned and each column is located at each corner of the tank as shown in Figure 4.

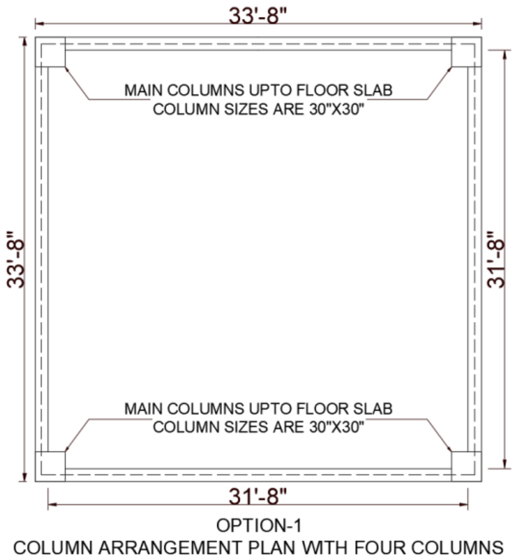

Fig. 4: Column Arrangement Option-I

In option-II, eight number of columns are planned and each column is located at each corner of the tank and center of each tank wall as illustrated in Figure 5. The distance in-between columns is mentioned as well on both column arrangement plans.

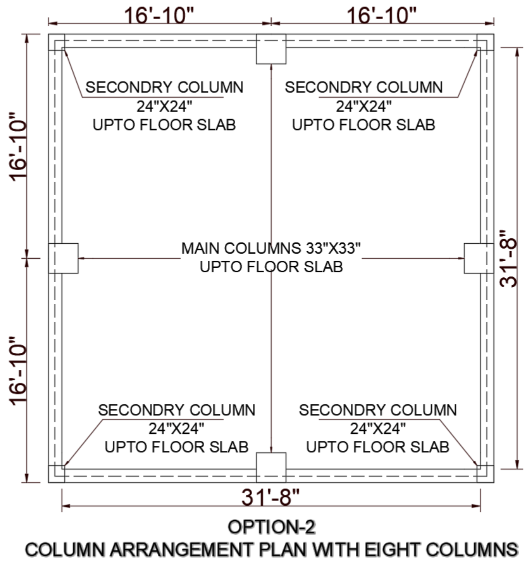

Fig. 5: Column Arrangement Option-II

Column Arrangement Elevation, Option-I is shown in Figure 6 and Option-II is shown in Figure 7. Both elevation options show the *7 feet* distance between the top of the foundation and top of the plinth beam, *10 feet* distance between each bracing beams, and *11.875 feet* distance between the top of the floor and bottom of the roof.

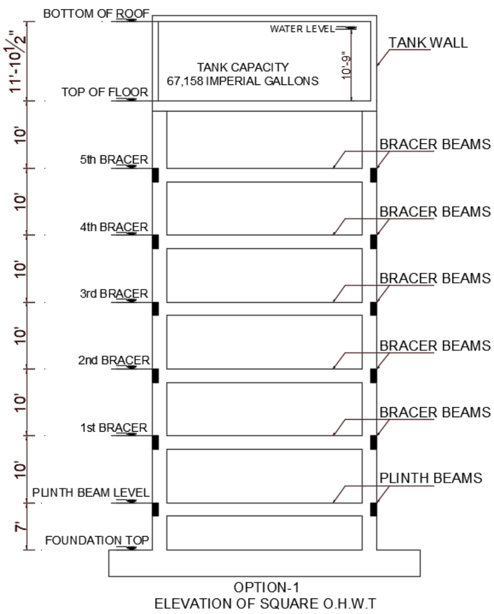

Fig. 6: Column Arrangement Option-1 Elevation

Elevation of Column Arrangement Option-II with the central column is shown in Figure 7. The estimated size of Structural members and strength of the overhead water tank is shown in Table 1.

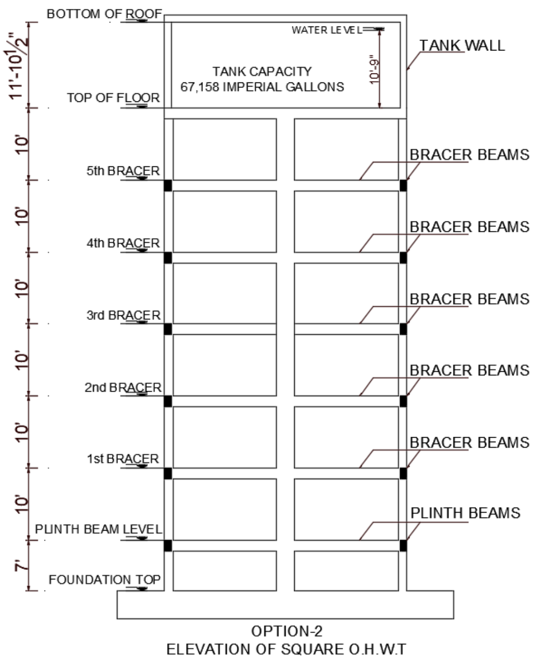

Fig. 7: Column Arrangement Option-II Elevation

TABLE I. ESTIMATED SIZE AND STRENGTH OF STRUCTURAL MEMBERS

Member	Option-I	Option-II	Strength
Roof	12”	12”	3 ksi
Tank Walls	12”	12”	4 ksi
Floor	18”	18”	4 ksi
Bracer Beam	12”x24”	12”x18”	3 ksi
Plinth Beam	12”x24”	12”x18”	3 ksi

Main Columns up to Plinth Level	30”x30”	N/A	3 ksi
Main Columns above Plinth Level	27”x27”	N/A	3 ksi
Main Columns up to First Bracer Beam	N/A	33”x33”	3 ksi
Main Columns above First Bracer Beam	N/A	30”x30”	3 ksi
Secondary Columns up to Plinth Beam	N/A	24”x24”	3 ksi
Secondary Columns below First Bracer Beam	N/A	21”x21”	3 ksi
Secondary Columns above First Bracer Beam	N/A	18”x18”	3 ksi
Raft	24”	24”	3 ksi
60 grade steel will be considered for design of all structural members			

VII. METHODOLOGY

The methodology of this investigation is divided into five stages. The diagram of the investigation methodology is illustrated in Figure 8 and the stages of the investigation are as under:

A. Stage-1

In this stage, the planning drawings for the tanks will be furnished, the soil bearing capacity will be supposed, and then the concrete properties will be selected. At last of this stage, codes related to design will be reviewed.

B. Stage-2

The detailed investigation of software SAP2000 is performed in this stage.

C. Stage-3

Response spectrum analysis will be used to analyze both tanks according to the Building Code of Pakistan.

D. Stage-4

After analysis stage, the code of ACI will be utilized for design purpose.

E. Stage-5

The stage-5 contains the study of the response of the both structural systems.

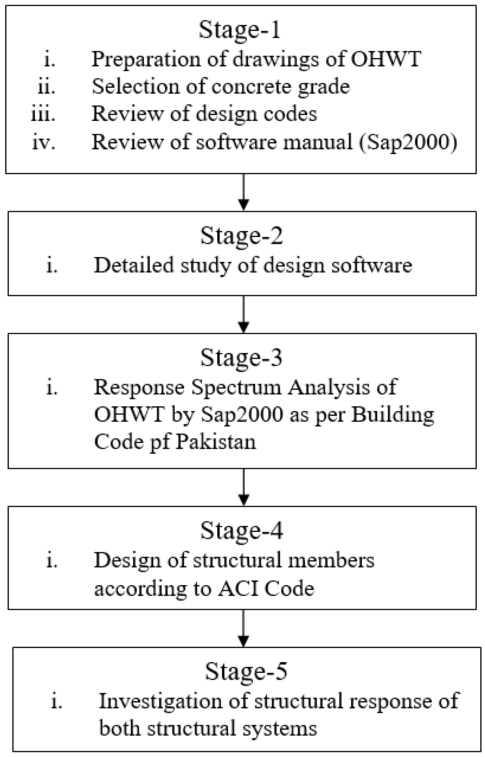

Fig. 8: Research Methodology

VIII. DESIGN LOADS

A. Dead Loads

Structural weight is calculated by SAP2000 automatically.

B. Water Load

Water load is assigned on the floor slab and on walls of the tank with the help of surface pressure and joint pattern options respectively in SAP2000.

C. Water Conditions

Water container with full of water and empty both cases are considered in this research. Water container with full of water case involves water pressure, structural weight, and earthquake load whereas empty case involves structural weight and earthquake loads only.

D. Floor Cover

Floor cover is lies in the category of dead load. The floor cover dead load is applied on the top roof with *30 psf* intensity.

E. Live Load

Live load is applied on the top roof with *20 psf* intensity.

F. Earthquake loads

According to BCP-SP 2007 seismic zoning and site characteristics etc. will be considered in the structural design of the square overhead water tank. These parameters are given in Table II.

ISSN:1813-1786 (Print) 2313-7770 (Online)

TABLE II. Earthquake Loading Parameters

Seismic Zone	2A
Seismic Zone Factor	0.15
Soil Profile Type	S_D
Seismic Source Type	B
Seismic Response	C_a=0.22 &
Seismic Importance Factor	1
Framing Type	IMRF

IX. Structural Analysis and Design Phase

SAP2000 model perspective view of both structural systems of square overhead water tanks is shown in Figure 9 and Analysis of roof slab, tank walls, columns, bracing beams, and raft are involved in this phase and shown in Figure 10.

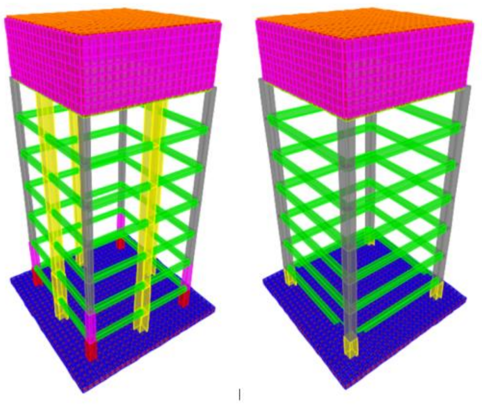

Fig. 9: Sap2000 model with 8-columns and 4-columns in the staging system

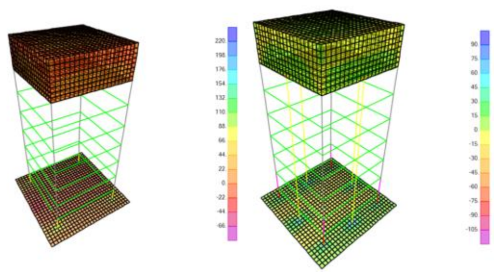

Fig. 10: Working Stress Diagram of both structural system with container full of water condition

SAP2000 gives the design results of all structural members such as top slab, tank walls, columns, beams, and raft.

X. Results and Conclusions

A. Results

In this research, two types of column arrangement in staging system of square overhead water tank modelled, analyzed, and designed using SAP2000. Square overhead water tank design parameters are compared in this section as under:

1) Base Shear

The Base Shear magnitude in column arrangement option-I of overhead water tank is 132 kips and 94 kips with water container full and empty conditions respectively whereas in column arrangement option-II of overhead water tank is 138 kips and 97 kips with water container full and empty conditions respectively.

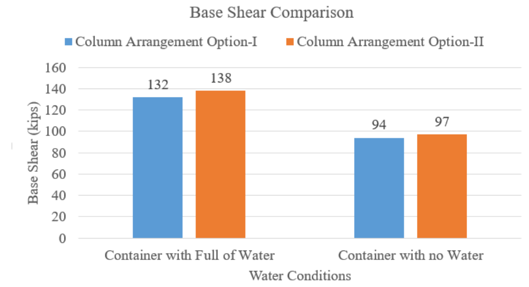

Fig. 11: Base Shear Comparison

2) Fundamental Time Period

The Time Period in column arrangement option-I of overhead water tank is 3.34 seconds and 2.37 seconds with water container full and empty conditions respectively whereas in column arrangement option-II of overhead water tank is 2.58 seconds and 1.88 seconds with water container full and empty conditions respectively.

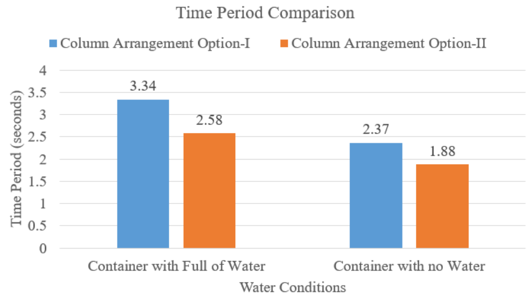

Fig. 12: Time Period Comparison

3) Axial Force in Main Column at Base Level

The Axial Force magnitude in column arrangement option-I of overhead water tank is 484 kips and 301 kips with water container full and empty conditions respectively whereas in column arrangement option-II of overhead water tank is 311 kips and 191 kips with water container full and empty conditions respectively.

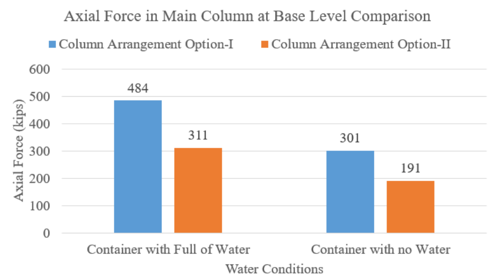

Fig. 13: Axial Force Comparison

4) Moments in Main Column

The Moment magnitude in column arrangement option-I of overhead water tank is 106 kips-ft and 63 kips-ft at column base level with water container full and empty conditions respectively whereas in column arrangement option-II of overhead water tank is 117 kips-ft and 26 kips-ft at column top end level with water container full and empty conditions respectively.

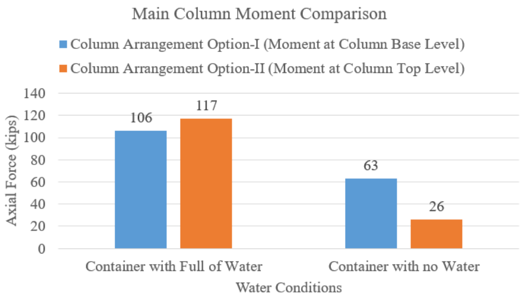

Fig. 14: Moment Comparison

B. Conclusions

- Base shear is directly proportional to structural weight. The structural weight of column arrangement option-II is greater than column arrangement option-I due to a larger number of columns. That's why base shear is more in column arrangement option-II as compared to column arrangement option-I.
- Time period of both structural systems shows that the column arrangement option-I is more flexible as compared to column arrangement option-II.
- Axial force in the corner column of column arrangement option-I is more as compared to the central column of column arrangement option-II due to greater catchment area of corner column.
- Column moment is produced at base level in corner column of column arrangement option-I due to vertical distribution of loads whereas column moment is produced at the top level in the central column of column arrangement option-II due to outward bending of tank wall by water pressure.

XI. Summary

The magnitude of Base Shear, Time Period, Axial Force, and Main Column Moment for Column Arrangement Option-I container full of water are 132 kips, 3.34 seconds, 484 kips and 106 kip-ft respectively whereas with empty container are 94 kips, 2.37 seconds, 301 kips and 63 kip-ft respectively. Similarly, for Column Arrangement Option-II container full of water are 138 kips, 2.58 seconds, 311 kips, and 117 kip-ft respectively whereas with empty container are 97 kips, 1.88 seconds, 191 kips and 26 kip-ft respectively.

XII. Future Application

This study is helpful in future for economical and stable structural design of overhead water tanks because proper location of columns underneath the tank slab improves the seismic performance of structural system instead of number of columns.

XIII. Recommendations

- The numbers of columns and placement in the staging system of the overhead water tank should be adequate to control the structural cost, structural behavior, and construction duration.
- The structural behavior of the square overhead water tank can be checked by different bracing heights and bracing types.

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