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PERFORMANCE ANALYSIS OF TUNED LIQUID DAMPED STRUCTURES FOR BETTER EARTHQUAKE RESISTANCE

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Abstract : Tuned liquid dampers (TLDs) have been used as passive or semi-active control devices in a wide range of applications, such as tall buildings and high-rise structures. TLDs are passive energy absorbing devices that have been suggested for controlling vibrations of structures under different dynamic loading conditions. This paper is focused on the study of an earthquake protection system, the tuned liquid damper (TLD), which can, if adequately designed, reduce earthquake demands on buildings. A series of experimental tests have been conducted on a scaled model of structure tuned liquid damper systems to evaluate their performance under harmonic excitation. It has been found that with the help of TLD one can resist the structure from lateral failure by 37.4 % which is necessary for the structure to be in its permissible limit.

Keywords **- tuned liquid damper, Building Design, Seismic Zone. earthquakes**

INTRODUCTION:

The seismic waves cause the shaking of the ground surface; where this ground shaking is the most crucial concern for the structural engineers. By using these data they can construct new structures which can be resisted against earthquakes. Although, the main data sources to estimate the ground shaking or the seismic level at a specific location; is taken from previous geological and historical records. The main difference between the structural and earthquake response considering the loadings is that the structural response is static and earthquake response is dynamic [1]. The earthquake response in the structure is considered above ground level, and the forces are generated by the inertia of buildings when they respond to earthquake induced ground shaking. Moreover, in designing, the structure's response against earthquake is predicted from a design spectrum; which is specified in EC8:1[2], and the first step of creating a design response spectrum is to determine the maximum response of the structure to a specific ground motion. Normally, this first step is prepared from the seismologists and geotechnical engineers where they are presenting a response spectrum such as displacement, acceleration or velocity against the response period [1]. The role of earthquake resistant design is to prevent buildings from collapse during an earthquake event, and minimizing the injuries to people. The seismicity differs from place to place due to the morphology of ground; thus, low seismicity has less effect on injuries and collapse of structures. Furthermore, in earthquake design the structure is permitted to undergo beyond the elastic limit which is called inelastic; this is mostly common for severe earthquakes which can cause inelastic deformations and it relies on the ductility and energy dissipation capacity of the structure in order to avoid the collapse. A Multi-storey building is a three-dimensional or light weight steel building that has multiple number of storeys, containing vertical circulation by means of lift and stairs. The construction of multi-storeyed buildings is dependent on available materials, the level of construction technology and the availability of services such as elevators necessary for the use in the building. Even though in the last two decades a number of multi-storeyed buildings have been constructed in India, the tall building technology is at its infancy in India, particularly in structural steel.

Gravity/Dead loads are due the weight of every element within the structure and live loads that are acting on the structure when in service constitute gravity loads. The dead loads are calculated from the member sizes and estimated material densities. Live loads prescribed by codes are empirical and conservative based on experience and accepted practice. Reduction in imposed load may be made in designing columns, load bearing walls etc., if there is no specific load like plant or machinery on the floor. This is allowed to account for improbability of total loading being applied over larger areas. The wind loading is the most important factor that determines the design of tall buildings over 10 storeys, where storey height approximately lies between 2.7 – 3.0 m. Buildings of up to 10 storeys, designed for gravity loading can accommodate wind loading without any additional steel for lateral system. Usually, buildings taller than 10 storeys would generally require additional steel for lateral system. This is due to the fact that wind loading on a tall building acts over a very large building surface, with greater intensity at the greater heights and with a larger moment arm about the base. Seismic motion consists of horizontal and vertical ground motions, with the vertical motion usually having a much smaller magnitude. Further, factor of safety provided against gravity loads usually can accommodate additional forces due to vertical acceleration due to earthquakes. So, the horizontal motion of the ground causes the most significant effect on the structure by shaking the foundation back and forth. The mass of building resists this motion by setting up inertia forces throughout the structure.

The inclusion of passive energy dissipation devices is seen as a cost effective way to improve protection against seismic loads. A considerable number of these devices have already been installed in structures throughout the world. In the recent years devices such as Tuned Liquid Dampers (TLD) have been receiving increasing attention as a simple but effective way of reducing building response to dynamic loads. The TLDs are essentially tanks filled with water, with depth to length ratio set that the natural frequency of the sloshing in the tank closely matches the natural frequency of the structure The vibration energy of the structure is transferred to the moving water where is dissipated reducing the structural response. These devices present a good performance for high rise tall buildings, or flexible low frequency structures.

LITERATURE REVIEW

[3] (Konar and Ghosh, 2021) Despite the proven effectiveness of tuned liquid dampers (TLDs), readily available liquid storage tanks are rarely utilized for vibration control of laterally-excited structures, as these are deep tanks with low inherent damping. Further, the fluctuation in liquid level in these tanks also causes variation in the fundamental sloshing frequency, leading to detuning. To overcome these problems, a novel TLD with floating base (TLD-FB) is proposed, in which a constant and shallow liquid level is maintained between the free liquid surface and the floating base. The liquid above the floating base acts as a conventional shallow TLD that always remains tuned to the structural frequency. The paper demonstrates how the TLD-FB can be incorporated into a water storage tank system on an example building without disturbing its functionality and achieves structural response reduction, despite water level fluctuations in the tanks.

[4] (Novo et al., 2013) This paper is focused on the study of an earthquake protection system, the tuned liquid damper (TLD), which can, if adequately designed, reduce earthquake demands on buildings. This positive effect is accomplished taking into account the oscillation of the free surface of a fluid inside a tank (sloshing). The behaviour of an isolated TLD, subjected to a sinusoidal excitation at its base, with different displacement amplitudes, was studied by finite element analysis. The efficiency of the TLD in improving the seismic response of an existing building, representative of modern architecture buildings in southern European countries was also evaluated based on linear dynamic analyses.

[5] (Vajreshwari Umachagi et al., 2013) Dampers have become more popular recently for vibration control of structures, because of their safe, effective and economical design. This paper presents an overview of literature related to the behavior of dampers on seismically affected structures. The review includes different types of dampers like metallic dampers, viscoelastic dampers, frictional dampers etc.

[6] (Shejul, 2017) an earthquake is a natural phenomenon occurring worldwide. Depending upon the intensity, it may cause damage to life and property. Continuous research is carried out to find the different methods that can provide a solution to minimize this damage. The idea of seismic response control of the structures by using overhead water tank as a passive TMD's is considered for the study. The main objective of this study is to find out response reduction of the structure subjected to different earthquake data. Analysis is carries out for six storied building with and without water tank for different water tank positions and different water levels such as empty water tank, half-filled water tank and full filled water tank. Three types of earthquake data are considered for the study namely, El-Centro, Kobe and loma prieta. For performing Time history analysis SAP 2000 software is used in this study. Results show that tuning the parameters of water tank, it can be used as passive TMD to reduce the seismic response.

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[7] (Corbi, 2006) The paper focuses on the possibility of coupling Sloshing Water Dampers with rigid blocks moving on a foundation base subject to a horizontal ground motion. One considers pure rocking of blocks, moving according to a dynamic excitation inferred by means of a shaking table facility; experimental data are derived in order to compare the dynamic response of the blocks equipped or not with the devices for various liquid levels of the tanks.

LOAD CALCULATIONS AND GEOMETRICAL FORMULATIONS

This chapter deals with loading calculation of the critical load placing over the considered building applying seismic loading and Non-linear analysis method. In this research work, we have used ETABS software which is based on the application of Finite Element Method. In this study two cases (tall steel structure with TLD & general tall steel structure) are considered for comparative analysis with same loading conditions, geometric details and same material properties.

Following loadings are adopted for analysis:-

1. **Self weight:** Self weight can be defined as the total weight of the structure as per assigned material density. It comprises of weight of beams, slab, tuned dampers and columns in the structure.
2. **Dead Load:** It is calculated as per IS-875 (Part I): 1987
   Self-weight of slab
   Floor load = (Density of concrete X Slab thickness)
   a) 25KN/m3 X 0.125m
   b) 3.125KN/ m2
   Floor finishing = 0.900 KN/ m2
   Total Weight of slab = 5.00 KN/ m2 + 0.900 KN/ m
   = 4.025KN/ m2
3. Live Load: It is calculated as per IS-875 (Part II): 1987 Live load on floors = 3KN/ m2for room
   = 4 kN/m2 for Stairs
   = 3 kN/m2 for sunken slab
   = 2 kN/m2 for open area
4. Earthquake Load: It is calculated as per IS-1893 (Part I): 2016
   a) Seismic Definition
      Earthquake zone – III &V (Z=0.16 &0.36)
      Response reduction factor – 4 for steel structure
      Importance Factor – 1.2
      Damping – 5%
      Soil Type: Medium
      Natural Time Period (Ta) - 0.075h0.75 (Ta = 2.145 sec)
      h = Height of building, in m. This excludes the basement storeys, where basement walls are connected with the ground floor deck or fitted between the building columns. But it includes the basement storeys, when they are not so connected.
   b) Seismic weight of floor = (Total Applied Dead load + 50% of Imposed load)

BOUNDARY CONDITIONS AND ANALYSIS

For comparative analysis of tall steel TLD structure and tall steel general structure we are using analysis tool ETABS software. This software is a widely used in the field of structural design and analysis. Now a day this software is very much friendly for the analysis of different type of structures and to calculate the result at every node & element wise.

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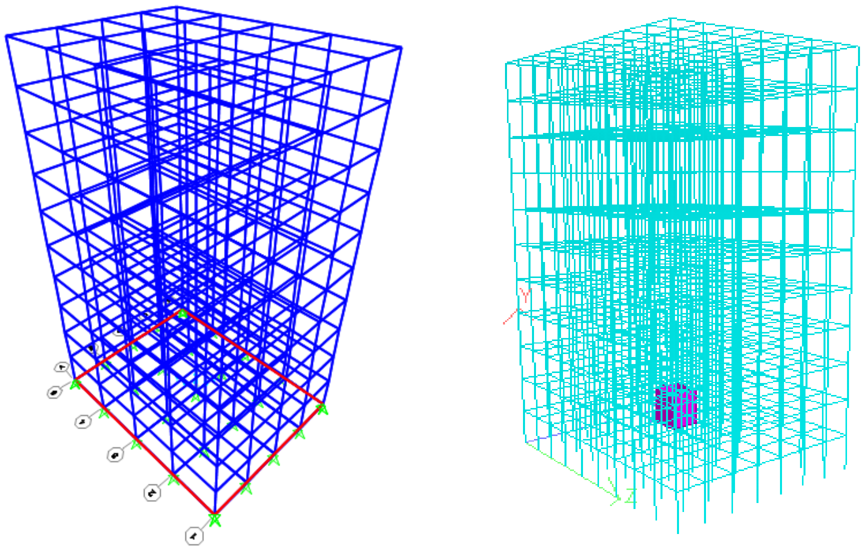

(a) (b)

Figure 1 (a) Model of the Building (b) Building with Tuned Dampe

Table 1 Geometrical Data

Plan dimension	14 x 18 m
Length (m)	14 m
Width (m)	18 m
Height each floor(m)	3.2 m
Number of floors	G+10
Tuned damper	4x4 m
Column Size	I.S.M.B.200
Beam Size	I.S.M.B.200

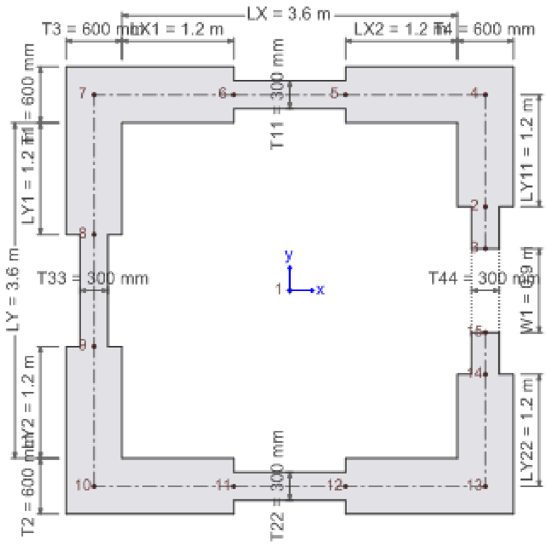

Figure 2 Assigning Tuned Dampers

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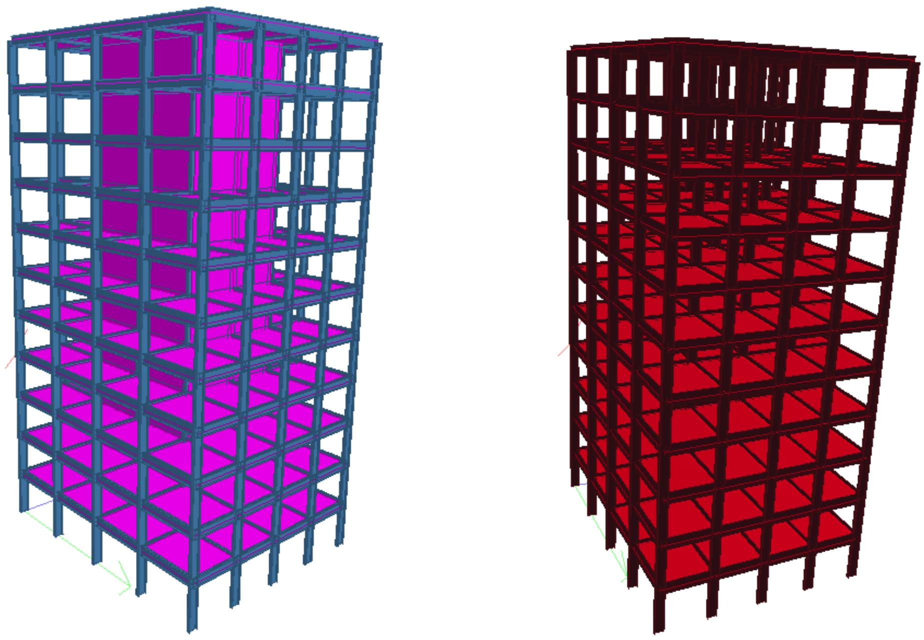
Analysis was done as per the standards of Indian provisions code, ie., IS 800:2007 for the steel design and IS 456:2000 for the concrete design. The loads assigned have been calculated above. The same structure has been analysed and compared, for seismic zone III and V, for two different cases (a) With Tuned liquid dampers, (b) General structure without any dampers.



(a) (b)

Figure 3 (a) Building with Tuned dampers (b) General Structure

RESULTS AND DISCUSSIONS

Comparison between general structure and TLD structure in Zone III & V

- Maximum Shear Force in Zone III & V
- Maximum Axial Force in Zone III & V
- Maximum Story displacement in Zone III
- Maximum Story displacement in zone V
- Plate Stresses in TLD structure
- Plate Stresses in general structure

1) Maximum Shear Force

Table 2 Maximum Shear Force

Max. Shear Force (KN)		
Zone	**General structure**	**TLD structure**
III	**490.34**	**443.2**

V	877.4	794.55

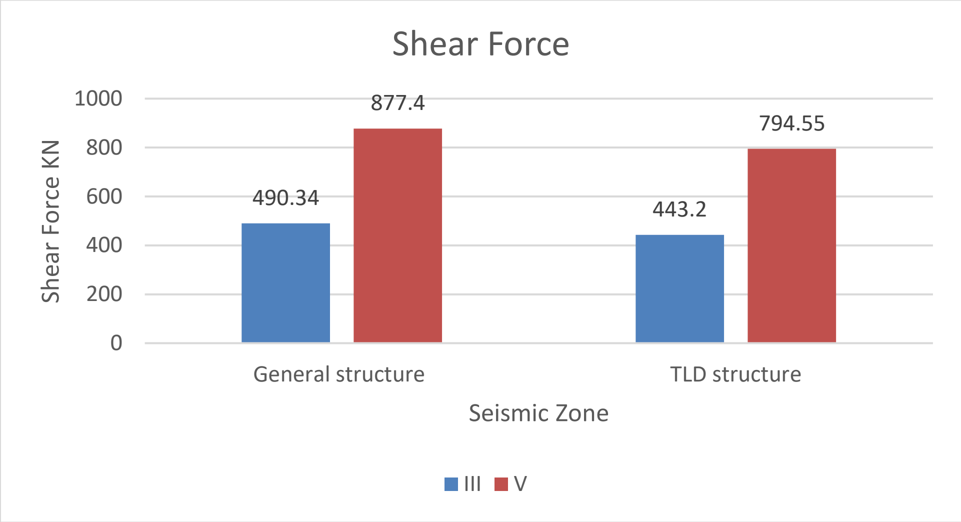


Figure 4 Max. Shear Force

Discussion:
Unbalanced forces generally develop due to rigidity in joints which cause un-proper distribution of load, In Figure 4, it has been observed that TLD steel structures are distributing lateral and vertical loads properly which cause low unbalance forces at the joints.

2) **Maximum Axial Force:**

Table 3 Max. Axial Force

Max. Axial Force (KN)		
Zone	**General structure**	**TLD structure**
III	**1076.5**	**1021.05**
V	**1013.21**	**1063.22**

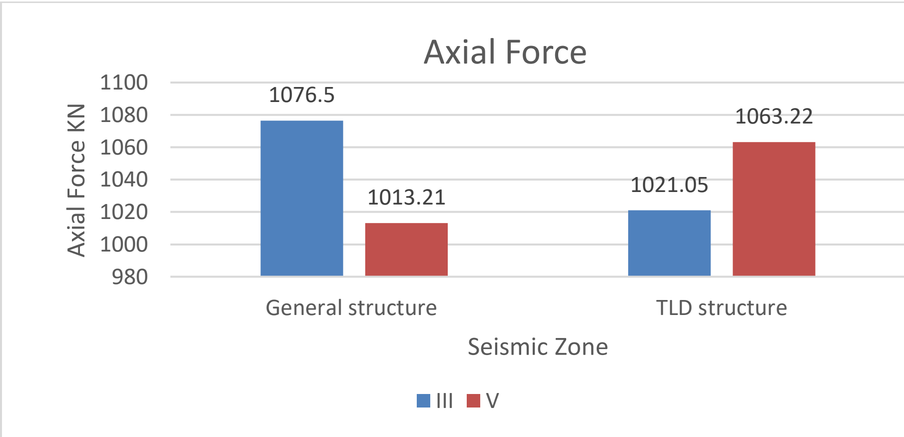


Figure 5 Max. Axial Force (KN)

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Inferences:

Axial forces are the vertical distribution of forces in column to distribute the building load to the footing, In this study ISMB 200 section is considered as structural members with the help of liquid dampers it is become more convenient for individual column to distribute the load properly to the footing.

3) Storey Displacement in Zone III

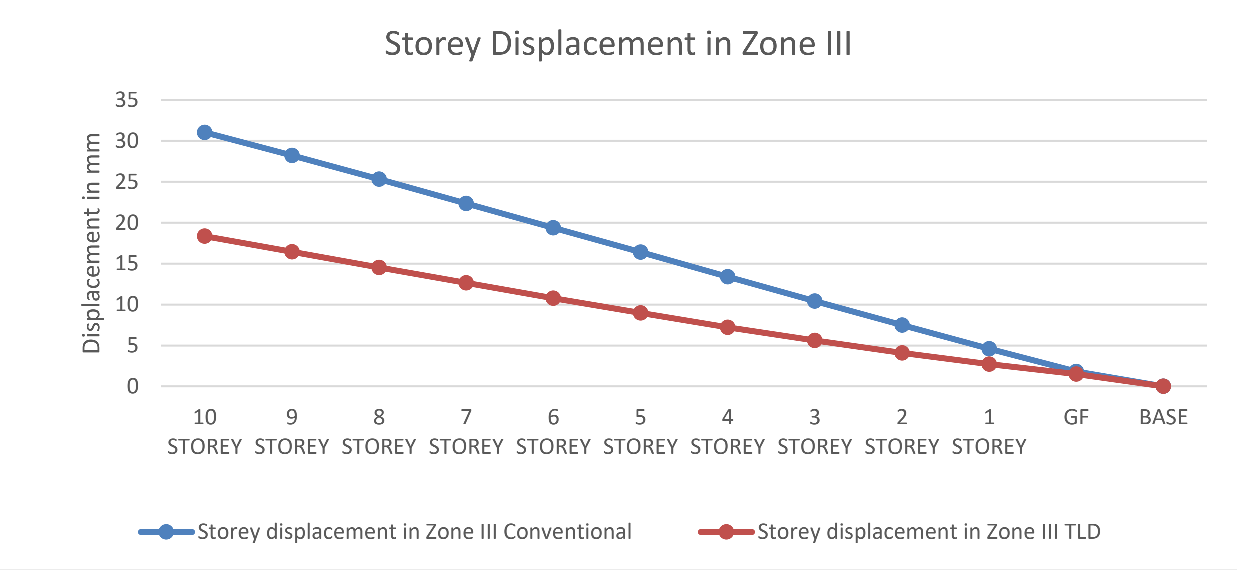

Figure 6 Storey Displacement in Zone III

Inferences:

As observed on Above Figure 6 it can be said that displacement is comparatively less in TLD steel structure due to its stiffness and stability to resist the structure in lateral pressure.

4) Max. Storey Displacement in Zone V

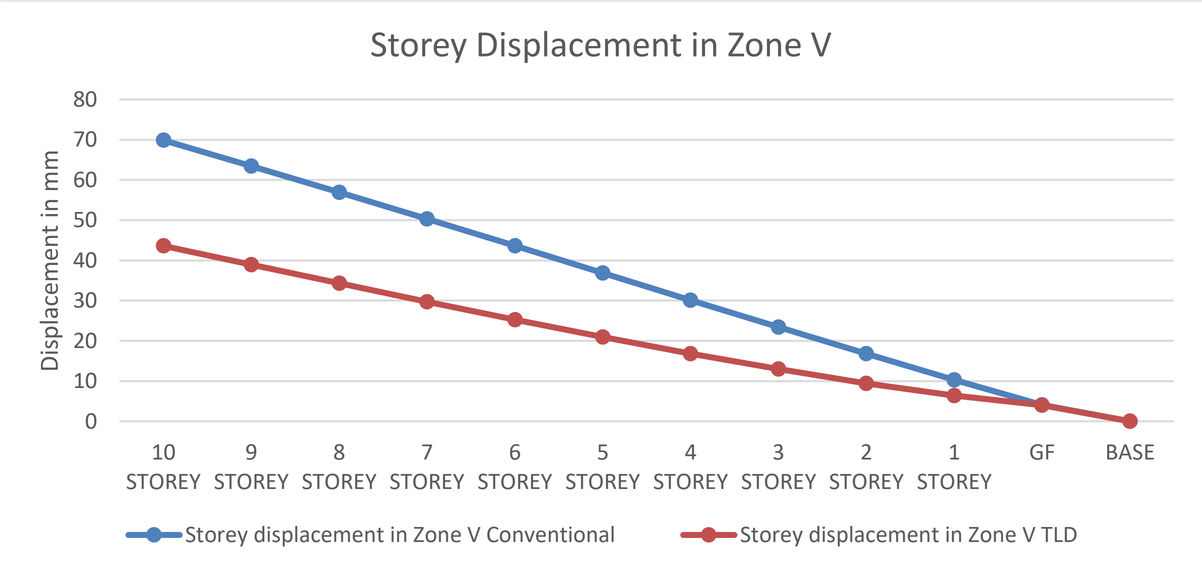

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Figure 7 Storey Displacement in zone V

Inferences:

As shown in Figure 7: It can be said that with the help of TLD one can resist the structure from lateral failure by 37.4 % which is necessary for the structure to be in its permissible limit.

5) Plate Stresses:

Table 4 For TLD Structure

Plate	SQX N/mm2	SQY N/mm2	MX kNm/m	MY kNm/m	MXY kNm/m	SX N/mm2	SY N/mm2	SXY N/mm2
1	6.45	-4.56	-380.34	-1903	1290.46	0.054	0.98	1.23
2	6.2	-2.58	-290.58	-1045.6	1589.03	-0.76	0.43	0.87
3	5.95	-0.6	-200.82	-188.29	1887.6	-1.574	-0.12	0.51
4	5.7	1.38	-111.06	669.05	2186.17	-2.388	-0.67	0.15
5	5.45	3.36	-21.3	-103.98	2484.74	-3.202	-1.22	-0.21
6	5.2	5.34	68.46	7.6	2783.31	-4.016	-1.77	-0.57
7	4.95	7.32	158.22	119.18	3081.88	-4.83	-2.32	-0.93
8	4.7	9.3	247.98	230.76	3380.45	-5.644	-2.87	2
9	4.45	11.28	337.74	342.34	3.43	-6.458	-3.42	0.027

Table 5 For General Structure

Plate	SQX N/mm2	SQY N/mm2	MX kNm/m	MY kNm/m	MXY kNm/m	SX N/mm2	SY N/mm2	SXY N/mm2
1	7.66	-5.77	-381.55	-1904.2	1289.25	-1.156	-0.23	2.44
2	7.18	-3.56	-291.56	-1046.6	1588.05	-1.74	-0.55	1.85

3	6.7	-1.35	-201.57	-189.04	1886.85	-2.324	-0.87	1.26
4	6.22	0.86	-111.58	668.53	2185.65	-2.908	-1.19	0.67
5	5.77	3.04	-21.62	-104.3	2484.42	-3.522	-1.54	0.11
6	5.65	4.89	68.01	7.15	2782.86	-4.466	-2.22	-0.12
7	5.53	6.74	157.64	118.6	3081.3	-5.41	-2.9	-0.35
8	5.41	8.59	247.27	230.05	3379.74	-6.354	-3.58	2.71
9	4.45	11.28	337.74	342.34	3.43	-6.458	-3.42	0.027

6) Cost Analysis in zone III and V

Table 6 Cost Analysis

Case	**Quantity (Kg)**	**S.O.R. Rate/Kg**	**Total Cost (Rs)**
General Structure Zone III	142800.67	48	6854432.16
TLD Structure Zone III	134220.21	48	6442570.08
General Structure Zone V	157004.00	48	7536192.00
TLD Structure Zone V	146000.54	48	7008025.92

CONCLUSION

It is concluded that TLD structures perform better than the general structures both in seismic zone III and V. The values of the Maximum Shear Force and Maximum Axial Force have been found to reduce in the case of TLD structures in the analysis. Likewise, the storey displacement is also less and the plate stresses are also low for the TLD structures. It can be said that with the help of TLD one can resist the structure from lateral failure by 37.4 % which is necessary for the structure to be in its permissible limit. Moreover,TLD structure is cost effective than general structure in both the seismic zone (III & V) with cost reduction of 8%.

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