COMPARATIVE STUDY OF DDBD AND FBD FOR ELEVATED METRO BRIDGE SUBSTRUCTURE

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Abstract
Monorail is transportation system in mega cities, urban area where the population growth become higher. Monorail is more preferred type because of easy construction and makes without any difficulty. FBD method for seismic design of metro bridge pier mostly used. Displacement can directly related to control damage but force cannot control damage. It has limitation to control damage of structure at design stage. The performance methodologies are becoming popular in recent years. This paper conduct to seismic design of metro reinforced concrete (RC) bridge Pier using direct displacement based design (DDBD) confirming to IS provisions and strength based traditional method. Structural analysis of pier was done by both the procedures and design carried out as per Indian railway standards for different configuration were compared.
Index Terms: Direct Displacement Based Design, Elevated Metro-Rail Bridge, Force Based Design, Indian Railway Standard, Performance Based Design

I. INTRODUCTION

The main Function of the pier is to transfer the vertical loads to the foundation and to resist all horizontal forces and transvers forces on the bridge. Selection of type of piers depends upon the site conditions, soil conditions and hydraulic data. Type of pier is also affected by type of superstructure. While viaduct constructed especially in the city areas and shopping areas, the aim should be to avoid too many pillars so that the driver can have a clear unobstructed view and minimum obstruction to the flow of traffic. Piers shall be design to be safe under the worst combination of loads and forces during construction and service conditions.

For substructure (pier) analysis, seismic forces are one of the most destructive forces on the earth. Earthquake cannot stopped but design of structures can made more efficient to prevent collapse of the structures. Conventionally the pier of a metro bridge is designed using a force based method. During a seismic loading, the behavior of the single pier elevated bridge relies mostly on the ductility and displacement capacity during the design. The codes are now moving the towards a performance-based (displacement based) design approach, which consider the design as per the target performance at the design stage.

In this paper seismic analysis of substructure (pier) as per Strength based method and Performance based method. Force based design (FBD) and direct displacement based design (DDBD) methods both analysis for single degree of freedom (SODF) structure as per IRS- CBC: 2014 and RDSO guideline: 2015. Seismic analysis is carried out using STAAD pro software and analytical design results are obtain from FBD compared with DDBD. Substructure shall be design to be safe under the worst combination of loads and forces during construction and service conditions both methods and accomplished by a comparative study of different configuration.

II. FORCE BASED DESIGN AND DISPLACEMENT BASED DESIGN

The primary difference between displacement based design (DBD) method and force based design (FBD) method is that the FBD method strength is used to mean of control damage while DBD method uses displacement as measure of seismic demand and damage in structure. Displacement based design takes advantages of displacement correlates better with damage than force.

FBD method based on assumption that strength and stiffness are independent while DBD method also overcomes serious problem of FBD such as ignoring proportionality between strength and stiffness.

In force based design reduction factor (R) are given generally for a simple level 'no –collapse' design. For multi-level design would require different R-value by its specification. Displacement based design can be used with any combination of earthquake level and performance criteria.

Force reduction factor (R) are used assuming that the ductility demand will be the same for each type of structure. DBD method overcomes problem of FBD such as generalization of ductility capacity by use of force reduction factor.

FBD method use initial stiffness in the calculation of strength while in DBD method we emphasis on secant stiffness to maximum displacement.

III. DIRECT DISPLACEMENT-BASED DESIGN

The Direct Displacement Design Procedure was developed Priestley et al., with the aim of providing a greater emphasis on displacement in contrast to conventional Force Based Design by a variety of performance limit state for a specified earthquake intensity rather than being bound by the very limit state as it is the case in current regulations.

A structure is design to achieve a predefined level of displacement when subjected to a given level of seismic intensity by selecting appropriate value of drift limit. It calculates base shear corresponding to secant stiffness at effective displacement of an equivalent single-degree-of-freedom (SODF) system using substitute structure approach. The basic step of the DDBD method for Bridge piers are describe briefly.

A. *Direct Displacement Based Design*

The Design procedure are define for a SODF vertical cantilever structures.

Yield Curvature-

Yield Curvature is essentially independent of reinforcement content and axial load level, and is a function of yield strain and section depth alone. Based on the section the yield curvature are

Circular concrete column $\emptyset_y = \frac{2.25\epsilon_y}{D}$

Square/Rec. concrete column $\emptyset_y = \frac{2.10\epsilon_y}{h_c}$

Where,

$\epsilon_y = f_y / E_s$

Yield Displacement-

For SODF system, the yield displacement required for two reasons. First, is structure consider define the limit Displacement. Second, in order to calculate the displacement ductility and equivalent viscous damping. For cantilever bridge pier, yield displacement can be developed from the yield curvature as below:

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

Where,

$L_{sp} = 0.022\, f_y\, d_{bl}$

Design Displacement and Ductility-

It is comparatively straightforward to compute the design displacement from strain limits. The Design Displacement of a SDOF system. Smaller value should be considered as Design Displacement:

$\Delta_d = \mu\, \Delta_y$

or

$\Delta_d = H\, \theta_d$

Ductility at design Displacement is given by,

$\mu_\Delta = \Delta_d / \Delta_y$

Equivalent Viscous Damping-

The Design Procedure requires relationship between displacement ductility and equivalent viscous damping. The damping is the sum of elastic and hysteretic damping:

$\xi_{eq} = \xi_{el} + \xi_{hyst}$

Where, hysteretic damping depends on the hysteresis rule appropriate for structure and elastic damping for concrete taken as 0.05.

Equivalent Viscous damping for bridges is given by

$$\xi_{eq} = 0.05 + 0.444 \left(\frac{\mu_\Delta - 1}{\mu_\Delta \pi}\right)$$

Time Period-

The effective period, corresponding to design displacement and viscous damping is to be obtain from the design displacement spectra. RDSO guideline: 2015 gives the acceleration response spectrum for 5% damping for PGA of 1.0g. Figure-1 Shows displacement spectra corresponding to 2% and 5% damping for hard soil for PGA of 1.0g as per RDSO guideline: 2015. Using the, displacement Spectra can be obtain for ξ_{eq} damping.

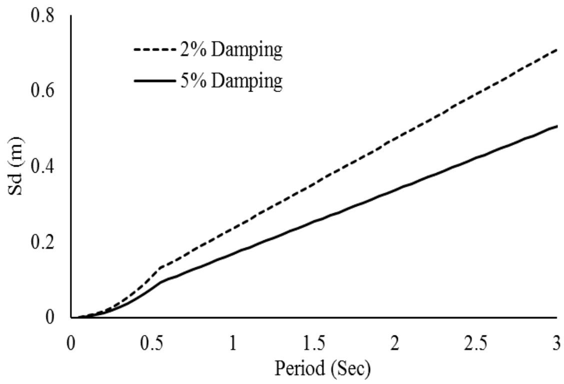


Fig. 1. Displacement spectra for Hard Soil (1.0g PGA)

Design Base Shear-

The effective stiffness K_e, of the substitute SDOF structure, derived from its effective mass m_e and effective period T_{eff} is given by

$$K_e = \frac{4\pi^2 m_e}{T_e^2}$$

The Base Shear can be determine from the relation

$$V_{base} = K_e \Delta_d$$

IV. ANALYSIS & DESIGN OF BRIDGE PIER BY FBD AND DDBD METHODOLOGIES

Seismic analysis of bridge substructure (pier) is carried out to be obtain the base shear and analyze in software. The design of several RC bridge piers. The traditional FDB method describe in IRS- CBC: 2014 and RDSO guideline: 2015 are used for analysis of pier. The bridge superstructures are simple supports box girder type and 37m length of span, pier height of 8m, 10m, 12m, 15m and the cross-sectional size are 2m diameter in circular. It is located in Zone-V and situated in hard soil condition. Response Reduction factor (R) of 4 is used for RC bridge piers. The material property considered for pier analysis for reinforcement concrete and steel are given in table-1.

Table 1. Material properties of pier

Properties of concrete	
Comp. Strength of Concrete	50 N/mm^2
Density of Concrete	25 kN/m^3
Elastic Modulus of Concrete	34000 N/mm^2
Thermal Expansion Coefficient	1.17 x 10^5 / ^0C
Properties of Steel	
Yield Strength of Steel	500 N/mm^2
Young modulus of Steel	2 x 10^5 N/mm^2
Density of Steel	78.5 kN/m^3

For design loading, consider self-weight of super structure, substructure, live load and earthquake load on the pier. The design acceleration and displacement spectrum are used, with corresponding to RDSO guideline: 2015 for hard soil for 5% damping. The pier is analyze for 3.5% target drift using DDBD method as presented in section above.

The Parameter for analysis of 12m height of pier that support 37m span on both side are presented in table-2.

Table 2. Parameter for circular pier

Data for Viaduct	
Height of Pier	12 m
Shape of Pier	Circular
Size of Pier	2 m
Effective span	35.3 m
Superstructure Quantity	207 m^3
Substructure Quantity	50 m^3
Loading Parameter	
DL of Superstructure	7365 kN
DL of Substructure	1935 kN
SIDL	666 kN
LL per wheel	160 kN
Traction Load	256 kN
Breaking Load	230 kN

The direct displacement based design carried out as per Priestley et al and the result are shown in below.

Yield Displacement (Δ_y) : 0.135 m

Design Displacement (Δ_d) : 0.42 m

Design Ductility Factor (μ_Δ) : 3.09
Viscous Damping (ξ_{eq}) : 0.145
Damping Reduction Factor (R_ξ) : 0.709
Building is located in Zone-V, so design PGA = 0.36/2 = 0.18g
Effective Response Period (T_{eff}) : 6.34 sec
Effective Stiffness (K_{eff}) : 1090 kN/m
Design Base Shear (V_b) : 458 kN

It is note that the higher T_{eff} value of 6.34 sec is for the equivalent SDOF system of the bridge pier for computing design base shear as per DDBD. The lengthening of time period (from fundamental time period to 6.34 sec) results from consideration of higher damping based on ductility which is obtain from displacement spectra. Further, for the system having more than 3.00 sec time period, the spectral acceleration are calculated as per proposed draft provision and commentary on IS 1893, RDSO guideline.

Table 3. Base shear value

Height (m)		8	10	12	15
Base Shear (kN)	FBD	993	780	937	494
	DDBD	434	443	458	481

A. DESIGN STANDARDS

Design of bridge now design by new Provisions of Indian railway standard of Research Design and Standard Organization on seismic design of railway bridges. For concrete bridge design by IRS- CBC: 2014 and IRS-Bridge substructure and foundation: 2003.

To providing the longitudinal reinforcement and transverse reinforcement as per new design load combination and to check the other design parameters.

V. RESULTS

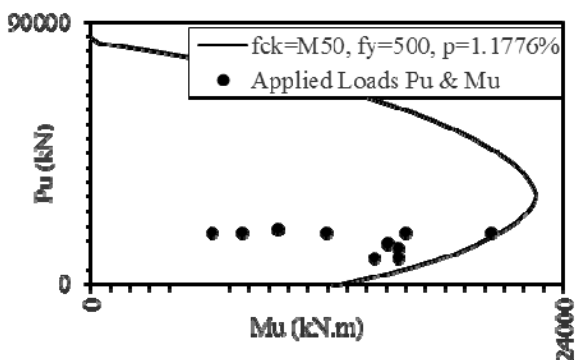
Providing reinforcement with the different load combination as per RDSO guideline and IRS: CBC. Here, in cantilever pier where the position of plastic hinge has been determine in bottom and these region detailed to secure a ductile performance, the surface between the plastic hinges is design considering the capacity of plastic hinges. Design the between plastic hinges is known as "capacity design".

Table 4. Reinforcements detail of Pier

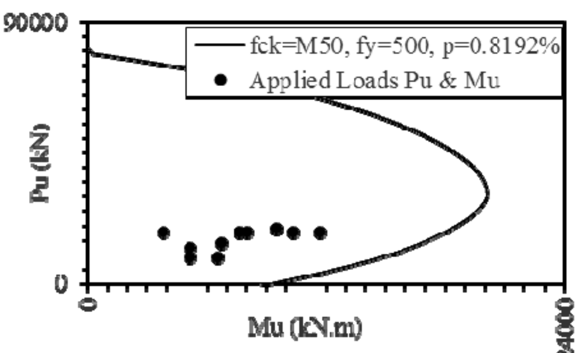
Height	FBD		DDBD	
	Pt %	No. of bar & Dia.	Pt %	No. of bar & Dia.
8 m	1.177	46nos-32#	0.819	32nos-32#
10 m	1.229	48nos-32#	0.819	32nos-32#
12 m	1.843	72nos-32#	1.229	48nos-32#
15 m	2.304	90nos-32#	2.099	82nos-32#

Comparison by Interaction curve of pier subjected to axial compression force with bi-axial bending moment for FBD and DDBD shown in fig 2.

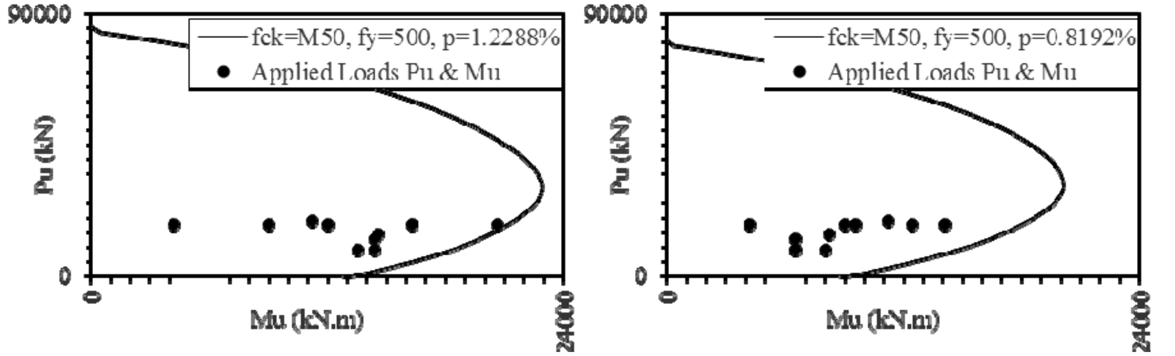
In this design, the direct displacement based design by Priestley et al. and other has been develop on Indian standard criteria for conventional bridges, to special case of reinforced pier.



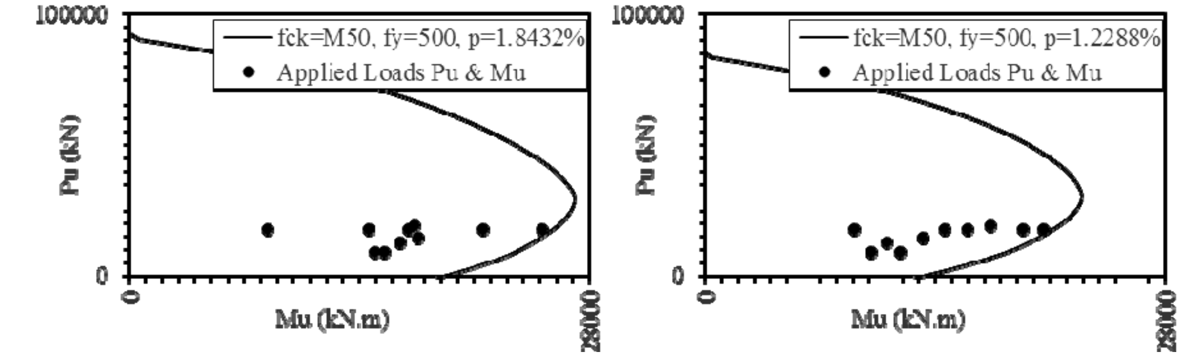
(A) 8m FBD



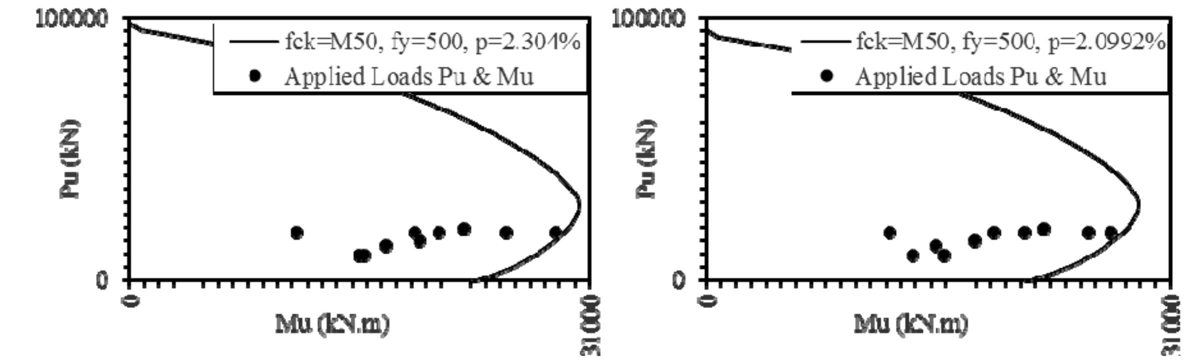
(B) 8m DDBD



(C) 10m FBD (D) 10m DDBD



(E) 12m FBD (F) 12m DDBD



(G) 15m FBD (H) 15m DDBD

Fig. 2. Interaction curve for circular column subjected to axial compression load and uniaxial bending moment with different height and comparision of FBD and DDBD methodologies

VI. CONCLUSION

In this work, Forced Based and Direct Displacement Based analysis procedure is carried out for Single Degree of freedom (SDOF) Systems. Different pier configurations are considered and following are some of the conclusions from work.

- It is seen that the difference in the base shear is significant for circular sections for seismic region.
- However, pier heights increasing the difference in the base shear is comparatively decrease & similar observations where found. In few cases, height increases the Base shear obtained from DDBD is slightly higher than that for FBD.
- From the above conclusions we can say that, as the base shear obtained is less, the resulting moment will be also comparatively lesser & hence corresponding Percentage of steel (Pt %) to be provided will be less.
- So we can say that this analytical approach strives to meet the prescribed performance objective at the optimum life-cycle cost.

This study on the seismic design of RC bridge piers designed as per the new Indian code provisions. This paper extended to multi –degree-freedom (MODF) structure with different configuration.

VII. NOMENCLATURES

D [m] sectional depth of circular column
d_{bl} [m] diameter of longitudinal reinforcement
E_s [N/mm^2] steel modulus of elasticity
f_{ck} [N/mm^2] compressive strength of concrete
f_y [N/mm^2] yield strength of steel
H [m] height of structure
h_c [m] sectional depth of square column
K_e [kN/m] effective stiffness
L_{sp} [m] strain penetration length
m_e [kN] effective mass (inertia force on pier)
p percentage of steel
R` reduction factor
T_{eff} [Sec] effective time period
V_{base} [kN] base shear
Δ_d [m] design displacement
Δ_y [m] yield displacement
ε_y yield strain of flexural reinforcement
ϕ_y [/m] yield curvature
μ design ductility factor
μ_Δ design ductility factor
θ_d drift ratio
ξ_{el} viscous damping ratio in elastic range of material response
ξ_{eq} equivalent viscous damping ratio
ξ_{hyst} hysteretic component of equivalent viscous damping ratio for DDBD

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