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Stability Analysis of a Real Life Tilted RCC Over Head Reservoir (Tank) considering Soil-Structure and Fluid-Structure Interaction

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Abstract

Tilt and settlement of RCC structures with foundations over alluvial soil of greater Kolkata and surrounding Ganges Flood Basin is a frequent problem with respect to the stability of these structures. The tilt and subsequent distress have a significant effect on the overall stability of the Over Head Reservoirs (Tanks); which also depend on the nature of the supporting soil, Fluid Structure Interaction (FSI). Various NDTs can be performed to assess the condition of the concrete members, but this piecewise assessments may not adequately address the overall stability of the OHRs subjected to various loadings including lateral seismic forces, particularly for a tilted one. Thus, numerical analysis of the tilted OHR is significantly important to assess its overall stability considering its global behaviour. The present numerical study aims to evaluate the effect of the tilt on the overall stability of a real life existing RCC OHR supported on frame staging. The increase in design reinforcement demand and lateral displacement at crown top level are compared to assess the effect of tilt from the Limit State of Collapse and Limit State of Serviceability points of view. The global effect of the tilt is studied based on the changes of its fundamental period of vibrations of the OHR. Subsequently, Pushover analysis is also performed to evaluate the effect of the tilt on the various parameters e.g. base shear capacity, inelastic displacement at crown top level, global ductility. The vulnerability index based on the pushover analysis results are also compared to ascertain the effect of the tilt. Soil-Structure Interaction and Fluid-Structure Interaction have been duly considered in the Finite Element models on SAP2000 platform to study the effect of tilt on the OHR stability. It is found that the tilt plays a great role on the overall stability and safety of the frame staging OHR, which further get aggravated due to softer supporting soil and considering Fluid-Structure Interactions. The proposed stability analysis of this case study seems to have a great potential for its practical application in safety evaluation and retrofit of existing OHRs subjected to tilt.

Keywords: Fluid-Structure-Interaction, Over Head Reservoir, Push Over Analysis, Soil-Structure-Interaction, Stability, Tilt, Vulnerability Index.

1. Introduction

Over Head Reservoirs (Tanks) are a very essential part of public water distribution systems for potable water as well as firefighting operations and are considered as life line structures. Kolkata is situated on an alluvial flood plain and thus it is prone to differential settlement and subsequent tilt for structures. Most of the added areas to the existing city of Kolkata are developed using filled up soils over the low marshy lands. The soils below these fill up soil are irregular in nature. In addition, there are uncertainties associated with the consolidation over the entire area. Thus, inadequately assessed soil characteristics and or improperly constructed pile foundations in terms of material or workmanship may even cause tilt to the overhead tanks. In addition, tilt may also be caused due to other constructional defects, extreme loading etc. A portion of greater Kolkata is situated in the earthquake zone IV (IS 1893: 2016), consideration of tilt in the numerical modelling to predict the stability of the structures is further justified. So, the tilt of these tanks (**Figure 1**) have become a common concern, as it plays a vital role on their overall stability and the damage suffered by these structures. The present study compares the changes in structural responses due to tilt; e.g. column reinforcement demand, crown top displacements under design loadings including earthquake, modal time periods of the tank to assess the overall stability. The effect of Soil Structure Interaction and Fluid Structure Interaction on the stability of the considered real life RCC overhead tank are also studied in the FEM framework of SAP2000. It is observed that there is a significant effect of the tilt on the tank stability. The Nonlinear Pushover Analysis of the tank is also performed to assess the effect of tilt. Vulnerability Indices of the tank models are further computed to evaluate the effect of tilt.

2. Literature Review

Acharjee et al [1] studied effect of tilt on RCC buildings situated in different seismic zones. It is reported that the effect of the tilt was the most on the ground floor columns. Further, the biaxial tilt was also reported to be more alarming for the building stability. The buildings with three bays in their structural systems performed better than two bay models against seismic loadings.

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Fig. 1. RCC Over Head Reservoir (Tank) supported on frame staging subjected to tilt

. **Acharjee et al** [2] studied the effect of incremental tilt on the G+4 storied RCC buildings considering P-Delta effect. Parametric study on the effect of different types and extent of tilt with different number of bays were duly considered. It was found that types and extent of tilt played a significant role on the overall structural stability of the buildings. The threat of vulnerability was more in case of columns of two bay model compared to that of the three bay models and the biaxial tilt was found to be more detrimental for stability of the buildings. **Lakhade et al** [17] proposed drift limits for RCC framed staging in EWTs for different seismic damage states evaluated based on Park and Ang damage index. Some Elevated Water Tanks were designed considering the variation in tank capacity, staging height and structural configuration of framed staging using relevant IS codes. Pushover curves were generated from the pushover analysis of the 3-D models. Those curves were further bi-linearized to obtain the yield and ultimate capacities. Finally, by doing regression analysis of damage indices and top drift, the drift values for each damage state was estimated. It was used for performance-based seismic evaluation and fragility assessment of existing RCC EWTs supported on frame staging. It was concluded that the performance of tanks with small capacity and supported on shorter frame staging were good. The drift limits varied significantly from the drift limits of building frames; indicating the seismic behaviour of frame staging for Elevated Water Tanks was different than the building frames. **Afshin Mellati** [19] proposed a new pushover procedure to evaluate the seismic responses of Elevated Water Tanks supported on the RCC shaft staging considering soil-structure and fluid-structure interactions. Parametric studies were conducted to investigate the effects of various essential parameters like soil type, water level and tank capacity on seismic responses of EWTs using Incremental Dynamic Analysis to generate fragility curves for the assessed conditions of the tanks. Thereafter, pushover analyses were performed and it was proposed to predict the mean IDA curve of the Elevated Water Tanks supported on the RCC shaft staging by using the results and comparing those with mean IDA curve, as an exact solution. It was observed that the increase in tank capacity and shaft stiffness have resulted an increase in structure dynamic capacity (IDA curve). Comparing the IDA curves, it was concluded that the full-filled water level was the critical one due to increased seismic mass and increased shaft axial force. **N. Lakshmanan** [18] studied the seismic qualification of existing buildings using nonlinear behaviour from various available approaches and also discussed the methods to determine seismic vulnerability index for structures, which is a useful parameter to assess the structural performance along with repair suitability. It was observed that the inherent deficiencies in the detailing of the beam column joints got reflected even after repair, though the performance factors indicated significant improvement. **IS 1904** [15] has recommended the allowable limit of angular distortion for framed RCC overhead tanks as 1/400 for both hard and soft soils. This value may not eliminate cracks in structural and non-structural members; but would not cause a very large structural damage. **Bjerrum et al** [5] specified the damage limits due to angular distortions for different performance criteria of the structures. The permissible value of angular distortion should be less than 1/500 to eliminate the cracks in a RCC structure, as reported.

3. Numerical Model

A real life tilted OHR is analyzed and designed in FE platform of SAP2000 to evaluate the effect of tilt on its structural stability. The salient features of the OHR considered for the numerical model are given below.

- **Description of the OHR**

A particular RCC OHR structure with 400 cum capacity and 20 m high frame staging is considered for the analysis and design based on the available architectural and structural drawings of the real life OHR structure. The depths of foundations of 2.3m from GL as available in the respective drawing are duly considered in the numerical model for analysis.

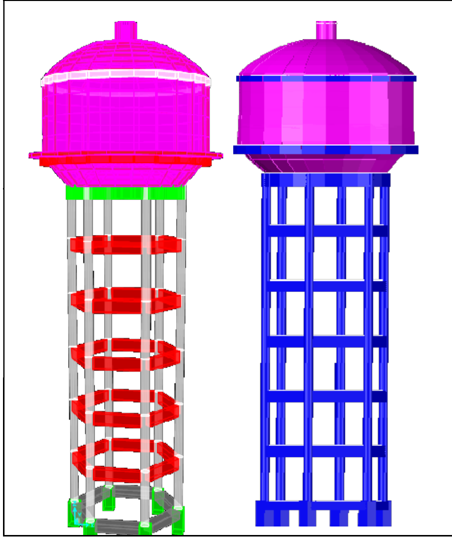
➢ **Material Specifications for the RCC OHR**

The considered material properties of all the RCC structural members of the OHR are given below in **Table-1**.

Table-1. Material specifications used in OHR Models

Materials	Grade of materials
Concrete	M25 (with characteristic strength of 25 MPa)
Steel	Fe500 D (with minimum yield & tensile strength of 500 MPa & 545 MPa respectively)

Table-2. Number of Elements in Numerical Model of OHR

	No of Nodes	684
	No of Frames	150
	No of Shells	600

➢ **Section Details for the RCC OHR**

The considered RCC slab (thin shell) and frame section properties are tabulated in **Table-3** to **Table-5**.

Table-3. Section Properties of Shell Element of OHR Model

Shell Sections	Thickness (mm)
Top Dome	125
Bottom Dome	150
Cylindrical Wall	200-300 (Linearly Varying from top to bottom ring beam level)
Conical Shell	300

Table-4. Properties of Beam Sections of the OHR Model

Beam Sections	Width (mm)	Depth (mm)
Bracing Beams	400	675
Tie Beams	500	800
Heal Beams	500	800
Top Ring beams	350	350
Bottom Ring Beams	600	500

Table-5. Properties of Column Sections of the OHR Model

Column Sections	Diameter(mm)/ Width (mm) X Depth (mm)
Circular Columns	600
Pedestal Columns	800 X 800

➢ **Load considered for the Analysis and Design of OHR**

The considered loads applied on the structural members of numerical models of the RCC OHR as per the stipulations of various IS codes are discussed below in **Table-6** to **Table-8**.

Table-6. Gravity Loads Considered in the RCC OHR Model

Codal Stipulations used	Type of Loading	Applied Load
IS 875 (Part 1): Dead Loads-Unit Weights of Building Materials & Stored Materials	Dead Load (DL)	Self-weight of the structural members.
	SIDL of Water on Bottom Dome	35.12 kN/m^2
	SIDL of Water on Conical Slab	35.12 kN/m^2
IS 875 (Part 2)	Live Load (LL) on Accessible Slabs over Top Dome	1.5 kN/m^2

Table-7. Wind Load parameters considered for the OHR as per IS 875 (Part 3): 2015

Basic Wind Speed, V_b (Considered city is Kolkata)	50 m/s
Risk coefficient, K_1	1.08
Terrain category	III
Topography factor, K_3	1
K_4	1.30
Design wind speed, V_z	V_bx K_1x K_2x K_3x K_4
Design wind pressure, P_z	(0.6 xV_z^2)

Table-8. Seismic Load Parameters considered for the OHR as per IS 1893 (Part 2):2014

Importance Factor (Considered structure is OHR)	I=1.5
Response Reduction Factor (Considered staging is of OMRF type)	R=2.5
Soil Type	Medium Stiff
Seismic Zone Considered	IV
Seismic Mass Considered	100% of DL+100% of SIDL+25% of LL

➢ **Amount of Tilt Considered for the OHR**

The considered OHR is observed to be tilted 250 mm at the top level of heal beam. The deformation due to tilt is considered as rigid body movement and the deformations of other nodes at other bracing levels are computed using linear interpolation.

➢ **Soil-Structure Interaction Considered for the OHR**

Soil as well as RCC raft foundation are modelled using 8 noded 3 dimensional solid elements in FE platform of SAP2000. The soil and RCC raft foundation properties are given below in **Table-9** & **Table-10**.

Table-9. Properties of the Soil Considered for the OHR

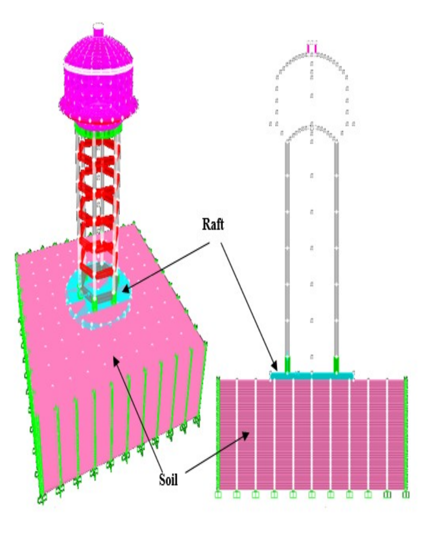
Soil Type	C (kPa)	Φ (deg)	G (kN/m^2)	μ	E (kN/m^2)	N value	γ_b (kN/m^3)
Soft Cohesive Soil	25	0	4700	0.33	12500	2	17.2

Table-10. Properties of the Raft Foundation of the OHR

Foundation Type	Grade of Concrete	Thickness (mm)
Raft	M 30	600

The number of various elements in the numerical model of the OHR supported on RCC raft are given in **Table-11**.

Table-11. Numerical Model Details of the OHR considering Soil Structure Interaction

	No of Nodes	6904
	No of Frames	150
	No of Shells	600
	No of Solids	5024

➢ **Fluid-Structure Interaction Considered for the OHR**

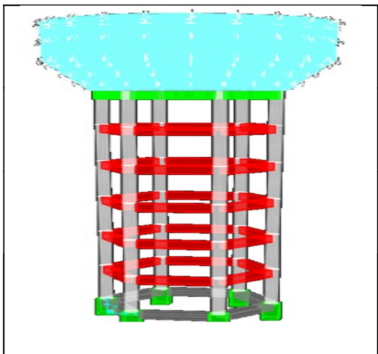
The stored water is explicitly modelled using 8 noded 3 dimensional solid elements in finite element platform of SAP2000. Gap links are used to connect the water to the structure. The water is modeled using 3 dimensional solid elements made up of a material with a small shear modulus when compared to that of bulk modulus; so that poison's ratio becomes around 0.5. Based on available literatures, following approximate properties (given below in **Table-12**) are considered to model water as solid element:

Table-12. Properties of Water Considered for OHR

Young's Modulus (kN/m^2)	6205
Poisson's Ratio	0.4995
Shear Modulus (kN/m^2)	2068
Bulk Modulus (kN/m^2)	2068000
Weight Density (kN/m^3)	10

The number of various elements in the numerical model of the OHR supported on raft foundation, considering FSI are tabulated in **Table-13**.

Table-13. Numerical Model details of OHR considering FSI

	No of Nodes	5436
	No of Frames	150
	No of Shells	600
	No of Solids	4440

4. Results And Discussions

The FE models of the RCC OHRs are analyzed and the various structural responses are presented to evaluate the effect of tilt on the stability of the OHR structures.

➢ **Reinforcement Demand of Columns for the OHR**

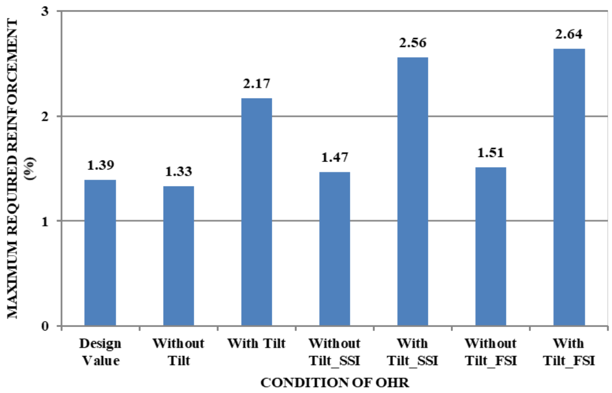


Fig. 2. Maximum required reinforcement (%) of columns for various conditions of OHR

It is observed that the results of the numerical models are in tune with the designed values of reinforcement as provided in the columns of the OHR. However, the maximum column reinforcement demands have significantly increased due to the considered tilt. The consideration of soil structure interaction and fluid structure interaction have further increased the reinforcement demand. This emphasizes that consideration of soil structure interaction and fluid structure interaction are significantly important factors to assess the stability of the tilted OHR.

➢ **Displacement of the OHRs at Crown Top Level**

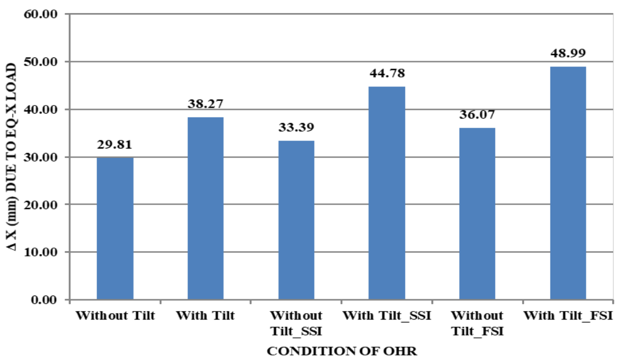


Fig. 3. Comparison of crown top displacement (mm) for various conditions of OHR

The displacements of the OHRs at crown top level due to lateral seismic loading gets higher due to tilt, which further increases as soil structure interaction and fluid structure interaction are considered. It indirectly indicates about a decrease in overall structural stiffness as the OHRs are subjected to tilt. The significant increase in lateral displacements also indicate about the distress in terms of cracks etc. the structures would be subjected to. This further emphasizes the importance of soil structure interaction and fluid structure interaction in the numerical modelling of the OHRs subjected to tilt.

➢ **Fundamental Natural Time Period of the OHRs**

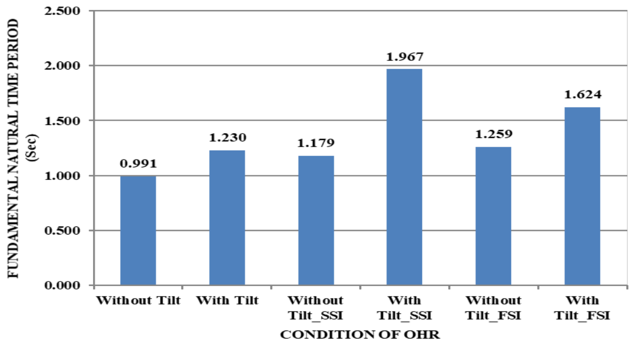


Fig. 4. Fundamental natural time period for various conditions of OHR

The fundamental natural time period of the OHRs get higher due to tilt, which further increases as soil structure interaction and fluid structure interaction are considered. The increase in fundamental period of vibration indicates about an increase in flexibility due to tilt. This again emphasizes the importance of soil structure interaction and fluid structure interaction in the numerical modelling, when the OHRs are subjected to tilt.

➢ **Comparison of Push Over Analysis Results of the OHRs**

The structural models of the RCC OHRs are analyzed using the non-linear static pushover analysis in the platform of SAP2000. From the various results as obtained from the pushover analysis; the following parameters are compared to study the global effect of tilt on the stability of the considered RCC OHRs.

1) Base Shear Capacity
2) Inelastic Roof Displacement
3) Global Ductility (μ)
4) Vulnerability Index

▪ **Results Based on Base Shear Capacity**

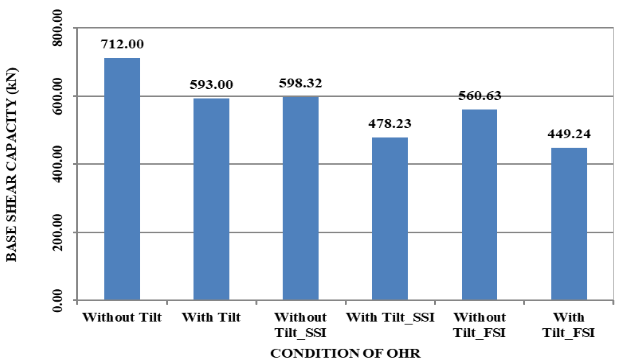


Fig. 5. Typical pushover capacity curve and its bilinearization

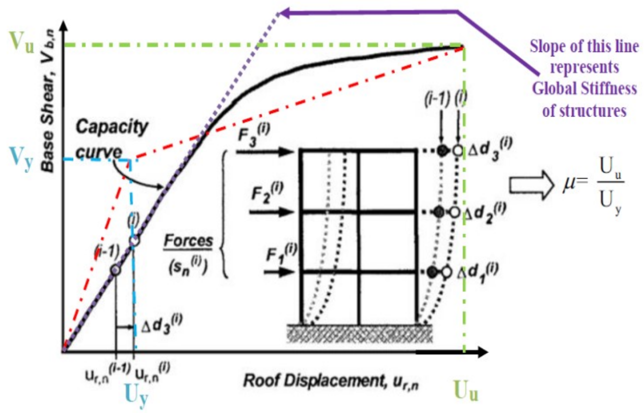


Fig. 6. Comparison of base shear capacity (kN) for various conditions of OHR

The base shear capacity of the OHRs get decreased due to tilt, which further decrease as soil structure interaction and fluid structure interaction are considered. This indicates tilted OHRs cannot tolerate higher base shear; which suggests that stability of the concerned real life OHRs get significantly affected due to the tilt. The soil structure interaction and fluid structure interaction further affects the capacity of the structures to withstand seismic load during earthquake, irrespective of the tilt extent; as evident from the above graphs.

▪ **Results Based on Inelastic Crown Displacement (mm)**

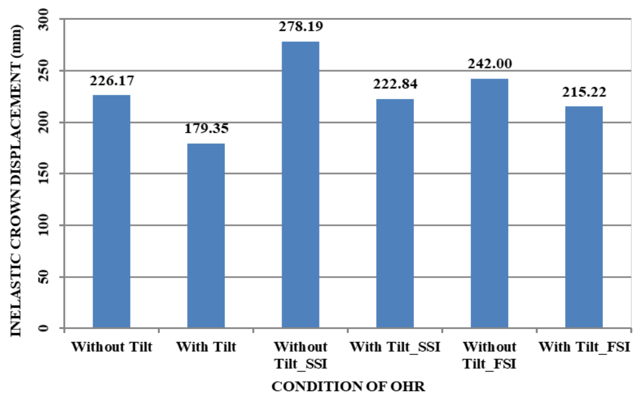


Fig. 7. Comparison of inelastic crown displacement (mm) for various conditions of OHR

The inelastic crown displacements of the OHRs decrease due to tilt, which slightly increase as soil structure interaction and fluid structure interaction are considered. It indicates about a decrease in global stiffness as the structure is subjected to tilt, thus the ultimate displacement decreases. Here the consideration of soil structure interaction and fluid structure interaction imparts some flexibility to the structure as evident from the above graph; which is irrespective of the tilt extent.

- **Results Based on Global Ductility**

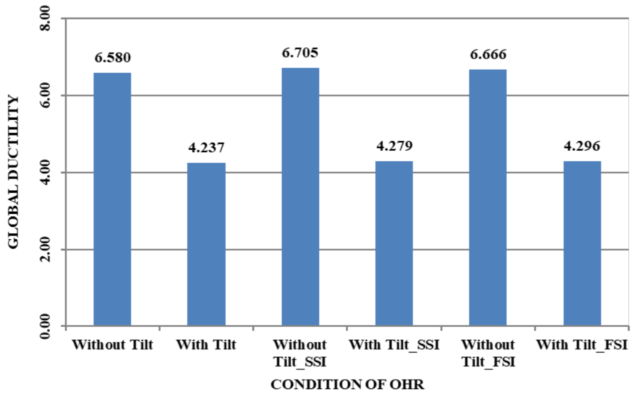


Fig. 8. Comparison of global ductility for various conditions of OHR

The global ductility of the considered OHRs decrease significantly due to tilt, which slightly increases as soil structure interaction and fluid structure interaction are considered. It indicates about a decrease in the ratio of ultimate to yield displacements of the structures as the OHRs get tilted. Here the consideration of soil structure interaction and fluid structure interaction imparts some sort of flexibility to the structure as evident from the above graphs; thus the global ductility increases slightly.

- **Results Based on Vulnerability Index**

From disaster mitigation point of view, it is important to evaluate the present capacity as a preparedness strategy and deficient structures need to be retrofitted. Thus, a function may be used as a test of repair/ damage against seismic excitation.

The vulnerability index [20] may be considered as a parameter for quantification of damage (or repair effectiveness) in a structure using the results obtained from the pushover analysis. For pushover analysis, nonlinear push can be considered as the seismic excitation force, while the indication of damage is considered from formation of plastic hinges with different performance levels.

The various steps for determining vulnerability index are discussed below:

1. Pushover analysis of the considered structure is performed and the performance levels of the components at the performance point or at the point of termination of the pushover analysis is evaluated.
2. A weighted average of the different performance measures of the hinges in the different frame elements is calculated.
3. The plastic plateau (B-C as shown in **Figure 15**) in the load-deformation curve is subdivided into the performance ranges of B-IO, IO-LS, LS-CP, CP-C, D-E, and > E. From the output results of the pushover analysis, the number of hinges formed in the frame elements along with their performance ranges can be evaluated easily.
4. Each performance range is assigned a proposed value of 'weightage factor' (x_i) given below in the **Table-14**.
5. Generally it is observed that the columns are more important for structural stability and global safety than that of beam members. So, an additional 'importance factor' of 1.5 is assigned in case of columns.
6. Finally, the structural vulnerability index VI_{str} is calculated using the following formula:

$$VI_{str} = \frac{1.5\sum N_i^c x_i + \sum N_i^h x_i}{\sum N_i^c + \sum N_i^h} \quad (1)$$

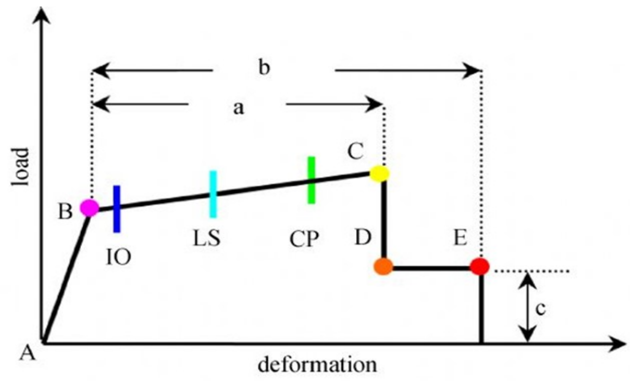


Fig. 9. Idealized load deformation curve and various structural performance levels

Table-14. Weightage Factors for Different Performance Ranges

Serial Number	Performance Range (i)		Weightage Factor (x_i)
	From	To	
1	<B		0.000
2	B	IO	0.125
3	IO	LS	0.375
4	LS	CP	0.625
5	CP	C	0.875
6	C	D	1.000
7	D	E	1.000
8	>E		1.000

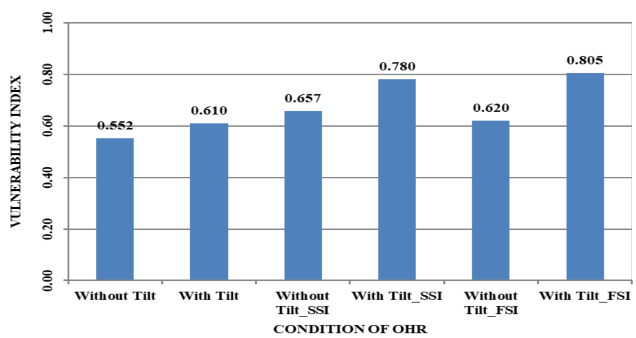


Fig. 10. Comparison of vulnerability index for various conditions of OHR

The vulnerability indices of the structures increase significantly due to tilt, which is further increased as soil structure interaction and fluid structure interaction are considered. It indicates that vulnerability during earthquake are greater & repair feasibility after earthquake are lesser as the OHR structures get tilted, and the scenario gets worse when the soil structure interaction and fluid structure interaction comes into play. This further justifies the need to consider soil structure interaction and fluid structure interaction during numerical analysis of the tilted OHRs to assess their stability.

5. Conclusions

Tilt and settlement of Reinforced Concrete structures including Over Head Reservoirs with foundations supported on alluvial soil is a frequent problem with respect to the stability of the concerned structure. The present study is based on the numerical analysis of a real life RCC OHR supported on frame staging systems subjected to tilt. Based on the numerical study the following conclusions may be drawn.

1. The tilt has significant effect on the overall structural stability of the OHR. The reinforcement demand increases with the tilt.
2. The crown top lateral displacements and fundamental period of vibration also increase with the tilt.
3. These increases in reinforcement demand, lateral displacements and also developed higher reaction forces due to the tilt indicate threat to the overall structural stability of the OHR, which may result in distress.
4. The increase in flexibility of the OHR due to the tilt has an effect on the serviceability aspect of the OHR due to the increasing seismic responses.
5. The base shear capacity of the OHR at performance point decreases with the tilt indicating greater vulnerability against earthquake load.
6. These adverse effects due to the tilt further gets aggravated considering Fluid Structure Interaction of the OHR to an extent.
7. There is a greater effect of the tilt is observed when the Soil Structure Interaction is duly considered for soft soil.

Thus, the detail numerical analysis of the tilted RCC OHR seems to be significant for the overall stability of the structure. The proposed study may subsequently be extended to evaluate the efficiency and feasibility of the various retrofit schemes for the safety of the OHR.

Disclosures

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References

1. Acharjee D, Basu DJ, Sing D, Bandyopadhyay D. Stability Assessment of Tilted G+4 RCC Buildings Located at Different Seismic Zones: A Parametric Study. Proceedings of International Conference on Sustainable Environment & Civil Engineering (ICSECE'21), 2021; ISBN: 978-93-5351-791-5: 76.
2. Acharjee D, Sing D, Bandyopadhyay D. Numerical Study on Effect of Seismic Load on The Stability of Tilted RCC Building. Proceedings of First National Conference on Sustainable Innovative Trends in Civil Engineering (SITCE 2021), 2021; ISBN: 978-81-9270-510-1: 167-173.
3. ATC-40: (Volume 1): Seismic Evaluation and Retrofit of Concrete Buildings, Third Revision, 1996; Applied Technology Council, 555 Twin Dolphin Drive, Suite 550 Redwood City, California 94065.
4. ATC-55: (Volume 1): Evaluation and Improvement of Inelastic Seismic Analysis Procedures, Third Revision, 2005; Applied Technology Council, 555 Twin Dolphin Drive, Suite 550 Redwood City, California 94065.
5. Bjerrum L. Relation between Obstressed and calculated Settlement of Structures in Clay and sand. Norwegian Geotechnical Bulletin, 1969.
6. FEMA 273: NEHRP Guidelines for the seismic Rehabilitation of Buildings, 1997; Federal Emergency Management Agency, Washington, D.C.
7. FEMA 365: Pre standard and Commentary for the Seismic Rehabilitation of Buildings, 2000; Federal Emergency Management Agency, Washington, D.C.
8. FEMA 440: Improvement of Nonlinear Static Seismic Analysis Procedures, 2005; Federal Emergency Management Agency, Washington, D.C.
9. IITK-GSDMA Guidelines for Seismic Design of Liquid Storage Tanks, 2007; National Information Center of Earthquake Engineering.
10. IS 456:2000: Plain and Reinforced Concrete - Code of Practice, Fourth Revision, 2000; Bureau of Indian Standards, Manak Bhavan-9 Bahadur Shah Zafar Marg, New Delhi-110002.
11. IS 875 (Part 1): Code of Practice for Design Loads (Other than Earthquake) For Buildings and Structures. Part 1: Dead Loads-Unit Weights of Building Materials and Stored Materials, Second Revision, 1987; Bureau of Indian Standards, Manak Bhavan-9 Bahadur Shah Zafar Marg, New Delhi-110002.
12. IS 875 (Part 2): Code of Practice for Design Loads (Other than Earthquake) For Buildings and Structures. Part 2: Imposed Loads, Second Revision, 1987; Bureau of Indian Standards, Manak Bhavan-9 Bahadur Shah Zafar Marg, New Delhi-110002.
13. IS 875 (Part 3): Code of Practice for Design Loads (Other than Earthquake) For Buildings and Structures. Part 3: Wind Loads, Third Revision, 2015; Bureau of Indian Standards, Manak Bhavan-9 Bahadur Shah Zafar Marg, New Delhi-110002.
14. IS 1893 (Part 2): Criteria for Earthquake Resistance design of Structures, Part-II Liquid Retaining Tanks, 2014; Bureau of Indian Standards, Manak Bhavan-9 Bahadur Shah Zafar Marg, New Delhi-110002.

15. IS 1904: Code of Practice for Design and Construction of Foundations in Soils: General Requirements, Third Revision, 1986; Bureau of Indian Standards, Manak Bhavan-9 Bahadur Shah Zafar Marg, New Delhi-110002.

16. IS 11682: Criteria for Design of RCC Staging for Overhead Water Tanks, 1985; Bureau of Indian Standards, Manak Bhavan-9 Bahadur Shah Zafar Marg, New Delhi-110002.

17. Lakhade SA, Kumar R, and Jaiswal OR. Estimation of drift limits for different seismic damage states of RC frame staging in elevated water tanks using Park and Ang damage index. Journal of Earthquake Engineering and Engineering Vibration, 2020; 19: 161-177.

18. Lakshmanan N. Seismic Evaluation and Retrofitting of buildings and Structures. ISET Journal of Earthquake Technology, 2006; Paper No. 469, 26th ISET Annual Lecture.

19. Mellati A. Predicting Dynamic Capacity Curve of Elevated Water Tanks: A Pushover Procedure. Civil Engineering Journal, 2018; Vol. 4, No. 11: 2513-2528.

20. SAP 2000 v 21.2.0: Integrated Software for Structural Analysis and Design, Computers and Structures, Inc. Structural and Earthquake Engineering Software.