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A Study of Regular Structures Incorporating Low-Cost Earthquake-Resisting Techniques Such as Mass Irregularity, Bracing, and Belt Walls

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ABSTRACT

This study explores the integration of low-cost earthquake-resisting techniques into regular building structures, focusing on the implementation of mass irregularity, bracing systems, and belt walls. Regular structures, while efficient in design, can be vulnerable to seismic forces, necessitating affordable and effective methods to enhance their resilience. The research investigates how introducing mass irregularity can modify the dynamic characteristics of a building, potentially reducing its susceptibility to seismic damage by altering natural frequencies and modes of vibration. Bracing systems, known for their simplicity and effectiveness, are analyzed for their ability to improve lateral stability and reduce inter-story drifts, making them a viable option for seismic reinforcement. Belt walls, which act as horizontal diaphragms, are also examined for their effectiveness in redistributing seismic forces across the structure, thus reducing localized stress concentrations and improving overall structural integrity. Through a combination of analytical modeling and comparative analysis, the study assesses the performance of these techniques in various seismic scenarios. The findings highlight the potential of these low-cost solutions to significantly enhance the earthquake resistance of regular buildings, providing valuable insights for engineers and architects working in earthquake-prone regions, particularly where budget constraints limit the use of more advanced seismic mitigation technologies. The research contributes to the development of practical, cost-effective strategies for improving the safety and resilience of regular structures in the face of seismic hazards. The study proves the idea that cheap earthquake resisting strategies can have considerable influence on seismic behavior of usual structures. Belt walls prevent lateral displacement the best, enhance storey-stiffness, and decrease bending moments and axial forces, and will play a major role in enhancing stability of the structure. Bracing systems are very useful in reducing shear and mass irregularity is efficient in countering torsion but it has more lateral movements. It goes to suggest that there is great potential in the application of low-cost means of increasing seismic resilience, in appropriately built structures that provide cost-effectiveness in terms of safer building design.

Keywords: Earthquake-Resisting Techniques, Regular Structures, Mass Irregularity, Bracing Systems, Belt Walls And Dynamic Analysis Etc.

I. INTRODUCION

Background

Earthquakes are one of the most devastating natural hazards, which cause a lot of damage to infrastructure and loss of life across the world. In seismic area, structural stability of a building during earthquakes is an important consideration of the design. The existing conventional design approaches to seismic resistance in most cases involve the use of sophisticated materials as well as highly integrated systems that are considered to be expensive such that their applications in low budget constructions, especially in developing nations may be rather impracticable. Thus, scientists and engineers are carrying out extensive studies on inexpensive but potentially efficient earthquake resisting approaches that can be implemented into normal building models without causing people much economic distress. The vital issue in the case of seismic design is the management of side area movements, torsional impacts, and inter-story movements and they are the most important parameters of seismic performance. Research (e.g. Ahmed & Tanoli, 2025; Sberna et al., 2025) points out that subpar seismic performance in the functioning Reinforced Concrete (RC) structures results in a high seismic vulnerability and expensive post-earthquake refurbishing costs. Other types of techniques that have elicited

attention are the optimization in mass distribution, bracing systems and belt walls, which are very cost effective, in addition to increasing structural stiffness and stability.

Although the methods used are individually demonstrated to be very effective, little research has been conducted to study the merged use of the methods in general buildings under the loading situation of earthquakes, particularly in the sense of economic viability. Previous research has dealt with irregular or high-rise buildings, retrofitting techniques and superior structural forms (Alt iok et al., 2025; Kumar et al., 2025), which left unanswered the question about how effective simple and regular building forms will be with low-cost strengthening methods added to them.

Irregularity in Structure

Regularity is used critically in structural engineering as it is an important parameter to calculate how a building will react to external forces that behave laterally like the ones caused by earthquakes or wind. A structure can be defined as regular when it will have a uniform and a somewhat symmetrical distribution of mass, stiffness, and geometrical extent in both elevation and the plan. Such uniformity would make the structure behave in a predictive and uniform way under dynamic loading conditions, resulting in safer as well as more economical design. In practice, however, building architectural demands, functional necessities and aesthetic demands tend to be irregular. These irregularities impose complexities in the structure behavior, especially subjected to earthquake loading hence concentrating the stresses in particular structures. This can greatly increase both the dynamic response, and an especially-sensitive structure is more susceptible to be damaged or even collapsed in case of an earthquake.

The irregularities can be either in plan (or horizontal configuration) or in elevation (or vertical profile) and are mostly linked to asymmetry in layout either due to variations in stiffness or in mass, or abrupt variations in layout geometry. Irregular buildings will have a torsion effect, stress concentration, and local failure that complicate the task of designing to resist earthquakes. Previous earthquake disasters, including the 1999 Kocaeli Earthquake (Turkey) and the 2001 Bhuj Earthquake (India), have demonstrated most of the building failures involved irregularly-designed buildings, and hence, there is a great significance to emphasize upon this aspect. Proper consideration of this aspect led to the development of particular criteria of the identification and classification of structural irregularities in various building codes (Indian Standard, ASCE 7, and Eurocode 8, among others). In these codes, the more sophisticated dynamic analysis techniques of response spectrum analysis and nonlinear time history analysis are additionally suggested in the case of a structure with irregular characteristics. Thus, knowledge of the types, causes, and implications of irregularity is critical to structural engineers in efforts to maintain safety and ability to meet seismic design specifications. It is important to have mitigation strategies in order to curb the negative effects of irregularities, examples being development of symmetry, introducing stiffness in forms of shear walls, bracings and use of belt walls or outriggers.

Low-Cost Earthquake-Resisting Techniques

Earthquake-resistant design is an important aspect of minimizing damage to a structure and the safety of people striving there during an earthquake. Nevertheless, in developing countries and rural places, the capital of expensive earthquake-resisting systems usually becomes a determining factor. To counter this, low cost earthquake resisting measures have been devised which offer a good level of performance without incurring excessive amounts of extra costs to the construction project. These solutions are mostly in enhancing ductility, strength and energy absorption capacity of structures by employing cost-effective locally available materials.

- **Structural Design and Symmetry:** One of the easiest and cheapest to apply options is to have a regular and symmetrical structural design. The irregularity in mass, stiffness or geometry frequently contributes to torsion effect and also to stress concentrations, and thus making the building susceptible. The layout of structures with even distributions of loads and rigidity in the horizontal plane and vertically reduces seismic demand with no cost.

- **Use of Lightweight Construction:** Lowering the weight of the structure lowers the seismic loads directly as they cause the structure to experience earthquake loads in direct proportion to that of the weight. Lightweight construction can be used to reduce earthquake generated forces dramatically as with lightweight hollow concrete blocks, lightweight roof framing systems made of aerated concrete blocks as well as the core of hollow blocks of concrete that are filled up with lightweight materials to reduce weight and consequently the forces induced by earthquake.
- **Bracing Systems:** Bracing systems are a facile method of increasing the lateral resists of buildings. With properly positioned steel or concrete bracings the structure will be stiffer and less prone to lateral sway in case of an earthquake. Local available steel sections can be utilized in diagonal or cross-brace components of non-structural wall, which are affordable in contrast to costly seismic isolation systems.
- **Belt Walls and Shear Walls:** A row of belt walls are incorporated at special intervals along the building height to control lateral displacement and help the building be more rigid in general. On the same note, shear walls of the reinforced concrete can be really useful when placed strategically to give an adequate resistance to horizontal forces. These walls can be incorporated in staircases or elevator shafts which means they are a cost-effective solution without involving additional space.
- **Cost-effective Isolation System with Low cost base isolation systems:** Advanced base isolation is an expensive cost but affordable systems such as the use of elastomeric pads or recycled rubber bearings can be applied on small or medium sized buildings. These minimise the transmission of seismic forces to the superstructure increasing earthquake resistance.
- **Recycled and Local Materials:** Utilization of locally available and recycled materials including fly ash concrete, bamboo and industrial waste in concrete, etc., would keep the cost down and they are as strong as other materials. The application of bamboo bracing, mud-stabilized walls, when suitably reinforced, has proven to behave well in low-rise buildings.
- **Low-cost Retrofitting Methods:** In an existing structure, low cost methods such as jacketing of columns, providing steel braces and Ferro cement overlay in walls can go a long way in enhancing seismic performance. These solutions demand very few materials and labor force but increase the earthquake resistance of the building to a great extent.

II. RESEARCH GAPS

- Combined effect of multiple irregularities under realistic seismic conditions, however, are not adequately explored by most studies as they either concentrate on plan or vertical irregularities (mass or stiffness).
- Whereas certain studies apply performance based design in retrofitting, there is no thorough provision on its implementation in the case of buildings which have severe irregularities.
- Most of the research is based on a numerical model and non-linear analysis, but experimental or shake table verification of irregular or retrofitted structure is scarce.
- New structural geometries like Y-shaped towers or sloping rests on the ground are investigated exclusively but their seismic behavior under different loads distribution and soil/structure interaction is inadequately developed.
- A similar number of papers (e.g., reliability-based retrofitting) address uncertainty in the material properties, loading, and modeling, explaining a deficiency in probabilistic seismic performance assessment.
- Whereas certain studies speak of outriggers and belt walls, the optimal location and configuration of these post buckling stiffeners and walls to a mass/stiffness irregular structure has not been extensively investigated.
- Techniques of retrofitting the buildings have not been scrutinized in regard to cost-effectiveness and strengthening resilience in a comprehensive way.
- The bracing results (X-brace, chevron, split-X) are mostly studied with respect to seismic forces, not regarding wind, earthquake, and sloping ground interaction.
- The existing screening procedures (e.g. seismic vulnerability indicators) are not accompanied by higher strengthening and expanded nonlinear analysis.
- Only a limited number of studies use actual earthquake case data (e.g., Kahramanmaraes earthquakes) and no generalisation to global irregular structures exists.

III. OBJECTIVES

- In order to examine the response of regular building structures to dynamic loading conditions by taking into consideration their intrinsic inability to resist lateral loading forces.
- To study the effect of the incorporation of irregularity in regular structures in terms of dynamic properties of the structure such as natural frequencies, mode shapes, and seismic response parameters.
- To assess how effective bracing systems are to enhance lateral stiffness, lower inter-story drifts and mitigate displacement during earthquakes.
- To evaluate the influence of the use of belt walls in the seismic performance upgrade, with particular emphasis on the role of redistribution of lateral loads and a decrease in local stress concentrations, as well as on the interrelation of the two effects.
- To achieve a comparative study between the combined and separate use of mass irregularity, bracing systems and belt walls in regular structures to identify the most efficient combination in that way of seismic resistance.

IV. METHODOLOGY

The aim of the given study is to consider the effects of low-cost earthquake resisting methods in ordinary buildings with consideration to mass irregularity, bracing, and belt walls. A normal reinforced concrete (RC) structure is taken as the basis case, which is designed as per provisions of IS 456:2000 and IS 1893:2016. The design and the analysis are performed with SAP2000 capable of providing the correct seismic performance evaluation using the Response Spectrum Method. In attainment of the research objectives, four models are developed:

(a) a control model that assumes straight structure,

(b) a model that considers mass irregularity,

(c) a model that considers bracing systems, and

(d) a model that considers belts walls.

Same loading and boundary conditions are imposed to all models, and their seismic performance is evaluated by using important parameters namely, base-shear, storey drift, inter-storey drift and time period. Comparative study of these models can bring about the weight and efficacy of every earthquake resisting method to improve the performance of the structure by seismatic loads.

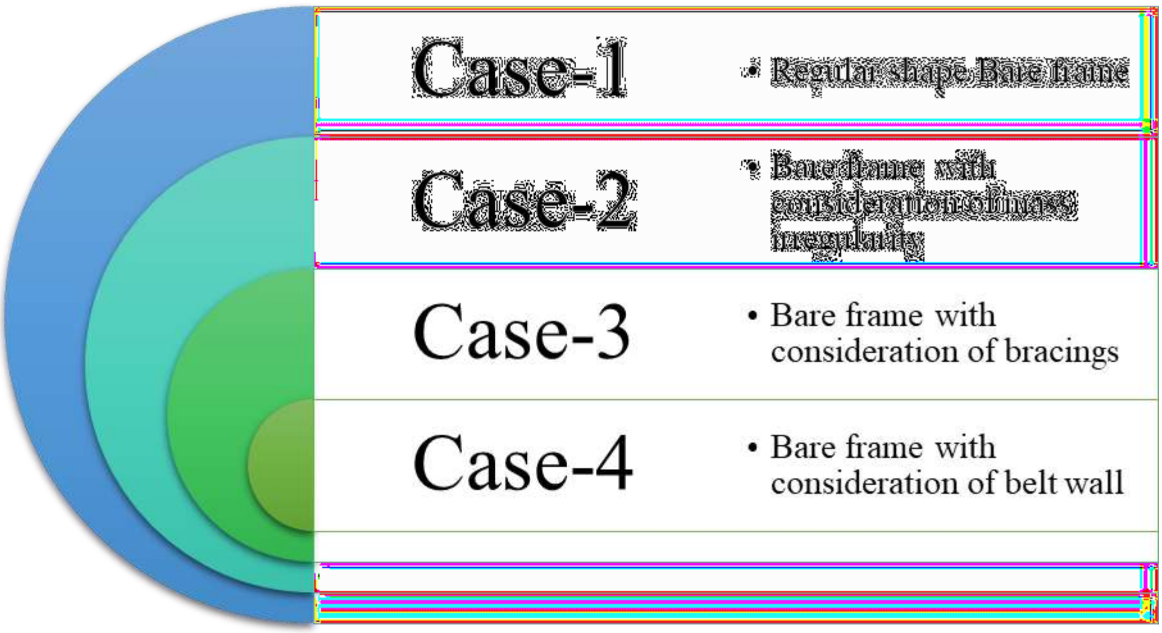

Fig 1: Research Cases

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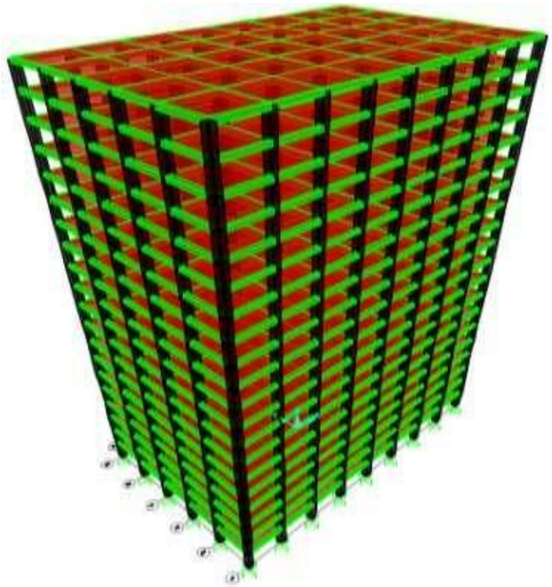

Fig 2: Case-1 Model with 3D View

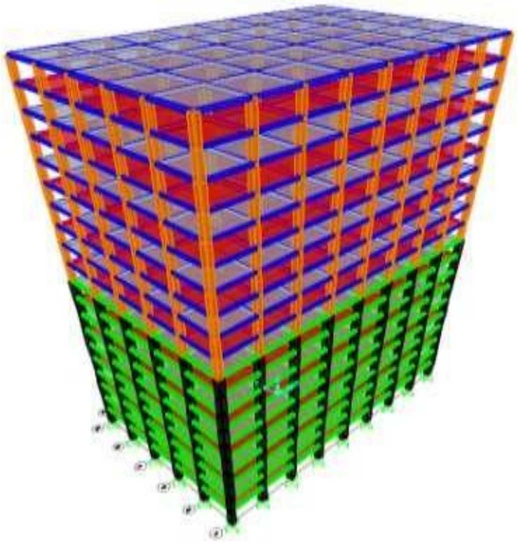

Fig 3: Case-2 Model with 3D View

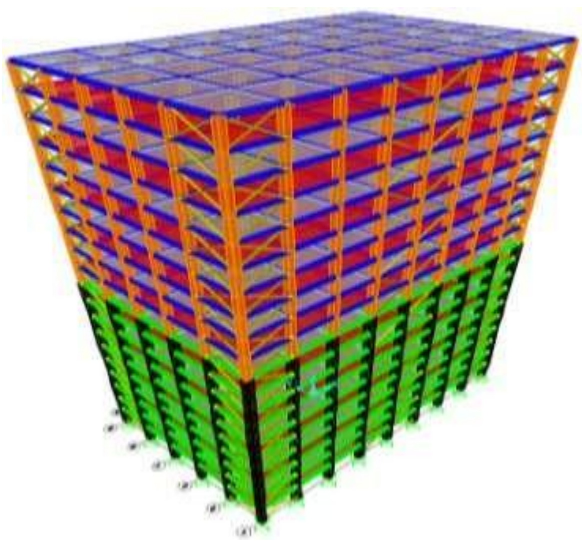

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Fig 4: Case-3 Model with 3DView

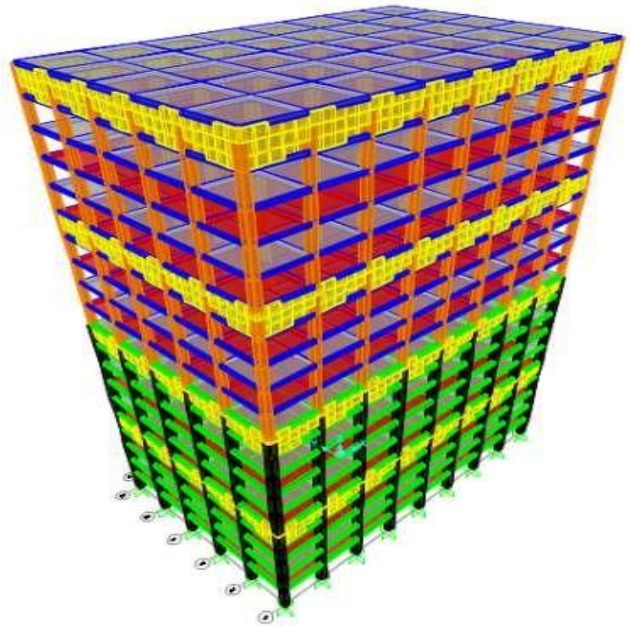

Fig 5: Case-4 Model with 3D View

V. RESULT AND DISCUSSIONA

VI. comparison graph is presented to understand how different techniques, i.e., the use of mass irregularity, belt walls, and bracing system affects the overall structural performance of the building design both in weight and lateral seismic loads.

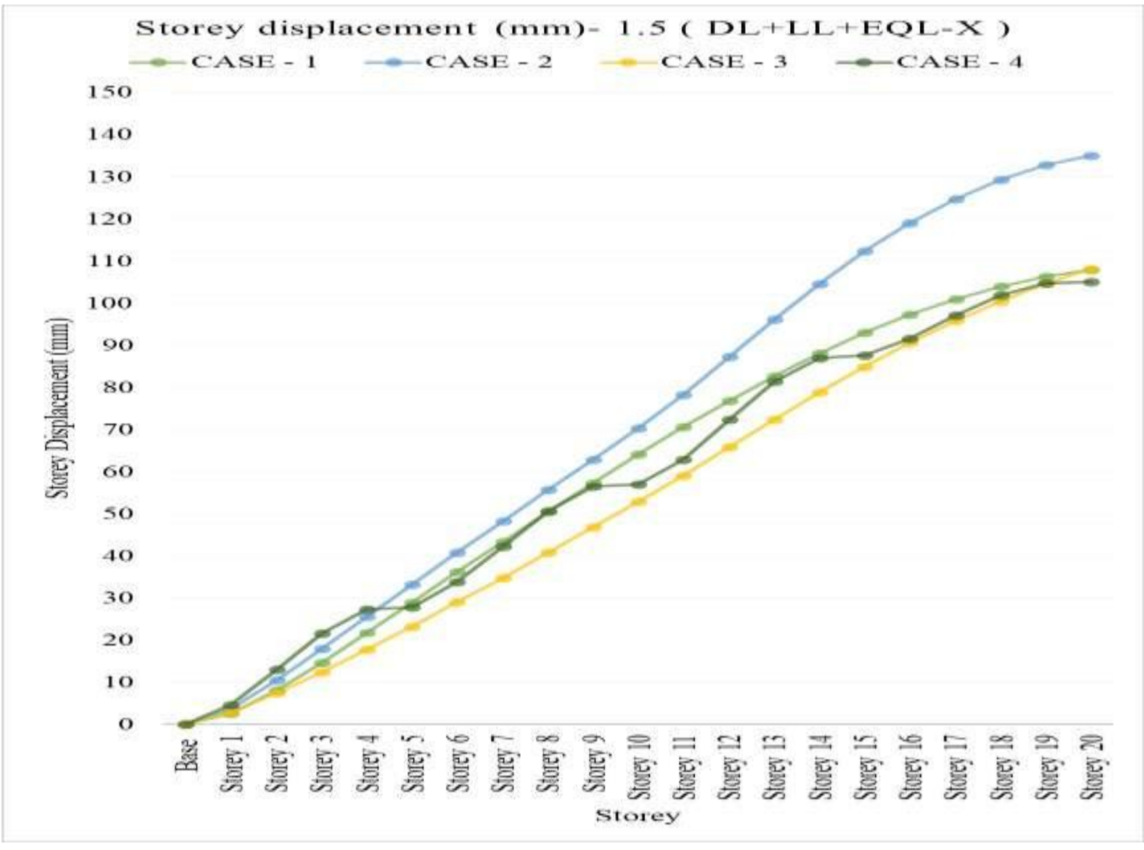

Fig 6: Storey Displacement in Various Cases of Low-Cost Earthquake-Resisting Techniques

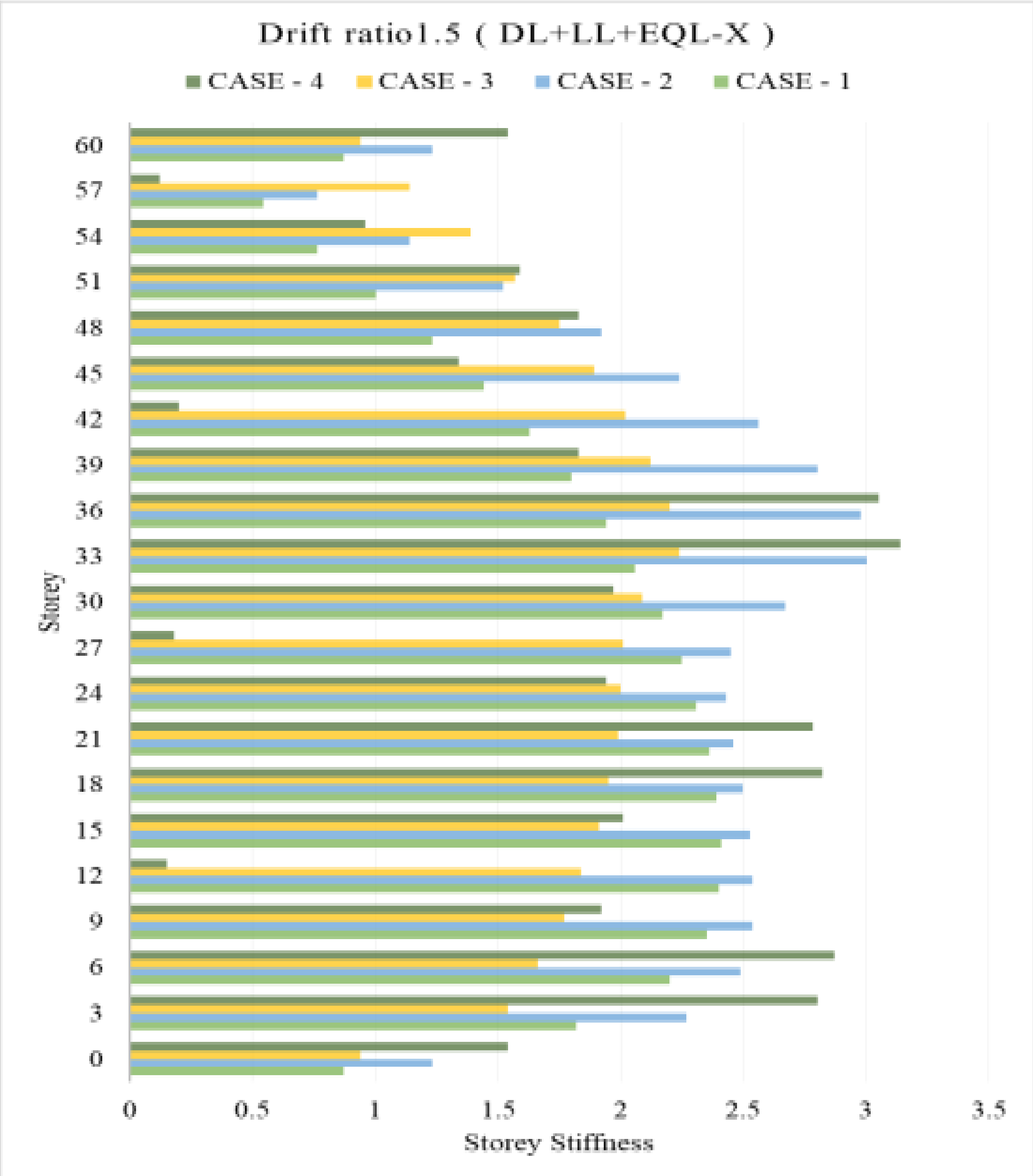

Fig 7: Drift ratio in Various Cases of Low-Cost Earthquake-Resisting Techniques

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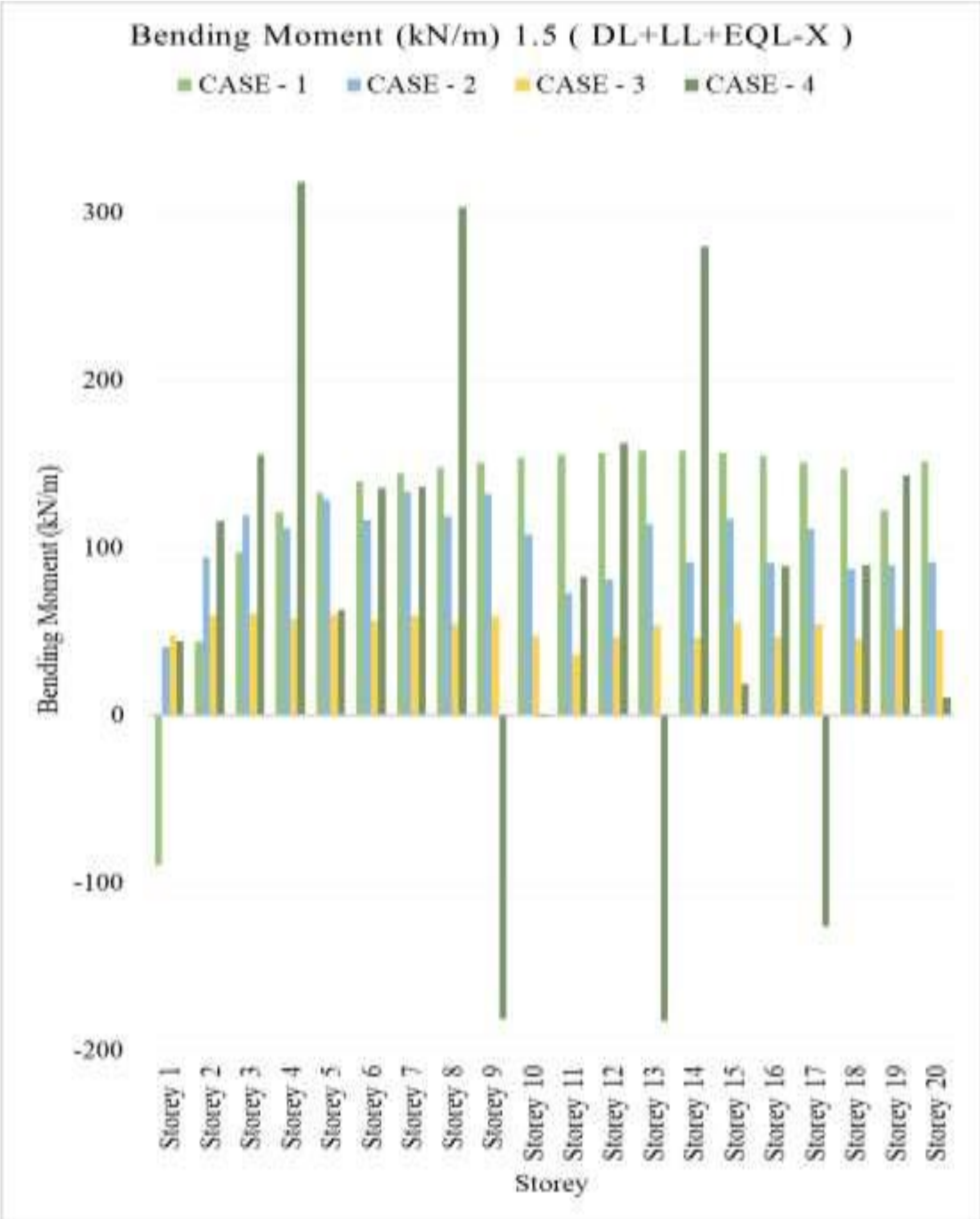


Fig 8: Bending Moment in Various Cases of Low-Cost Earthquake-Resisting Techniques

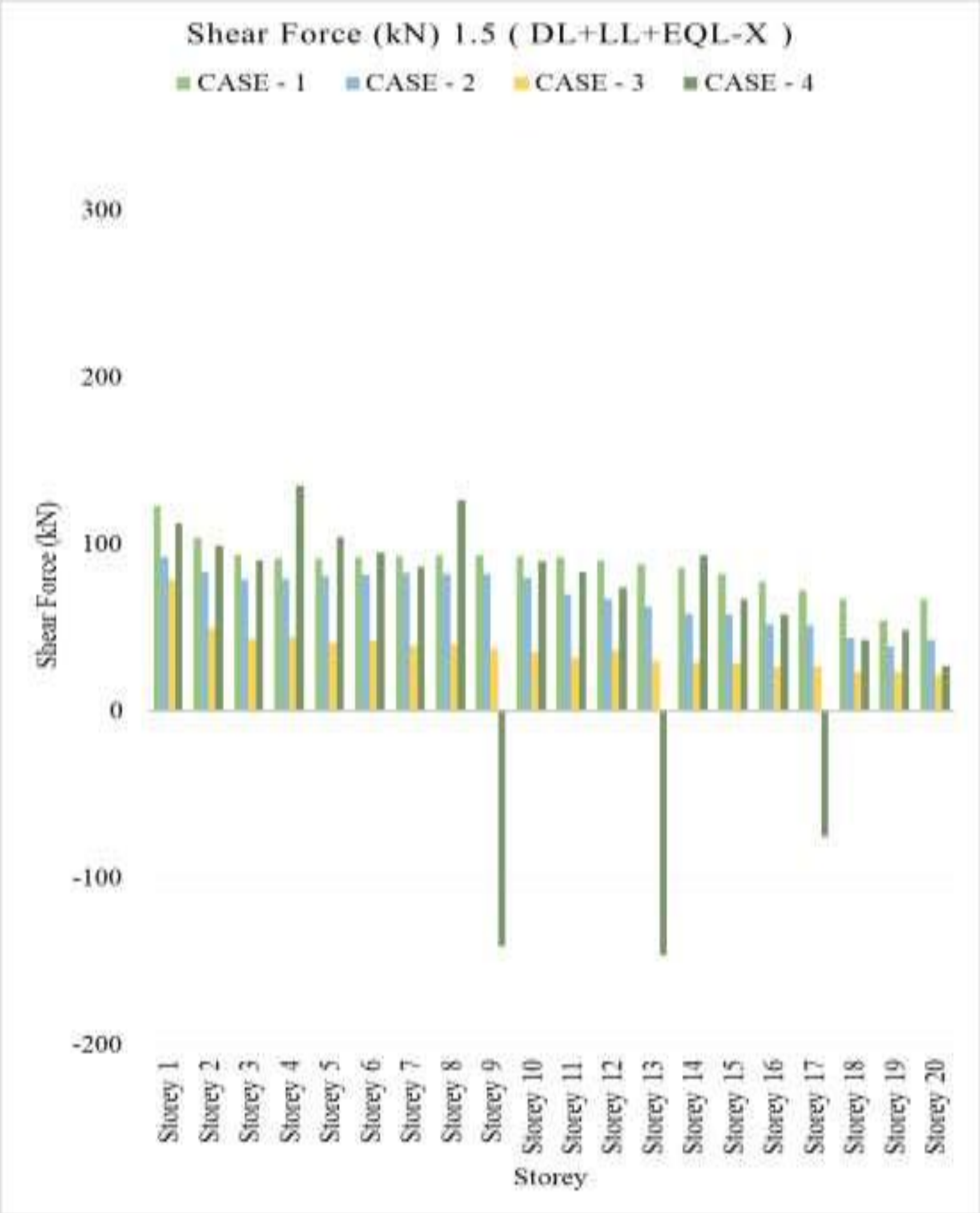
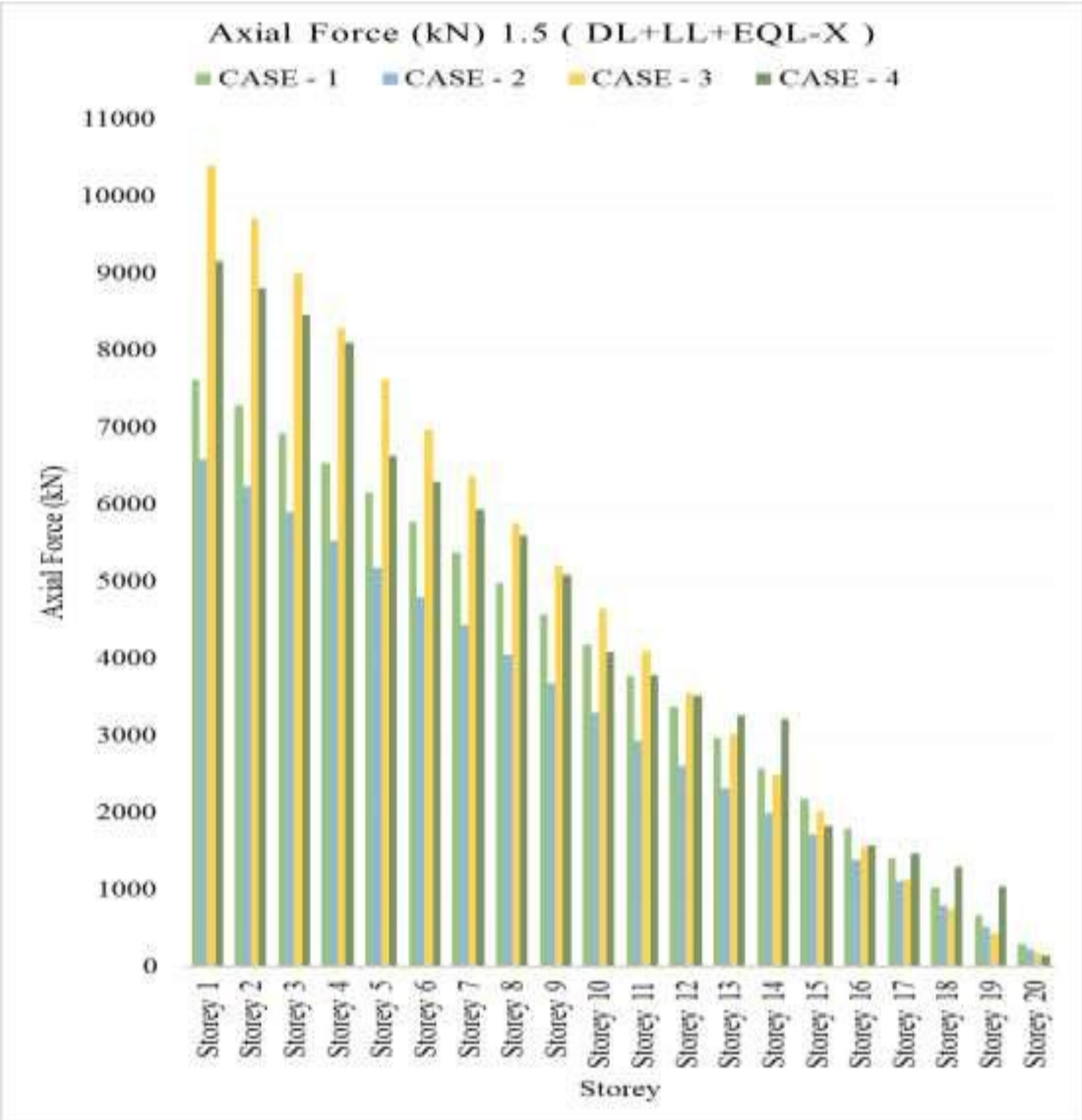


Fig 9: Shear Force in Various Cases of Low-Cost Earthquake-Resisting Techniques

Fig 10: Axial Force in Various Cass of Low-Cost Earthquake-Resisting Techniques



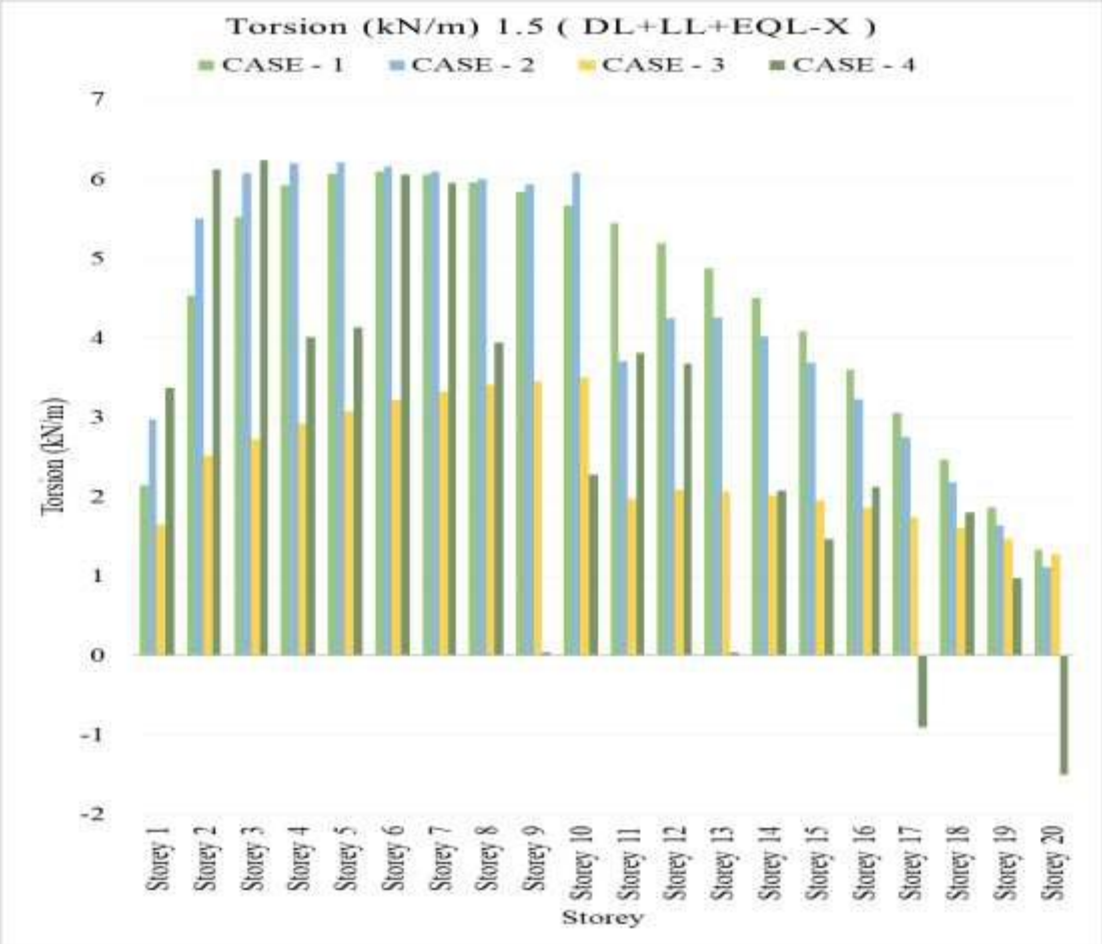
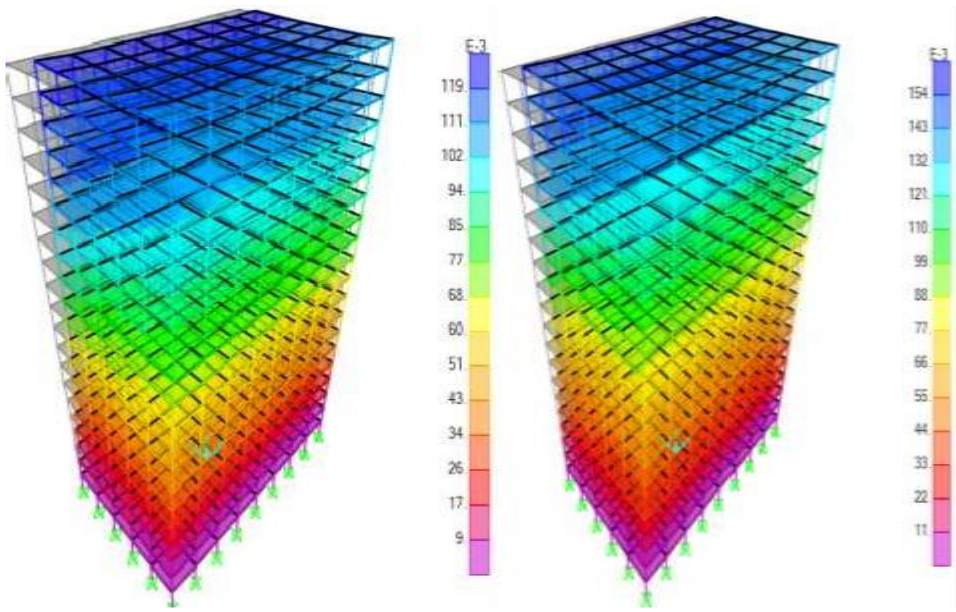
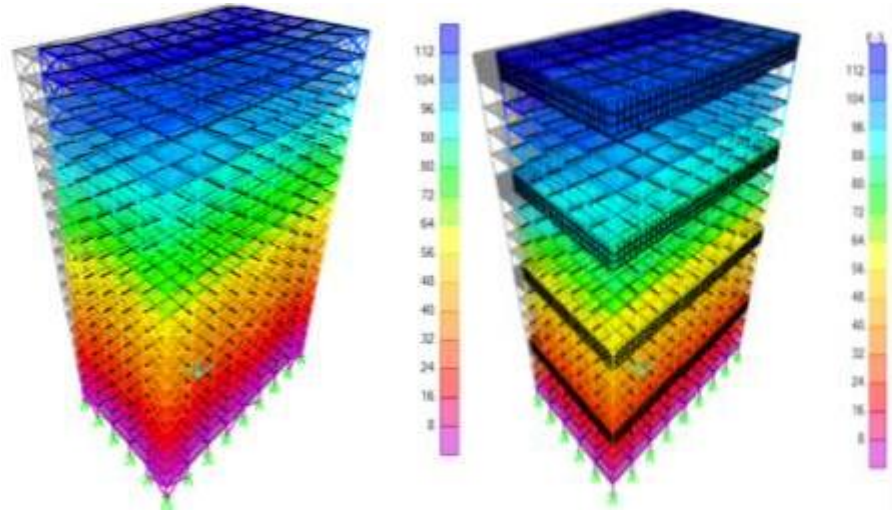


Fig 11: Axial Force in Various Cases of Low-Cost Earthquake-Resisting Techniques



Case-1 **Case-2**



Case-3 **Case-4**

Fig 12: Deformed shape of models frame due to 1.5(DL+LL+EQL)

VII. CONCLUSION

The comparative analysis of low-cost earthquake-resisting methods of regular structures shows that differences in structural behavior to lateral instigation of the seismic threat widely fluctuate and may be defined by the principles of structural mechanics.

Storey Displacement: Case-2 demonstrates the largest displacement top-storey (135.000 mm), which is 25.1% more than in Case-1(107.862 mm), suggesting the poor performance of control of the displacement. Case-3 exhibits nearly the same performance as Case-1 with only 0.21 % reduction (108.086 mm) whereas Case-4 performs the best and cuts down the displacement by 2.61 % (105.047 mm). On the whole, Case-4 offers the most effective lateral displacement control.

Drift Ratio: Case-4 provides the greatest Drift ratio (1.54), which is 77.01 % and 41.38 % more than that of Case-1 (0.87) and Case-2 (1.23), respectively. This demonstrates the excellent ability of Case-4 to improve the performance of structures in terms of stability.

Bending Moment: All alternative cases have top-storey bending moment reduced significantly. Case-4 reduces the seismic demands the most (10.911kNm, -92.80 percent) followed by Case-3 (51.154kNm, -66.27 percent) and Case-2 (91.330kNm, -39.76 percent), thereby showing that Case-4 is the efficacious act to reduce seismic demands on the structure.

Shear Force: Solution-Case-3 minimizes shear force or changes the most (21.821kN, -67.45 percent) and Case-4 also worked out well (27.156kN, -59.48 percent) and Case-2 is moderately reduced (42.922kN, -35.95 percent). Reduced shear stress will increase structural safety in seismic conditions

Axial Force: Case-4 shows the biggest decrease in axial force (141.63kN, -52.33%) including, Case-3 (175.72kN, -40.85%) and Case-2 (223.46kN, -24.82%).. This column reduction in loads and overall stability.

Torsion: Case-2 performs best in case of torsional behavior (1.117kNm, -16.20%), Case-3 performing slightly worse (1.275kNm, -4.35%). Case-4 has a negative torsional value (-1.501kNm), which would provide a reversal influence and perhaps a tendency to instability and is therefore uneconomical in torsion control.

Base Reaction: Case-4 has a moderate base force reduction of base reaction (563,339.55kN, -5.94%), which reduces base forces in Case-2 (551,643kN, -7.92%) and Case-3 (552,654.5kN, -7.73%) as well. This implies that Case-4 is effective in reducing the demand of foundations and keeps the structure stable.

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