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COMPARATIVE SEISMIC PERFORMANCE EVALUATION OF HIGH-RISE BUILDINGS WITH SHEAR WALL–OUTRIGGER, SHEAR WALL–BELT WALL AND COMBINED OUTRIGGER–BELT WALL SYSTEMS

Chinmay D[1], Dr. M. Keshavamurthy[2]

[1]Postgraduate Researcher, [2]Professor & Chairman, Department of Civil Engineering, UVCE, Bengaluru, India

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Abstract - *The seismic performance of high-rise reinforced-concrete buildings is strongly influenced by the configuration and stiffness of the lateral-load-resisting system. This study compares three 22-storey (G+21) building configurations: Shear Wall–Outrigger System (SW-OTS), Shear Wall–Belt Wall System (SW-BWS), and Outrigger–Belt Wall System (OT-BW). Three-dimensional models were developed and analysed in ETABS using modal analysis, Equivalent Static Analysis (ESA), Response Spectrum Analysis (RSA), and Nonlinear Time History Analysis (NLTHA). The building has a 35 m × 35 m plan, 3 m typical storey height and a total height of 65.4 m. Outrigger and belt-wall restraint levels are provided at Stories 7, 14 and 21. The nonlinear assessment uses Imperial Valley, Kobe and Trinidad ground-motion records. SW-BWS produced the shortest fundamental period (1.886 s) and the lowest roof displacement under linear response-spectrum analysis (50.782 mm in X and 50.541 mm in Y). OT-BW showed directional displacement asymmetry, particularly in the Y direction. Under nonlinear analysis, response varied significantly with the ground-motion record: SW-BWS recorded the highest Kobe base shear (172,417.77 kN) and roof displacement (549.257 mm), while SW-OTS showed a more balanced response across the selected records. The results demonstrate that no single configuration is optimal for every response parameter; system selection should consider stiffness, drift, displacement and acceleration demands together.*

Keywords - High-rise buildings, seismic performance, shear wall, outrigger, belt wall, response spectrum analysis, nonlinear time history analysis.

1. INTRODUCTION

Rapid urbanisation and limited urban land have increased the demand for high-rise buildings. As building height increases, lateral actions from earthquakes and wind become increasingly important in structural design. Excessive lateral displacement and inter-storey drift can affect structural stability, non-structural components and occupant comfort. The lateral response of a tall building depends on its mass and stiffness distribution, structural configuration, dynamic characteristics and the frequency content of the applied ground motion.

Shear-wall cores provide substantial lateral stiffness. Outrigger systems connect the core to perimeter columns and mobilise the axial stiffness of the building perimeter, while belt walls distribute forces among perimeter elements. The effectiveness of these systems depends on their arrangement and vertical location. Earlier studies have examined outrigger locations, belt-wall behaviour and combined systems [1]–[7]. The present work compares three configurations in a common building model and evaluates their response using linear and nonlinear seismic analysis.

2. RESEARCH GAP AND OBJECTIVES

The thesis literature review identifies a need for a direct comparison of SW-OTS, SW-BWS and OT-BW within the same high-rise building model. It also identifies the need to assess multiple response measures under ESA, RSA and NLTHA using more than one earthquake record. Accordingly, the objectives are to develop the three ETABS models; compare their modal characteristics; evaluate base shear, storey displacement, inter-storey drift and acceleration; and identify the relative performance and trade-offs of the three structural configurations.

3. BUILDING CONFIGURATION AND MODELLING

A 22-storey (G+21) reinforced-concrete building was considered. The overall plan dimensions are 35 m × 35 m, the typical storey height is 3 m, and the total building height is 65.4 m. The bay spacing is 5 m. A central shear-wall core is included in the building configuration, with the investigated lateral-load-resisting arrangement varying between the three models. The outrigger and belt-wall restraint levels are located at Stories 7, 14 and 21.

Parameter	Value
Number of storeys	G+21 (22 storeys)
Total height	65.4 m
Plan dimensions	35 m × 35 m

Typical storey height	3.0 m
Bay spacing	5.0 m
Outrigger / belt-wall levels	Stories 7, 14 and 21
Analysis software	ETABS

The three configurations are defined as follows: (i) SW-OTS shear-wall system with outriggers; (ii) SW-BWS shear-wall system with belt walls; and (iii) OT-BW combined outrigger and belt-wall system. The thesis specifies 150 mm slabs, 200 mm shear walls and 150 mm outrigger/belt walls. For SW-OTS and SW-BWS, the listed beam and column sizes are 300 mm × 500 mm and 1000 mm × 1000 mm, respectively. For OT-BW, the listed beam and column sizes are 250 mm × 600 mm and 1200 mm × 1200 mm, respectively.

Model	Lateral system	Beam (mm)	Column (mm)
SW-OTS	Shear wall + outrigger	300 × 500	1000 × 1000
SW-BWS	Shear wall + belt wall	300 × 500	1000 × 1000
OT-BW	Outrigger + belt wall	250 × 600	1200 × 1200

The analysis programme includes modal analysis, ESA, RSA and NLTHA. The thesis lists dead load of 1.5 kN/m^2 and live load of 3.0 kN/m^2. The stated code framework includes IS 456:2000, IS 1893 (Part 1):2016 and IS 16700:2023. The earthquake records used for NLTHA are Imperial Valley (IMPV), Kobe and Trinidad (referred to as TD in portions of the thesis).

4. RESULTS AND DISCUSSION

4.1 Modal characteristics

The fundamental time periods obtained from the models are 2.057 s for SW-OTS, 1.886 s for SW-BWS and 2.472 s for OT-BW. SW-BWS has the shortest period among the three configurations, indicating the greatest global lateral stiffness in the comparative model set. OT-BW has the longest period and therefore the most flexible global response. The period of SW-BWS is approximately 8.3% lower than SW-OTS and 23.7% lower than OT-BW.

Model	Fundamental period (s)	Relative observation
SW-OTS	2.057	Intermediate
SW-BWS	1.886	Shortest period / stiffest
OT-BW	2.472	Longest period / most flexible

4.2 Base shear

The linear base-shear values are similar between ESA and RSA. Under ESA, the reported base shears are 18,557.76 kN for SW-OTS, 19,370.58 kN for SW-BWS and 19,493.66 kN for OT-BW. Under RSA, the corresponding values are 18,557.76 kN, 19,369.12 kN and 19,494.31 kN. Thus, OT-BW has the highest linear base shear, while SW-OTS has the lowest.

Model	ESA base shear (kN)	RSA base shear (kN)
SW-OTS	18,557.76	18,557.76
SW-BWS	19,370.58	19,369.12
OT-BW	19,493.66	19,494.31

The nonlinear time-history results show a strong dependence on the selected ground motion. The Imperial Valley peak base shears range from 125,951.46 kN to 142,018.23 kN, while the Kobe results range from 121,638.81 kN to 172,417.77 kN. The Trinidad/TD record produces lower values, from 16,623.49 kN to 18,296.06 kN. SW-BWS attracts the largest reported Kobe base shear (172,417.77 kN), indicating that a stiffer configuration can also attract greater inertial demand under a particular ground-motion frequency content.

Ground motion	SW-OTS (kN)	SW-BWS (kN)	OT-BW (kN)
Imperial Valley	125,951.46	142,018.23	132,420.56
Kobe	121,638.81	172,417.77	158,534.10
Trinidad / TD	17,057.86	16,623.49	18,296.06

4.3 Roof displacement

Under RSA, SW-BWS records the lowest roof displacement, with 50.782 mm in the X direction and 50.541 mm in the Y direction. The thesis reports 56.888 mm (X) and 84.513 mm (Y) for OT-BW under ESA, and 54.562 mm (X) and 80.523 mm (Y) under RSA, indicating a marked directional difference in the OT-BW model. Under NLTHA, roof displacement is strongly record-dependent. The thesis reports 382.841 mm for SW-BWS and 416.986 mm for SW-OTS under Imperial Valley; under Kobe, SW-BWS reaches 549.257 mm, compared with 462.032 mm for SW-OTS. The reported Trinidad values are 23.832 mm for SW-BWS, 24.709 mm for OT-BW and 29.377 mm for SW-OTS.

Ground motion	SW-OTS (mm)	SW-BWS (mm)	OT-BW (mm)
Imperial Valley	416.986	382.841	400.226

Kobe	462.032	549.257	477.103
Trinidad / TD	29.377	23.832	24.709

4.4 Inter-storey drift

Under linear analysis, the maximum drift values remain below the 0.004 limit cited in the thesis. SW-BWS records maximum RSA drift ratios of 0.001115 in X and 0.001120 in Y. OT-BW has a higher Y-direction RSA drift of approximately 0.002231 around Stories 10–11, indicating greater lateral racking in that direction. In nonlinear time-history analysis, the peak drift ratios reported are 0.010194 for SW-OTS, 0.012668 for SW-BWS and 0.013060 for OT-BW. These nonlinear values are substantially higher than the linear response and indicate inelastic response under the selected records. The thesis also reports local reductions in drift at Stories 7 and 14, consistent with the restraint action of the outrigger and belt-wall levels.

4.5 Acceleration response

The acceleration results also depend on the ground-motion record and structural configuration. For the Kobe record, SW-BWS has the highest reported top-storey acceleration (9,268.76 mm/s^2), while OT-BW has the lowest (5,854.87 mm/s^2). The thesis reports an output acceleration of 10,383.82 mm/s^2 for SW-BWS under Kobe, corresponding to an amplification of approximately 3.07 relative to the input peak ground acceleration of 3,382 mm/s^2. OT-BW has a lower reported output acceleration of 8,298.07 mm/s^2, or approximately 2.45 times the input. This illustrates that increased stiffness and reduced displacement do not necessarily correspond to lower floor acceleration demand.

5. CONCLUSIONS

The comparative analysis demonstrates that the three structural configurations exhibit different balances of stiffness, deformation control and acceleration response. SW-BWS has the shortest fundamental period (1.886 s) and the lowest roof displacement under RSA, indicating superior stiffness and linear serviceability response among the models. OT-BW has the longest period (2.472 s) and pronounced Y-direction displacement and drift asymmetry. SW-OTS provides an intermediate modal period and, as discussed in the thesis, a comparatively balanced nonlinear response across the selected earthquake records.

The nonlinear results show that ground-motion characteristics have a major influence on response. SW-BWS experiences the highest Kobe base shear and roof displacement, despite its favourable linear response. OT-BW produces the lowest reported Kobe top-storey acceleration but has the highest peak nonlinear drift ratio. The restraint levels at Stories 7 and 14 are associated with local reductions in storey drift. Therefore, selection of a lateral-load-resisting system should not be based on a single parameter; displacement, drift, base shear and acceleration should be evaluated together for the relevant seismic hazard and ground-motion characteristics.

Based on the thesis conclusions, SW-BWS is suitable where linear stiffness and serviceability drift control are primary considerations, provided that ductile detailing and non-structural component anchorage are carefully addressed. SW-OTS is identified in the thesis as a balanced alternative under varying seismic frequency content. Further work may consider soil–structure interaction, supplemental energy-dissipation devices and optimisation of the number and vertical location of outrigger/belt-wall levels.

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