

Literature Review on Design of Metro Bridge Piers

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ABSTRACT: A metro system is a railway transport system in an urban area with a high capacity, frequency and the grade separation from other traffic. An elevated metro system is more preferred type of metro system due to ease of construction and also it makes urban areas more accessible with very less construction difficulty. An elevated metro system has two major elements pier and box girder. The present study focuses on pier of an elevated metro structural system. Conventionally the pier of a metro bridge is designed using a force based approach. During a seismic loading, the behaviour of a single pier elevated bridge relies mostly on the ductility and the displacement capacity. It is important to check the ductility of such single piers. Force based methods do not explicitly check the displacement capacity during the design. The codes are now moving towards a performance-based (displacement-based) design approach, which consider the design as per the target performances at the design stage. Performance of a pier designed by a Direct Displacement Based Design is compared with that of a force-based designed one. The design of the pier is done by both force based seismic design method and direct displacement based seismic design method the study.

KEYWORDS: Elevated Metro Structure, Bridge Pier, Direct Displacement Based Seismic Design, Force Based Design

I. INTRODUCTION

A metro system is an electric passenger railway transport system in an urban area with a high capacity, frequency and the grade separation from other traffic. Metro System is used in cities, agglomerations, and metropolitan areas to transport large numbers of people at high frequency. The grade separation allows the metro to move freely, with fewer interruptions and at higher overall speeds. Metro systems are typically located in underground tunnels, elevated viaducts above street level or grade separated at ground level. An elevated metro structural system is more preferred one due to ease of construction and also it makes urban areas more accessible without any construction difficulty. An elevated metro structural system has the advantage that it is more economic than an underground metro system and the construction time is much shorter.

An elevated metro system has two major components pier and box girder. A typical elevated metro bridge model is shown in Figure 1.1 (a). Viaduct or box girder of a metro bridge requires pier to support the each span of the bridge and station structures. Piers are constructed in various cross sectional shapes like cylindrical, elliptical, square, rectangular and other forms. The piers considered for the present study are in rectangular cross section and it is located under station structure.

Box girders are used extensively in the construction of an elevated metro rail bridge. The torsional and warping rigidity of box girder is due to the closed section of box girder. The box section also possesses high bending stiffness and there is an efficient use of the complete cross section. Box girder cross sections may take the form of single cell, multi spine or multi cell as shown in Figure 1.2.



Fig. 1.1 Typical Elevated Metro Bridge and its Elements .

The current study focuses design of pier of elevated metro bridge using Force Based Design Method and Direct Displacement Based Design Method.

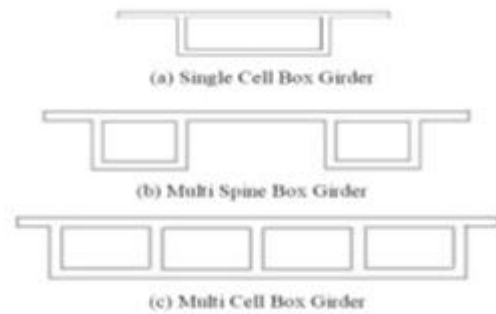


Fig. 1.2 Types of Box Girder

II. FORCE BASED DESIGN METHOD

Force Based Design Method (FBD) is the conventional method to design the metro bridge pier. In Force based design method, the fundamental time period of the structure is estimated from member elastic stiffnesses, which is estimated based on the assumed geometry of the section. The appropriate force reduction factor (R) corresponding to the assessed ductility capacity of the structural system and material is selected in the force based design and applied to the base shear of the structure.

The design of a pier by force based seismic design method is carried out as per IS 1893: 2002 Code. The design procedure to find the base shear of the pier by FBD method is summarized below.

Step 1: The structural geometry of the pier is assumed.

Step 2: Member elastic stiffness are estimated based on member size.

Step 3: The fundamental period is calculated by:

$$T = 0.075 h^{0.75}$$

Where h = Height of Building, in m

Step 4: Seismic Weight of the building (W) is estimated.

Step 5: The design horizontal seismic coefficient Ah for a structure determined by

$$A_h = \frac{Z I S_a}{2 R g}$$

Where, Z = Zone factor

I = Importance factor

R = Response reduction factor,

Sa/g = Average response acceleration coefficient

Z, I, R and Sa/g are calculated as per IS 1893:2002 Code.

Step 6: The total design lateral force or design seismic base shear force (VB) along any principal direction is given by

$$V_B = A_h W$$

Where Ah = Design Horizontal Seismic Coefficient and

W= Seismic Weight of the Building

III DIRECT DISPLACEMENT BASED DESIGN METHOD

The direct displacement based seismic design (DDBD) is proposed by Priestley et al. (2007) is used in the present study to design a metro bridge pier. The design philosophy of DDBD is based on the determination of the optimum structural strength to achieve a given performance limit state, related to a defined level of damage, under a specified level of seismic intensity. Priestley et al. (2007). The pier designed by DDBD method gives the uniform risk factor for the whole structure.

The design procedure to find the base shear of the pier by DDBD method is summarized below.

Step 1: Yield Curvature is calculated by

$$\Phi_y = (2.10 \times \epsilon_y) / h_c$$

Where, ϵ_y is the yield strain and

h_c is the section depth of rectangular column

Step 2: Yield Displacement is calculated by

$$\Delta_y = \Phi_y (H + L_{sp})^2 / 3$$

Where, H is the Column height and

L_{sp} is the Effective additional height representing strain penetration effects

Step 3: Design Displacement is lesser of

$$\Delta_d = \theta_d \times H \text{ or } \mu \times \Delta_y$$

The ductility at design displacement is, $\mu = \Delta_d / \Delta_y$

Where, θ_d = Drift limit

Step 4: Equivalent viscous damping

$$\xi_{eq} = 0.05 + 0.444(\mu - 1 / \mu \pi)$$

Step 5: Maximum spectral displacement is calculated from Design Displacement Spectra given in Priestley et al. (2007).

Step 6: Design Strength/Base Shear is given by

$$V_B = K_e \Delta_d$$

$$V_B = \left[\frac{4m_e \pi^2}{T_e^2} \frac{\Delta_{c,n}^2}{\Delta_d} \left(\frac{0.07}{0.02 + \epsilon} \right) \right]$$

Where, K_e = Effective Stiffness at peak response

T_e = Effective response period of pier

ϵ = Damping \square

$\Delta_{c,n}$ = Displacement at the corner period for n % damping.

IV. ANALYSIS RESULTS

4.1 Design of Pier Using Force Based Design

The geometry of pier considered for the present study is based on the design basis report of the Bangalore Metro Rail Corporation (BMRC) Limited. The piers considered for the analysis are located in the elevated metro station structure. The effective height of the considered piers is 13.8 m. The piers are located in Seismic Zone II, as per IS 1893 (Part 1): 2002. The modelling and seismic analysis is carried out using the finite element software STAAD Pro. The typical pier models considered for the present study are shown in figure 4.1.

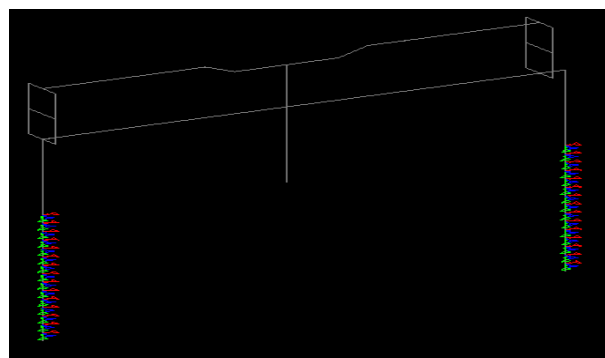


Figure 4.1: Typical Pier Model

Material Property

The material property considered for the present pier analysis for concrete and reinforcement steel are given in Table 4.1.

Table 4.1: Material Property for Pier

Properties of Concrete	
Compressive Strength of Concrete	60 N/mm ²
Density of Reinforced Concrete	24 kN/m ³
Elastic Modulus of Concrete	36000 N/mm ²
Poisson's Ratio	0.15
Thermal Expansion Coefficient	1.17 x 10 ⁻⁵ / ⁰ C
Properties of Reinforcing Steel	
Yield Strength of Steel	500 N/mm ²
Young's Modulus of Steel	205,000 N/mm ²
Density of Steel	78.5 kN/m ³
Poisson's Ratio	0.30
Thermal Expansion Coefficient	1.2 x 10 ⁻⁵ / ⁰ C

Design Load

The approximate loads considered for the analysis are shown in Table 4.2. The total seismic weight of the pier is 17862 kN.

Table 4.2: Approximate design Load

Load from Platform Level	Load (KN)	Load from Track Level	Load (KN)
Self weight	120	Self weight	160
Slab weight	85	Slab weight	100
Roof weight	125	Total DL	260
Total DL	330	SIDL	110
SIDL	155	Train Load	190
Crowd Load	80	Breaking + Tractive Load	29
LL on Roof	160	Long Welded Rail Force	58
Total LL	240	Bearing Load	20
Roof Wind Load	85	Temperature Load	
Lateral	245	For Track Girder	20
Bearing Load	14	For Platform Girder	14
		Derailment Load	80(KN/m)

The force based design is carried out for Pier as per IS 1893:2002 and IRS CBC 1997 Code and the results are shown in Table 3.3. From the FBD, it is found out that the minimum required cross section of the pier is only 1.5 m x 0.7 m for 2 % reinforcement. The base shear of the pier is 891 kN.

Table 4.3: Reinforcement Details as per Force Based Design

Pier Type	Cross Section (m)	Diameter of Bar (mm)	Number of Bars	% of Reinforcement	
				Required	Provided by BMRC
Pier Type A	2.4x1.6	32	#32	0.8%	1.48%
Pier Type B	2.4x1.6	32	#38	0.8%	1.48%

4.2 DESIGN OF PIER USING DIRECT DISPLACEMENT BASED DESIGN

The direct displacement based seismic design method proposed by Priestley et al. (2007) and IRS CBC 1997 Code is used to design of Pier Type B and the results are shown in Table 3.4. The performance level considered for the study is a Life Safety (LS) level.

Table 4.4 Reinforcement Details as per Direct Displacement Based Seismic Design

Displacement Ductility	Displacement Ductility Cross Section (m)	Base Shear V _b (kN)	Diameter of Bar (mm)	Number of Bars	% of Reinforcement Required
1	0.276	604	32	#16	1.2%
2	0.276	150	32	#12	0.8%
3	0.276	86	32	#12	0.8%
4	0.276	60	32	#12	0.8%

The parametric study is carried to know the effect of displacement ductility on base shear for different Performance levels and the results are shown in Figure 4.2. The figure shows that as the displacement ductility level increases the base shear of the pier decreases and also the difference between different performance levels is about 40 %.

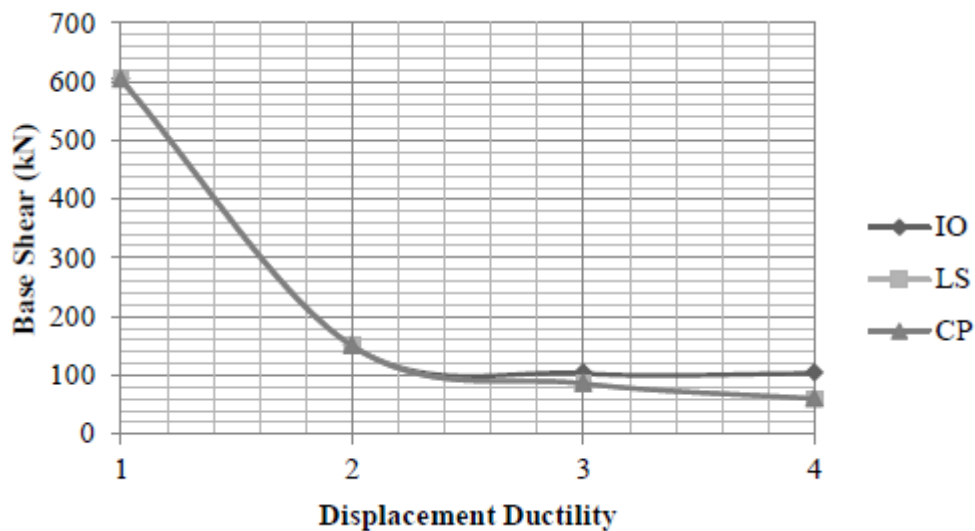


Figure 4.2: Effect of displacement ductility on base shear for different Performance levels

V. CONCLUSION

The performance assessment of selected designed pier showed that,

- Force Based Design Method may not always guarantee the performance parameter required and in the present case the pier just achieved the target required.
- In case of Direct Displacement Based Design Method, selected pier achieved the behaviour factors more than targeted Values.

These conclusions can be considered only for the selected pier. For General conclusions large numbers of case studies are required and it is treated as a scope of future work.

REFERENCES

- [1] Buchanan, J. D., Yoo, C. H., and Heins, C. P. (1974). Field study of a curved box-girder bridge. Civ. Engrg. Rep. No. 59, *University of Maryland*, College Park, Md.
- [2] Chang, S. T., and Zheng, F. Z. (1987). Negative shear lag in cantilever box girder with constant depth. *J. Struct. Eng.*, 113 (1), 20–35.
- [3] Chapman, J. C. , Dowling, P. J. , Lim, P. T. K. , and Billington, C. J. (1971). The structural behavior of steel and concrete box girder bridges. *Struct. Eng.*, 49 (3), 111–120.
- [4] Cheung, M. S., and Megnounif, A. (1991). Parametric study of design variations on the vibration modes of box-girder bridges. *Can. J. Civ. Engrg.*, Ottawa, 18(5), 789-798.
- [5] Cheung, M. S., and Mirza, M. S. (1986). A study of the response of composite concrete deck-steel box-girder bridges. *Proc., 3rd Int. Conf. on Computational and Experimental Measurements*, Pergamon, Oxford, 549-565.
- [6] Cheung, M. S., Chan, M. Y. T., and Beauchamp, T. C. (1982). Impact factors for composite steel box-girder bridges. *Proc., Int. Assn. for Bridges and Struct. Engrg. IABSE Colloquium, Zurich*, 841-848.
- [7] Sisodiya, R. G., Cheung, Y. K., and Ghali, A. (1970). Finite-element analysis of skew, curved box girder bridges. *Int. Assoc. Bridges Struct. Eng., (IABSE)*, 30 (II), 191–199.
- [8] STAAD.Pro V8i (2008). *Bentley Systems, Inc.* Research Engineers, International Headquarters, CA, USA.
- [9] Tabbal, M. M. (1972). Free-vibration of curved box-girder bridges. MEng thesis, Dept. of Civ. Engrg. and Appl. Mech., *McGill University*, Montreal.
- [10] Templeman, A. B., and Winterbottom, S. K. (1979). Optimum design of concrete cellular spine beam bridge decks. *Proc., Inst. Civ. Eng., London*, 67(2), 389–409.