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Effects of Soil Condition on Elevated Water Tank Using Time History Analysis with Different Staging Systems

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Abstract

Due to colossal needs by the public, water has to be stored and supplied according to their requirements. Water demand is not constant throughout the day. It fluctuates from hour to hour. To supply a constant amount of water, we need to store water. To fulfill the water demand, water tanks need to be constructed. Water tanks are playing an important role in municipal water supply and firefighting systems. As Known from very upsetting experiences, elevated water tanks were heavily damaged or collapsed during the earthquake. This was might be due to the lack of knowledge regarding the proper behavior of the supporting system of the tank again dynamic effect and also due to improper geometrical selection of staging patterns. Without taking into consideration seismic load is one of the most critical facts for reducing seismic vulnerability. Therefore different configurations of liquid storage tanks have been constructed. This paper presents a time history analysis of intze elevated liquid storage tanks supported on RC framed structure with different capacities, different Staging configurations, and full and empty conditions on three different soil types (Hard rock, Medium soil, Soft soil). Tank responses including base shear, overturning moment, and roof displacement have been observed, and then the results have been compared. Results state that the dynamic analysis replies as base shear, overturning moment, and displacement are vastly influenced.

Keyword — *Elevated water tank, Bracing Configurations, SSI, Time History Analysis, SAP 200*

I. INTRODUCTION

Elevated liquid storage tanks are used broadly by municipalities for distribution of water supply at a sufficient height to pressurize a water distribution system and industries for storing water, inflammable liquids, and other chemicals. Thus seismic safety of elevated liquid storage tanks is very important for public utility and industrial structure. An earthquake can induce large horizontal and overturning forces in elevated water tanks. Such tanks are quite vulnerable to damage in earthquakes due to their basic configuration involving large mass intense at the top with the comparatively slender supporting system. When the tank is in full condition, earthquake forces almost govern the design of these structures in zones of high seismic activity. It is important to ensure that the essential requirement such as the water supply is not damaged during earthquakes. In extreme cases, the total collapse of tanks shall be avoided. However, some repairable damage may be acceptable during shaking not affecting the functionality of the tanks. Due to the lack of knowledge of the supporting system, some of the water tanks were collapsed or heavily damaged. So there is a need to focus on the seismic safety of lifeline structure using concerning alternate supporting system which is safe during the earthquake and also takes more design forces.

The frame support of the elevated water tank should have sufficient strength to resist axial loads, moment, and shear force due to lateral loads. These forces depend upon the total weight of the structure, which varies with the amount of water present in the tank container. An analysis of the dynamic behavior of such tanks must take into account the motion of the water relative to the tank as well as the motion of the tank relative to the ground. The main aim of the present work is to understand the seismic behavior of different staging height and arrangements of elevated water tanks considering variations in staging height for different earthquake time history records by nonlinear dynamic analysis.

II. METHODOLOGY

The methodology includes fixing the dimensions of components for the selected water tank and carrying out nonlinear dynamic analysis (Time History Analysis) using IS 1893 (Part 1): 2016 and IS 1893 (Part 2): 2014 code concept. Time History analysis is a well-organized strategy where the loading and the response history are assessed at progressive time increases. The function values in a time history function to be normalized ground acceleration values and they may be multiplying for specified (displacements and velocities) load pattern and the loading history in the interval. Time history analysis uses the blend of ground movement records with detailed structural supplementary model consequently it is equipped for creating comes about with generally low vulnerability.

In this strategy, the structure is subjected to genuine ground movement records. This makes the examination technique and very unique concerning all of the different analysis strategies as the inertial forces are specifically decided from these ground movements or in forces are calculated as the capacity of time, to taking dynamic properties of the structure. It is an examination of the dynamic reaction of the structures at every augmentation of time when its base is subjected to particular ground movement. In this analysis, the load combinations are to be designed as per IS 1893(Part 1): 2016. All seismic parameters are used as per IS 1893(Part1): 2016, 1893 (Part 2):2014 and IITK-GSDMA guidelines for seismic design of liquid storage tanks. This work proposes to study intze tanks of different staging height and stiffness of staging. Sap2000 v20 programming is utilized to perform the nonlinear dynamic time history analysis of frame supported water tank. The 250 m^3 intze water tank was analyzed employing structural analysis program2000 (SAP2000) software also, apart from theoretical measures using IS 1893-2014 Part-2), for zones V & Soil types (Hard rock, Medium soil, soft soil) and two different tank-fill conditions.

III. MATHEMATICAL MODELLING

Seismic loads were taken as equivalent static accelerations which were modified by various factors, depending on the location's seismicity, its soil properties, the natural frequency of the structure, and its proposed use. The elevated water tank can be analyzed for both the condition i.e. tank full condition and tank empty condition. For both the condition, the tank can be idealized by one- mass structure. For equivalent static analysis, water-structure interaction shows, both water, and structure reach a peak at the same time due to the assumption that water is wedged to the container and acts as a structure itself and both water and structure have the same stiffness. The response of elevated water tanks obtained from the static analysis shows the high scale value. So that for large capacities of tanks, static response is not precise. If we analyzed the elevated water tank by static method and design by the same, we get over stabilized or say over reinforced section but it will be uneconomical. So static systems of designing elevated water tanks are not useful in seismic zones.

After the Chilean Earthquake of 1960, two mass-spring models were proposed by Housner to distinguish basic dynamic properties of the elevated tank, which is commonly used and more appropriate by the majority of the codes including Gujarat State Disaster Management Authority (GSDMA) guideline. The dynamic motion of the tank can be separated into two parts i.e. convective and impulsive when the pressure is generated within the fluid. Horizontal acceleration developed on tank wall and liquid due to horizontal earthquake ground motion when containing liquid with a free surface. The lower region liquid mass of the tank is rigidly connected to the tank wall and it behaves like a mass, defined as impulsive liquid mass. Upper region liquid mass tank undergoes sloshing motion, defined as convective liquid mass. To include hydrodynamic pressure in analysis representing these two masses, two mass models are adopted for elevated tanks. Lower region liquid mass, i.e. Impulsive mass (m_i) is rigidly attached to the tank wall, whereas Upper region liquid i.e. convective mass (m_c) is attached to the tank wall by the spring having stiffness (K_c) in the spring-mass model. Instead of the spring-mass model elevated tanks are considered as two-mass model systems with two degrees of freedom because two-mass model idealization is nearer to actuality. Figure 1 shows a two-mass model of the elevated water tank. Using elementary structural dynamics the response can be obtained for two-degree of freedom systems. However, it is observed that both the periods are well separated in most of the cases.

Hence, two uncoupled single degrees of freedom system can be used for two mass idealizations. The stiffness (k_s) and mass (m_s) is lateral stiffness of staging, structural mass respectively of the elevated tank. Structural mass (m_s) includes one-third mass of the staging and the mass of the tank container will act as a lateral spring.

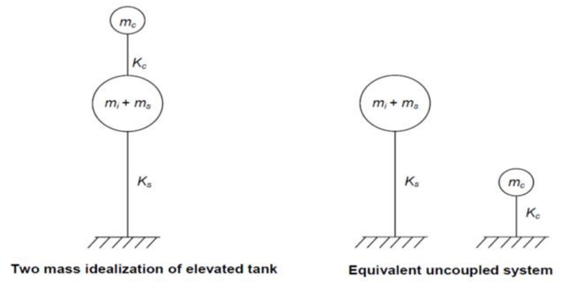

Figure 1: Two Mass Idealizations for Elevated Tank

IV. STRUCTURAL GEOMETRY & MODELLING

The frame type is the most commonly used staging in practice. The main components of the frame type of staging are columns and braces. In frame staging, columns are arranged on the periphery and it is connected internally by bracing at various levels. The staging is acting as a bridge between container and foundation for the transfer of loads acting on the tank. In elevated water tanks, the head requirement for the distribution of water is satisfied by adjusting the height of the staging portion. A reinforced elevated intze water tank having different staging arrangements and staging levels has been considered for the present study.

Table 1. Structural Data for Water Tank

Tank Vessel property		Tank Staging property	
Capacity of Tank	250m^3	No. of Column	8
Diameter of tank	10.4 m	Column Diameter	0.45 m
Cylindrical Height Wall	3.5 m	Column Height	16 m, 20 m,24 m
Top Dome Rise	2.2 m	Staging Diameter	6.5 m
Conical Dome Rise	2 m	Bracing Interval	4 m
Bottom Dome Rise	1.3 m	Beam Bracing Size	0.35 m x 0.35 m
Top ring Beam	0.25 x 0.25 m	Material	M30 Grade of Concrete
Bottom ring beam	0.750 x 0.350 m	Type of Bracing	Normal Cross Radial
Lower Circular ring beam	0.350 x 0.750 m		
Top dome Thickness	0.1 m	Seismic Data	
Cylindrical Wall Thickness	0.15 m	Zone	V
Conical dome Thickness	0.2 m	Response Reduction Factor	2.5
Bottom dome Thickness	0.1 m	Soil Type	Rocky Medium Soft

A reinforced elevated water tank with fixed base frame type, tank with normal bracing, radial bracing, and cross-bracing system have been measured for the present study. The storage capacity of the water tank is 250 m^3. The conical part, bottom, and top domes and container walls are modeled with thin shell elements. Other dimensions of the elevated tanks are illustrated in Table I. Total of four numbers of earthquake records were used; the maximum PGA based on acceleration gravity Kachchh, Dharmsala, Chamba, and Uttarkashi 0.106, 0.248, 0.146, and 0.253 for respectively.

In the present study alternate staging configurations are those which can be achieved by simple modifications to the basic configuration(Figure 2a) instance by adding radial bracing (Figure 2b) and cross-bracing (Figure 2b) at the levels of circumferential beams and all these FEM model are analyzed in SAP2000 for seismic behavior under different earthquake time history data.

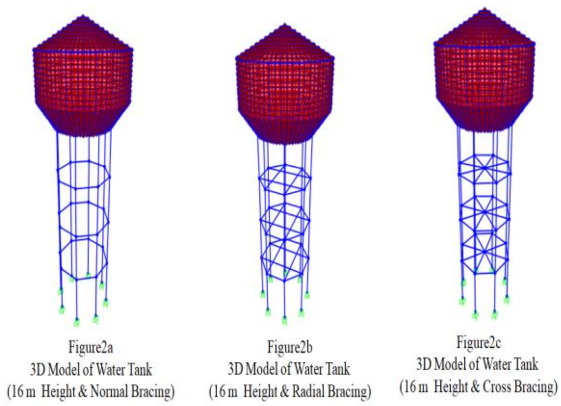

Figure 2: Modeling of 250 m^3 water tank with different stiffness of staging in SAP 2000.

V. RESULTS & DISCUSSIONS

Results for different important properties of this study are displayed in graphical form for base shear, overturning moment, and displacement as in following

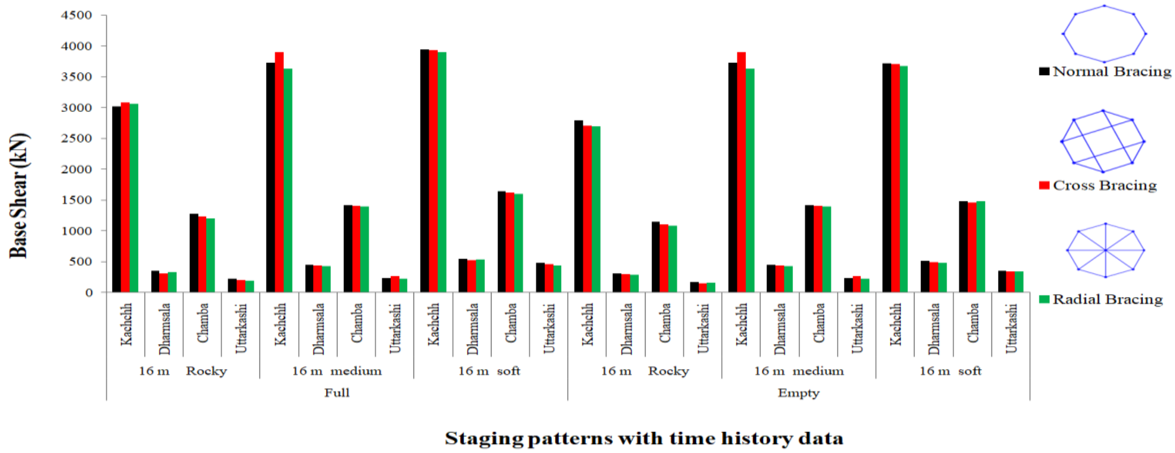

Figure 3: Base Shear force variation based on staging patterns and tank filled up a condition for 16 m height

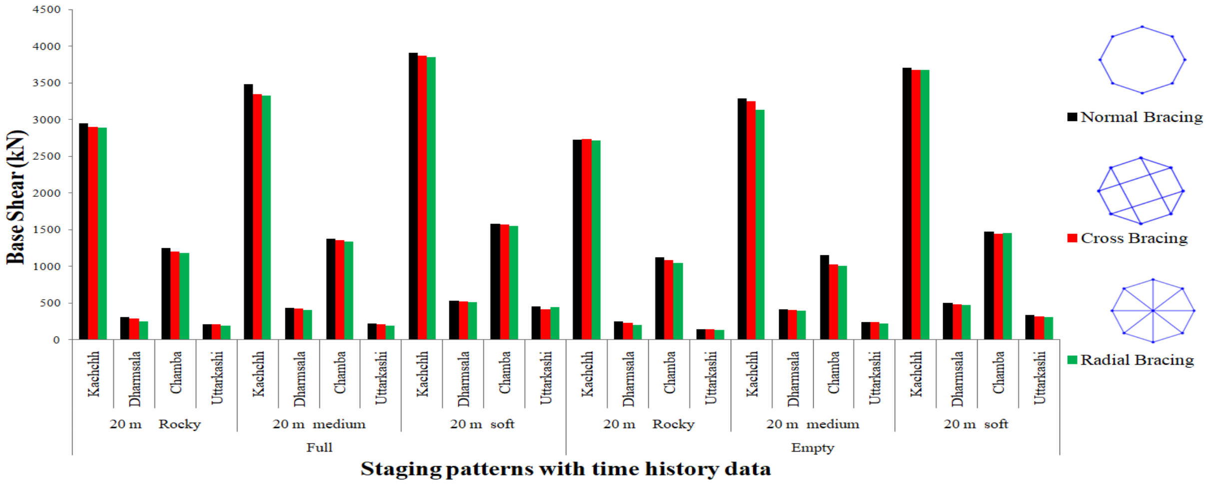

Figure 4: Base Shear force variation based on staging patterns and tank filled up a condition for 20 m height

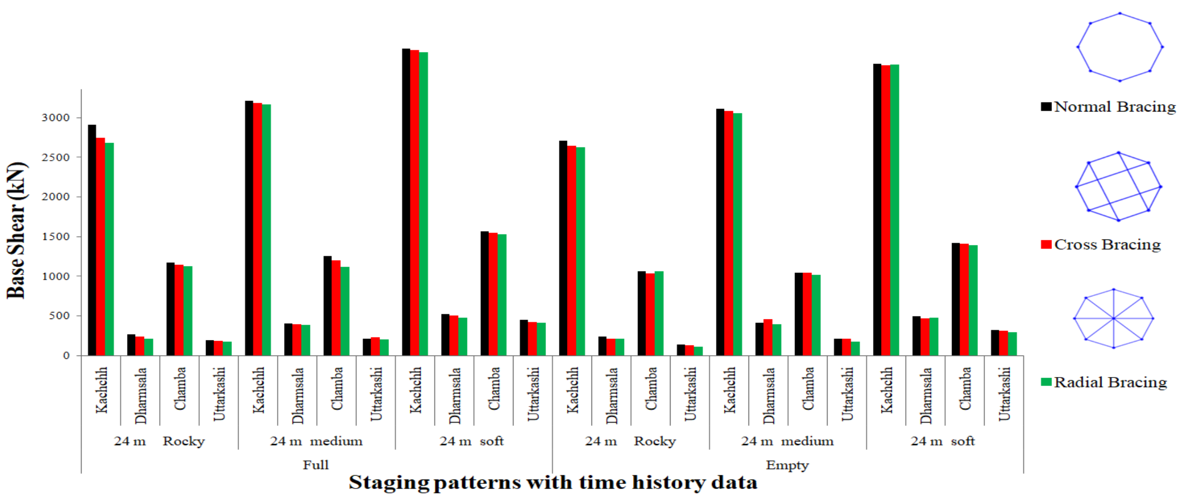

Figure 5: Base Shear force variation based on staging patterns and tank filled up condition for 24 m height

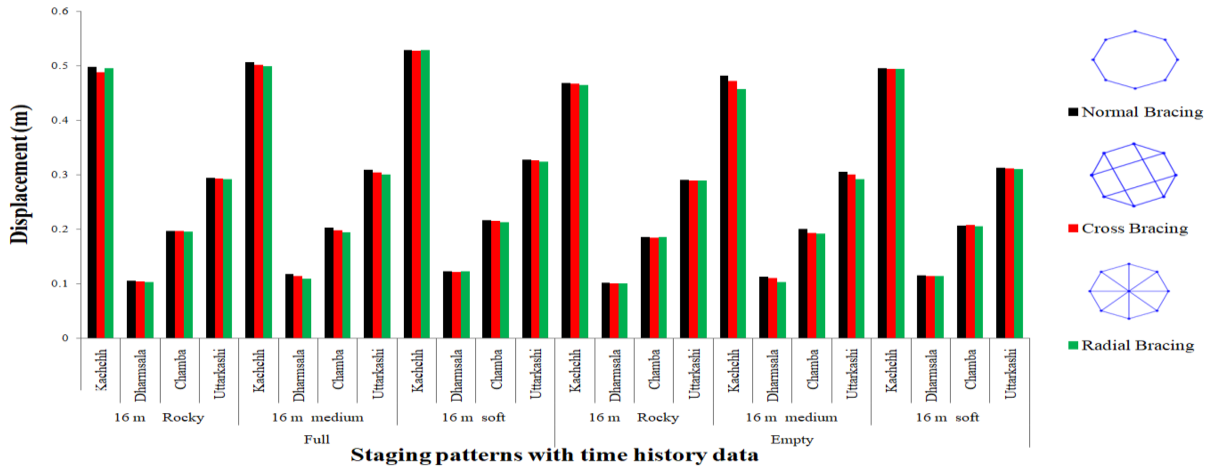

Figure 6: displacement variation based on staging patterns and tank filled up condition for 16 m height

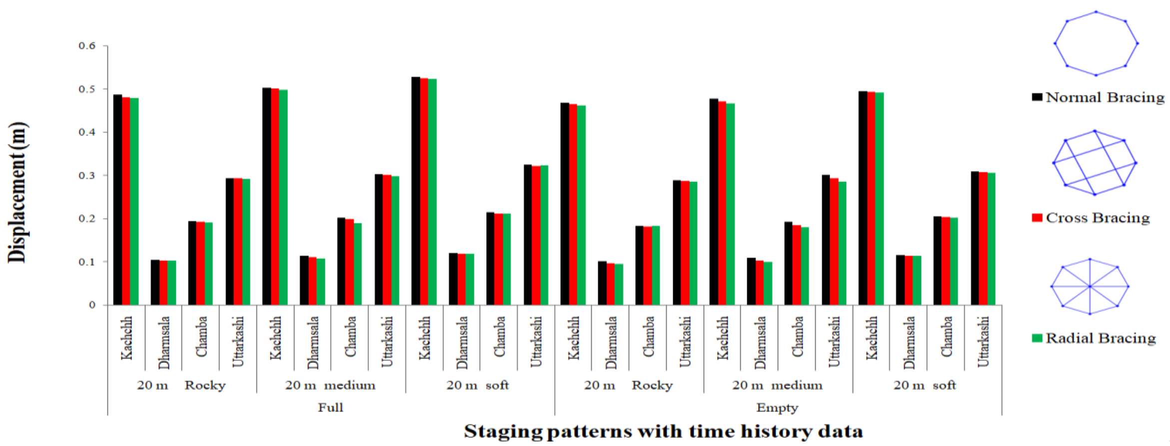

Figure 7: displacement variation based on staging patterns and tank filled up condition for 20 m height

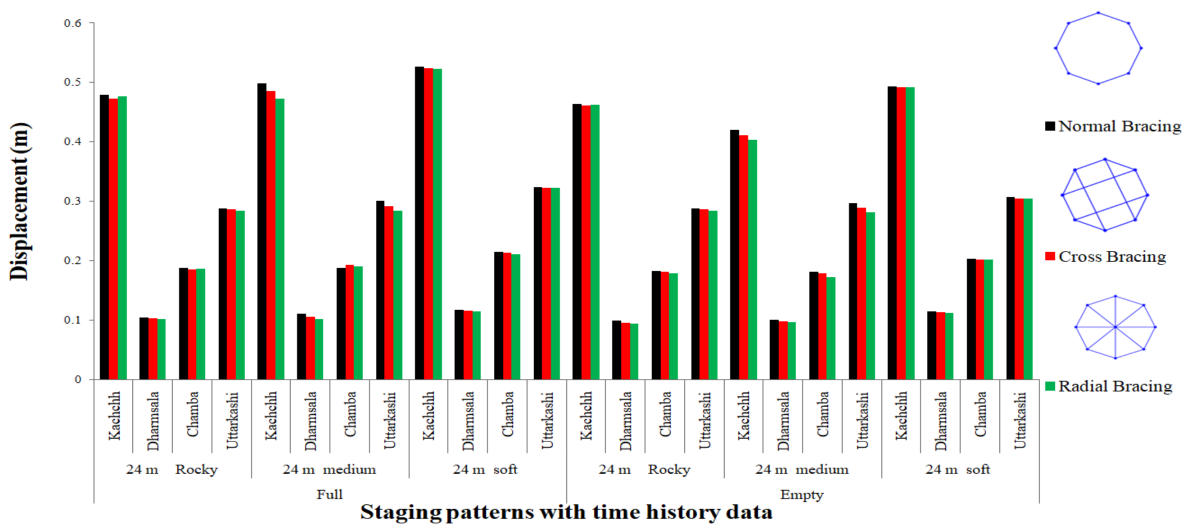

Figure 8: displacement variation based on staging patterns and tank filled up condition for 24 m height

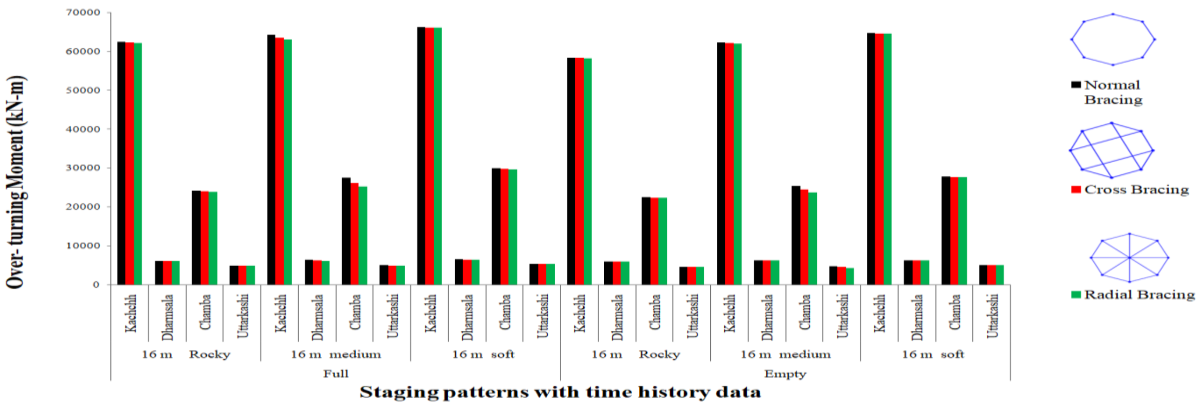

Figure 9: Overturning moment variation v based on staging patterns and tank filled up condition for 16 m height

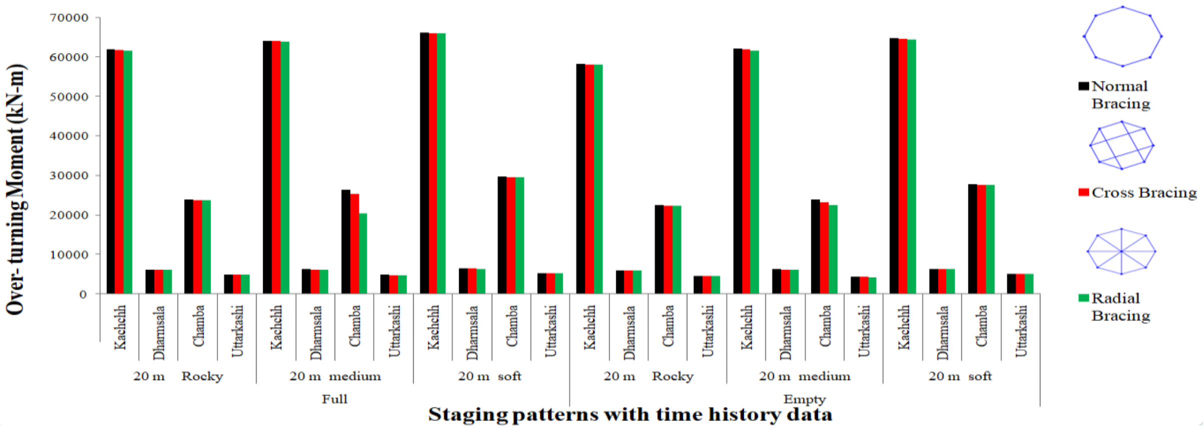

Figure 10: Overturning moment variation based on staging patterns and tank filled up condition for 20 m height

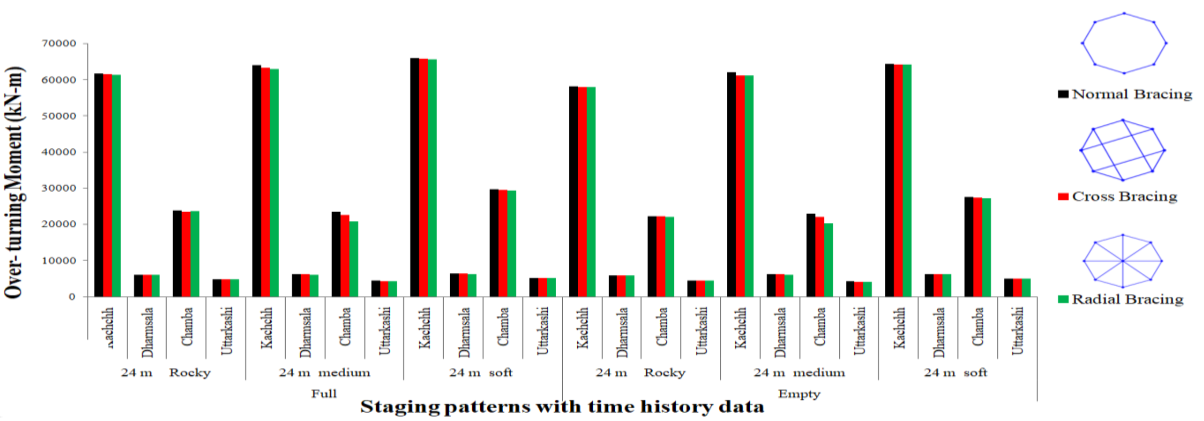

Figure 11: Overturning moment variation based on staging patterns and tank filled up condition for 24 m height

All the above-modeled water tanks show maximum base shear for Kachchh earthquake data and minimum base shear for Dharmsala earthquake data for all Staging height and staging patterns in a full tank and empty tank conditions.

Displacement is considerably decreased with an increase in PGA value of earthquake time history and also noted that higher value in Kachchh earthquake.

All the above-modeled water tanks show maximum displacement for Kachchh earthquake data and minimum displacement for Dharmsala earthquake data for all Staging height and staging patterns in a full tank and empty tank conditions.

All the above-modeled water tanks show maximum Overturning moment for Kachchh earthquake data and minimum Overturning moment for Dharmsala earthquake data for all Staging height and staging patterns in a full tank and empty tank conditions.

It is not that elevated water tank's critical response always occurs in the full condition it may be happening in empty tank condition and even in the low percentage of filling. The reason depends on the accordance of the earthquake characteristics in reduction or amplification of system responses and frequency content. Thus, structure responses for each record depend upon not only the structure's dynamic features but also the frequency content and the earthquake characteristics.

Time history analysis result shows that decreasing responses including base shear, overturning moment and displacement as the height increasing in both full and empty condition when compared to all three types of the bracing Radial bracing pattern shows minimum displacement, which indicates that Radial type bracing is more effective than other two types of bracing configuration.

VI. CONCLUSIONS

Water tank supported by a moment-resisting frame of 250 m^3 capacity analyzes using Time History Analysis. The dynamic responses were assessed under different earthquake time history records for empty and full conditions. The critical response occurs in the case of a full tank and an empty tank. In addition, it can be also assigned to the effect of the frequency content of earthquake records. The frequency content and properties of the earthquake in ranges of natural frequency elevated tanks are the most important factors in the reduction of the intensity of tank responses. Thus, structure responses to each record in addition to the dynamic properties of the structure also depend on the above-mentioned properties. Earthquake records with high-frequency content because excitation of responses such as base shear force, overturning moment, and displacement are compared, and obtained results are briefly summarized below.

1. Radial bracing configuration attracts more seismic forces in tank full condition and results in higher base shear and fewer tank displacements compared to another bracing pattern.
2. The performance of the Radial type bracing pattern is better than the other two types of bracing configurations.
3. The critical response depends on the earthquake characteristics and particularly the frequency content of earthquake records.
4. The Static and Dynamic analysis replies as base shear and displacement are vastly influenced.
5. The critical response occurs in case of full tank conditions. This result maybe because of the hydrodynamic pressures higher in tank full case as compared to the empty water tank.
6. Soil type has a considerable effect on soil and structure interaction. Soft soil has more interaction with structure than rocky and medium soil.

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