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Structural Behaviour of Metro Rail Piers Under Wind Forces

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***Abstract* - India is prone to severe earthquakes in the last century. More than fifty per cent area in the country is considered prone to damaging earthquakes. There is nationwide attention to the seismic vulnerability assessment of existing buildings comparatively existing bridges have less attention towards it. However, bridges are essential and critical components of transportation networks in any country. The majority of the Indian bridges were inadequately designed to resist seismic and Wind forces as per outdated building codes. The design shear capacities for short piers is found to be smaller than the corresponding shear demand under condition of flexural over strength. In case of buildings, for high rise structure, as per the structural designer, wind and earthquake load is predominant. As height of building increases it is important to understand the wind profile. In the past, many researchers have carried out wind load analyses including dynamic wind effect on high rise structure. As the height increases, the rigidity and stability of structure gets affected and it becomes necessary to design the structure preferably for lateral forces, moments, story drift and total horizontal deflection at top most story level. There are lots of literatures available to design and analyze the piers. However, the discussion and study about an arrangement and seismic performance of metro bridge pier is not done. The various wind load combinations are applied to a pier of 20 m height located in zone III. The analysis is performed using STAAD-ProV8i software. Axial force, Shear force, bending moment and storey displacement are computed.**

***Index Terms* – Displacement, Metro, Pier, Response Spectrum Analysis, Shear.**

I. INTRODUCTION

India is one of the country which is exposed to earthquakes in the world in the last few centuries. In fact, more than 50 percent of the country is affected by severe earthquakes. However, bridges are an important part of transportation for the development of a country. According to modern regulations, most bridges in India are not designed to withstand earthquakes and wind loads. The metro piers are also mostly taller compared to other bridges and also have huge lateral forces due to the effect of centrifugal forces. It is necessary to determine the specific size of the pier for the change in heights along the alignment.

II. REVIEW OF LITERATURE

Michael J. Karantzikis Constantine C. Spyrakos [1] and RNP Singh, Hemant Kumar Vinayak [10] presented the seismic analysis of bridge piers. DS Wang et al. [5] provided valuable information about the displacement-based seismic design of reinforced concrete bridge piers with the help of methods and experimental assessment is given by Hussam K. Al-Sayed et al. [16]. The main purpose of the study conducted by Ali Fadhil Naser [20] is to compare the capacities of different structural elements of bridge structures under seismic load. However, George Mylonakisa et al. [4] provided valuable information on various aspects of seismic analysis and the design of foundations supporting bridge abutments.

Bernardo Frère [6], Mohammad Farhan and Mohd Tasleem [17] and Alessandro Vittorio Bergami et al. [18] provided the pushover seismic analysis of the bridge structure. Limin Sun and Chennai Zhang [3] studied and presented the actual development of dynamic analysis considering the pier-pile-soil interaction. Mr. Apurwa Yawale and P. S. Lande [7] conducted a comprehensive review on the assessment of deterioration in bridges using pushover analysis. Fulin Yang et al. [11] have summarized the basic principles and assumptions of pushover analysis and then introduced two important factors that may make the results of the analysis different for lateral load patterns and calculation of maximum displacement. The most suitable model for modelling the non-linear behaviour of reinforced concrete bridge piers is done by Rui Faria et al. [2].

RNP Singh and Dr Hemant Kumar Vinayak [9] provided a very detailed analysis of soil-structure interactions in seismic pier analysis using force and displacement-based methods. Whereas Islam Ezz al-Arab [14] proposed three-dimensional finite element modelling of a nonlinear pushover analysis of short-span reinforced concrete (RC) bridges with circular pier cross-sections to present the effects of soil-structure interaction (SSI).

Rakhi Kulkarni et al. [8] studied the seismic performance of a proposed railway bridge with tall piers. Harshvardhan Sule Patil and ML Waikar [12] presented a literature review on metro design. Manish T. Khedikar et al. [21] studied the two main elements of an elevated metro structural system, which are piers and box girders.

A.A. Kale and Dr. S. A. Rasal [13] used advanced CSI ETABS software to analyze wind and earthquakes in complex structures. However, information on the impact of external forces on wall structures comes from Vishal V. Kamble and Dr. S.A. Rasal [15].

Aniket Bangar and Dr. S.A. Rasal [23] conducted a literature survey on the seismic performance of piers and other parts of concrete bridges under various conditions.

III. OBJECTIVES OF THE STUDIES

1. To determine the seismic performance and lateral deflections of the typical reinforced concrete Metro pier designed as per Indian codes.
2. To evaluate their various response of structure such as base shear, lateral displacement.
3. To study the effect on the pier by comparing the responses.
4. To calculate the deflection check for the wind load as per codal provision.

IV. METHODS OF ANALYSIS

A. Equivalent Static Analysis Method

The dynamic character of seismic loads must be taken into account in every designs. However, similar static linear techniques are insufficient for analyzing simple regular structures. Most of the low-to medium-rise building codes of practice allow this. For this approach Dynamic analysis isnot required.; rather, it approximates building dynamics.The static technique is the easiest because it involves less processing work and it is based on formulas in the practice code. Design foundation base shear, determined for entire building at first and after then followed by distribution together with the building's height. The resultant lateral forces are allocated to the individual's lateral load resisting equipment at each floor level.

B. Response Spectrum Method

The dynamic linear analysis approach is the response spectrum method. The highest crest responses shown by the structure during a natural disaster (earthquake) are directly calculated from the seismic response (or design) spectrum using this appropriate method. During earthquake ground motion, the assumed maximum response SDOF systemswith a particular damping and time period are represented. The maximum response can be defined in associates of max. relative displacement or max. relative displacement and is plotted versus the natural period with no dampingand for various damping levels.

V. STRUCTURAL MODELLING AND ANALYSIS

The Example considered contains seismic analysis of pile with IRS and IRC code provisions. Pile, Pile cap, and pier till the level of the flyover are designed with both the codes and. The pier above the flyover level is designed as per IRS code specifications. Viaduct levels load are calculated asper IRS and flyover level loads are calculated as per IRC. The following data is considered for analysis: Type of Structure – cantilever pier, No. of Stories –2, Zone (Z) – III, Response reduction factor (R) – 1 for Pile, Pile cap and 3 for Pier, Importance factor (I) – 1.5, Live load – As per IRS and IRC, Height of Pier – 20m, Soil strata – Hard, Density of concrete – 25 kN/m^3, Grade of Concrete M – 35 for Pile, Pile cap and M40 to M50 for Pier and M55 for Superstructure concrete and FE-500D steel is used.

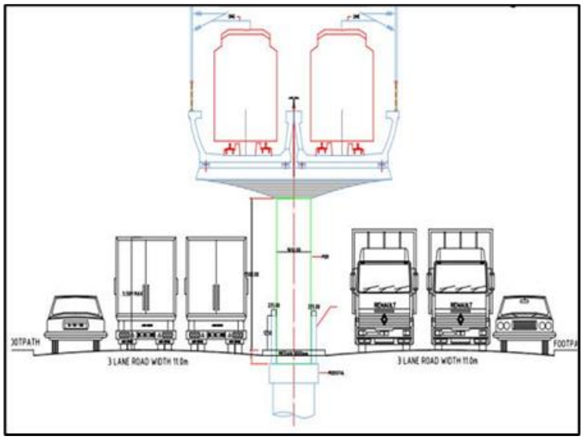

Fig. 1 Elevation of Pier for Metro

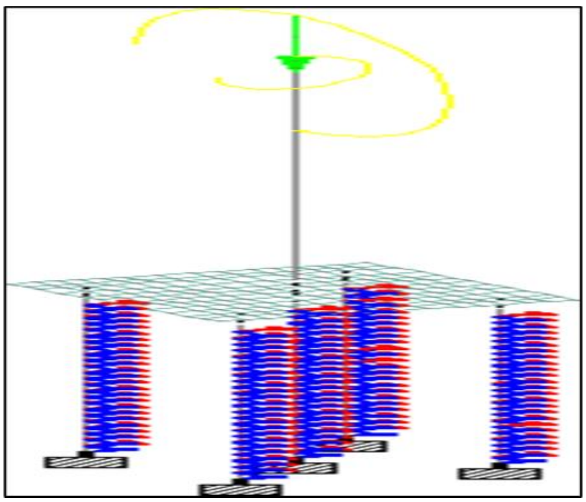

Fig. 2 Elevation of Pier and Piles model in STAAD

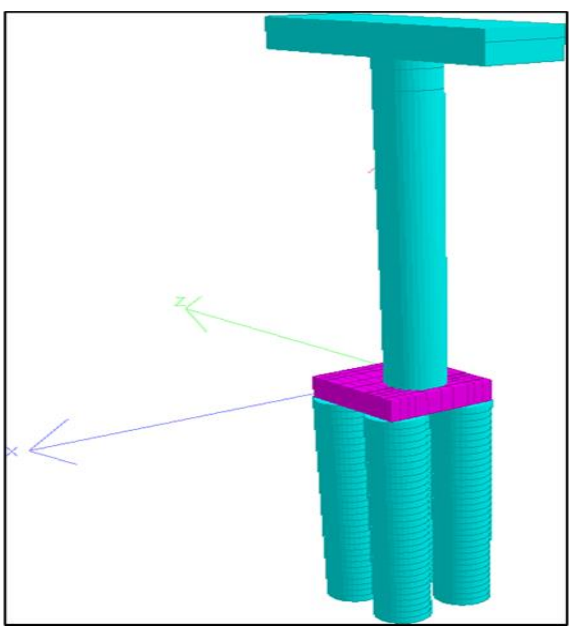

Fig.3 3D Elevation of Pier and Piles model in STAAD

VI. RESULTS & DISCUSSION

The Analytical study of displacement, base shear, in spectrum analysis for a variety of storiesof single pier is performed here. The resulting conclusions obtained from the analysis, and are mentioned down below in the paper.

A. *Pier deflections*

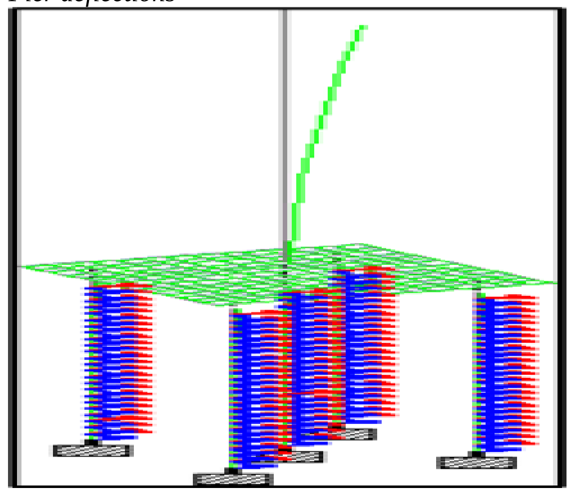

Fig.4 Pier deflection in Wind case as per UIC 776

It has been observed that Pier with Tall heights say above 20m and in curvature, spans are critical for wind case and shall satisfy UIC

Table 1: Maximum CF at pier (circular 1.8 m Diameter)

Pier Id	P222	P223	P224
Live load centrifugal force displacement (mm)	22.223	65.128	28.326
Wind Displacement at 25m/s in mm	30.322	22.125	25.324
Wind Displacement at 44m/s in mm	68.124	53.147	46.223
CF + WIND 25 in mm	52.545	87.253	53.65
WIND 44 in mm	68.124	53.147	46.223
Pier Height Pile cap top to Pier cap Top (m)	21.789	21.758	19.354
Left span (m)	18 U-G	18 U-G	18 U-G
Right span (m)	18 U-G	18 U-G	22 I-G
Allowable Displacement (mm)	31.5	31.5	31.5
Relative Displacement (mm)	34.708	34.708	33.603
Check	FAIL (10.18%)	FAIL (10.18%)	FAIL (6.67%)

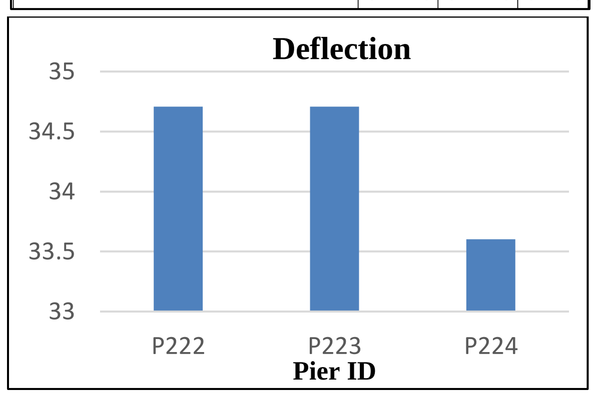

Fig.5 Maximum Lateral Displacement (mm) in Z Directionfor Circular 1.8m diameter Pier

Table 2: Maximum CF at pier (circular 2m Diameter)

Pier Id	P222	P223	P224
Live load centrifugal force displacement (mm)	19.128	60.145	25.145
Wind Displacement at 25m/s in mm	28.114	18.945	22.284
Wind Displacement at 44m/s in mm	65.125	48.552	43.286
CF + WIND 25 in mm	47.242	79.09	47.429
WIND 44 in mm	65.125	48.552	43.286
Pier Height Pile cap top to Pier cap Top (m)	21.789	21.758	19.354
Left span (m)	18 U-G	18 U-G	18 U-G
Right span (m)	18 U-G	18 U-G	22 I-G
Allowable Displacement (mm)	31.5	31.5	31.5
Relative Displacement (mm)	31.848	31.848	31.661
Check	FAIL (1.1%)	FAIL (1.1%)	FAIL (0.51%)

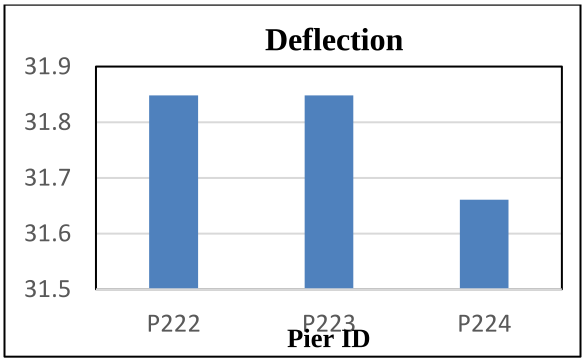

Fig.6 Maximum Lateral Displacement (mm) in Z Directionfor Circular 2.0 m diameter Pier

Table 3: Maximum CF at pier (circular 2.2 m Diameter)

Pier Id	P222	P223	P224
Live load centrifugal force displacement (mm)	18.164	39.531	14.145
Wind Displacement at 25m/s in mm	22.178	12.955	12.331
Wind Displacement at 44m/s in mm	60.327	44.831	37.251
CF + WIND 25 in mm	40.342	52.486	26.476
WIND 44 in mm	60.327	44.831	37.251
Pier Height Pile cap top to Pier cap Top (m)	21.789	21.758	19.354
Left span (m)	18 U-G	18 U-G	18 U-G
Right span (m)	18 U-G	18 U-G	22 I-G
Allowable Displacement (mm)	31.5	31.5	31.5
Relative Displacement (mm)	12.144	12.144	26.01
Check	SAFE (61.44%)	SAFE (61.44%)	SAFE (17.42%)

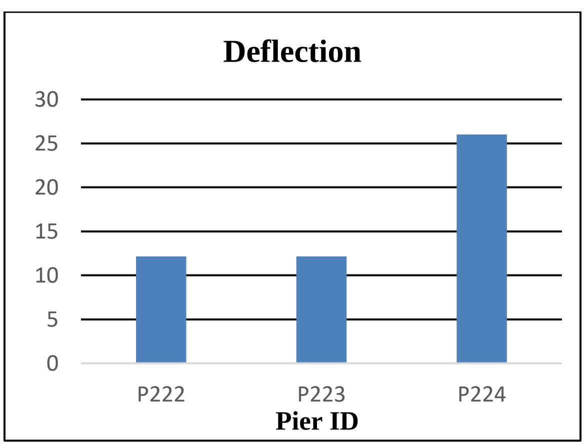

Fig.7 Maximum Lateral Displacement (mm) in Z Directionfor Circular 2.2 m diameter Pier

Table 4: Maximum CF at pier (oblong)

Pier Id	P222	P223	P224
Live load centrifugal force displacement (mm)	14.374	25.304	10.037
Wind Displacement 25m/s	17.238	7.678	8.8
Wind Displacement 44m/s	44.464	28.818	26.269
CF + WIND 25	31.612	32.982	18.837
WIND 44	44.464	28.818	26.269
Pier Height Pile cap top to Pier cap Top (m)	21.789	21.758	19.354
Left span	18 U-G	18 U-G	18 U-G
Right span	18 U-G	18 U-G	22 I-G
Allowable Displacement	31.5	31.5	31.5
Relative Displacement	10.37	10.37	14.15
Check	SAFE (67.07%)	SAFE (67.07%)	SAFE (55.07%)

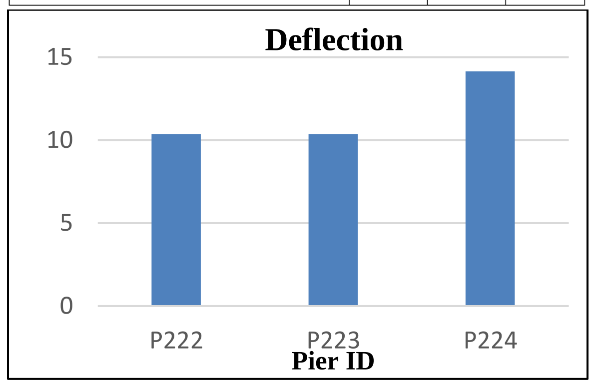

Fig. 8 Maximum Lateral Displacement (mm) in Z Direction for oblong diameter 2 × 2.2 m Pier

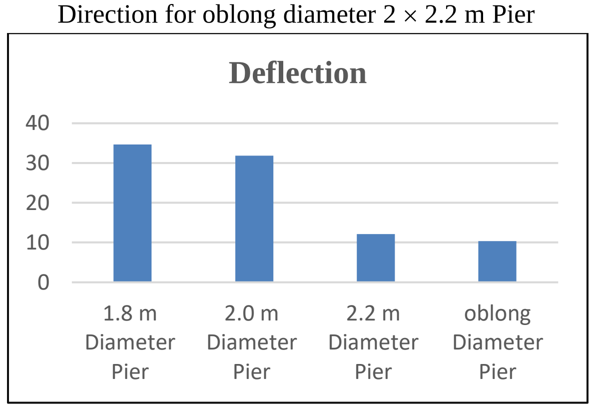

Fig. 9 Comparison of maximum lateral displacement (mm) for Z direction for different diameter pier

B. *Base Shear*

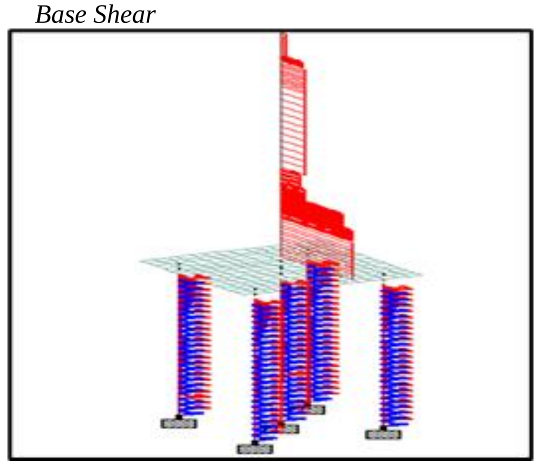

Fig.10 Base Shear in Pier

Table 5 Different height of piers on base shear -X Direction

Height (m)	Base Shear (KN) X Direction		
	P222	**P223**	**P224**
21.76	346.118	341.39	343.215
20	377.921	372.921	368.23
18	409.732	407.23	402.13
16	441.543	438.25	435.21
14	473.354	472.125	469.99
12	505.165	499.32	502.32
10	536.976	528.365	531.856

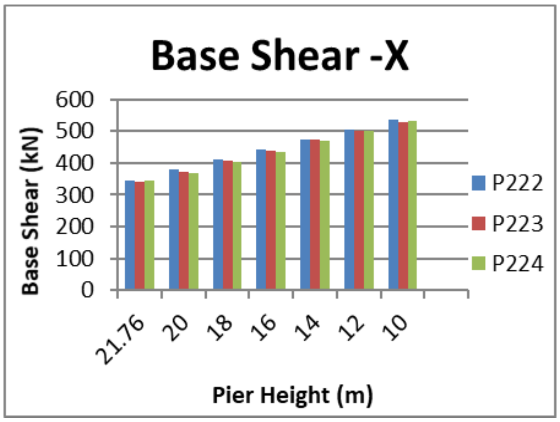

Fig.11 Base Shear (kN) in X Direction

Table 6 Different height of piers on base shear-Z Direction

Height (m)	Base Shear (KN) Z Direction		
	P222	**P223**	**P224**
21.76	321.72	317.231	319.12
20	353.531	345.21	347.85
18	385.342	382.32	379.99
16	417.153	410.53	412.23
14	448.964	436.23	441.314
12	480.775	472.31	472.36
10	512.586	504.23	506.12

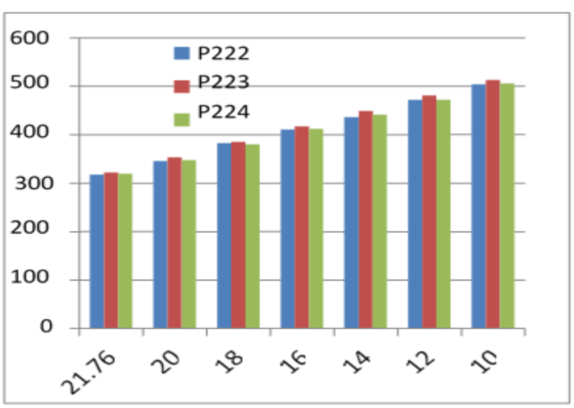

Fig.12 Base Shear (kN) in Z Direction

VII. CONCLUSION

1. The lateral displacement of pier can be reduced by increasing the shape and size of pier. Rectangular or oblong shape can be used to control the deflection criteria as per UIC code.
2. Base shear for the short pier is more than the tall piers and accordingly shear reinforcement requirement will be more.
3. The lateral deflection in the long pier with curved spans is more and the shape and size of the pier need to be changed.
4. The lateral displacement is approximately 10.18% more than permissible displacement of 31.5 mm as per UIC Code in Z direction at pier P223 for circular pier of 1.8 m diameter and the size cannot be adopted for the design of pier.
5. The lateral displacement is approximately 1.1% more than permissible displacement of 31.5 mm as per UIC Code in Z direction at pier P223 for circular pier of 2.0 m diameter respectively and the size cannot be adopted for the design of pier.
6. The lateral displacement is approximately 61.44% less than permissible displacement of 31.5 mm as per UIC Code in Z direction at pier P223 considering the 2.2 m diameter pier and size can be adopted for the design of pier.
7. The percentage reduction in the maximum displacement for pier P223 with oblong shape is approximately 67.07% in Z direction.
8. The Base shear of Pier P223 is 1.38% and 0.53% less than pier P222 and P224 respectively in X Direction.
9. The Base shear of Pier P223 is 1.41% and 0.58% less than pier P222 and P224 respectively in Z Direction.

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