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ANALYSIS OF ELEMENTS OF AN ELEVATED METRO BRIDGE

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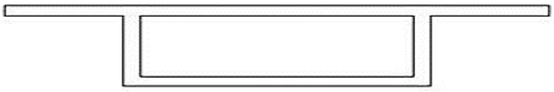
Abstract: A metro system is a railway transport system in an urban area with a high capacity, frequency and the grade separation from other traffic. Metro System is used in cities, agglomerations, and metropolitan areas to transport large numbers of people. An elevated metro system is more preferred type of metro system due to ease of construction and also it makes urban areas more accessible without any construction difficulty. An elevated metro system has two major elements pier and box girder. The present study focuses on two major elements, pier and box girder, 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 in the first part of the study.

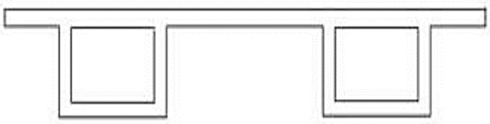
I. INTRODUCTION

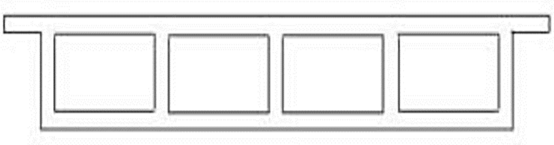
A metro system is an electric passenger railway transport system in an urban area with a high capacity, frequency and the grade separation from other traffic. Metro System is used in cities, agglomerations, and metropolitan areas to transport large numbers of people at high frequency. The grade separation 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. A typical pier considered for the present study is shown in Figure. Box girders are used extensively in the construction of an elevated metro rail bridge and the use of horizontally curved in plan box girder bridges in modern metro rail systems is quite suitable in resisting torsional and warping effects induced by curvatures.



Single Cell Box Girder

Multi Spine Box Girder





Multi Cell Box Girder

Figure 1.2: Types of Box Girder

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 3.1.

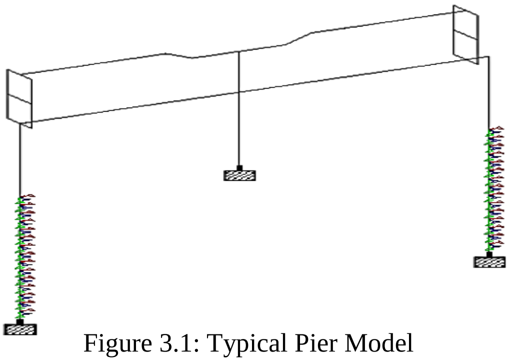


Figure 3.1: Typical Pier Model

Material Property: The material property considered for the present pier analysis for concrete and reinforcementsteel are given in Table 3.1.

Table 3.1: Material Property for Pier

Properties of Concrete	
Compressive Strength of Concrete	60 N/mm2
Density of Reinforced Concrete	24 kN/m3
Elastic Modulus of Concrete	36000 N/mm2
Poisson’s Ratio	0.15
Thermal Expansion Coefficient	1.17 x 10 -5 /0C
Properties of Reinforcing Steel	
Yield Strength of Steel	500 N/mm2
Young’s Modulus of Steel	205,000 N/mm2
Density of Steel	78.5 kN/m3
Poisson’s Ratio	0.30
Thermal Expansion Coefficient	1.2 x 10 -5 /0C

Design Load
The elementary design load considered for the analysis are Dead Loads (DL), Super Imposed Loads (SIDL), Imposed Loads (LL), Earthquake Loads (EQ), Wind Loads (WL), Derailment Load (DRL), Construction & Erection Loads (EL), Temperature Loads (OT) and Surcharge Loads (Traffic, building etc.) (SR). The approximate loads considered for the analysis are shown in Table 3.2. The total seismic weight of the pier is 17862 kN.

Table 3.2: Approximate design Load

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

Performance assessment: The performance assessment is done to study the performance of designed pier by Force Based Design Method and Direct Displacement Based Design Method. For this purpose, Non-linear static analysis is conducted for the designed pier using SeismoStruct Software and the results are shown in Table 3.5. The section considered is 1.5 m x 0.7 m. Performance parameters behaviour factor (R´), structure ductility (μ’) and maximum structural drift (Δ’max) are found for both the cases. The behaviour factor (R´) is the ratio of the strength required to maintain the structure elastic to the inelastic design strength of the structure. The behaviour factor, R´, therefore accounts for the inherent ductility, over the strength of a structure and difference in the level of stresses considered in its design. FEMA 273 (1997), IBC (2003) suggests the R factor in force-based seismic design procedures. It is generally expressed in the following form taking into account the above three components,

Where, Ve, Vy, Vs and Vw correspond to the structure’s elastic response strength, the idealised yield strength, the first significant yield strength and the allowable stress design strength, respectively as shown in the Figure 3.3.

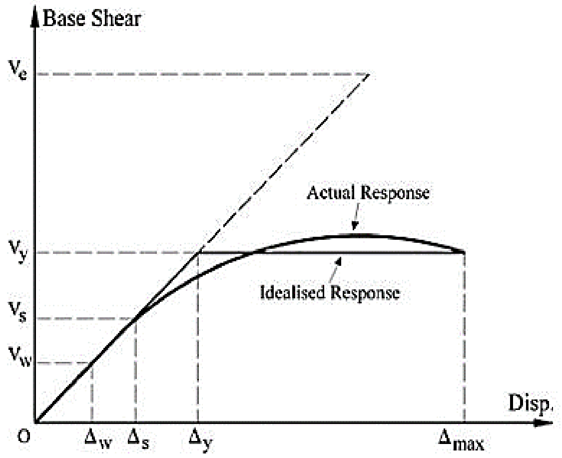
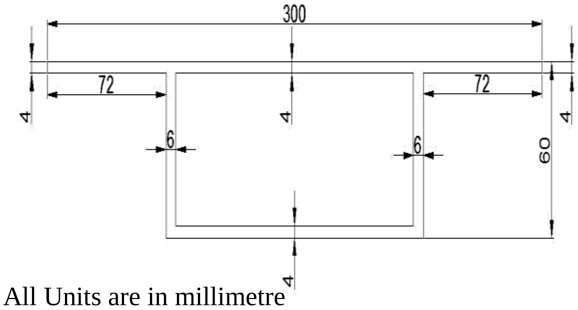


Figure 3.3: Typical Pushover response curve for evaluation of performance parameters

Validation of the finite element model: To validate the finite element model of box girder bridges in SAP 2000, a numerical example from the literature (Gupta et al., 2010) is considered. Figure 4.1 shows the cross section of simply supported Box Girder Bridge considered for validation of finite element model. Box girder considered is subjected to two concentrated loads (P = 2 X 800 N) at the two webs of mid span. Span Length assumed in this study is 800 mm and the material property considered are Modulus of elasticity (E) =2. 842GPa and Modulus of rigidity (G) =1. 015GPa. the mid span deflection of the modelled box girder bridge is compared with the literature and it is presented in the Table 4.1. From the Table 4.1, it can be concluded that the present model gives the accurate result.



All Units are in millimetre

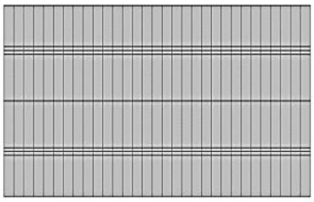
Figure 4.1: Cross Section of Simply Supported Box Girder Bridge

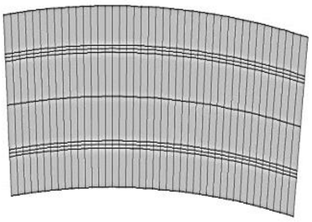
Table 4.1: Mid Span Deflection of Simply Supported Box Girder Bridge

Parameter	Gupta et al. (2010)	Present Study
Mid Span Deflection (mm)	4.92	4.91

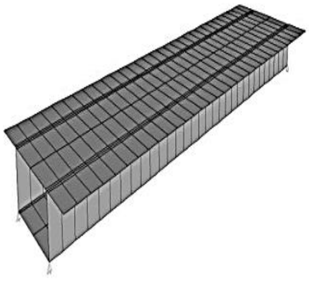
Case study of box girder bridges: The geometry of Box Girder Bridge considered in the present study is based on the design basis report of the Bangalore Metro Rail Corporation (BMRC) Limited. In this study, 60 numbers of simply supported box girder bridge model is considered for analysis to study the behaviour of box girder bridges. The details of the cross section considered for this study is given in Figure 4.2 and various geometric cases considered for this study are presented in Table 4.2. The material property considered for the present study is shown in Table 4.3.

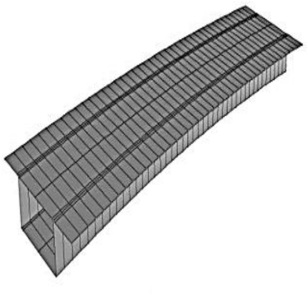
Finite element modelling: The finite element modelling methodology adopted for validation study is used for the present study. The modelling of Box Girder Bridge is carried out using Bridge Module in SAP 2000. The Shell element is used in this finite element model to discretize the bridge cross section. At each node it has six degrees of freedom: translations in the nodal x, y, and z directions and rotations about the nodal x, y, and z axes. The typical finite element discretized model of straight and curved simply supported box Girder Bridge in SAP 2000 is shown in figure 4.3(a) and 4.3(b).





Plan Plan





3D Mode

Figure 4.3(a): Discretized model of simply supported Straight Box Girder Bridge in SAP 2000

3D Model

Figure 4.3(b): Discretized model of simply supported curved box girder in SAP 2000

Parametric study: The parametric study is carried out to investigate the behaviour (i.e., the longitudinal stress at the top and bottom, shear, torsion, moment, deflection and fundamental frequency) of box girder bridges for different parameters viz. radius of curvature, span length, span length to radius of curvature ratio and number of boxes.Two lane 31 m Single Cell Box Girder (SCBG), Double Cell Box Girder (DCBG) and Triple Cell Box Girder (TCBG) Bridge are analysed for different radius of curvatures to illustrate the variation of longitudinal stresses at the top and bottom, shear, torsion, moment, deflection and fundamental frequency with radius of curvature of box girder bridges.To express the behaviour of box girder bridges curved in plan with reference to straight one, a parameter α is introduced. α is defined as the ratio of response of the curved box girder to the straight box girder.The variation of longitudinal stress at top with radius of curvature of box girder bridges is shown in Figure 4.4. As the radius of curvature increases, the longitudinal stress at the top side of the cross section decreases for each type of Box Girder Bridge. Variation of Stress between radius of curvature 100 m and 400 m is only about 2 % and it is same for all the three cases. Stress variation between each type of box girder is only about 1 %. Figure 4.5 represents a non-dimensional form of the stress variation for all the three types of box girder. It shows that stress variation pattern is same for all the three types of box girder.

II. CONCLUSIONS

The performance assessment of selected designed pier showed that the 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.The parametric study on behaviour of box girder bridges showed as the radius of curvature increases, responses parameter longitudinal stresses at the top and bottom, shear, torsion, moment and deflection are decreases for three types of box girder bridges and it shows not much variation for fundamental frequency of three types of box girder bridges due to the constant span length.As the span length increases, responses parameter longitudinal stresses at the top and bottom, shear, torsion, moment and deflection are increases for three types of box girder bridges and fundamental frequency decreases for three types of box girder bridges.As the span length to the radius of curvature ratio increases responses parameter longitudinal stresses at the top and bottom, shear, torsion, moment and deflection are increases for three types of box girder bridges and as span length to the radius of curvature ratio increases fundamental frequency decreases for three types of box girder bridges.

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