METRO RAIL BRIDGE PIERS BY FORCE BASED APPROACH AND DIRECT DISPLACEMENT BASED APPROACH

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Abstract — now a days the Force based design (FBD) method is used for seismic design of metro bridge pier which has limitation to damage control of structure. It is understood that Displacement can be directly related to damage control not by force. This paper contains to design of metro bridge pier using direct displacement based design (DDBD) method confirming to IS provisions and traditional strength based method. Parametric analysis of pier is considered by different circular and square cross section having different heights of 8m, 10m, 12m and 15m are carried out using FBD and DDBD procedure. The seismic assessment obtains from the analysis of the pier design using both methods are compared.

Keywords- Force Based Design, Direct Displacement Based Design, Bridge substructure, Performance Based Design, Elevated metro system

1 INTRIDUCTION

The Metro system is railway transportation system in an urban area with a high frequency and the grade severance from other traffic. Elevated metro system is more preferred type of system due to easy of construction without any difficulty. For substructure (pier) analysis, load combination with seismic forces is critical in design. Seismic forces are one of the most destructive forces on the earth. Earthquake cannot be stooped but design of structures can be made more efficient to prevent collapse of the structures.

Conventionally the pier of a metro bridge is designed using a strength based approach. 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[15,16], IS 1893(Part 1):2002[17] and RDSO guideline[13] and analytical results obtain from FBD compared with DDBD. This both methods are accomplished by a comparative study of different configuration.

2 DIRECT DISPLACEMENT-BASED DESIGN

The Direct Displacement Design Procedure was developed by Priestley et al. [1], 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 designed 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.

2.1 Direct Displacement Based Design Profile

2.1.1.1 Yield Curvature

The Yield Curvature of some different section shapes is given by following equations

Circular concrete column, $\emptyset y = \frac{2.25\epsilon y}{D}$

Rectangular concrete column, $\emptyset y = \frac{2.10\epsilon y}{hc}$

Flanged concrete beam, $\emptyset y = \frac{1.70\epsilon y}{hb}$

Symmetrical steel section, $\emptyset y = \frac{2.10\epsilon y}{hs}$

Where, ϵy (yield strain of flexural reinforcement) = (fy/Es)

2.1.1.1 Yield Displacement

For a single degree of freedom (SDOF) vertical cantilever, such as a bridge pier, the Yield Displacement can be approximated for the Design purpose by the following Equation:

$$\Delta y = \frac{\Phi y\,(H + Lsp)^2}{3}$$

Where,
Δy = Yield displacement
$\emptyset y$ = Yield curvature

H = Effective height of structure
Lsp = Effective additional height representing strain Penetration effects

2.1.1.2 Design Displacement and Ductility
It is comparatively straight-forward to compute the design Displacement from strain limits. The most realistic structure conforming to the assumptions of a SDOF approximation is a regular bridge under transverse seismic excitation.

$$\Delta d = \theta d * H \text{ or } \Delta d = \mu * \Delta y$$

Where,
θd = Drift Ratio
H = Effective Height of Pier
μ= Design Ductility
Δy = Yield Displacement
The smaller value should be considered as Design Displacement.

DUCTILITY at Design Displacement is given by,

$$\mu d = \frac{\Delta d}{\Delta y}$$

Where,
Δd = Design displacement
Δy = Yield displacement

2.1.1.3 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

$$\xi eq = 0.05 + 0.444 \left\{\frac{\mu\Delta - 1}{\mu\Delta\ \pi}\right\}$$

2.1.1.4 Time Period
The effective period Teff, 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 4.3 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 ξeq damping.

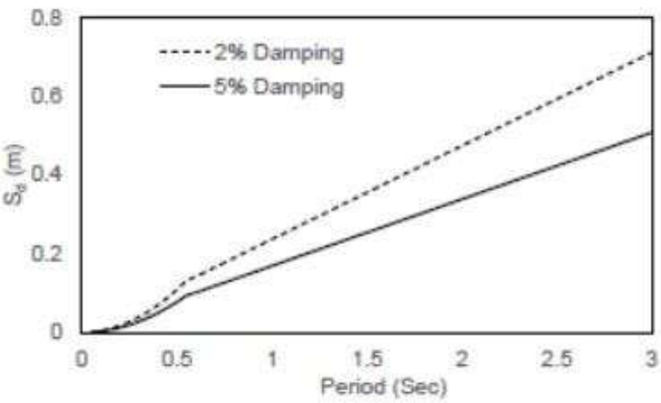


Figure 2.1 Displacement spectra for hard Soil (1.0g PGA)

2.1.1.5 Design Base Shear
The effective stiffness Keff, of the substitute SDOF structure, derived from its effective mass me and effective period Te is given by

$$Keff = \frac{4\pi^2 \text{meff}}{\text{Teff}^2}$$

Where,
Meff = effective mass (inertia force on pier)
Teff = effective time period

The **Base Shear** can be determine from the relation

$Vbase = Keff * \Delta d$

Where,

Keff = effective Stiffness

Δd = Design Displacement

For a single degree of freedom Structures the procedure ends here, the design lateral force is the corresponding base shear of the system.

3 SEISMIC ANALYSIS OF BRIDGE PIER BY FBD AND DDBD METHODOLOGIES

Seismic analysis of bridge substructure (pier) was carried out to be obtain the base shear. The design of several RC bridge piers with circular and square in shape The traditional FDB method describe in IS 1893:2002 and RDSO guideline:2015 were also used for analysis of pier. The bridge superstructures were simple supports box girder type and symmetrical with both side of 25m and 31m length of span, pier height of 8m, 10m, 12m, 15m and the cross-sectional size were 2m diameter in circular and 2m x 2m in square. It was located in Zone-V ad assumed to be constructed in hard soil condition. Response Reduction factor (R) of 4 was used for RC bridge piers.

The material property considered for pier analysis for reinforcement concrete and steel are given in table-1.

Table 3.1 material property

Properties of concrete		Properties of Steel	
Compressive Strength of Concrete	50 N/mm^2	Yield Strength of Steel	500 N/mm^2
Density of Concrete	25 kN/m^3	Young modulus of Steel	2×10^5 N/mm^2
Elastic Modulus of Concrete	34000 N/mm^2	Density of Steel	78.5 kN/m^3
Thermal Expansion Coefficient	$1.17 \times 10^5 / {}^{O}C$		

For design force loading considered was self-weight of super structure, substructure, live load and earthquake load on the pier. The substructure has to load combination (1) 1.25DL + 1.5SIDL + 1.5EQ (2) 1.25DL + 1.5SIDL + 0.5LL + 1.2EQ as per the Indian Standard code. The design acceleration and displacement spectrum were used, with corresponding to RDSO guideline: 2015 for hard soil for 5% damping. In order to compare the both the method, the pier was analysed for 3.5% target drift using DDBD method as presented in section 2. The Parameter for analysis of 10m height of pier that support 25m span on both side are presented in table-2.

Data for Viaduct		Loading Parameter	
Height of Pier	m	of Superstructure	kN
Shape of Pier	Circular	of Substructure	kN
Size of Pier	m	SIDL	kN
Effective span	23.3 m	LL per wheel	kN
Superstructure Quantity	m^3	Traction Load	kN
Substructure Quantity	m^3	Breaking Load	kN

For the given data, total seismic weight of pier 14620 kN. From the FBD, it is found out that the seismic shear of the pier is 693 kN. The direct displacement based design carried out as per Priestley et al and the result are shown in below.

Yield Displacement (Δ_y) : 0.094 m

Design Displacement (Δ_d) : 0.35 m

Design Ductility Factor (μ_Δ) : 3.71

Viscous Damping (ξ_{eq}) : 0.153

Damping Reduction Factor (R_ξ) : 0.694

Building is located in Zone-V, so design PGA = 0.36/2 = 0.18g

Effective Response Period (T_{eff}) : 5.85 sec

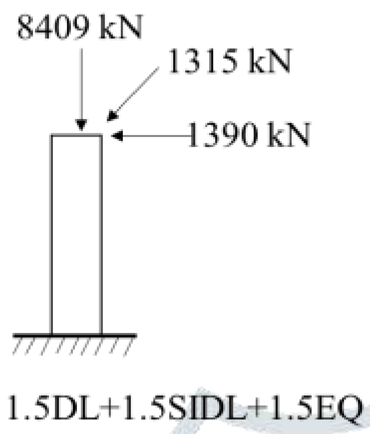
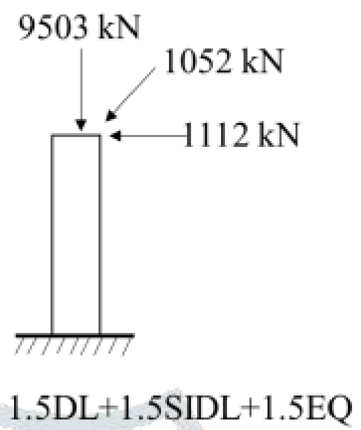
Effective Stiffness (K_{eff}) : 925 kN/m

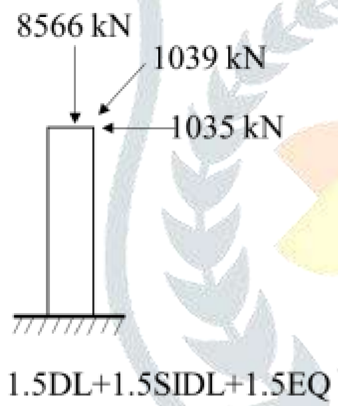
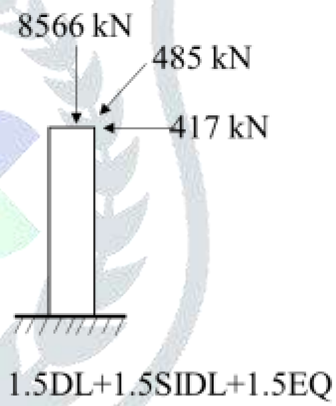
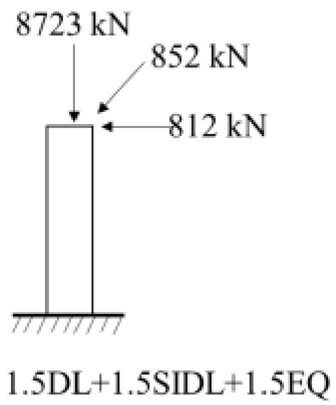
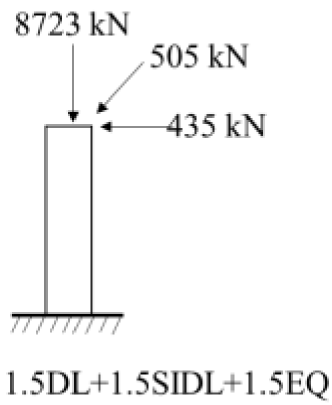
Design Base Shear (V_b) : 324 kN

It is note that the higher T_{eff} value of 5.85 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 5.85 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.

4 SEISMIC ASSESSMENT

Table 4.1 Span = 25 m, Circular 2m in diameter Pier, Zone- V, Hard Soil

Height of Pier 8m	
FBD	DDBD
	

Height of Pier 10m	
FBD	DDBD
	
Height of Pier 12m	
FBD	DDBD
	
Height of Pier 15m	
FBD	DDBD

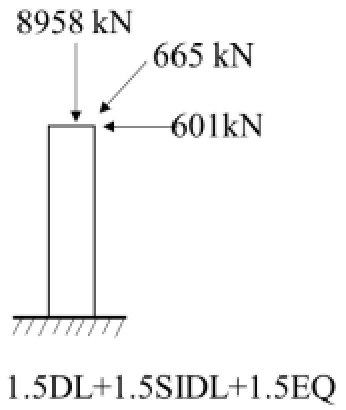
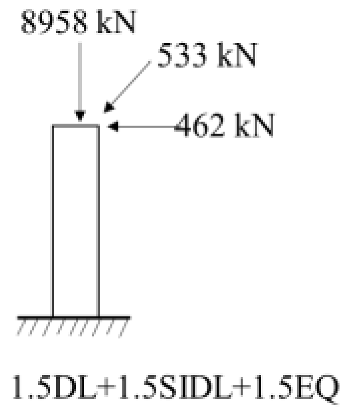
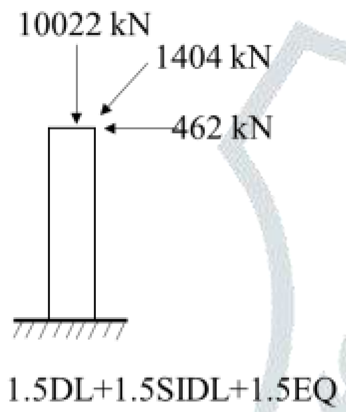
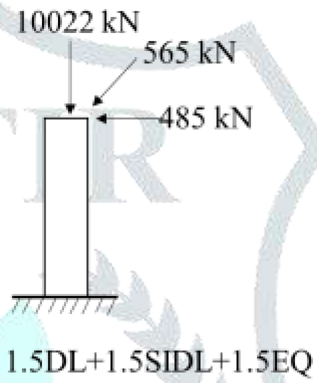
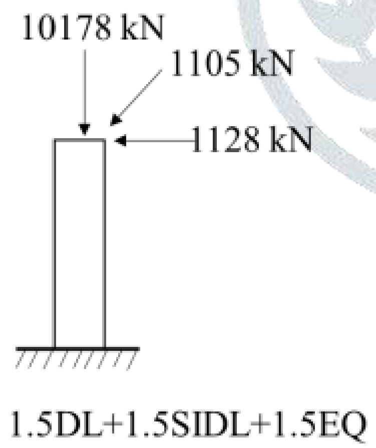
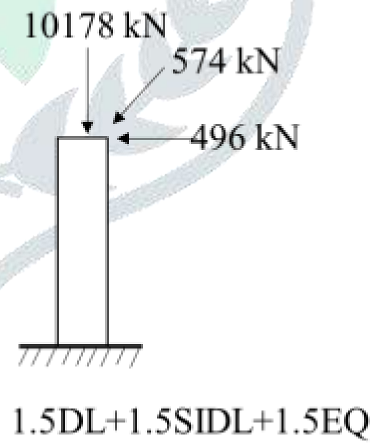
	

Table 4.2 Span = 31 m, Circular 2m in diameter Pier, Zone- V, Hard Soil

Height of Pier 8m	
FBD	DDBD
	
Height of Pier 10m	
FBD	DDBD
	
Height of Pier 12m	
FBD	DDBD

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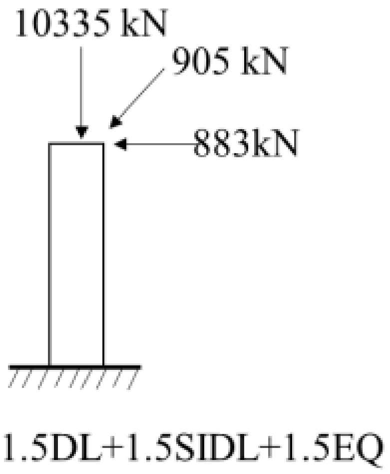
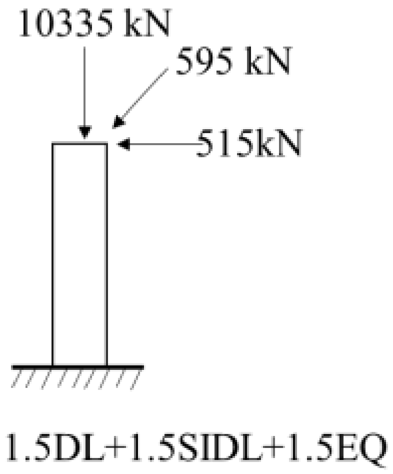
<tr><td>
</td><td>
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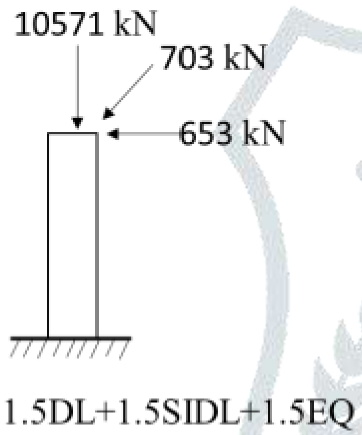
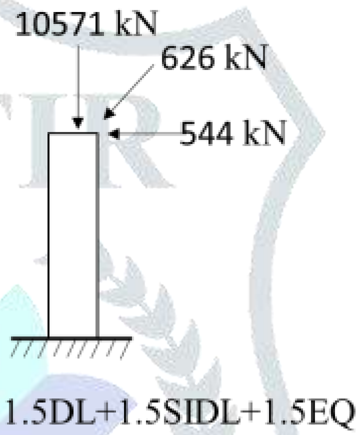
<tr><td>Height of Pier 15m</td><td></td></tr>
<tr><td>FBD</td><td>DDBD</td></tr>
<tr><td>
</td><td>
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Table 4.3 Span = 31 m, Circular 2m in diameter Pier, Zone- V, Hard Soil

<table>
<tr><td colspan="2">Height of Pier 8m</td></tr>
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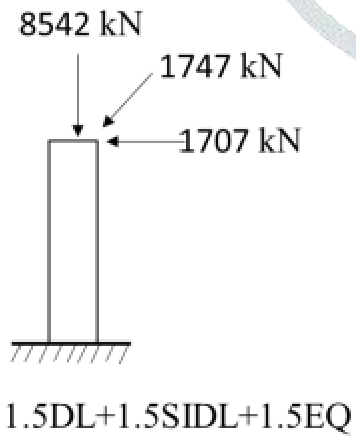
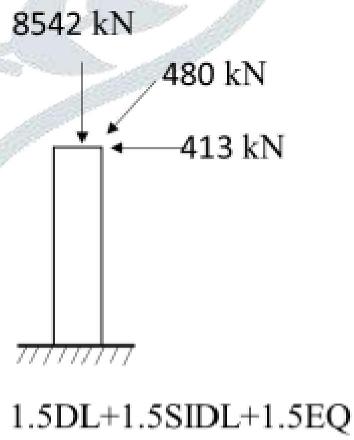
<tr><td>
</td><td>
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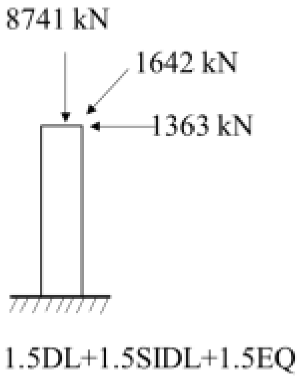
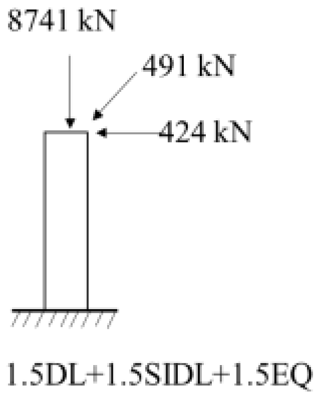
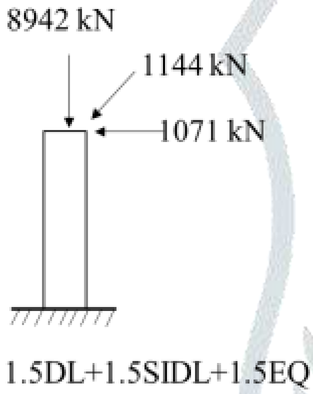
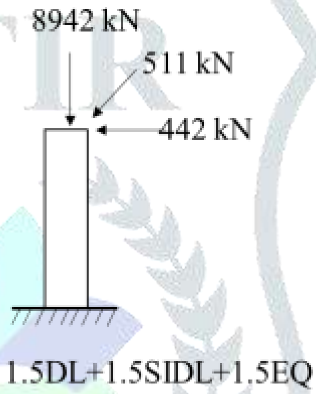
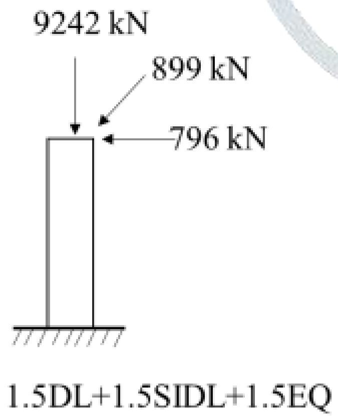
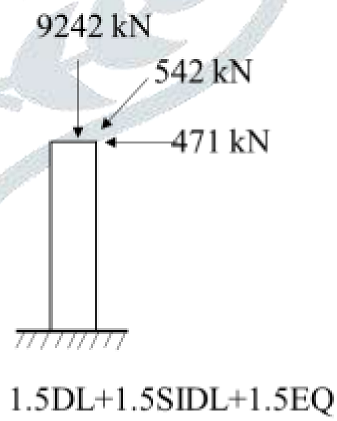
Height of Pier 10m	
FBD	DDBD
	
Height of Pier 12m	
FBD	DDBD
	
Height of Pier 15m	
FBD	DDBD
	

5 CONCLUSION

The advantages of adopting Displacement Based design is that it uses displacement as a measure of seismic demand and also as an indicator of damage in the structure & it takes advantage of the fact that displacement co-relates better with the damage than force. Another advantage of using DBD is that it can be used with any combination of earthquake level and performance criteria.

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 drawn from work.

- Difference in the base shear is significant for both rectangular and circular sections under all seismic zones.
- Pier heights increasing the difference in the base shear is comparatively decreases & similar observations were found.
- Base shear obtained from DDBD is slightly higher than that of FBD.

From the above conclusions, we can say that, as the base shear obtained is less, the resulting moment will be also comparatively reduce & hence corresponding Percentage of steel (Pt %) provided will be less.

- FBD the base shear difference was more in circular and square section. While In the DDBD is very less.

- The Direct Displacement Based Design can also be implemented on Multiple Degree of Freedom (MDOF) Bridge structures.
- The MDOF structure can be analysed for performance evaluation of results using Nonlinear Time History Analysis (NLTHA) and Pushover analysis by softwar

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