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Effective Positioning of Outrigger in Non-Orthogonal Rcc High-Rise Building under Wind Loading for Different Seismic Zones and Soil Conditions using Etabs

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Abstract -The present research concentrates on finding the optimum outrigger location in a 60-storey non-orthogonal reinforced cement concrete (RCC) high-rise structure subjected to wind loads, considering variations in seismic zones and soil conditions. The building is modelled and analyzed using ETABS, with three different outrigger configurations located at 0.3H, 0.56H, and 0.75H. The structural behavior is examined under varying wind-speed conditions associated with the selected seismic zones and soil classifications. The analytical results indicates that changes in seismic zone and soil type do not influence the modal time period of the structure. Among the configurations considered, the outrigger system placed at 0.3H demonstrates better performance in controlling the building deflection. The findings emphasize that the strategic placement of outriggers plays a significant role in enhancing the lateral stability and overall wind-resistant performance of non-orthogonal high-rise RCC buildings.

Keywords -High-rise building, non-orthogonal RCC structure, outrigger system, wind loading, seismic zones, soil conditions, ETABS.

I. INTRODUCTION

The construction of high-rise buildings has become an integral part of contemporary urban development, driven by rapid population growth, increasing urbanization, and the growing demand for residential, commercial, and institutional spaces. Such buildings provide an efficient solution to land scarcity in densely populated metropolitan areas. Nevertheless, increasing building heights introduce greater challenges in structural engineering, particularly due to the influence of lateral loads induced by wind and earthquakes. Unlike low-rise structures, tall buildings are more susceptible to lateral deflections, overturning effects, and complex dynamic responses. Wind loading, in particular, can generate substantial lateral displacement and inter-storey drift, which may adversely affect structural integrity, cause damage to non-structural components, and reduce the comfort and safety of occupants. Consequently, the selection of an appropriate structural system is essential to achieve adequate strength, stiffness, stability, and satisfactory performance under extreme wind conditions.

Reinforced cement concrete (RCC) is widely adopted in high-rise construction owing to its strength, durability, widespread availability, and versatility in architectural applications. However, conventional RCC moment-resisting frame systems, when used independently, may not provide adequate lateral stiffness for buildings of considerable height. To overcome this limitation and improve resistance against lateral forces, various structural systems are incorporated into high-rise buildings. These include shear wall systems, central core walls, braced frames, belt trusses, and outrigger systems, which enhance the overall stiffness, stability, and lateral load-resisting capacity of the structure.

II. BUILDING CONFIGURATION AND ANALYTICAL MODEL

A. Building configuration

TABLE 1 BUILDING CONFIGURATION

Total Number of Floors	Ground +60 floors
How many basements	No Basements
Number of Residential Floors	35 Floors
Number of Refuge Floors	5 Floors (Partly)
Total Height of the building above ground floor	206 Meter (Above Ground Level)

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B. Sesimic and Wind Parameter

TABLE 2 SEISMIC PARAMETERS

Structural system	Seismic Zone	Zone factor (Z)	Soil Type	Importance Factor (I)	Response Reduction factor (R)
Building with ductile RC shear walls	II	0.10	Hard/Medium/Soft	1.2	4
	III	0.16			
	IV	0.24			
	V	0.36			

TABLE 3 WIND PARAMETERS

	Zone II	Zone III	Zone IV	Zone V
	Jaipur	Pune	Patna	Guwahati
Vb (basic wind speed)	47 m/sec	39 m/sec	47 m/sec	50 m/sec
K1 (Risk coefficient) (for **20 years** mean probable design life)	0.88	0.9	0.88	0.874
k2 (Terrain category 3)	1.31	1.31	1.31	1.31
K3 (Topography factor)	1	1	1	1
K4 (Importance factor)	1	1	1	1

C. Analytical Modeling And Outrigger Locations

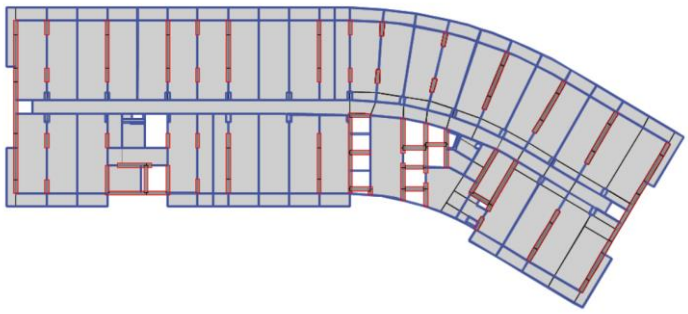


Fig. 1 Non-Orthogonal Structural Framing Plan with outrigger locations

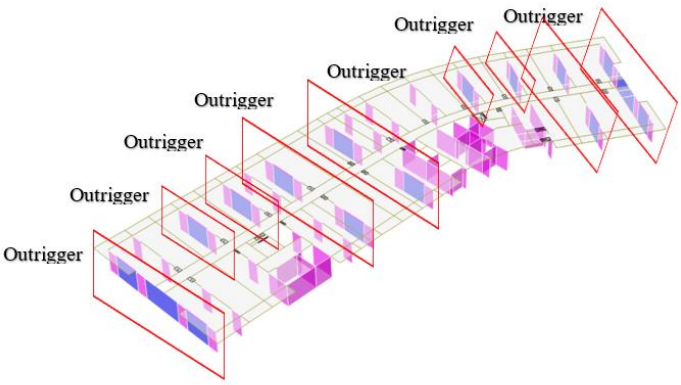


Fig. 2 3-D View of outrigger locations

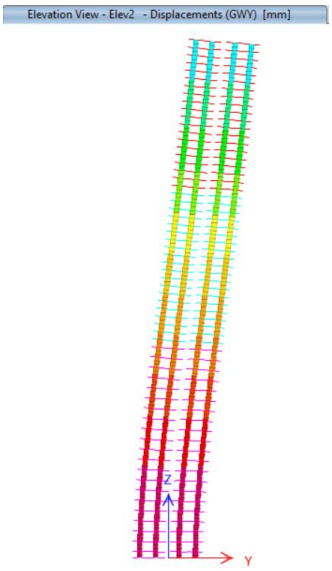


Fig. 3 Deflection Profile of Building without outrigger

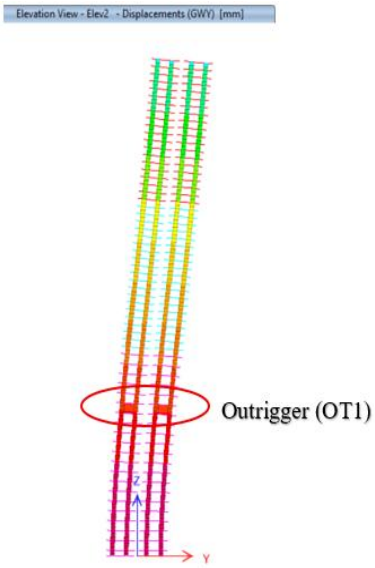


Fig. 4 Deflection Profile of Building -Outrigger At 0.3H

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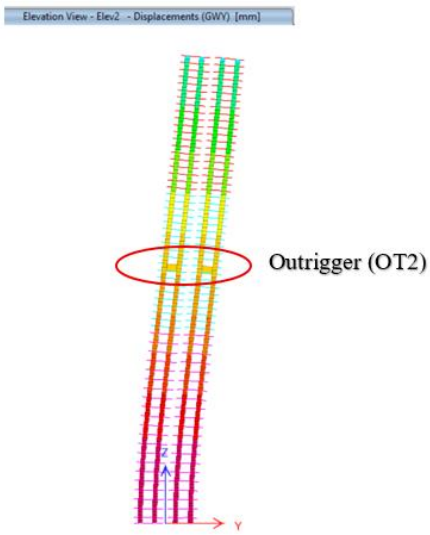


Fig. 5 Deflection Profile of Building -Outrigger At 0.56H

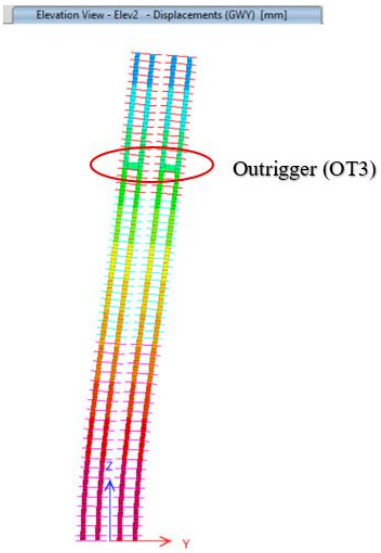


Fig. 6 Deflection Profile of Building -Outrigger At 0.75H

III. RESULTS AND DISCUSSION

A. *Modal Time Period Comparison at Different Outrigger Locations Across Zones and Soil Strata*

TABLE 4 TIME PERIOD ZONE 2 & HARD STRATA

Z2_H	Mode	Period	UX	UY	RZ
		sec			
	1	10.30	0.48	0.00	0.26
	2	8.74	0.04	0.56	0.10
	3	8.49	0.20	0.13	0.37

Z2_H_OT1	Mode	Period	UX	UY	RZ
		sec			
	1.00	10.07	0.58	0.01	0.15
	2.00	8.40	0.00	0.67	0.02
	3.00	7.98	0.14	0.01	0.55

Z2_H_OT2	Mode	Period	UX	UY	RZ
		sec			
	1.00	10.16	0.55	0.00	0.19
	2.00	8.47	0.00	0.65	0.06
	3.00	8.08	0.17	0.05	0.50

Z2_H_OT3	Mode	Period	UX	UY	RZ
		sec			
	1.00	10.23	0.52	0.00	0.22
	2.00	8.60	0.02	0.61	0.08
	3.00	8.25	0.18	0.09	0.44

TABLE 5 TIME PERIOD ZONE 3 & HARD STRATA

Z3_H	Mode	Period	UX	UY	RZ
		sec			
	1.00	10.30	0.48	0.00	0.26
	2.00	8.74	0.04	0.56	0.10
	3.00	8.49	0.20	0.13	0.37

Z3_H_OT1	Mode	Period	UX	UY	RZ
		sec			
	1.00	10.07	0.58	0.01	0.15
	2.00	8.40	0.00	0.67	0.02
	3.00	7.98	0.14	0.01	0.55

Z3_H_OT2	Mode	Period	UX	UY	RZ
		sec			
	1.00	10.16	0.55	0.00	0.19
	2.00	8.47	0.00	0.65	0.06
	3.00	8.08	0.17	0.05	0.50

Z3_H_OT3	Mode	Period	UX	UY	RZ
		sec			
	1.00	10.23	0.52	0.00	0.22
	2.00	8.60	0.02	0.61	0.08
	3.00	8.25	0.18	0.09	0.44

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TABLE 6 TIME PERIOD ZONE 4 & HARD STRATA

Z4_H	Mode	Period	UX	UY	RZ
		sec			
	1.00	10.30	0.48	0.00	0.26
	2.00	8.74	0.04	0.56	0.10
	3.00	8.49	0.20	0.13	0.37

Z4_H_OT1	Mode	Period	UX	UY	RZ
		sec			
	1.00	10.07	0.58	0.01	0.15
	2.00	8.40	0.00	0.67	0.02
	3.00	7.98	0.14	0.01	0.55

Z4_H_OT2	Mode	Period	UX	UY	RZ
		sec			
	1.00	10.16	0.55	0.00	0.19
	2.00	8.47	0.00	0.65	0.06
	3.00	8.08	0.17	0.05	0.50

Z4_H_OT3	Mode	Period	UX	UY	RZ
		sec			
	1.00	10.23	0.52	0.00	0.22
	2.00	8.60	0.02	0.61	0.08
	3.00	8.25	0.18	0.09	0.44

TABLE 7 TIME PERIOD ZONE 5 & HARD STRATA

Z5_H	Mode	Period	UX	UY	RZ
		sec			
	1.00	10.30	0.48	0.00	0.26
	2.00	8.74	0.04	0.56	0.10
	3.00	8.49	0.20	0.13	0.37

Z5_H_OT1	Mode	Period	UX	UY	RZ
		sec			
	1.00	10.07	0.58	0.01	0.15
	2.00	8.40	0.00	0.67	0.02
	3.00	7.98	0.14	0.01	0.55

Z5_H_OT2	Mode	Period	UX	UY	RZ
		sec			
	1.00	10.16	0.55	0.00	0.19
	2.00	8.47	0.00	0.65	0.06
	3.00	8.08	0.17	0.05	0.50

Z5_H_OT3	Mode	Period	UX	UY	RZ
		sec			
	1.00	10.23	0.52	0.00	0.22
	2.00	8.60	0.02	0.61	0.08
	3.00	8.25	0.18	0.09	0.44

Observation & Discussion

Time Period Comparison Across Zones-Hard Soil Strata

Mode 1: The modal time period is nearly similar in Zones Z2, Z3, Z4, and Z5 for all four models. Model Z2/Z3/Z4/Z5_H shows the highest time period (approximately 10.30 sec), while OT1 shows the lowest (approximately 10.07 sec).

Mode 2: The modal time period remains constant in all zones. Model Z2/Z3/Z4/Z5_H has the highest value of 8.74 sec, followed by OT3 (8.60 sec), OT2 (8.47 sec), and OT1 (8.40 sec).

Mode 3: Model Z2/Z3/Z4/Z5_H shows the highest time period of 8.49 sec, followed by OT3 (8.25 sec), OT2 (8.08 sec), and OT1 (7.98 sec).

TABLE 8 TIME PERIOD ZONE 2 & MEDIUM STRATA

Z2_M	Mode	Period	UX	UY	RZ
		sec			
	1	10.30	0.48	0.00	0.26
	2	8.74	0.04	0.56	0.10
	3	8.49	0.20	0.13	0.37

Z2_M_OT1	Mode	Period	UX	UY	RZ
		sec			
	1.00	10.07	0.58	0.01	0.15
	2.00	8.40	0.00	0.67	0.02
	3.00	7.98	0.14	0.01	0.55

Z2_M_OT2	Mode	Period	UX	UY	RZ
		sec			
	1.00	10.16	0.55	0.00	0.19
	2.00	8.47	0.00	0.65	0.06
	3.00	8.08	0.17	0.05	0.50

Z2_M_OT3	Mode	Period	UX	UY	RZ
		sec			
	1.00	10.23	0.52	0.00	0.22
	2.00	8.60	0.02	0.61	0.08
	3.00	8.25	0.18	0.09	0.44

TABLE 9 TIME PERIOD ZONE 3 & MEDIUM STRATA

Z3_M	Mode	Period	UX	UY	RZ
		sec			
	1.00	10.30	0.48	0.00	0.26
	2.00	8.74	0.04	0.56	0.10
	3.00	8.49	0.20	0.13	0.37

Z3_M_OT1	Mode	Period	UX	UY	RZ
		sec			
	1.00	10.07	0.58	0.01	0.15
	2.00	8.40	0.00	0.67	0.02
	3.00	7.98	0.14	0.01	0.55

Z3_M_OT2	Mode	Period	UX	UY	RZ
		sec			
	1.00	10.16	0.55	0.00	0.19
	2.00	8.47	0.00	0.65	0.06
	3.00	8.08	0.17	0.05	0.50

Z3_M_OT3	Mode	Period	UX	UY	RZ
		sec			
	1.00	10.23	0.52	0.00	0.22
	2.00	8.60	0.02	0.61	0.08
	3.00	8.25	0.18	0.09	0.44

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TABLE 10 TIME PERIOD ZONE 4 & MEDIUM STRATA

Z4_M	Mode	Period	UX	UY	RZ
		sec			
	1.00	10.30	0.48	0.00	0.26
	2.00	8.74	0.04	0.56	0.10
	3.00	8.49	0.20	0.13	0.37

Z4_M_OT1	Mode	Period	UX	UY	RZ
		sec			
	1.00	10.07	0.58	0.01	0.15
	2.00	8.40	0.00	0.67	0.02
	3.00	7.98	0.14	0.01	0.55

Z4_M_OT2	Mode	Period	UX	UY	RZ
		sec			
	1.00	10.16	0.55	0.00	0.19
	2.00	8.47	0.00	0.65	0.06
	3.00	8.08	0.17	0.05	0.50

Z4_M_OT3	Mode	Period	UX	UY	RZ
		sec			
	1.00	10.23	0.52	0.00	0.22
	2.00	8.60	0.02	0.61	0.08
	3.00	8.25	0.18	0.09	0.44

TABLE 11 TIME PERIOD ZONE 5 & MEDIUM STRATA

Z5_M	Mode	Period	UX	UY	RZ
		sec			
	1.00	10.30	0.48	0.00	0.26
	2.00	8.74	0.04	0.56	0.10
	3.00	8.49	0.20	0.13	0.37

Z5_M_OT1	Mode	Period	UX	UY	RZ
		sec			
	1.00	10.07	0.58	0.01	0.15
	2.00	8.40	0.00	0.67	0.02
	3.00	7.98	0.14	0.01	0.55

Z5_M_OT2	Mode	Period	UX	UY	RZ
		sec			
	1.00	10.16	0.55	0.00	0.19
	2.00	8.47	0.00	0.65	0.06
	3.00	8.08	0.17	0.05	0.50

Z5_M_OT3	Mode	Period	UX	UY	RZ
		sec			
	1.00	10.23	0.52	0.00	0.22
	2.00	8.60	0.02	0.61	0.08
	3.00	8.25	0.18	0.09	0.44

Time Period Comparison Across Zones-Medium Soil Strata

Mode 1: The modal time period remains same across Zones Z2, Z3, Z4, and Z5 for all four models. Model Z2/Z3/Z4/Z5_M indicates the highest time period of approximately 10.30 sec, while OT1 has the lowest value of approximately 10.07 sec.

Mode 2: The modal time period is unchanged across all four seismic zones. Model Z2/Z3/Z4/Z5_M has the highest value of 8.74 sec, followed by OT3 at 8.60 sec, OT2 at approximately 8.47 sec, and OT1 at 8.40 sec.

Mode 3: Model Z2/Z3/Z4/Z5_M shows the highest time period of 8.49 sec, followed by OT3 at 8.25 sec, OT2 at 8.08 sec, and OT1 at 7.98 sec. These values remain constant across all zones.

TABLE 12 TIME PERIOD ZONE 2 & SOFT STRATA

Z2_S	Mode	Period	UX	UY	RZ
		sec			
	1	10.30	0.48	0.00	0.26
	2	8.74	0.04	0.56	0.10
	3	8.49	0.20	0.13	0.37

Z2_S_OT1	Mode	Period	UX	UY	RZ
		sec			
	1.00	10.07	0.58	0.01	0.15
	2.00	8.40	0.00	0.67	0.02
	3.00	7.98	0.14	0.01	0.55

Z2_S_OT2	Mode	Period	UX	UY	RZ
		sec			
	1.00	10.16	0.55	0.00	0.19
	2.00	8.47	0.00	0.65	0.06
	3.00	8.08	0.17	0.05	0.50

Z2_S_OT3	Mode	Period	UX	UY	RZ
		sec			
	1.00	10.23	0.52	0.00	0.22
	2.00	8.60	0.02	0.61	0.08
	3.00	8.25	0.18	0.09	0.44

TABLE 13 TIME PERIOD ZONE 3 & SOFT STRATA

Z3_S	Mode	Period	UX	UY	RZ
		sec			
	1.00	10.30	0.48	0.00	0.26
	2.00	8.74	0.04	0.56	0.10
	3.00	8.49	0.20	0.13	0.37

Z3_S_OT1	Mode	Period	UX	UY	RZ
		sec			
	1.00	10.07	0.58	0.01	0.15
	2.00	8.40	0.00	0.67	0.02
	3.00	7.98	0.14	0.01	0.55

Z3_S_OT2	Mode	Period	UX	UY	RZ
		sec			
	1.00	10.16	0.55	0.00	0.19
	2.00	8.47	0.00	0.65	0.06
	3.00	8.08	0.17	0.05	0.50

Z3_S_OT3	Mode	Period	UX	UY	RZ
		sec			
	1.00	10.23	0.52	0.00	0.22
	2.00	8.60	0.02	0.61	0.08
	3.00	8.25	0.18	0.09	0.44

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TABLE 14 TIME PERIOD ZONE 4 & SOFT STRATA

Z4_S	Mode	Period	UX	UY	RZ
		sec			
	1.00	10.30	0.48	0.00	0.26
	2.00	8.74	0.04	0.56	0.10
	3.00	8.49	0.20	0.13	0.37

Z4_S_OT1	Mode	Period	UX	UY	RZ
		sec			
	1.00	10.07	0.58	0.01	0.15
	2.00	8.40	0.00	0.67	0.02
	3.00	7.98	0.14	0.01	0.55

Z4_S_OT2	Mode	Period	UX	UY	RZ
		sec			
	1.00	10.16	0.55	0.00	0.19
	2.00	8.47	0.00	0.65	0.06
	3.00	8.08	0.17	0.05	0.50

Z4_S_OT3	Mode	Period	UX	UY	RZ
		sec			
	1.00	10.23	0.52	0.00	0.22
	2.00	8.60	0.02	0.61	0.08
	3.00	8.25	0.18	0.09	0.44

TABLE 15 TIME PERIOD ZONE 4 & SOFT STRATA

Z5_S	Mode	Period	UX	UY	RZ
		sec			
	1.00	10.30	0.48	0.00	0.26
	2.00	8.74	0.04	0.56	0.10
	3.00	8.49	0.20	0.13	0.37

Z5_S_OT1	Mode	Period	UX	UY	RZ
		sec			
	1.00	10.07	0.58	0.01	0.15
	2.00	8.40	0.00	0.67	0.02
	3.00	7.98	0.14	0.01	0.55

Z5_S_OT2	Mode	Period	UX	UY	RZ
		sec			
	1.00	10.16	0.55	0.00	0.19
	2.00	8.47	0.00	0.65	0.06
	3.00	8.08	0.17	0.05	0.50

Z5_S_OT3	Mode	Period	UX	UY	RZ
		sec			
	1.00	10.23	0.52	0.00	0.22
	2.00	8.60	0.02	0.61	0.08
	3.00	8.25	0.18	0.09	0.44

Time Period Comparison Across Zones-Medium Soil Strata

Mode 1: The time period remains unchanged across Zones Z2, Z3, Z4, and Z5 for all four structural models. Model Z2/Z3/Z4/Z5_S exhibits the highest time period of approximately 10.30 sec, while OT1 has the lowest value of approximately 10.07 sec.

Mode 2: The time period remains similar across all four seismic zones. Model Z2/Z3/Z4/Z5_S has the highest value of 8.74 sec, followed by OT3 at 8.60 sec, OT2 at approximately 8.47 sec, and OT1 at 8.40 sec.

Mode 3: The time period remains similar across all four seismic zones. Model Z2/Z3/Z4/Z5_S has the highest value of 8.49 sec, followed by OT3 at 8.25 sec, OT2 at approximately 8.08 sec, and OT1 at 7.98 sec

B. Building Displacement at Different Outrigger Locations Due To Along Wind & Across Wind Forces

TABLE 16 TIME ALONG WIND (GWX, GWY) & ACROSS WIND (AWYX, AWXY) DISPLACEMENT AT OUTRIGGER LOCATIONS IN ZONE 2 & 4 IN HARD, MEDIUM & SOFT SOIL STRATA

Z2/Z4_H/M/S	Story	Height	GWX	GWY	AWYX	AWXY
	TERRACE	3.10	121.92	397.88	324.89	193.14
Z2/Z4_H/M/S_OT1	Story	Height	GWX	GWY	AWYX	AWXY
	TERRACE	3.10	121.13	393.49	318.83	186.75
Z2/Z4_H/M/S_OT2	Story	Height	GWX	GWY	AWYX	AWXY
	TERRACE	3.10	121.44	394.40	321.19	188.08
Z2/Z4_H/M/S_OT3	Story	Height	GWX	GWY	AWYX	AWXY
	TERRACE	3.10	121.68	396.08	323.03	190.57

Observation

The highest GWY value is 397.88 for the original configuration, while the highest AWYX value is 324.89 for the same configuration. Both values decrease with OT1 and increase slightly with OT2 and OT3

GWX: The maximum value is 121.92 for the original configuration, and the minimum is 121.13 at OT1. AWXY: The maximum value is 193.14 for the original configuration, and the minimum is 186.75 at OT1

TABLE 17 TIME ALONG WIND (GWX, GWY) & ACROSS WIND (AWYX, AWXY) DISPLACEMENT AT OUTRIGGER LOCATIONS IN ZONE 3 & 4 IN HARD, MEDIUM & SOFT SOIL STRATA

Z3_H/M/S	Story	Height	GWX	GWY	AWYX	AWXY
	TERRACE	3.1	83.35	273.14	200.62	124.42
Z3_H/M/S_OT1	Story	Height	GWX	GWY	AWYX	AWXY
	TERRACE	3.1	82.84	270.49	196.31	122.20
Z3_H/M/S_OT2	Story	Height	GWX	GWY	AWYX	AWXY
	TERRACE	3.1	83.04	271.04	197.98	122.65
Z3_H/M/S_OT3	Story	Height	GWX	GWY	AWYX	AWXY
	TERRACE	3.1	83.20	272.05	199.30	123.50

Observation

The highest GWY value is 273.14 for the original configuration, while the highest AWYX value is 200.62 for the same configuration. Both values decrease with OT1 and increase slightly with OT2 and OT3

GWX: The maximum value is 83.35 for the original configuration, and the minimum is 82.84 at OT1. AWXY: The maximum value is 124.42 for the original configuration, and the minimum is 122.20 at OT1

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TABLE 18 TIME ALONG WIND (GWX, GWY) & ACROSS WIND (AWYX, AWXY) DISPLACEMENT AT OUTRIGGER LOCATIONS IN ZONE 3 & 4 IN HARD, MEDIUM & SOFT SOIL STRATA

Z5_H/M/S	Story	Height	GWX	GWY	AWYX	AWXY
	TERRACE	3.1	138.58	451.99	382.32	227.02
Z5_H/M/S_OT1	Story	Height	GWX	GWY	AWYX	AWXY
	TERRACE	3.1	137.67	446.82	374.73	219.39
Z5_H/M/S_OT2	Story	Height	GWX	GWY	AWYX	AWXY
	TERRACE	3.1	138.03	447.89	377.68	220.94
Z5_H/M/S_OT3	Story	Height	GWX	GWY	AWYX	AWXY
	TERRACE	3.1	138.30	449.87	379.99	223.84

Observation

Highest values: The original configuration has the highest GWY (451.99) and AWYX (382.32).

Lowest values: Both GWY (446.82) and AWYX (374.73) reach their minimum at OT1

GWX: Maximum = 138.58 for the original configuration; minimum = 137.67 at OT1.

AWXY: Maximum = 227.02 for the original configuration; minimum = 219.39 at OT1

IV. VALIDATION AGAINST PUBLISHED BENCHMARK

The model validation was carried out with reference to two previously published studies: Haghollahi et al. (2012), Optimization of Outrigger Locations in Steel Tall Buildings Subjected to Earthquake Loads, presented at the 15th World Conference on Earthquake Engineering (15WCEE), Lisbon, and Samat et al. (2008), The Optimum Location of Outrigger in Reducing the Along-Wind and Across-Wind Responses of Tall Buildings, published in the Malaysian Journal of Civil Engineering. These studies investigated the influence of outrigger positioning on the structural response of tall buildings under earthquake and wind loading, respectively. Their findings indicate that effective outrigger positioning generally lies within the middle-to-lower and middle portions of the building height, depending on the structural configuration and loading conditions. Based on the comparison with these studies, the present investigation considers outrigger locations of 0.3H, 0.56H and 0.75H measured from the building base. The results identify the 0.3H location as the most effective among the configurations investigated for the non-orthogonal RCC high-rise building.

V. CONCLUSION

1. The fundamental modal time period of the building remains unchanged with variations in seismic zone and soil strata. This indicates that, the modal time period is primarily governed by the structural mass and stiffness properties.

2. The seismic zone influences the seismic demand on the structure; however, it does not alter the fundamental modal time period in the present study. This is because the seismic zone factor affects the magnitude of seismic forces rather than the inherent mass and stiffness characteristics of the structural system.

3. Similarly, variations in soil strata do not produce a noticeable change in the fundamental modal time period of the building models considered. The soil classification influences the seismic design response and corresponding spectral acceleration, while the structural modal properties remain approximately constant.

4. Among the three investigated configurations, the outrigger positioned at 0.3H where ‘H’ is height of the building exhibited the most effective structural performance. This configuration provided better control of the overall building deflection compared with the other investigated outrigger locations.

5. The effectiveness of the outrigger positioned at 0.3H was observed under different wind-speed conditions associated with the seismic zones considered in the study.

6. The comparison of different outrigger configurations demonstrates that the vertical positioning of outriggers plays an important role in controlling the lateral response of high-rise buildings. Therefore, appropriate selection of outrigger location is essential for achieving improved structural performance.

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