Parametric Studies in Design of Staging Configuration for Elevated Service Reserviour for Seismic Consideration

P. S. Nemade
M. Tech Student
Yeshwantrao Chavan College of Engineering, Nagpur

Prof. D. G. Agrawal
Assistant Professor
Yeshwantrao Chavan College of Engineering, Nagpur

Dr. A. M. Pande
Professor
Yeshwantrao Chavan College of Engineering, Nagpur

Abstract

Earthquake being one of the most dangerous and hazardous kind of natural disaster which not only leads to loss of human life but also causes economic loss. Hence utmost care is necessary for designing any structure specially elevated structure which are more likely to get affected by earthquake. Stability of water tank against earthquake forces depends upon the supporting structure provided to elevated water tank. More the stability of the supporting structure more it is safe from earthquake point of view. Stability of supporting structure can be achieved by providing bracing patterns. So selection of bracings patterns plays an important role in achieving stability of water tank in earthquake prone areas. Seismic coefficient method for 22 different bracing patterns and arrangement and circular shaft applied to elevated water tank in Zone 3, 4 and 5 is studied by using Staad Pro software. Comparison is carried out for displacement of the container for tank full and tank empty conditions and ratio of deflection of tank full to tank empty for each case and pattern is studied.

Keywords: Elevated circular water tank, bracing patterns, circular shaft, Staad pro

I. INTRODUCTION

One of the basic needs of all human beings is water. There are various types of water tank depending upon their size, shapes and position such as Circular water tank , Intze water tank, Rectangular water tank , Underground water tank, Ground supported water tank or Elevated water tanks etc. Elevated water tanks are specially constructed to maintain high pressure during supply of water at required locations. Capacity of water tank depends upon the population of locality where tank is to be constructed. Elevated water tank are most prone to get affected by earthquake forces, since large concentrated fluid mass is at top which is supported by some staging system. Damage caused to elevated water tank due to earthquake force leads to sudden collapse of structure, if it is not designed properly, which will affect the services such as supply of drinking water, firefighting etc. and may cause major accident due to flood. After the occurrence of Killari and Bhuj Earthquake many elevated water tanks collapse which leads to design of elevated water tank for seismic point of view. This can be achieved by increasing the stability of Water tank by providing various bracing patterns to the supporting structure.

The reports of past earthquakes have indicated that often damage of elevated water tanks was due to the failure of the supporting structure [1]. Elevated water tanks are critical and strategic structures and damage of these structures during earthquakes may endanger drinking water supply, cause to fail in preventing large fires and substantial economic loss [2]. When the tank is in full condition, earthquake forces almost govern the design of these structures in zones of high seismic activity. The failure of these structures may cause some hazards for the health of the citizens due to the shortage of water or difficulty in putting out fire during the earthquake golden time [2]. The elevated tanks have to remain functional in the post-earthquake period to ensure water supply to earthquake affected regions. But, several elevated tanks damaged or collapsed during the past earthquakes [3]. An elevated water tank is a large water storage container constructed for the purpose of holding water supply at certain height to pressurization the water distribution system.[4] Depending upon the location of the water tank, the tanks can be name as overhead, on ground and underground water tank. The tanks can be made in different shapes like rectangular, circular and Intze types. [5] The shaft support of elevated tanks should have adequate strength to resist axial loads, and moment and shear forces due to lateral loads [6]. Past earthquakes have demonstrated the seismic vulnerability of tanks and the damage occurred in the form of buckling of tank wall due to excessive development of compressive stresses, failure of piping system and uplift of anchorage. [7] Elevated water tanks consist of huge water mass at the top of a slender staging which are most critical consideration for the failure of the tank during earthquakes [8] .Due to the lack of knowledge of supporting system some of the water tank were collapsed or heavily damages. So there is need to focus on seismic safety of lifeline structure using with respect to alternate supporting system which are safe during earthquake and also take more design forces [9].The Design seismic force for the water tank depends upon its flexibility and hence on time period [10]. The main components of 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 [11]. The current designs of supporting structures of elevated water tanks are extremely vulnerable under lateral forces due to an earthquake [12].

The main aim is to study the Behaviour of elevated water tank with different bracing arrangements. Moreover as compared to different shapes of water tank circular water tank has less surface area for same capacity. Due to which quantity of material required is also very less as compared with different shapes of same capacity. Therefore for study purpose circular water tank has been adopted.

II. BRACINGS

Bracing provide high load lateral carrying capacity since they are light in weight and contributes less to the structural mass and contributes more to the stiffness of frames. Many patterns are also possible which can allow for opening passages, services etc. and two storeys cross configuration increases the stability of frame with less obstruction. Bracing will also reduce the time period of the structure , the brace must be design for excellent response and inelastic action confined to ductile brace and design is in such a way that it should be weak brace and strong beam system.

A. *Types of Brace:*

1) *Concentric Brace Frames:*

Concentric Brace Frames do not have extensive requirements regarding members or connections, and are frequently used in areas of low seismic risk. Concentric Steel frames originated in Chicago and reinforces concentric frames originated in Germany and France where earthquake were not an engineering consideration.

Types of Concentric Brace Frames

1) Cross Bracings
2) Chevron Type Brace
3) V- Type Bracings
4) K- Type Bracing

2) *Eccentric Braced frames:*

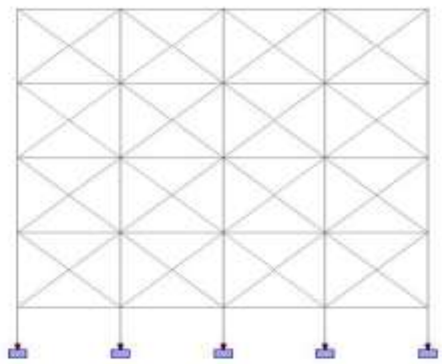
The Eccentric Brace frame is relatively new type of frame in this the diagonal member is joint with an offset from the joint. This offset joint in the beam is called as linked beam which is specially used for control of yeilding. As with any braced frame the function of diagonal brace is to provide stiffness and trasmit lateral forces from upper to the lower level.The length of link beam is limited to control the shear deformation and rotation due to flextural rigidity at the ends of link.The brace and connection are design to devlop forces consistent with the strenght of the link.

Types of Eccentric Brace Frame

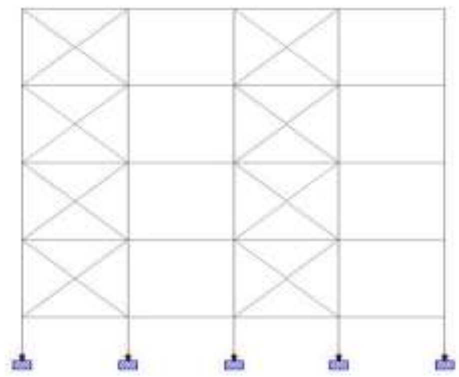
1) Link Beam at one End
2) Link Beam at Centre
3) Link Beam at Both Ends

III. PROBLEM FORMULATION

The problem considered for the study is taken by selecting a circular water tank of capacity 1500 m3. This specific water tank is designed with various types of bracings by considering seismic force from (IS 1893-1984) in zone 3, 4 and 5 by seismic coefficient method. Analysis is carried out using Bentley Staad Pro software. For comparison four groups are formed. First group consists of bracing provided throughout the staging. Second group consists of bracings provided in alternate pattern throughout staging. Third group consists of bracing provided in cross alternate pattern throughout staging. Fourth group consists of cylindrical shell of 6 different thicknesses. Comparison is done for displacement of container for tank empty and tank full condition and also for ratio of deflection of Tank Full to Tank Empty.



Group 1



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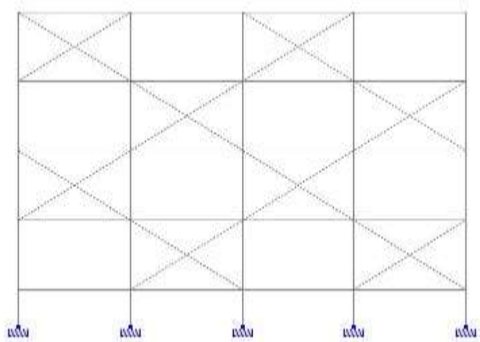
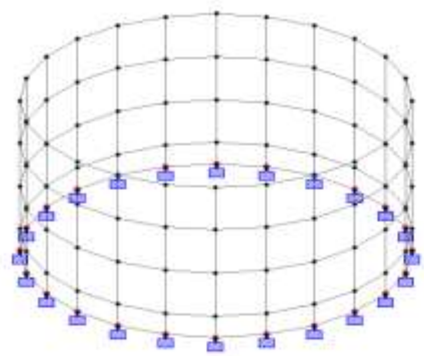


Group 3



Group 4

IV. ANALYSIS RESULTS

The 22 different bracings patterns and 6 different thicknesses cylindrical shells are analyzed and their displacement of container for tank full and tank empty conditions have been computed. The displacement of container for various bracing pattern in X direction is in the direction of earthquake forces.

Models with Bracings (Zone 3)

Table – 1
Deflection of Models for different Bracings Patterns (Zone 3)

		Deflection (mm)					
		Complete Bracings		*Alternate Bracings*		*Cross Alternate Bracings*	
Sr. No	*Models*	*Tank Full*	*Tank Empty*	*Tank Full*	*Tank Empty*	*Tank Full*	*Tank Empty*
1	*Simple Staging*	*41.391*	*19.176*	*41.391*	*19.176*	*41.391*	*19.176*
2	*Cross Bracings*	*2.547*	*1.215*	*4.531*	*2.131*	*5.667*	*2.665*
3	*Chevron Bracings*	*2.888*	*1.366*	*5.17*	*2.42*	*6.65*	*3.113*
4	*V Type Bracings*	*3.13*	*1.48*	*5.332*	*2.496*	*6.861*	*3.212*
5	*K Type Bracings*	*4.431*	*2.106*	*7.973*	*3.742*	*8.621*	*4.046*
6	*Link Beam at One End*	*8.977*	*4.208*	*14.761*	*6.88*	*15.082*	*7.029*
7	*Link Beam at Both Ends*	*13.168*	*6.156*	*19.363*	*9.012*	*24.744*	*11.517*
8	*Link Beam at Centre*	*9.833*	*4.639*	*15.727*	*7.353*	*16.723*	*7.819*

Models with Bracings (Zone 4)

Table – 2
Deflection of Models for different Bracings Patterns (Zone 4)

		Deflection (mm)					
		Complete Bracings		*Alternate Bracings*		*Cross Alternate Bracings*	
Sr. No	*Models*	*Tank Full*	*Tank Empty*	*Tank Full*	*Tank Empty*	*Tank Full*	*Tank Empty*
1	*Simple Staging*	*51.738*	*23.97*	*51.738*	*23.97*	*51.738*	*23.97*
2	*Cross Bracings*	*3.184*	*1.519*	*5.664*	*2.664*	*7.084*	*3.332*
3	*Chevron Bracings*	*3.61*	*1.707*	*6.462*	*3.025*	*8.313*	*3.892*
4	*V Type Bracings*	*3.912*	*1.85*	*6.665*	*3.12*	*8.576*	*4.015*

5	K Type Bracings	5.539	2.633	9.966	4.677	10.776	5.058
6	Link Beam at One End	11.221	5.26	18.451	8.6	18.852	8.786
7	Link Beam at Both Ends	16.46	7.696	24.204	11.266	30.93	14.396
8	Link Beam at Centre	12.291	5.798	19.659	9.192	20.904	9.774

Models with Bracings (Zone 5)

Table – 3
Deflection of Models for different Bracings Patterns (Zone 5)

		Deflection (mm)					
		Complete Bracings		Alternate Bracings		Cross Alternate Bracings	
Sr. No	Models	Tank Full	Tank Empty	Tank Full	Tank Empty	Tank Full	Tank Empty
1	Simple Staging	82.781	38.353	82.781	38.353	82.781	38.353
2	Cross Bracings	5.095	2.43	9.062	4.262	11.335	5.331
3	Chevron Bracings	5.776	2.731	10.34	4.84	13.301	6.227
4	V Type Bracings	6.259	2.96	10.664	4.992	13.721	6.423
5	K Type Bracings	8.862	4.212	15.946	7.484	17.242	8.093
6	Link Beam at One End	17.953	8.416	29.522	13.759	30.164	14.058
7	Link Beam at Both Ends	26.336	12.314	38.727	18.025	49.488	23.034
8	Link Beam at Centre	19.665	9.277	31.454	14.707	33.446	15.638

Models with Circular Shaft (Zone 3, 4 and 5)

Table – 4
Defelection of Models with Circular Shaft (Zone 3. 4 and 5)

		Deflection (mm)					
		Zone 3		Zone 4		Zone 5	
Sr. No	Thickness (mm)	Tank Full	Tank Empty	Tank Full	Tank Empty	Tank Full	Tank Empty
1	200	0.481	0.215	0.596	0.266	0.944	0.421
2	250	0.389	0.176	0.483	0.219	0.764	0.346
3	300	0.328	0.151	0.407	0.187	0.644	0.296
4	350	0.284	0.133	0.352	0.165	0.558	0.26
5	400	0.251	0.119	0.312	0.148	0.494	0.234
6	450	0.226	0.108	0.28	0.135	0.443	0.213

Quantity of Concrete (m^3)

Table – 5
Quantity of Concrete for models with different Bracings Patterns

Type of Brace	Complete Bracings	Alternate Bracings	Cross Alternate Bracings
Cross Brace	850.4	804.7	804.7
Chevron Brace	821.8	790.4	790.4
V Type Brace	821.8	790.4	790.4
K Type Brace	838.1	798.6	798.6
Eccentric brace at One End	794.6	776.7	776.6
Eccentric Brace at Both Ends	786.4	772.5	772.2
Eccentric Brace at Centre	814.3	786.5	786.3

Quantity of Steel (Kg)

Table – 6
Quantity of Steel for models with different Bracings Patterns

	Complete Bracings	Alternate Bracings	Cross Alternate Bracings
Cross Brace	85040	80470	80470
Chevron Brace	82180	79040	79040
V Type Brace	82180	79040	79040
K Type Brace	83810	79860	79860
Eccentric brace at One End	79460	77670	77660
Eccentric Brace at Both Ends	78640	77250	77220
Eccentric Brace at Centre	81430	78650	78630

V. RESULTS AND DISCUSSION

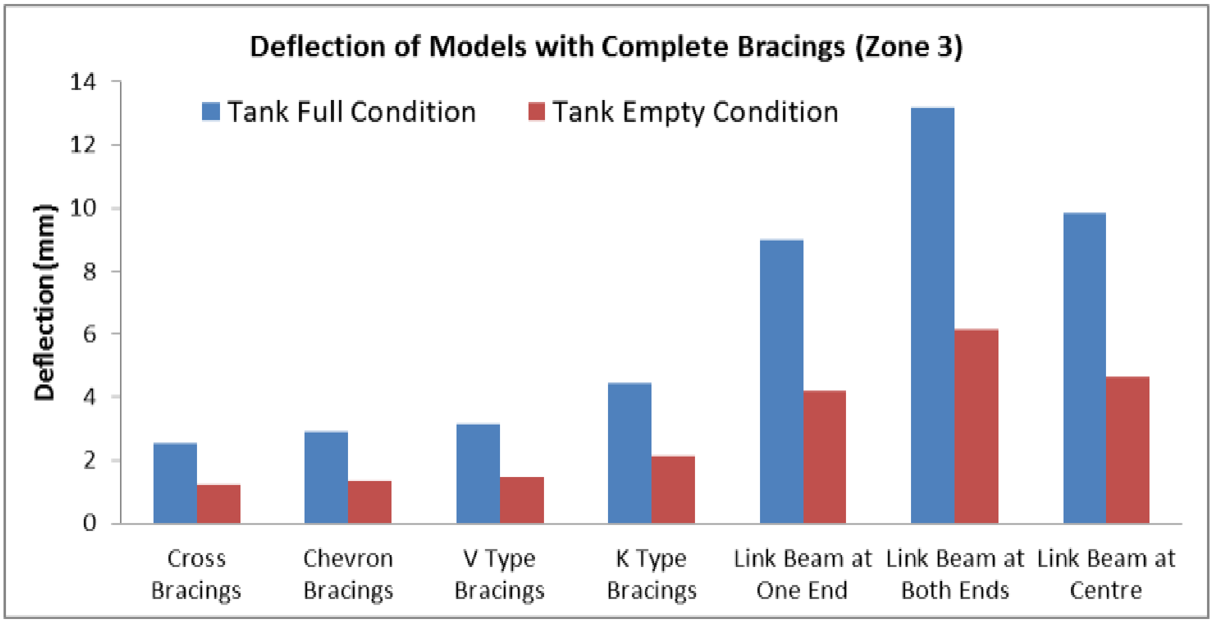


Fig. 1: Deflection of Models with Complete Bracings (Zone 3)

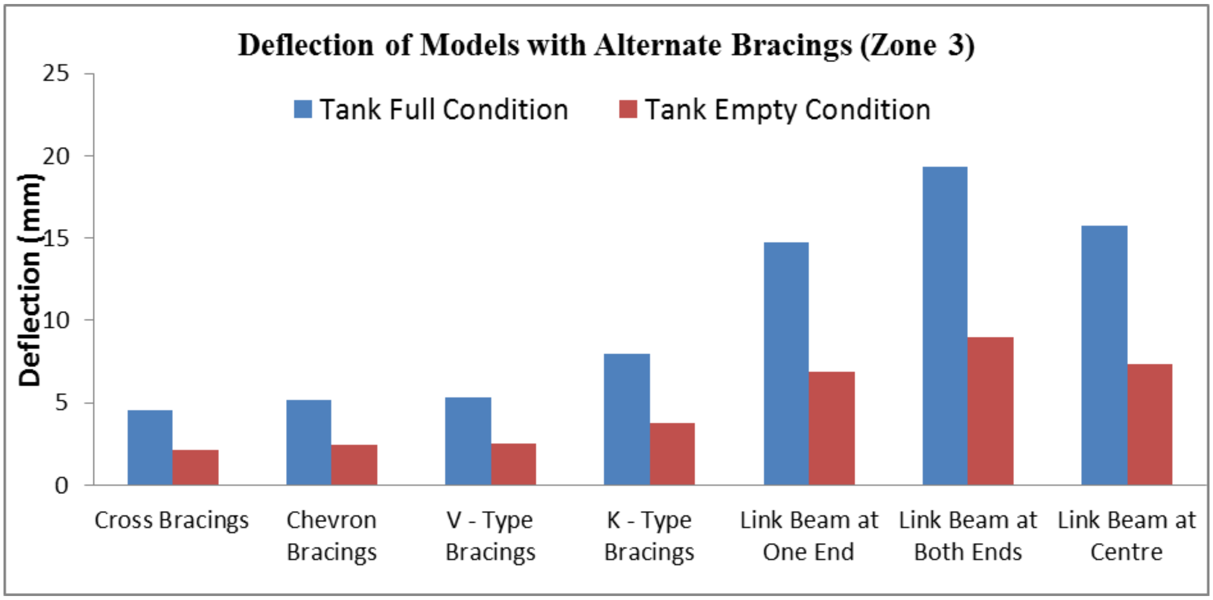


Fig. 2: Deflection of Models with Alternate Bracings (Zone 3)

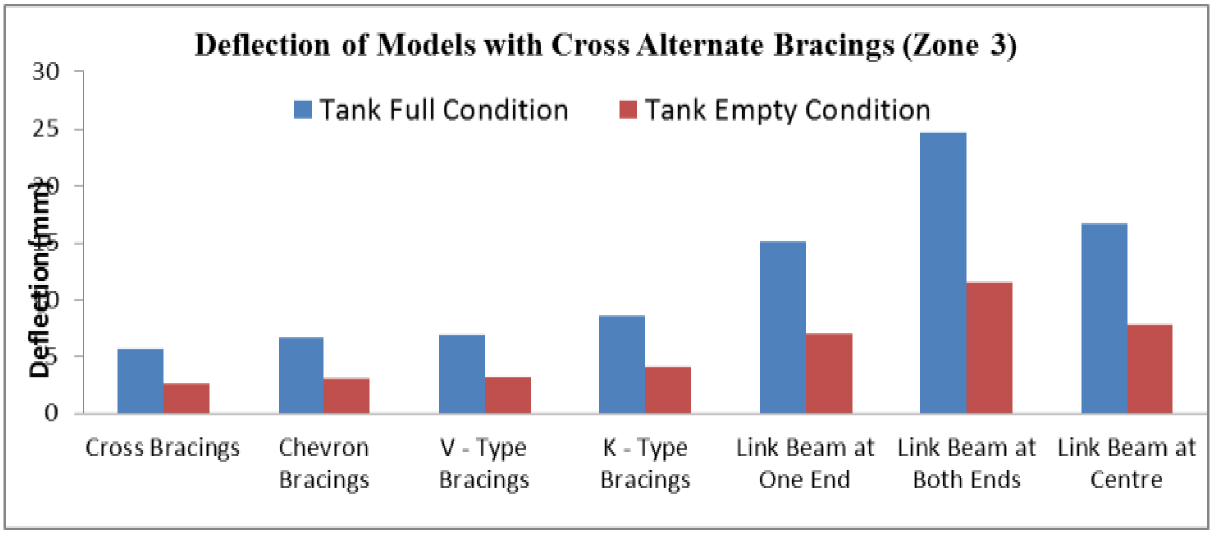


Fig. 3: Deflection of Models with Alternate Cross Bracings (Zone 3)

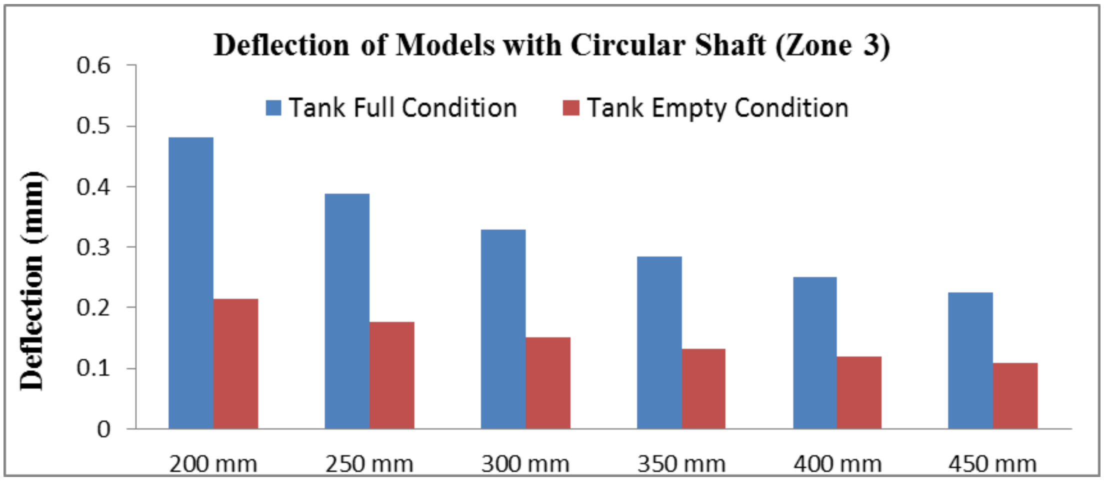


Fig. 4: Deflection of Models with Circular Shaft (Zone 3)

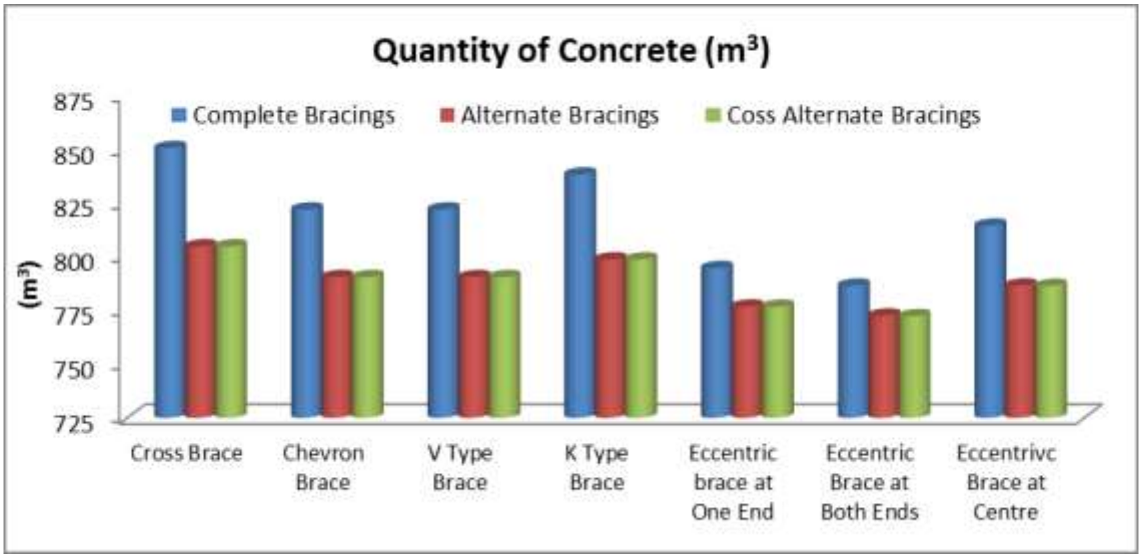


Fig. 5: Quantity of Concrete (m3)

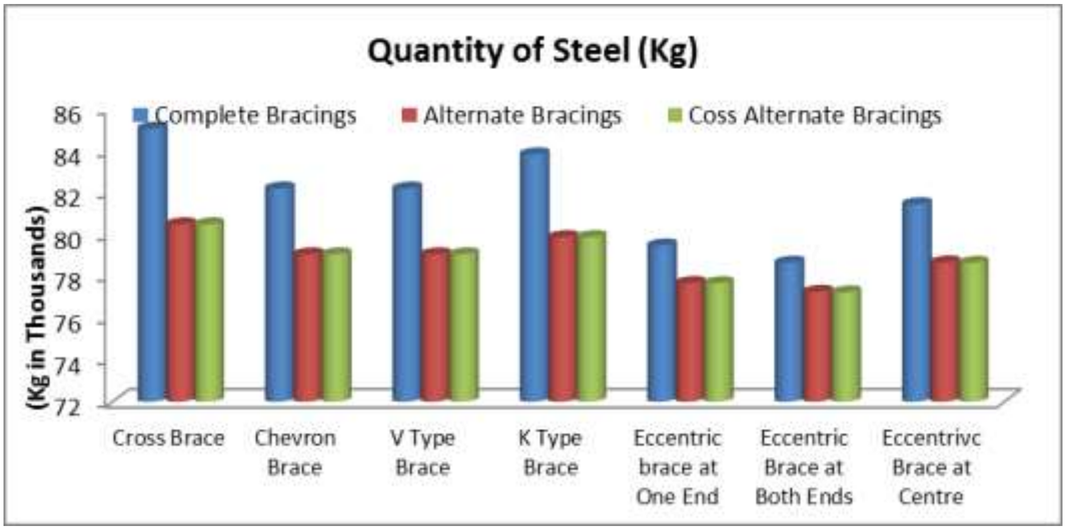


Fig. 6: Quantity of Steel (Kg)

1) From figure 1, 2 and 3 least deflection of container is found when Cross bracing were provided for entire staging.
2) From figure 1 it is found that for Chevron and V type bracings provided for complete staging pattern deflection of container is found to be increased as compared to cross bracing system.
3) The main disadvantage of these bracings is during earthquake for such type of brace one brace will be under compression and other will be under tension. Compression brace will buckle and still the tension brace is carrying the forces, due to this there will be unbalanced vertical force induced at the center of beam resulting in displacement of floor beam or damage to ceiling
4) From figure 1 K type bracings provided for complete staging deflection of container is seen to be more as compared to previous bracing pattern.
5) From figure 1 eccentric brace provided at one end for complete staging deflection of container is seen to be more as compared to K type braces.
6) From figure 1 eccentric brace provided at center for complete staging deflection of container is seen to be more as compared to eccentric brace provided at one end.
7) For eccentric brace provided at center for complete staging deflection of container was found to be highest than all other types of bracings provided from figure 1.
8) From figure 1 and 2 all bracings provided in alternate pattern deflection of container is seen to be more as compared to bracings provided for complete staging.
9) From Figure 1, 2 and 3 when all this bracings are provided in cross alternate pattern deflection of container is seen to be much more as compared to alternate pattern.
10) This is because load transfer mechanism does not take in proper manner since cross alternate pattern creates soft story below bracing provided and transfer of load from upper story to lower story does not takes place properly.
11) From table 1, 2 and 3 for increase in zone of earthquake the deflection pattern is observed to be same as discussed earlier, whereas deflection increases as the zone increases.
12) From figure 1, 2 and 3 it is observed that deflections are maximum in condition eccentric brace at both ends when it is compared with eccentric brace at one end and eccentric brace at center for zone 3, 4, and 5 with tank full condition and tank empty condition.
13) From table 1 it is seen that ratio of deflection of container for tank full to tank empty condition for bracings provided for entire staging pattern was approximately found to be 2.12 .
14) From table 2 and 3 it is observed that ratio of deflection of container for tank full to tank empty condition for bracings provided in alternate and cross alternate pattern was approximately found to be 2.14.
15) From figure 4 it is seen that when circular shaft was provided instead of column and staging deflection of container is seen to be reduced to great extent and deflection was found to be reduced as the thickness of circular shaft increases.
16) The main disadvantage of circular shaft was found that it acts as a shear wall and cracks are likely to be observed in such types of designing which may leads to sudden failure of structure under seismic loads.
17) The brace frames were found to be most economical frames with high lateral load resisting capacity because they are very light in weight and contributes less to the structural mass and contribute more to the stiffness of the frame.
18) Many configurations were found to be possible which allows for opening of passages, services etc. and two story's cross configuration increases stability of frame with less obstruction.
19) The main function of diagonal brace was found to provide stiffness and transmit lateral forces from upper story to lower story.
20) Bracings were found to reduce time period of the structure, and it was found that brace must be designed for excellent response and inelastic action confined to ductile brace and design is in such a wat that it should be weak brace and strong beam system.

21) Buckling of brace was found due to high loads, it can be prevented by filling the tubular brace with plane concrete or by using telescopic tubular braces.
22) It was found that braces being ductile enough exhibit excellent energy dissipation, hence the frame must be design for weak brace and strong brace.
23) Braces are mainly of two types
    1) Concentric Brace Frame (CBF)
    2) Eccentric Brace Frame (EBF)
24) The Eccentric Brace frame is relatively new type of frame; in this the diagonal member is joint with an offset from the joint. This offset joint in the beam is called as link beam which is specially used for control of yielding.
25) The length of link beam is limited to control the shear deformation and rotation due to flexural rigidity at the ends of the link.
26) When one end of link beam is connected to a column, the connection is full moment resistance connection.
27) When the lateral load exceeds the design load the inelastic action first initiates in the link beam and energy dissipation takes place in the link beam.
28) As compared to eccentric brace frames concentric brace frame have higher stiffness.
29) For reduction in slenderness ratio in eccentric brace frames, they perform better in compression as compared to concentric brace frames.
30) As compared to eccentric brace frames concentric brace frames do not have special energy dissipating element called as link beam.

VI. Conclusions

1) The base shear value reduces for alternate bracing pattern in staging. This is apparent because of the reduction of overall stiffness of the structure.
2) When alternate type bracings and cross alternate type bracings are compared alternate type bracing gives less deflection as compared to cross alternate.
3) Cross bracings with complete bracing gives least deflection.
4) For low seismic zones such as Zone 2 and 3, alternate type of bracings can be used.
5) For seismic Zone 4, complete type bracings should be used.
6) For extreme high seismic areas such as zone 5 models with circular shaft should be used.
7) For bracings provided for entire staging deflection for tank full condition can be obtained by multiplying value of deflection tank empty condition by factor 2.12.
8) For bracings provided for alternate staging deflection for tank full condition can be obtained by multiplying value of deflection tank empty condition by factor 2.14.
9) Instead of eccentric type brace concentric brace should be used since eccentric type brace are difficult to repair after earthquake damage as compared to concentric brace and also eccentric braces are costly as compared to concentric type brace2
10) Chevron or V type braces should be avoided because for such type of braces one brace will be under compression and other will be under tension. Compression brace will buckle and still the tension brace is carrying the forces, due to this there will be unbalanced vertical force induced at the center of beam resulting in displacement of floor beam or damage to ceiling.

References

[1] Sudhir K Jain, Sajjad Sameer U –A review of Requirements in Indian Codes for Aseismic Design of Elevated Water Tanks.
[2] G.P.Deshmukh, Ankush S Patekhede - Analysis of Elevated Water Storage Structure Using Different Staging system.
[3] Chirag N Patel, Burhan Kanjetawala and H S Patel - Influence of Frame Type Tapered Staging on sloshing Behaviour of Elevated Water Tank.
[4] Manish N Gandhi, Prof Rajan - Necessity of Dynamic Analysis of Elevated Water Storage Structure Using Different Bracing in Staging.
[5] Kanan Thakkar and Dr. R P Rethaliya - Parametric Study of Intze-Type Water Tank Supported on Different Staging Systems based on IS: 3370-1965 & IS: 33702009.
[6] Durgesh C Rai - Review of Code Design Forces for Shaft Supports of Elevated Water Tanks
[7] M K Shrimali and R S Jangid - Seismic analysis of base-isolated liquid storage tanks.
[8] Pavan S Ekbote and Dr. Jagdish G Kori - Seismic Behaviour of RC Elevated Water Tank under Different Types of Staging Pattern.
[9] Ayazhussian M Jabar and H S Patel - Seismic Behaviour of RC Elevated Water Tank Under Different Staging Pattern and Earthquake Characteristics.
[10] Jain Sudhir and Sameer U S – Seismic Design of Frame Staging for Elevated Water Tanks.
[11] S K Jangave and Dr. P B Murnal - Structural Assessment of Circular Overhead Water Tank Based on Frame Staging Subjected to Seismic Loading.
[12] D K Landge and Dr. P B Murnal - Structural Assessment of Circular Overhead Water Tank Based on Shaft Staging Subjected to Seismic Loading.