

Response of Single Support Structural Systems with Exoskeletons and Dampers under Seismic Loading

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Abstract

Building seismic performance is still a major structural engineering concern since earthquakes can exert powerful forces that, if left unchecked, might cause major damage or collapse. Because single-column supported structures are extremely susceptible to dynamic loading, the behavior of these systems is examined in this work. Ground motion records from the Imperial Valley and Northridge earthquakes were used for Nonlinear Time History Analysis. These records were chosen to reflect various seismic features and offer a realistic evaluation of structural reaction.

Two different kinds of protection mechanisms were included to improve performance. While base isolation in the form of Lead Rubber Bearings (LRB) and High Damping Rubber Bearings (HDRB) was introduced to manage vibrations, steel exoskeletons were utilized to boost stiffness and lateral resistance. The displacement, acceleration, and overall stability of the structural reaction were assessed. Exoskeletons and isolators were shown to dramatically minimize responsiveness, while the bare structure performed poorly under intense excitations. HDRB's greater damping capability allowed it to manage displacements more effectively than the other isolation system. The results demonstrate how well isolation devices and exoskeletons work together to increase the seismic safety of non-traditional structural systems.

Keywords

Mono-support structures; Exoskeletons; Dampers; Seismic performance; Time History Analysis; SAP-2000.

1. Introduction

Urbanization and increasing land scarcity have driven the development of unconventional building systems, including floating columns, Y-columns, and mono-support structures. Mono-support (single column) structures offer unique architectural aesthetics and free ground space but suffer from poor seismic resilience. To enhance their performance under earthquakes, supplemental structural systems such as exoskeletons and dampers are proposed. This study aims to evaluate the seismic performance of mono-support structures integrated with exoskeletons and damping devices using nonlinear time history analysis.

2. Literature Review

Extensive research has been conducted on innovative lateral load-resisting systems, including diagrids, bracings, outriggers, and exoskeletons. Previous studies confirm that exoskeletons can significantly reduce seismic demands by controlling displacements and shear forces. However, limited research exists on mono-support structural systems. Studies on single-column structures suggest higher costs and increased vulnerability under seismic loading. The gap identified is the lack of research on mono-support systems integrated with exoskeletons and damping devices analyzed through Time History Analysis.

3. Methodology

To evaluate the seismic performance of mono-support structures, eight analytical models were developed using SAP-2000. The models were designed with and without exoskeletons, and with two types of base isolation systems: Lead Rubber Bearings (LRB) and High Damping Rubber Bearings (HDRB). Nonlinear Time History Analysis was conducted using Imperial Valley and Northridge earthquake records. Structural parameters studied included axial forces, base reactions, maximum displacements, beam deflections, fundamental time period, and bending moments.

1.	Grade of concrete	M30/M50
2.	Grade of reinforcing steel	Fe 500
3.	Density of concrete	25 KN/m ³
4.	Density of brick masonry	19 KN/m ³
5.	Damping ratio	5%
1.	Plan Dimensions	24m X 24m
2.	Height of the structure	39 m

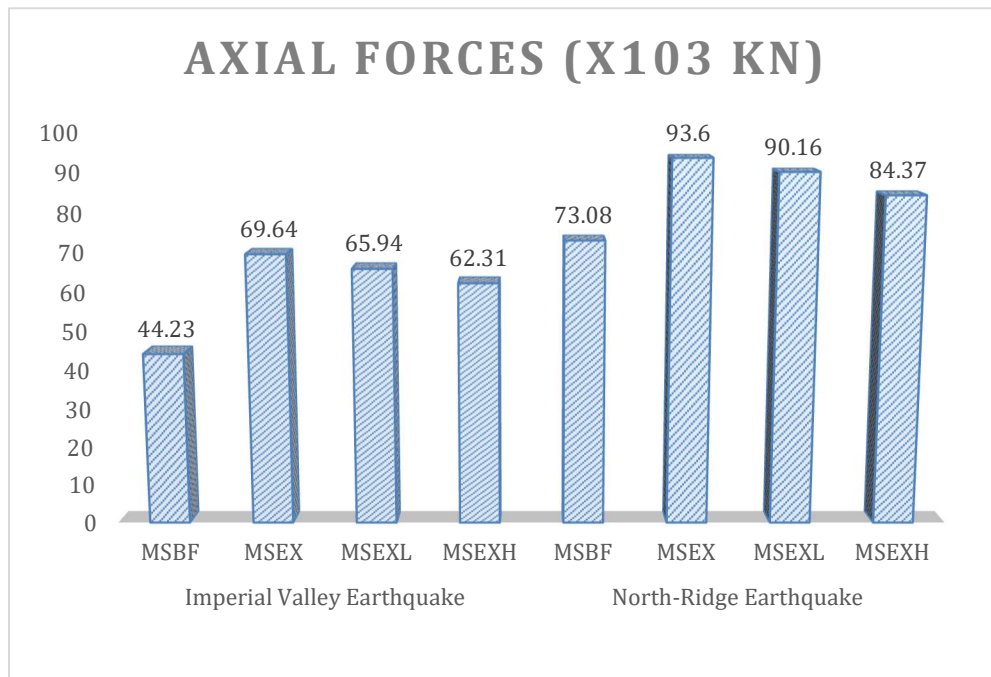
3.	Height of storey	4.6 m
4.	Thickness of Floor Slabs	250 mm
5.	Thickness of Internal Wall	150 mm
6.	Thickness of External wall	150 mm
c	Floor load	3.0 KN/m ²
2.	Live load	4.0KN/m ²
3.	Wall load	15KN/m
4.	Code for RCC	IS 456(2000)
5.	Code for Earthquake	IS 1893 (2016)
6.	Zone	IV
7.	Importance factor	1.5
8.	Moment resisting frame type	SMRF
1.	Type of sections	R.C.C Framed with Exoskeletons
Sizes of Column section		
2.	Columns (C1)	3500 X 3500
Sizes of beam sections		
4.	Beams (B1)	600 X 1500
5.	Beams (B2)	300 X 750
Bracing Details		
6.	Type of Bracings	X-Concentric
7.	Element Used	ISMC-250
1.	Dead Load	Linear Static
2.	Live load	Linear Static

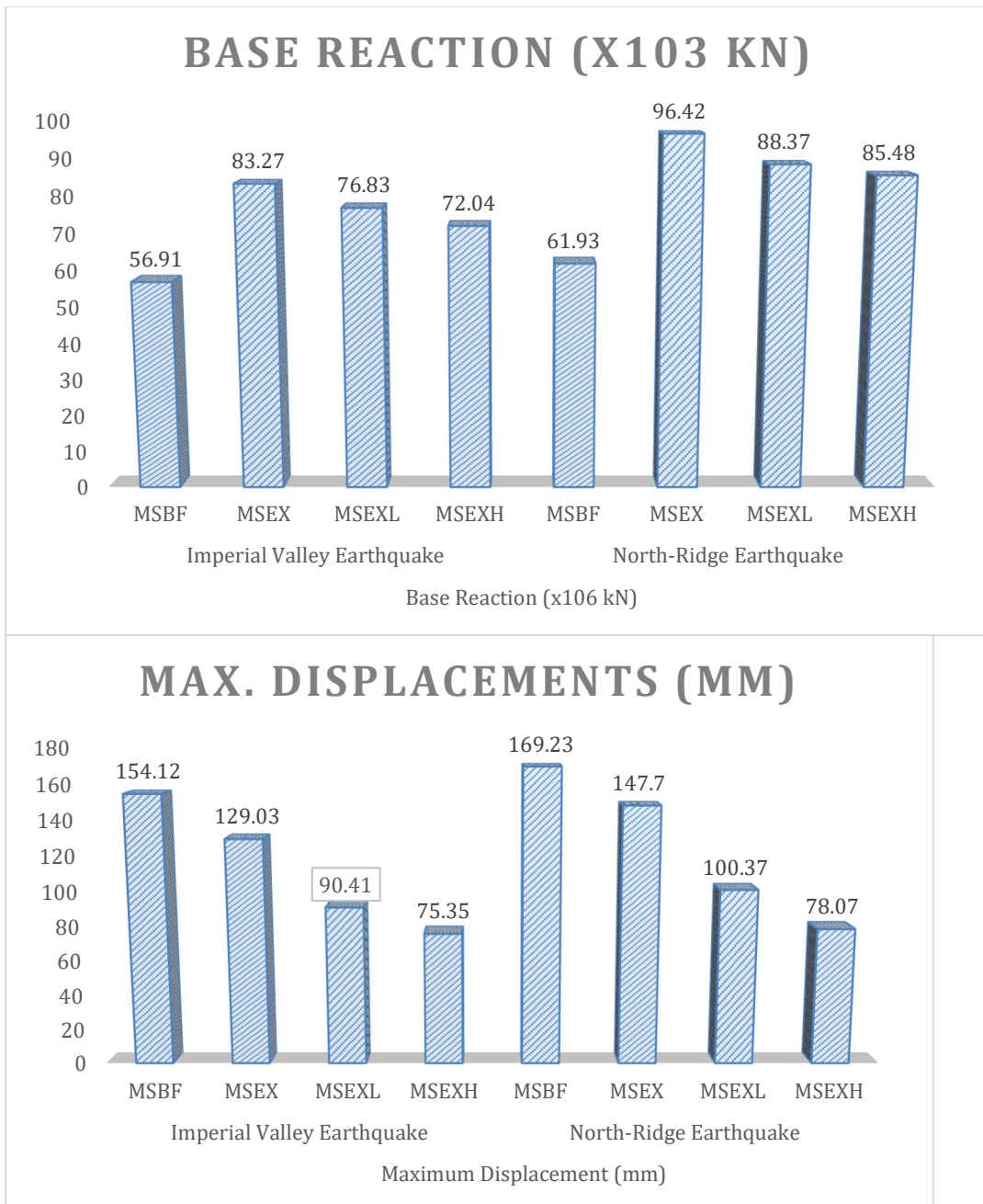
3.	Earthquake (EQX)	Linear Static
4.	Earthquake (EQY)	Linear Static
5.	Time History (THX)	Non-Linear Modal History (FNA)
6.	Time History (THY)	Non-Linear Modal History (FNA)
7.	Model	Eigen Value
1.	Diameter (mm) (LRB)	850
2.	Total height (mm)	340
3.	Maximum Static Load (kN)	10,000
4.	Maximum Seismic Load (kN)	8,500
5.	Design Displacement (mm)	200
6.	Horizontal Force Capacity (kN)	734
7.	Effective Stiffness (kN/mm)	3.67
8.	Characteristic Strength (kN)	198
9.	Energy Dissipated per Cycle (kN-m)	158.50
10.	Damping Ratio (%)	17
1.	Diameter (mm)(HDRB)	950
2.	No of Bearings	25
3.	Rubber Layer Thickness (mm)	10
4.	Cover Plate Thickness (mm)	40
5.	Elastic Modulus (kPa)	1350
6.	Shear Modulus (kPa)	400

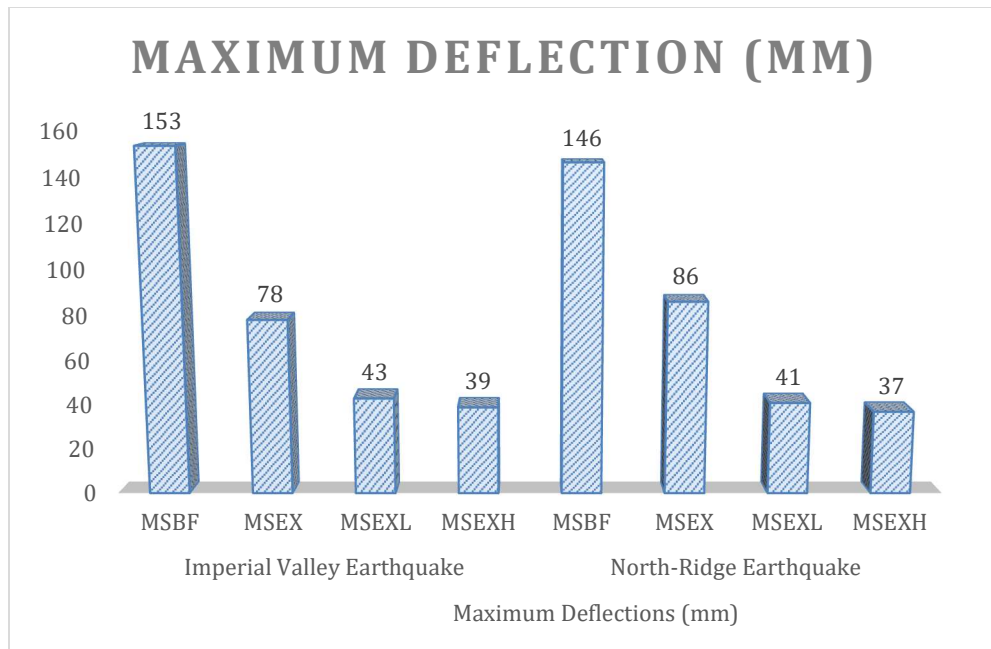
7.	Material Constant	0.87
8.	Ultimate Elongation (%)	650

4. Results and Discussion

The analysis revealed that bare mono-support structures exhibited excessive displacements and deflections, failing to meet code requirements. Exoskeletons improved stiffness, reducing deflections by nearly 50%. The integration of LRB further reduced displacements by approximately 42%, while HDRB achieved up to 68% reduction. Base shear and axial forces increased with exoskeletons but were partially countered by damping devices. HDRB consistently outperformed LRB in controlling dynamic responses, highlighting its superior energy dissipation capacity.







5. Conclusions

This study concludes that mono-support structures without supplemental systems are not seismically viable. Exoskeletons enhance lateral resistance, while damping systems significantly reduce seismic responses. HDRB proved more effective than LRB, offering enhanced stability and serviceability. The combination of exoskeletons and HDRB presents a promising strategy for improving the seismic resilience of mono-support structures.

6. Scope for Future Work

Future studies should investigate alternative damping systems such as viscous dampers, friction dampers, and tuned mass dampers. Further, research on vertical irregularities, diagrid patterns, and central core integration in mono-support structures could provide new insights into their seismic performance.

References

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