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SEISMIC VULNERABILITY ASSESSMENT OF COLD STORAGE FACILITIES: A STRUCTURAL ENGINEERING PERSPECTIVE

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ABSTRACT

Cold storage facilities are critical infrastructures designed to preserve perishable goods such as food, pharmaceuticals, and chemicals. These facilities operate under stringent environmental conditions, maintaining low temperatures (typically between -18°C to +4°C) and high humidity levels (85-95% RH). Given their importance in the supply chain, ensuring the structural integrity of cold storage facilities, especially in seismically active regions, is paramount. This study focuses on the seismic vulnerability assessment of a cold storage facility located in Seismic Zone V, as per the Indian Standard IS 1893:2016. The analysis is conducted using ETABS (Extended Three-Dimensional Analysis of Building Systems), a state-of-the-art structural analysis software, to evaluate the facility's response to seismic forces. Key structural parameters such as maximum story displacement, story drift, story shears, and overturning moments are analysed to assess the facility's performance under seismic loads. The results indicate that the structure performs within acceptable limits, with displacements and drifts conforming to Indian standards. This study provides critical insights for structural engineers and designers involved in the construction of cold storage facilities in earthquake-prone regions, ensuring both safety and operational continuity.

INTRODUCTION

Cold Storage Facilities

Cold storage facilities are specialized structures designed to maintain low temperatures and high humidity levels to preserve perishable goods. These facilities are integral to industries such as food processing, pharmaceuticals, and chemicals, where temperature control is crucial for product quality and safety. The construction of cold storage facilities involves unique challenges, including the use of thermal insulation materials like polyurethane foam (PUF) and prefabricated panels to minimize heat transfer. Additionally, the structural design must account for heavy loads from storage racks, forklifts, and trucks, as well as environmental loads such as snow and wind. Given the critical nature of these facilities, any structural failure, especially in seismically active regions, could lead to significant economic losses and pose risks to human safety. Therefore, a thorough seismic vulnerability assessment is essential to ensure the resilience of cold storage facilities.

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Seismic Analysis

Seismic analysis is a fundamental aspect of structural engineering, particularly in regions prone to earthquakes. The analysis involves evaluating the response of a structure to seismic forces, which can cause significant damage if not properly accounted for in the design. The Indian Standard IS 1893:2016 provides comprehensive guidelines for seismic design, including the classification of seismic zones, importance factors, and response reduction factors. In this study, the cold storage facility is located in Seismic Zone V, which is characterized by high seismic activity. The importance factor of 1.5 reflects the critical nature of the facility, while the response reduction factor of 5.0 indicates the use of a Special Moment Resisting Frame (SMRF) system, which is designed to absorb and dissipate seismic energy effectively.

ETABS

ETABS (Extended Three-Dimensional Analysis of Building Systems) is a widely used software tool for the analysis and design of multi-story buildings. It offers advanced capabilities for modelling complex structures, applying various loads, and evaluating the structural response under different conditions.

ETABS is particularly useful for seismic analysis, as it allows engineers to simulate the behaviour of structures under earthquake loads accurately. The software's ability to handle three-dimensional models, coupled with its user-friendly interface, makes it an ideal choice for assessing the seismic vulnerability of cold storage facilities. In this study, ETABS is used to model the cold storage facility, apply seismic loads, and analyse key structural parameters such as displacement, drift, shear forces, and overturning moments.

Objectives

The primary objectives of this study are:

a. To assess the seismic vulnerability of a cold storage facility located in Seismic Zone V as per IS 1893:2016.

b. To evaluate the structural response of the facility under seismic loads using ETABS.

c. To analyse key parameters such as maximum story displacement, story drift, story shears, and overturning moments.

LITERATURE REVIEW

a. Capacity Based Design of Cold Formed Storage Rack Structures Under Seismic Load For Rigid and Semi Rigid Connections by K.M.Bajoria and K.K. Sangle

b. Great differences in member geometry and in connection systems. In the pallet rack system, bracing systems are generally placed only in the cross-aisle direction. Therefore, design of pallet racks is quite complex. The capacity design based on deterministic allocation of strength and ductility in the structural elements for successful response and collapse prevention during a catastrophic earthquake by rationally choosing the successive regions of energy dissipation so that pre-decided energy dissipation mechanism would hold throughout the seismic action. The most accurate method of seismic demand prediction and performance evaluation of structures is nonlinear time history analysis

c. Seismic Analysis of Liquid Storage Tanks by Syed Saif Uddin Liquid storage tanks are used in industries for storing chemicals, petroleum products, and for storing water in public water distribution systems. Behaviour of liquid storage tanks under earthquake loads has been studied as per Draft code Part II of IS 1893:2002. A FEM based computer software used (SAP 2000) for seismic analysis of tanks which gives the earthquake induced forces on tank systems. Indian seismic code IS 1893:1984 had some very limited provisions on seismic design of elevated tanks. This code did not cover ground-supported tanks. Draft code Part II of IS 1893:2002 which will contain provisions for all types of liquid storage tanks. Dynamic analysis of liquid containing tank is a complex problem involving fluid-structure interaction. Under earthquake loads, a complicated pattern of stresses is generated in the tanks. Poorly designed tanks have leaked, buckled or even collapsed during earthquakes. Common modes of failure are wall buckling, sloshing damage to roof, inlet/outlet pipe breaks and implosion due to rapid loss of contents.

d. Pushover Analysis for Cold Formed Storage Rack Structures by Sreedhar Kalavagunta, Sivakumar Naganathan and Kamal NasharuddinBin Mustapha This study investigated the progressive collapse of cold formed storage rack structures subjected to seismic loading, using pushover analysis. A simple storage rack cold formed steel structure was analyzed with static, non-linear procedure in accordance with FEMA 356 specifications and progressive collapse recorded such as occupancy, immediate occupancy, life safety and collapse prevention. Pushover analysis was found to be a useful analysis tool for the conventional storage racking systems giving good estimates of the overall displacement demands, base shears and plastic hinge formation.

e. Seismic Analysis of High-Rise Building with Flat Slab Using ETABS by Manish Agrawal, Dinesh Sen. In today's modern construction procedure of high-rise building, flat slab is one of the important uses in modern structures because it increases the number of floors as compared to conventional method of construction. With high-rise structures, it will not be only having to take up gravity loads, but as well as lateral forces. Many important Indian cities fall under high seismic zones hence strengthening of buildings for lateral forces is a stipulation. In this study the aim is to analysis the response of a high-rise structure to ground motion using Response Spectrum Analysis as per IS code 1893 (Part 1):2016. Different models such as purely flat slab building, flat slab building with drop panel, flat slab building with perimeter beam and flat slab building with shear wall are consider in ETABS and change in the time period, stiffness, base shear, storey drifts and top-storey deflection of the building is observed and compared.

f. Seismic Analysis of Flat Slab Structure Using ETABS Software by Rajat Mahobe, R.K. Grover

Civil Engineers are facing a great challenge in structural designing. The design must fulfil various parameters which include economical structure, durability and serviceability. But taking these points in mind it becomes very difficult for an Engineer to fulfil all these requirements at a time when a design is performed manually. This digital tool used in civil engineering and comparing their results by taking in mind the requirements of the above points. In this research process a building is taken for analysis and design on well-known Software ETABS.

Due to the freedom of space design, quicker construction time, architectural functionality, and economic factors, flat-slab building designs have significant advantages over typical slab-beam-column systems. The lack of deep beams and shear walls makes flat-slab structural systems far more flexible for lateral stresses than standard RC frame systems, which increases the system's susceptibility to seismic occurrences. The critical moment in design of these systems is the slab-column connection, i.e., the shear force in the slab at the connection, which should retain its bearing capacity

even at maximal displacements.

Research Gap and Scope of current study

The existing literature extensively covers seismic analysis of various structural systems, such as storage racks, liquid storage tanks, and high-rise buildings, but there is a noticeable gap in research specifically addressing cold storage facilities. These facilities have unique structural and environmental requirements, including thermal insulation, low-temperature operation, and high humidity levels, which are not adequately explored in current studies. Additionally, while flat slab systems are widely used in modern construction, their application in cold storage facilities, particularly in high seismic zones, remains under-researched. Advanced seismic analysis techniques, such as nonlinear time history analysis and pushover analysis, have not been extensively applied to cold storage facilities. Furthermore, Indian seismic codes lack specific guidelines for the seismic design of cold storage facilities, leaving a critical gap in ensuring their safety and resilience in earthquake-prone regions.

The current study aims to address these gaps by conducting a comprehensive seismic vulnerability assessment of a cold storage facility located in Seismic Zone V as per IS 1893:2016. Using ETABS, the study evaluates the facility's response to seismic loads, focusing on key parameters such as maximum story displacement, story drift, story shears, and overturning moments. The research also explores the performance of flat slab systems in cold storage facilities, considering their unique structural and environmental requirements. By applying advanced analysis techniques and comparing the results with Indian standards, this study provides valuable insights for the design and construction of cold storage facilities in seismically active regions, ensuring their safety and operational continuity.

METHODOLOGY

Modelling Process in ETABS

The seismic vulnerability assessment of the cold storage facility was conducted using ETABS, following a detailed modelling process:

a. Geometry Definition:

- The cold storage facility was modelled as a two-story structure with a flat slab and column drop system. The slab thickness was defined as 200 mm, while the column size was set to 450 mm x 450 mm. The column drop panel size was 2 m x 2 m, with a thickness of 300 mm.
- The support conditions were set as fixed to simulate the actual foundation behaviour.

b. Material Properties:

- The concrete grade used was M-30, with a density of 25 kN/m³, as per IS 456:2000.
- The steel grade was Fe 500, with a density of 78.5 kN/m³, in accordance with IS 800:2007.

c. Load Application:

- Dead loads were applied as self-weight, while live loads were set at 7 kN/m², as per IS 875:1987.
- Snow loads of 1.5 kN/m² and wind loads of 50 m/s (Zone IV) were also applied.
- Seismic loads were applied based on IS 1893:2016, considering the facility's location in Seismic Zone V, an importance factor of 1.5, and a response reduction factor of 5.0 (SMRF).

d. Analysis Setup:

- The analysis was conducted using the response spectrum method, which is widely used for seismic analysis. The soil type was defined as Type I (Hard Soil), and a damping ratio of 5% was applied.
- The model was analysed for both X and Y directions to evaluate the structure's response to seismic forces.

e. Results Extraction:

- Key parameters such as maximum story displacement, story drift, story shears, and overturning moments were extracted from the analysis results.
- The results were compared against Indian standards to assess the structure's performance under seismic loads.

Structural Details

The structural details of the cold storage facility are summarized in the table below:

Table 1. Structural Parameters

Sl. No.	Parameters	Values	Remarks
01	Seismic Zone	Zone V (0.36)	IS 1893:016
02	Importance Factor (I)	1.5	
03	Response Reduction Factor (R)	5.0 (SMRF)	
04	Soil Type	Type I (Hard Soil)	
05	Damping Ratio	5%	
06	Concrete Grade	M – 30	IS 456:2000
07	Concrete Density	25 kN/m33	
08	Steel Grade	Fe 500	IS 800:2007
09	Steel Density	78.5 kN/m33	
10	Dead Load	Self-Weight	IS 875:1987
11	Live Load	7 kN/m22	
12	Snow Load	1.5 kN/m22	
13	Wind Load	50 m/s (Zone IV)	
14	Insulation Thickness Polyurethane Foam (PUF) Polystyrene	100 – 150 mm 150 – 200 mm	For -20C to +4C

Table 1. Structural Parameters			
Sl. No.	**Parameters**	**Values**	**Remarks**
15	Cladding Material Prefabricated PUF Panel	50 – 100 mm	
16	Internal Storage	-18C to +4C	
17	Humidity Levels	85 – 95% RH	
18	Forklifts Load Wheel Load	2 – 5 Tons 10 – 20 kN per Wheel	
19	Trucks Load Axle Load	10 – 20 Tons 80 – 120 kN per Axle	
20	Software used	ETABS	
21	Type of Structure	Flat Slab with Column Drop	
22	Slab Thickness	200 mm	
23	Column Size	450 mm X 450 mm	
24	Column Drop Panel Size	2 m X 2 m	
25	Drop Panel Thickness	300 mm X 300 mm	
26	Support Condition	Fixed	

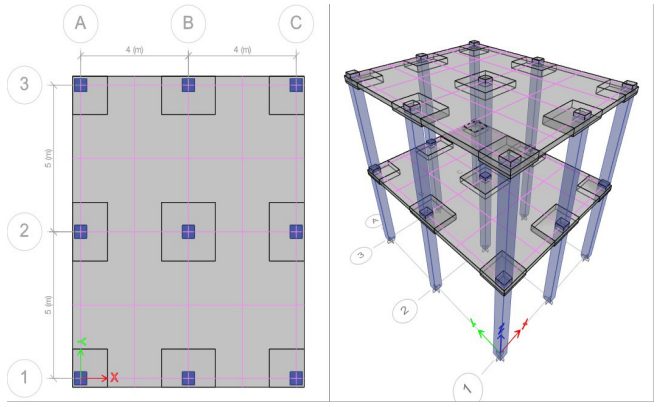

Fig. 1. 2D and 3D Model of proposed Cold Storage Facility

RESULTS AND DISCUSSIONS

Maximum Story Displacement

Table 2. Maximum Story Displacement		
Story	Maximum Story Displacement for	
	Earthquake Load in X - Direction (mm)	Earthquake Load in Y - Direction (mm)
Story 2	39.874	43.561
Story 1	22.585	23.994

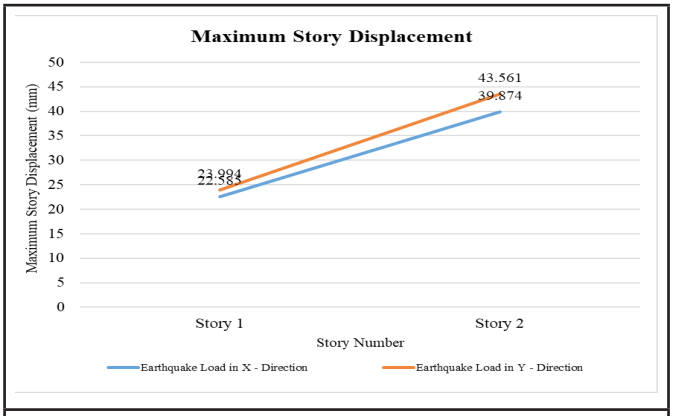

Fig. 2. Maximum Story Displacement

The maximum story displacement was analysed in both the X and Y directions. The results indicate that the displacement is within acceptable limits as per Indian standards. The maximum displacement in the X-direction was 38.874 mm at the top of Story 2, while in the Y-direction, it was 43.561 mm at the same location.

Maximum Story Drift

Table 3. Maximum Story Drift		
Story	Maximum Story Drift for	
	Earthquake Load in X - Direction	Earthquake Load in Y - Direction
Story 2	0.003458	0.003914
Story 1	0.004517	0.004799

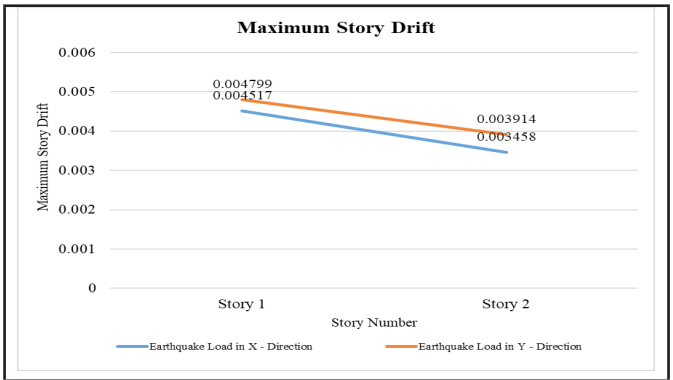

Fig. 3. Maximum Story Drift

The story drift was also evaluated, with the maximum drift observed in the X-direction being 0.004517 at Story 1. In the Y-direction, the maximum drift was 0.004799 at Story 1. These values are within the permissible limits, indicating that the structure is stable under seismic loads.

Story Shears

Table 4. Maximum Story Shears		
Story	Maximum Story Shears for	
	Earthquake Load in X – Direction (kN)	Earthquake Load in Y – Direction (kN)
Story 2	-525.5143	-519.5881
Story 1	-957.9242	-950.2393

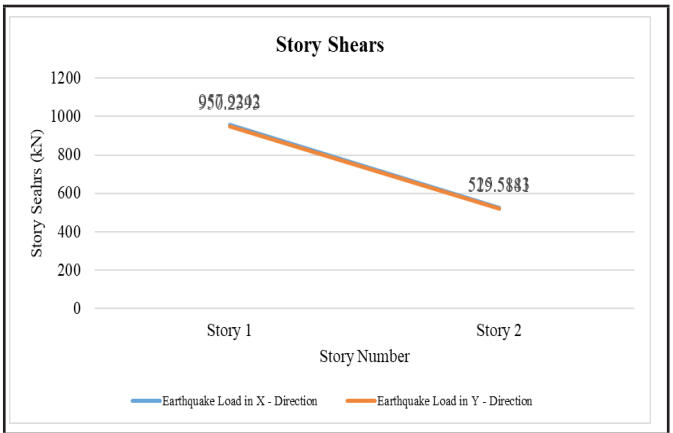

Fig 4: Maximum Story Shears

The story shears were analysed, with the maximum shear force in the X-direction being -957.9242 kN at Story 1. In the Y-direction, the maximum shear force was -950.2393 kN at Story 1. These values are consistent with the expected behaviour of the structure under seismic loads.

Story Overturning Moments

Table 5. Story Overturning Moments

Story	Maximum Story Shears for	
	Earthquake Load in X – Direction (kN-m)	Earthquake Load in Y – Direction (kN-m)
Story 2	0	0
Story 1	2627.5716	2597.9404
Base	7417.1928	7349.1368

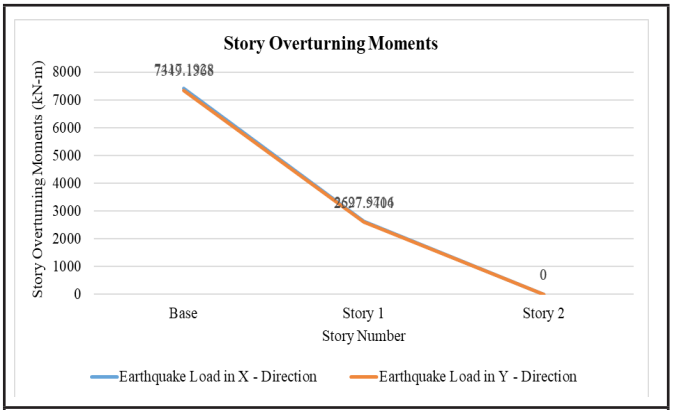

Fig. 5. Story Overturning Moments

The overturning moments were also evaluated, with the structure showing adequate resistance to overturning in both the X and Y directions. The results indicate that the structure is capable of withstanding seismic forces without significant risk of overturning.

CONCLUSIONS

The seismic vulnerability assessment of the cold storage facility indicates that the structure performs well under seismic loads. The maximum story displacement, story drift, story shears, and overturning moments are all within acceptable limits as per Indian standards. The use of ETABS for the analysis provided accurate and reliable results, demonstrating the effectiveness of the software in evaluating the seismic response of complex structures. This study provides valuable insights for the design and construction of cold storage facilities in seismically active regions, ensuring their safety and functionality.

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