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Behaviour of an Elevated Water Tank for Different Staging Patterns and Different Staging Heights

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ABSTRACT:

In areas with high probability of natural disasters, ability of lifeline systems to resist disaster related damages is one of the most important civil engineering challenges. Elevated water tanks are one of the most important lifeline structures. In this paper an extensive computational study has been conducted to find out the performance of elevated water tank under wind force. Since these structures have large mass concentrated at the top of slender supporting structure, these structures are especially vulnerable to horizontal forces due to wind. Finite element models of 24 elevated water tanks have been analyzed. Elevated water tanks are analyzed with different parameters to study the roof displacements, base shears and base moments. Findings of the present study shall lead us to better understanding of the behaviour of elevated water tank under wind load and safer design of such structure.

KEYWORDS: Elevated water tank, wind analysis.

INTRODUCTION:

Indian sub-continent is vulnerable to many natural disasters like earthquakes, draughts, floods, cyclones, landslides, avalanches etc. Many states and Union territories in our country are affected by one or more disasters. Innumerable Property loss takes place due to these natural calamities every year. From past few decades there is a increase in trend in occurrence of hazardous events. High wind storms occur in many parts of India, especially in the coastal states like Gujarat, Tamilnadu, Andhra Pradesh, Orissa and West Bengal get more seriously affected because of the occurrence of cyclonic storms. Wide spread damage takes place in such cyclonic storms. Hence, the study on response of structures under wind effects is very important area where the researchers should concentrate and bring out effective disaster mitigating techniques so that life line facilities remain in function.

Wind induced disaster is mainly due to its ferocity. Hence a proper understanding on performance of structure is required to withstand against impending disaster caused by wind. In this paper an extensive computational study has been presented to understand the behaviour of elevated water tank under wind force because these structures have large mass concentrated at the top of slender supporting structure and hence these structures are especially vulnerable to horizontal forces due to wind. Finite element models of 24 elevated water tanks have been analyzed to study the performance of this structure under wind force by changing various parameters like height of staging, staging patterns, wind zone. The results presented in this paper will be useful to understand the effect of various factors as mentioned above on the magnitude of wind force acting on the elevated water tank.

IMPORTANCE OF ELEVATED WATER TANK AND ITS STUDY:

Water supply is a life line facility that must remain functional following disaster. Most municipalities in India have water supply system which depends on elevated tanks for storage. Elevated water tank is a large elevated water storage container constructed for the purpose of holding a water supply at a height sufficient to pressurize a water distribution system. In major cities the main supply scheme is augmented by individual supply systems of institutions and industrial estates for which elevated tanks are an integral part. Elevated water storage tanks features to look for are strength and durability, and of course leakages can be avoided by identifying good construction practices. But in reality these structures do not often last as long as they are designed for. These structures have a configuration that is especially vulnerable to Lateral forces like earthquake, wind forces due to the large total mass concentrated at the top of slender supporting structure. So it is important to check the severity of these forces for particular region.

The study of damage histories revealed damage/failure of reinforced concrete elevated water tanks of low to high capacity. Investigating the effects of lateral forces has been recognized as a necessary step to understand the natural hazards and its risk to the society in the long run. Most water supply systems in developing countries, such as India, depend on reinforced cement concrete elevated water tanks. The strength of these tanks against lateral forces, such as those caused by lateral forces needs special attention. It is very important to analyze reinforced cement concrete elevated water tank properly.

COMPUTATIONAL MODELING:

It is very important to analyze reinforced cement concrete elevated water tank properly against horizontal forces. The present study has been planned to check the severity of wind forces with height, staging patterns of the elevated water tank in different zones of India. The analysis is carried out using Staad-pro V8i software as per IS 875 (Part 3): 1987.
The magnitude of wind force mainly depends on following factors:

Classification of Structure:

The structures are classified into the following three different classes depending upon their sizes;
Class A-Structures and/or their components such as cladding, glazing, roofing, etc, having maximum dimension (greatest horizontal or vertical dimension) less than 20m.
Class B-Structures and/or their components such as cladding, glazing, roofing, etc, having maximum dimension (greatest horizontal or vertical dimension) between 20 and 50 m.
Class C-Structures and/or their components such as cladding, glazing, roofing, etc, having maximum dimension (greatest horizontal or vertical dimension) greater than 50m.

Terrain Category:

There are four terrain categories. Terrain in which a specific structure stands shall be assessed as being one of the following terrain categories:
Category 1- Exposed open terrain with few or no obstructions and in which the average height of any object surrounding the structure is less than 1.5 m.
Category 2- Open terrain with well scattered obstructions having heights generally between 1.5 to 10 m.
Category 3- Terrain with numerous closely spaced obstructions having the size of structure up to 10 m in height with or without a few isolated tall structures.
Category 4- Terrain with numerous large high closely spaced obstructions.
Basic Wind Speed – For Seismic Zones III,IV & V , the maximum Wind speeds are considered for this Study and it came as
For Zone III the maximum basic wind speed is 47m/s and it is at Agra.
For Zone IV the maximum basic wind speed is 47m/s and it is at Almora.
For Zone V the maximum basic wind speed is 55m/s and it is at Dharbanga.
Design Wind Speed (Vz) - The basic wind speed (Vb) for any site shall be obtained from Fig. 1 and shall be modified to include the following effects to get design wind velocity at any height
a) Risk level;
b) Terrain roughness, height and size of structure; and
c) Local topography.
It can be mathematically expressed as follows:

$$Vz = Vb * k1 * k2 * k3$$

Where
Vb = design wind speed at any height z in m/s;
k1= probability factor (risk coefficient)
k2 = terrain, height and structure size factor and
k3= topography factor

NOTE: Design wind speed up to 10 m height from mean ground level shall be considered constant
Design Wind Pressure (Pz)- The design wind pressure at any height above mean ground level shall be obtained by the following relationship between wind pressure and wind velocity:

$$Pz = 0.6 * Vz2$$

Where

Pz = design wind pressure

Vz = design wind speed

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Table 1 : Risk coefficients for structure:

ZONES/ BASIC WIND SPEEDS	K_1
III (47 m/s)	1.07
IV (47 m/s)	1.07
V (55 m/s)	1.08

Table 2: Model Parameters of tank:

Capacity of water tank	1500 cu.m
Height of staging	18 m and 22.5 m
Diameter of the Cylindrical Portion (D1)	16 m
Height of water in the Cylindrical Portion (h1)	7 m
Height of the Conical Portion (h2)	3 m
Diameter of the tank at base of Conical portion (D2)	10 m
Height of the Bottom Dome (h3)	2 m
Radius of Bottom Dome (R1)	7.25 m
Height of the Top Dome (h4)	3 m
Radius of Top Dome (R2)	12.17 m
Cylindrical Wall Thickness	400 mm
Conical slab Thickness	450 mm
Thickness of Bottom Dome	200 mm
Thickness of Top Dome	150 mm
Ring Beams at Bottom slab level	650 X 1200 mm
Column size	650 X 650 mm
Brace Beams	300 X 600 mm
Ring Beams at Top slab level	400 X 400 mm

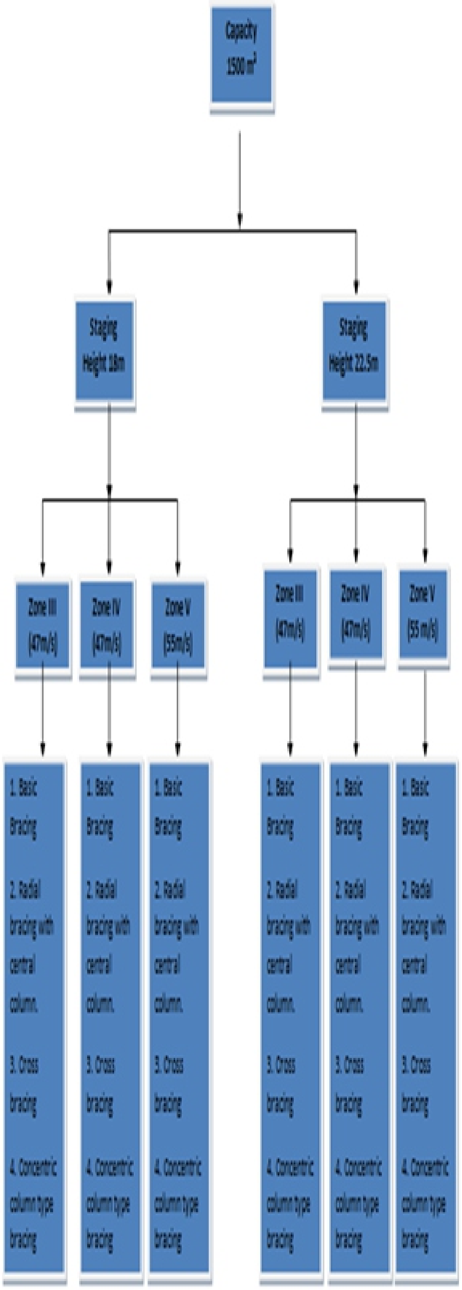

Fig:1 Flow Chart of different tanks

RESULTS AND DISCUSSIONS:

Calculation of wind force is a very important parameter for elevated water tank which is most susceptible to horizontal forces because of large massconcentrated at considerable height. The change of magnitude in wind force changed various parameters and compared for 24 tanks the results are tabulated.

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Table 3: Roof displacement summary for Wind load (18 m)

Tank condition	Staging Patterns	Roof Displacements in mm	
		Zone III & IV (47m/s)	Zone-V (55 m/s)
Empty	Basic Bracing	53.37	85.88
	Radial Bracing	45.02	59.88
	Cross Bracing	46.63	75.05
	Concentric Columns	24.7	24.7
Half Full	Basic Bracing	42.69	68.71
	Radial Bracing	35.99	58.73
	Cross Bracing	37.36	60.03
	Concentric Columns	19.76	19.77
Full	Basic Bracing	42.12	58.41
	Radial Bracing	35.64	57.95
	Cross Bracing	36.81	59.05
	Concentric Columns	19.76	19.77

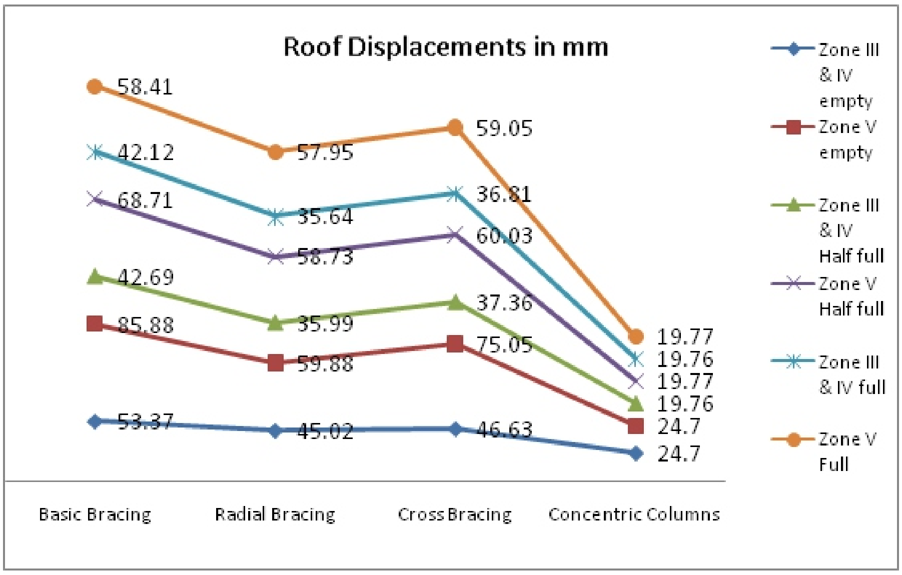

Fig: 2 Roof displacement summaries for Wind load (18 m)

The Roof displacements for tank empty, tank half and tank full conditions are taken from staad by applying the respective Wind forces to the FEM model. The Roof displacements in various tank filling condition for Basic, Radial, cross bracing and concentric column type system are shown in Table 3 for different Basic wind speeds. The roof displacement in the tank Empty condition is higher than the tank half and tank half condition this can be clearly seen in fig: 2 from this comparison table Concentric column type staging is having less displacement and Basic bracing type staging is having maximum displacement in any zone. For basic wind speed of 47m/s Tank fails only in Basic Bracing pattern (Limiting Displacement , hs/500= 49.2 mm for first 3 and for concentric column it is 45mm) and where as for basic wind speed for 55m/s Tank survives only in Concentric column type Staging pattern (Limiting Displacement , hs/500= 49.2 mm for first 3 and for concentric column it is 45 mm)

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Table 4 Base Shear summary for Wind Load (18 m)

Tank condition	Staging Patterns	Base Shear in kN	
		Zone III & IV (47m/s)	Zone – V (55m/s)
Empty	Basic Bracing	183.16	285.43
	Radial Bracing	172.69	267.86
	Cross Bracing	187.24	289.3
	Concentric Columns	107.8	107.8
Half Full	Basic Bracing	146.53	228.35
	Radial Bracing	138.18	214.32
	Cross Bracing	149.79	231.44
	Concentric Columns	86.236	86.23
Full	Basic Bracing	123.69	200.91
	Radial Bracing	136.05	210.51
	Cross Bracing	148.12	227.92
	Concentric Columns	86.236	86.23

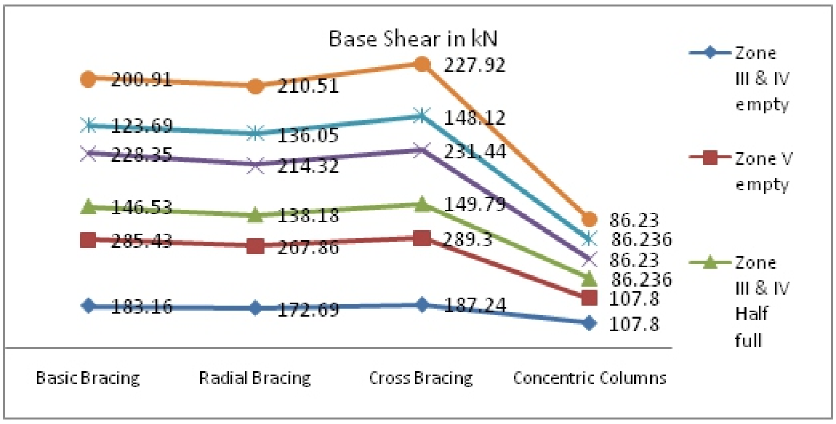

Fig: 3 Base Shear summaries for Wind load (18 m)

The Base shear for tank empty, tank half and tank full conditions are taken from staad by applying the respective Wind forces to the FEM model. The Base shear in various tank filling condition for Basic, Radial, cross bracing and concentric column type system are shown in Table 4. The Base shear in the tank Empty condition is higher than the tank half and tank half condition this can be observed in fig: 3. Hence tank Empty condition is the severest condition for design considerations. The base shears increased around 55% for first 3 staging patterns and remained unchanged for concentric column type bracing for basic wind speed 47m/s to 55m/s.

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Table 5 Base Moment summary for Wind Load (18 m)

Tank condition	Staging Patterns	Base Moment in kN-m Zone III & IV (47 m/s)	Zone – V (55 m/s)
Empty	Basic Bracing	353.01	549.56
	Radial Bracing	321.77	500.62
	Cross Bracing	343.09	530.69
	Concentric Columns	206.28	206.28
Half Full	Basic Bracing	282.41	439.65
	Radial Bracing	257.47	400.59
	Cross Bracing	274.47	424.53
	Concentric Columns	168.02	165.02
Full	Basic Bracing	279.13	386.99
	Radial Bracing	254.05	394.06
	Cross Bracing	271.33	417.95
	Concentric Columns	168.02	165.02

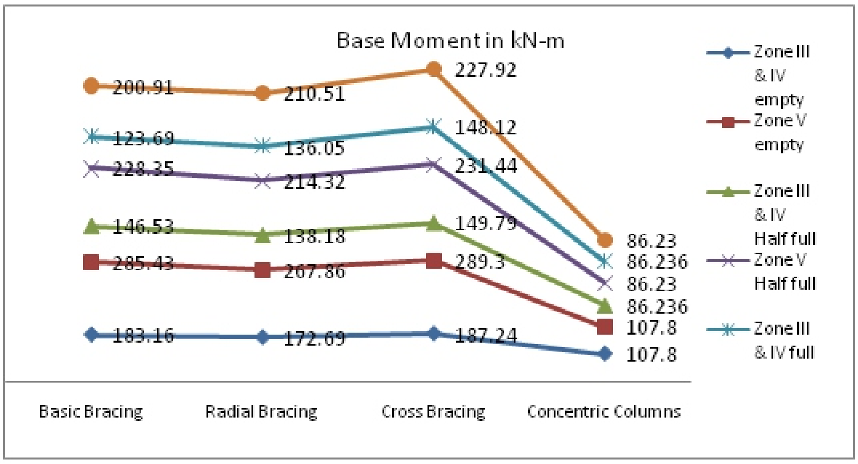

Fig: 4 Base Moment summaries for Wind load (18 m)

The Base Moment for tank empty, tank half and tank full conditions are taken from staad by applying the respective Seismic forces to the FEM model The Base Moment in various tank filling condition for Basic, Radial, cross bracing and concentric column type system are shown in Table 5. The Base Moment in the tank Empty condition is higher than the tank half and tank half condition this can be observed in fig: 4. Hence tank Empty condition is the severest condition for design considerations. The base moments increased about 55% for basic wind speed 47 m/s to 55 m/s.

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Table 6 Roof displacement summary for Wind load (22.5 m)

Tank condition	Staging Patterns	Roof Displacements in mm	
		Zone III & IV (47 m/s)	Zone – V (55 m/s)
Empty	Basic Bracing	72.26	114.21
	Radial Bracing	73.44	97.08
	Cross Bracing	62.44	99.74
	Concentric Columns	34.81	34.81
Half Full	Basic Bracing	57.77	91.43
	Radial Bracing	47.78	77.63
	Cross Bracing	49.95	79.79
	Concentric Columns	27.85	27.85
Full	Basic Bracing	57.01	89.92
	Radial Bracing	47.4	76.59
	Cross Bracing	49.29	78.52
	Concentric Columns	27.85	27.85

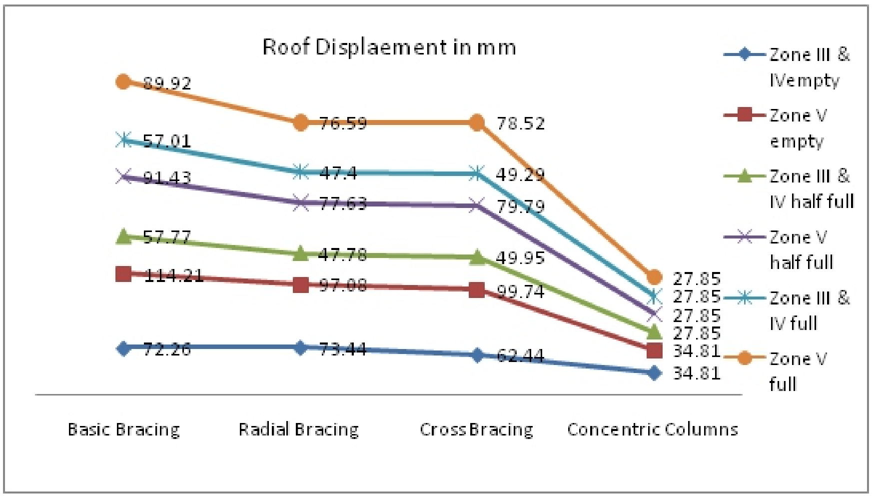

Fig: 5 Roof Displacement summaries for wind load (22.5 m)

The Roof displacements for tank empty, tank half and tank full conditions are taken from staad by applying the respective Wind forces to the FEM model. The Roof displacements in various tank filling condition for Basic, Radial, cross bracing and concentric column type system are shown in Table 6 for different Basic wind speeds. The roof displacement in the tank Empty condition is higher than the tank half and tank half condition. Hence tank Empty condition is the severest condition for design considerations and can be seen in fig: 5 From this comparison table Concentric column type staging is having less displacement and Basic bracing type staging is having maximum displacement for any basic wind speed. For Basic wind speeds 47m/s and for 55m/s Tank survives only in Concentric column type Staging pattern (Limiting Displacement hs/500= 58.2 mm for first 3 and for concentric column it is 54 mm)

Table 7 Base Shear summary for Wind Load (22.5 m)

Tank condition	Staging Patterns	Base Shear in kN	
		Zone III & IV (47 m/s)	Zone – V (55 m/s)
Empty	Basic Bracing	193.97	297.81
	Radial Bracing	183.27	283.18
	Cross Bracing	198.04	304.33
	Concentric Columns	119.66	119.66
Half Full	Basic Bracing	155.18	238.25
	Radial Bracing	146.21	226.18
	Cross Bracing	158.43	243.46
	Concentric Columns	95.73	95.73
Full	Basic Bracing	153.54	234.8
	Radial Bracing	146.51	224.74
	Cross Bracing	156.76	239.95
	Concentric Columns	95.73	95.73

The Base shear for tank empty, tank half and tank full conditions are taken from staad by applying the respective Wind forces to the FEM model. The Base shear in various tank filling condition for Basic, Radial, cross bracing and concentric column type system are shown in Table 7. The Base shear in the tank Empty condition is higher than the tank half and tank half condition. Hence tank Empty condition is the severest condition for design considerations in any Zone and can be clearly seen in fig: 6.

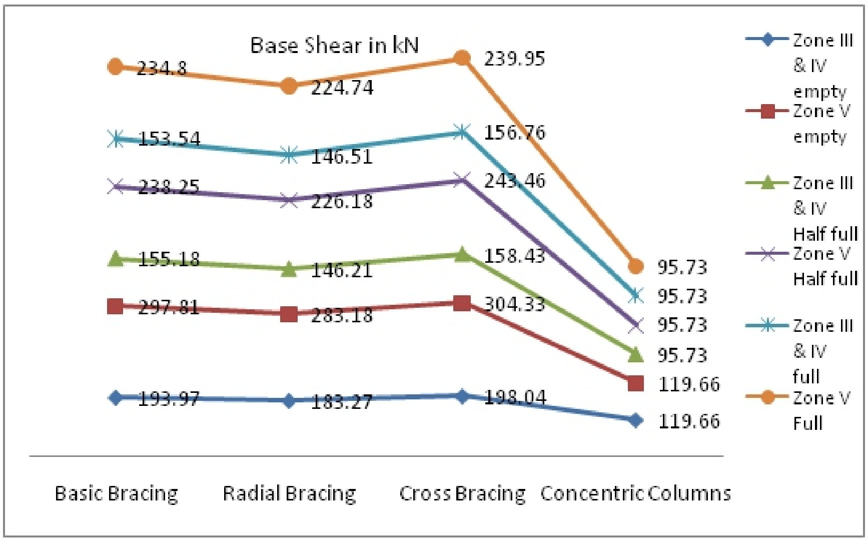

Fig: 6 Base Shear summary for Wind load (22.5 m)

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Table 8 Base Moment summary for Wind Load (22.5 m)

Tank condition	Staging Patterns	Base Moment in kN-m	
		Zone III & IV (47 m/s)	Zone – V (47 m/s)
Empty	Basic Bracing	375.23	575.21
	Radial Bracing	340.99	515.48
	Cross Bracing	364.116	559.93
	Concentric Columns	229.52	229.51
Half Full	Basic Bracing	300.18	460.17
	Radial Bracing	272.37	421.96
	Cross Bracing	291.29	447.94
	Concentric Columns	183.6	183.61
Full	Basic Bracing	296.89	453.27
	Radial Bracing	271.56	417.98
	Cross Bracing	288.13	441.33
	Concentric Columns	183.6	183.61

The Base Moment for tank empty, tank half and tank full conditions are taken from staad by applying the respective Wind forces to the FEM model The Base Moment in various tank filling condition for Basic, Radial, cross bracing and concentric column type system are shown in Table 8. The Base Moment in the tank Empty condition is higher than the tank half and tank half condition. Hence tank Empty condition is the severest condition for design considerations for any Basic wind speed and clearly observed from fig: 7.

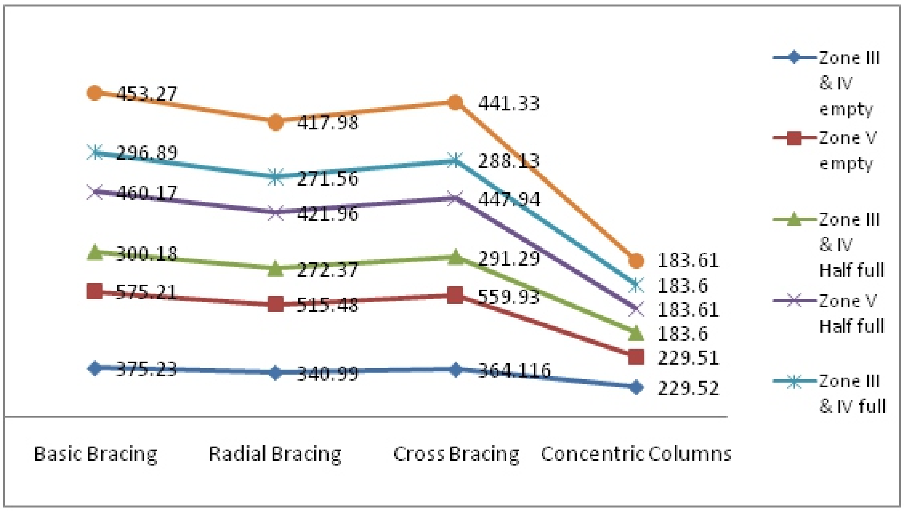

Fig: 7 Base Moment summaries for Wind load (22.5 m)

CONCLUSIONS:

The above study demonstrates the considerable change in Wind load behavior of elevated tanks with consideration of responses like base shear, base moment, displacement etc. when supporting system is used with appropriate modifications. Finally study discloses the importance of suitable supporting configuration to remain withstand against heavy damage/failure of elevated water tanks during wind load conditions.Wind load characteristics with different two basic wind speeds, which cause excitation of responses such as base shear force, overturning moment and roof displacement, are compared and following conclusions are obtained.

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1.For Staging Heights 18m and 22.5m the base shears are more for empty tank conditions than for half full and full tank conditions, also the base shears are increasing for basic wind speed 47m/s to 55 m/s by about 50% for basic, radial, cross bracing type staging patterns.

2.For Staging Heights 18m and 22.5m the base Moments are more for empty tank conditions than for half full and full tank conditions, also the base moments are increasing for basic wind speed 47m/s to 55 m/s by about 50% for basic, radial, cross bracing type staging patterns.

3.For Staging heights 18m and 22.5m the roof displacements are higher for empty tank conditions than for half full and full tank conditions, also in both staging heights for basic wind speeds 47 m/s and 55 m/s the roof displacements are not exceeding their limiting value only for concentric column type staging patterns.

NOMENCLATURE:

K1 : Wind Speed multiplication factor

K2: Wind Speed multiplication factor

K3: Wind Speed multiplication factor

K4 : Wind Speed multiplication factor

Pz: Wind pressure at height z

Vb : Regional basic wind speed

Vz: Design wind speed at height z

Vh: Design wind speed at height h

H: Height of structure above mean ground level

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