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Performance Study on a Pier Designed Using Force Based and Direct Displacement Methods

Ravinder[1], Mr. Ajit Singh[2]

1. PG Student, Deptt. Of Civil Engineering, CBS Group of Institution, Jhajjar
2. AP, Deptt. Of Civil Engineering, CBS Group of Institution, Jhajjar

Abstract-A Skytrain system is the type most preferred the metro because of the ease of construction and also makes it more accessible urban areas without any difficulty building. An elevated metro system has two major elements pier and caisson. This paper focuses only on the jetty design and performance. Typically the pier of a metro bridge is designed using an approach based on force. During a seismic load, the behavior of a single high bridge pier is essentially based on the ductility and displacement capacity. It is important to check the ductility of these simple pillars. strength based methods do not explicitly check the displacement capacity when designing. The codes are now moving towards a (based on movement) design approach based on performance, which consider the design according to the target performance design stage. In this article, the performance of a dock designed with direct displacement based design is compared to that of a designed on the basis of force. The design of a dock is done both by the strength of the seismic design method based on the method of seismic design and direct displacement based and perform ance assessment is based on both methods.

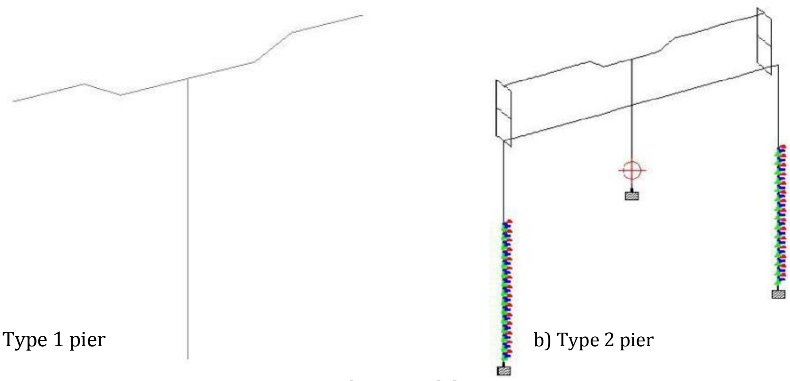
***Keywords*— Elevated Metro System, Bridge Pier, Direct Displacement Based Seismic Design, Performance Based**
Design, Force Based Design

I. INTRODUCTION

A seismic design approach based strength is typically used to design the backbone of the Metro bridge. During a seismic load, the behavior of high bridges is essentially based on the ductility and the pier displacement capacity. It is important to check the ductility of these simple pillars. strength based methods do not explicitly check the displacement capacity at the design stage. The codes are now moving towards a (based on movement) design approach based on performance, which consider the design according to the target performance design stage.

DESIGN OF PIER USING FORCE BASED DESIGN METHOD

The pillars considered for analysis are those normally adopted in the elevated subway station structure. The effective height of the pillars is considered of 13.8 m. The pillars are supposed to be located in the seismic zone II and the designs are as IS 1893 (Part 1): 2002. The modeling and seismic analysis is performed using the finite element softwar e STAAD Pro. The typical pier model is illustrated below.



a) Type 1 pier b) Type 2 pier

Fig 1. Typical pier model

A. Material Property Adopted

The material property considered for present pier analysis for concrete reinforcement and steel are given in table below.

TABLE I
MATERIAL PROPERTY OF THE PEIR

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^{-2}/ ^{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^{-2}/ ^{0}C

B. Design Loads

The burden of elementary design considered for the analysis are the dead load (DL), Super burdens (SIDL), imposed loads (LL), earthquake loads (EQ), wind loads (WL), Derailment load (DRL), Construction & Erection charges (EL), temperature loads (OT) and charges Surcharge (Traffic, building, etc.) (SR). The approximate charges considered for the analysis are presented in the table below. The total weight of the seismic pier is 17862 kN.

TABLE II APPROXIMATE
DESIGN LOADS

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

The strength-based design is performed according to Pier IS 1893: 2002 and 1997 CBC IRS Code and results are presented in the table below. From the FBD, we see that the cross section of the minimum jetty is only 1.5 m × 0.7 m to 2% reinforcement. The shear at the base of the pier is 891 kN

TABLE 33
REINFORCEMENT DETAILS AS PER FORCE BASED DESIGN

Pier Type	Cross Section	Diameter of Bar (mm)	Number of bars	Percentage of Reinforcement	
				Required	Provided
Pier A	2.4x1.6	32	#32	0.8	0.8
Pier B	2.4x1.6	32	#38	0.8	0.8

III. DESIGN OF PIER USING DIRECT DISPLACEMENT DESIGN

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

The parametric study is conducted to know the effect of the movement on ductility base shear for different levels of performance and the results are shown in Figure 2. The figure shows that the level of ductility increases the shear at the base of the lower platform and also the difference between the different levels of performance is approximately 40%.

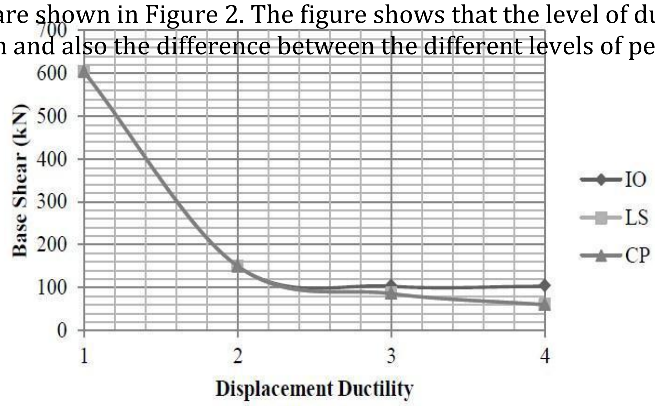


Fig 2. Effect of Displacement ductility on base shear of different Performance Levels

IV. PERFORMANCE ASSESSMENT

Performance evaluation is done to study the performance of the pier designed by the Force Based Design Method and Direct Displacement Based Design Method. For this purpose, the non-linear static analysis is performed to the dock designed using SeismoStruct Software and the results are shown in Table V. The treated section is 1.5 m x 0.7 m. performance parameters behavior factor (R '), ductility structure (μ') and the maximum structural drift (Δ'max) are found for the two cases.

The driving factor (R) is the ratio of the force required to maintain the elastic structure to the inelastic design strength of the structure. The driving factor, R ', and represents the intrinsic ductility, on the strength of the structure and the difference in the level of constraints taken into account in its design. FEMA 273 (1997), IBC (2003) suggests that the R factor in the procedures for seismic design based on force. It is usually expressed as follows in the light of the above three elements

$$,R = R_{\mu}.R_{S}.Y$$

$$R_{\mu}= V_e/V_y,\ R_S = V_y/V_s,\ Y = V_s/V_w$$

R_μ which is dependent component ductility also known as the ductility reduction factor, RS is the excessive force factor, and Y is called the allowable stress factor. Referring to Figure 3, wherein the real-forced displacement response curve is idealized by a bilinear perfectly elastic plastic response curve, the behavior factor parameters can be defined as

TABLE 44
REINFORCEMENT DETAILS AS PER DIRECT DISPLACEMENT BASED DESIGN

Displacement ductility	Drift Limit (m)	Cross Section (m)	Base Shear Vb (kN)	Diameter of Bars (mm)	No. of Bars	Percentage of Reinforcement Required
1	0.276	1.5 x 0.7	604	32	#16	1.2 %
2	0.276	1.5 x 0.7	150	32	#12	1.2 %
3	0.276	1.5 x 0.7	8	32	#12	0.8 %
4	0.276	1.5 x 0.7	6	32	#12	0.8 %

$$R'(R_w)=(V_e/V_y)(V_y/V_s)(V_s/V_w)=V_e/V_w$$

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 below.

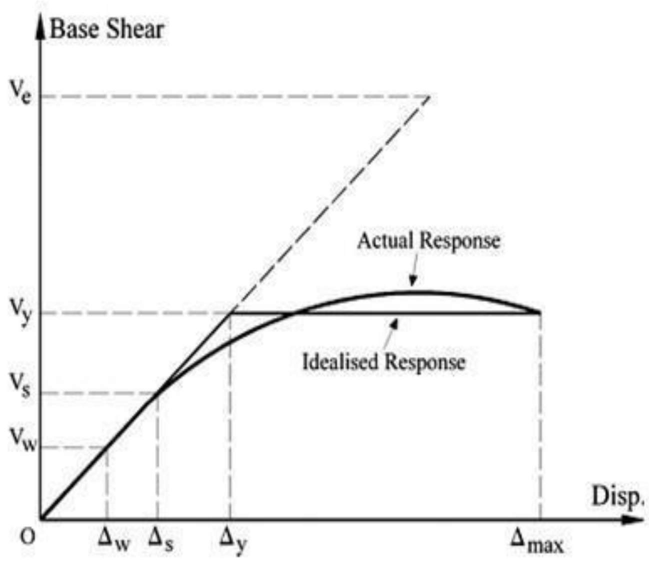


Fig 3. Typical pushover response curve for evaluation of performance parameters

The structure ductility, μ', is defined in as maximum structural drift (´max) and the displacement corresponding to the idealised yield strength (y) as,

μ' = ´max/ y

Based Design in effect, a reduction factor of force (R) 2.5 is used, and the shear core design is estimated to 891kN in the FBD. The section of the performance parameters designed using FBD behavior shows that the R factor is found to be about 2.74. The same platform is designed using a DDBD method for the target ductility and drift movement, the performance parameters structural ductility and structural drift are found for these cases. It shows that the performance parameters obtained were higher than expected in the design phase for both of DDBD. Although the FBD can not always guarantee the required performance parameter, in this case the jetty reached the target requirement. For DDBD, design considers the target displacement ductility and drift in the design stage, and this study shows that in the two examples of the method achieves DDBD behavioral factors more targeted values. These findings may be considered only for the selected platform. For general conclusions large nu mber of case studies is required.

V. CONCLUSIONS

T he paper co ncentr ates o n evaluation of performance on the pier designed by the Force Based Design and Direct Displacement Based Design is performed. The design of the pier is done both by the method of strength design based and direct design method of moving the base. The evaluation of the performance of selected designed pier showed that the Force Based Design Method can not always guarantee the performance parameter required and in this case of the pier just reached the target required. When moving Direct Based Design Method, selected pier reaches more behavioral factors that targeted values. These findings accord to only selected pier and to obtain new knowledge on the direct displacement approach many case studies should be performed.

TABLE 5
PERFORMANCE ASSESSMENT OF DESIGNED PIER

Designed			**Type of design**	**V_b (kN)**	**Percentage of Steel**	**Φ (mm)**	**No. of Bars**	**Performance Parameters Achieved**		
μ		**R**						**μ**		**R**
		2.5	FBD	891	2 %	32	#28			2.74
1	0.276		DBD	604	1.2 %	32	#16	3.5	0.35	3.25
2	0.276		DBD	150	0.8 %	32	#12	3.4	0.34	11.63

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