SEISMIC EVALUATION OF METRO-RAIL BRIDGE PIERS BY FORCE BASED APPROACH AND DISPLACEMENT BASED APPROACH

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ABSTRACT

Now a day the widely used the Force based design (FBD) method for seismic design of metro bridge pier has limitation to damage control of structure. It is understood that Displacement can be directly related to damage control not a force. The alternative design methods are becoming popular in recent years. 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 different circular and square cross-section having different heights of 8m, 10m, 12m and 15m were carried out using FBD and DDBD procedure. The seismic assessment obtains from the analysis of the pier design using both methods were compared.

Keyword: - *Force Based Design, Direct Displacement Based Design, Bridge substructure, Performance Based design, Elevated metro system, RC Bridge Pier*

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1. INTRODUCTION

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

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

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

$$\text{Rectangular concrete column } \emptyset_y = \frac{2.10\epsilon_y}{h_c}.$$

Where,
$\epsilon_y = f_y / E_s$
ϵ_y = Yield strain of flexural reinforcement
D, h_c = Sectional depth of circular and rectangular column section respectively.

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,
$L_{sp} = 0.022 f_y d_{bl}$
L_{sp} = strain penetration length
H = Height of Structure
d_{bl} = diameter of longitudinal reinforcement

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:

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

Where,
θ_d = Drift Ratio
μ = Design Ductility
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 T_e, 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.

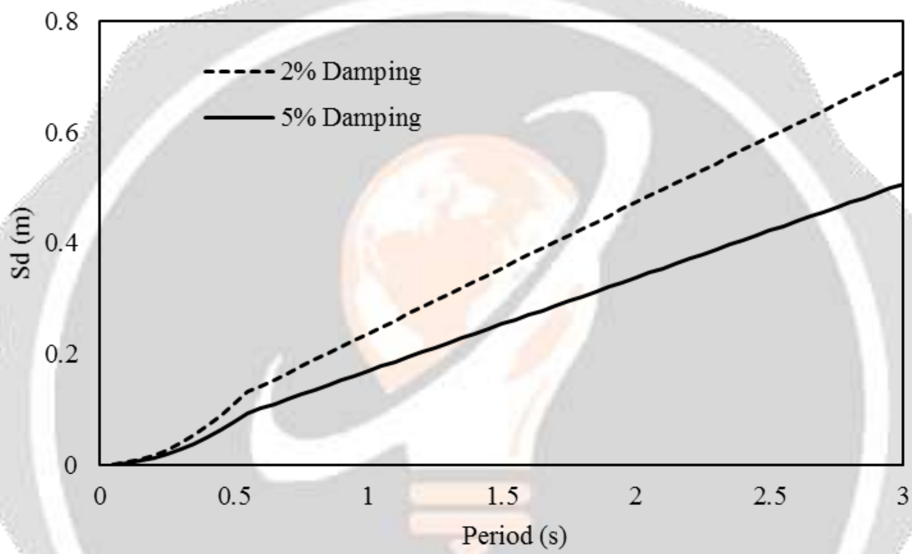


Figure -1: Displacement spectra for Hard Soil (1.0g PGA)

Design Base Shear

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

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

The Base Shear can be determine from the relation $V_{base} = K_e \Delta_d$

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 -1: Material properties of pier

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 x 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 x 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.

Table -2: Parameter for circular pier

Data for Viaduct		Loading Parameter	
Height of Pier	10 m	DL of Superstructure	7294 kN
Shape of Pier	Circular	DL of Substructure	1240 kN
Size of Pier	2 m	SIDL	450 kN
Effective span	23.3 m	LL per wheel	160 kN
Superstructure Quantity	146 m^3	Traction Load	192 kN
Substructure Quantity	50 m^3	Breaking Load	173 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

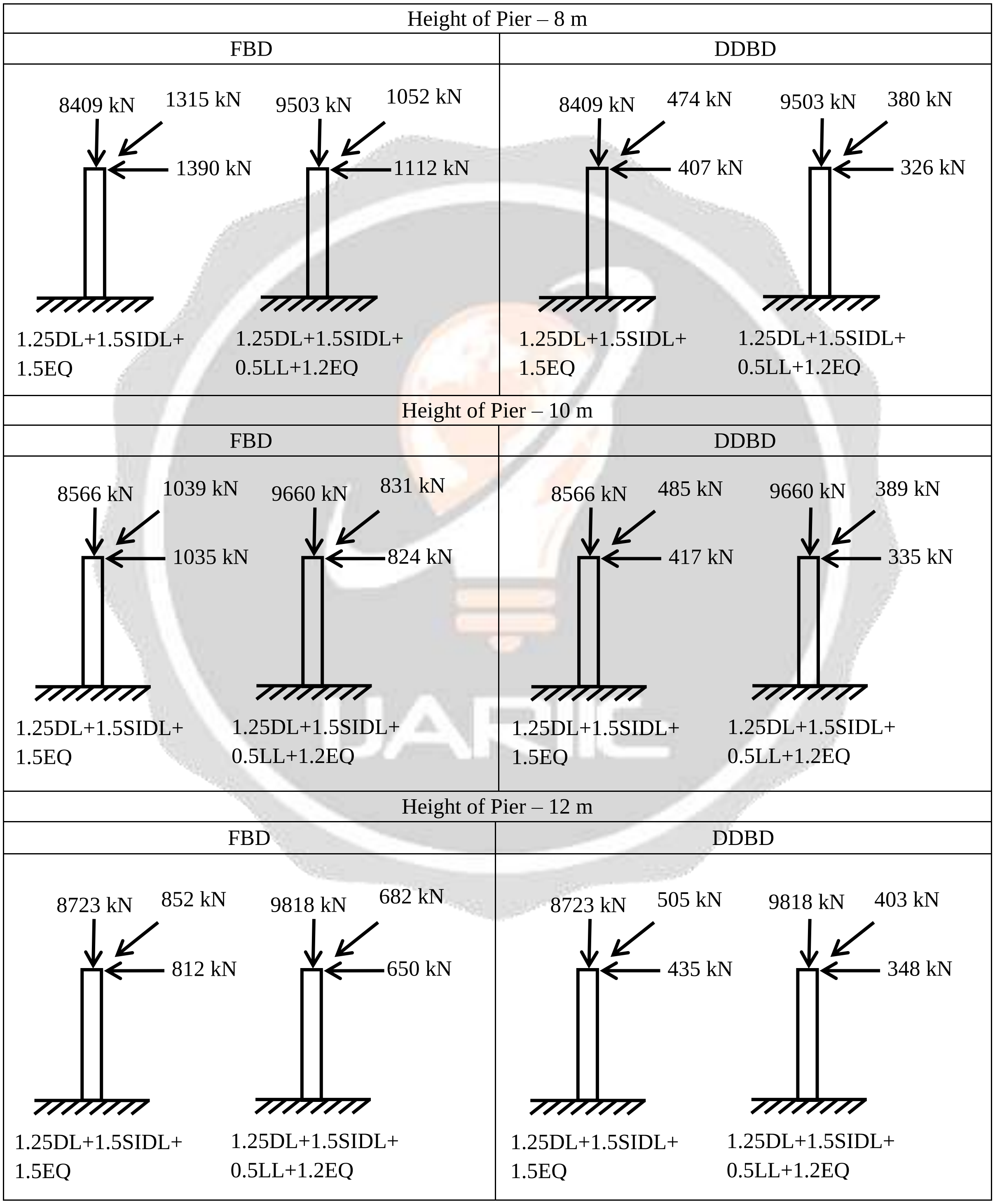
Design Base Shear (V_b) : 324 kN

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

The seismic assessment is done to compare the seismic shear on pier by Force Based Design method and Direct Displacement Based method. The analytic result is presented below in table graphical representation with design load combination.

Table -3: Span = 25 m, Circular 2m in diameter Pier, Zone- V, Hard Soil



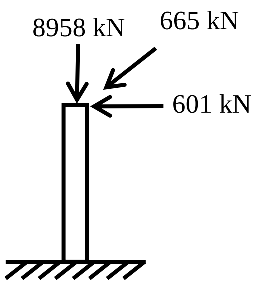
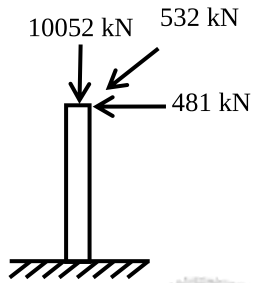
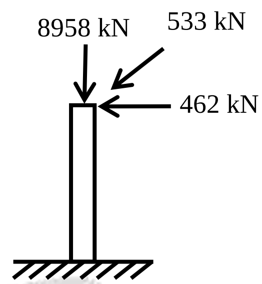
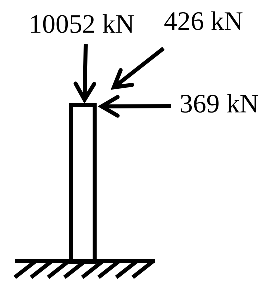
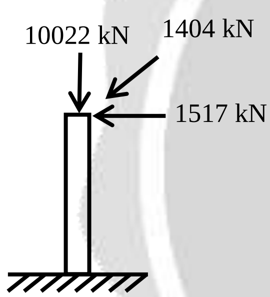
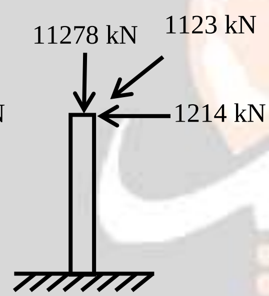
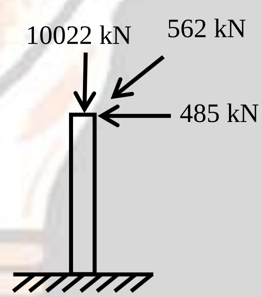
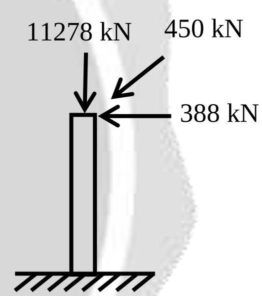
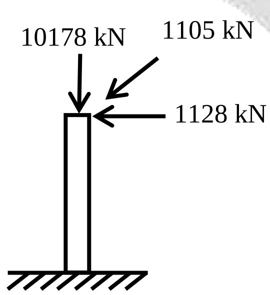
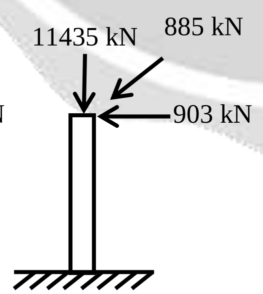
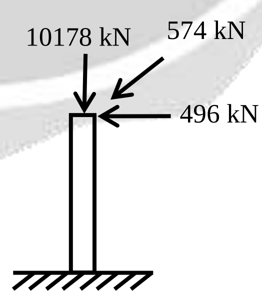
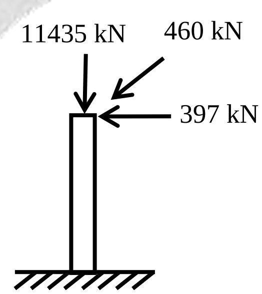
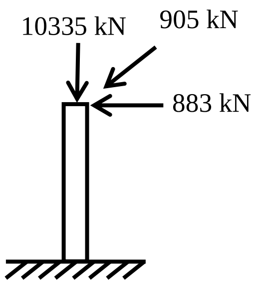
Height of Pier – 15 m	
FBD	DDBD
 1.25DL+1.5SIDL+ 1.5EQ  1.25DL+1.5SIDL+ 0.5LL+1.2EQ	 1.25DL+1.5SIDL+ 1.5EQ  1.25DL+1.5SIDL+ 0.5LL+1.2EQ

Table -4: Span = 31 m, Circular 2m in diameter Pier, Zone- V, Hard Soil

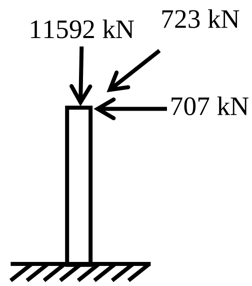
Height of Pier – 8 m	
FBD	DDBD
 1.25DL+1.5SIDL+ 1.5EQ  1.25DL+1.5SIDL+ 0.5LL+1.2EQ	 1.25DL+1.5SIDL+ 1.5EQ  1.25DL+1.5SIDL+ 0.5LL+1.2EQ
Height of Pier – 10 m	
FBD	DDBD
 1.25DL+1.5SIDL+ 1.5EQ  1.25DL+1.5SIDL+ 0.5LL+1.2EQ	 1.25DL+1.5SIDL+ 1.5EQ  1.25DL+1.5SIDL+ 0.5LL+1.2EQ

Height of Pier – 12 m

FBD

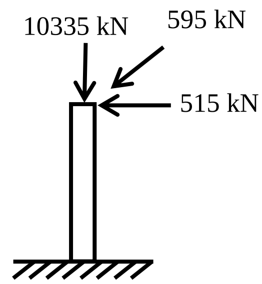


1.25DL+1.5SIDL+ 1.5EQ

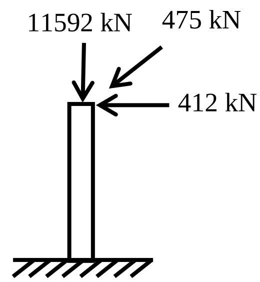


1.25DL+1.5SIDL+ 0.5LL+1.2EQ

DDBD



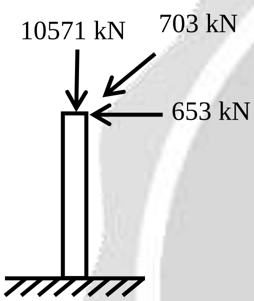
1.25DL+1.5SIDL+ 1.5EQ



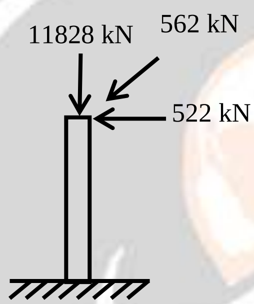
1.25DL+1.5SIDL+ 0.5LL+1.2EQ

Height of Pier – 15 m

FBD

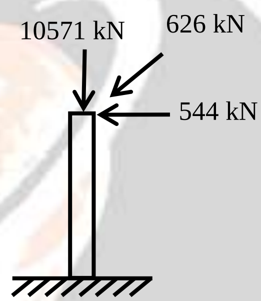


1.25DL+1.5SIDL+ 1.5EQ

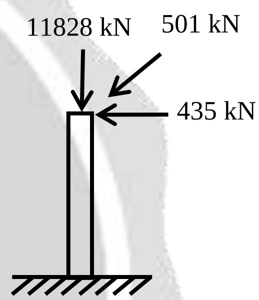


1.25DL+1.5SIDL+ 0.5LL+1.2EQ

DDBD



1.25DL+1.5SIDL+ 1.5EQ

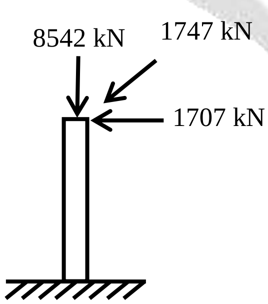


1.25DL+1.5SIDL+ 0.5LL+1.2EQ

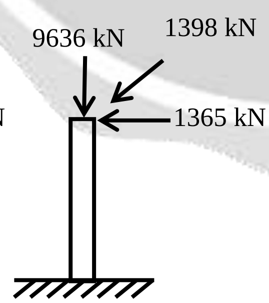
Table -5: Span = 25 m, Square 2 m x2 m Pier, Zone- V, Hard Soil

Height of Pier – 8 m

FBD

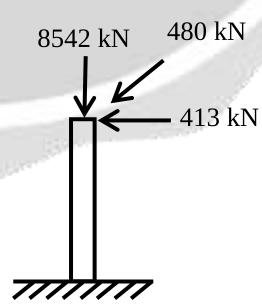


1.25DL+1.5SIDL+ 1.5EQ

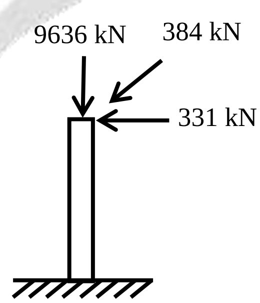


1.25DL+1.5SIDL+ 0.5LL+1.2EQ

DDBD



1.25DL+1.5SIDL+ 1.5EQ



1.25DL+1.5SIDL+ 0.5LL+1.2EQ

<table>
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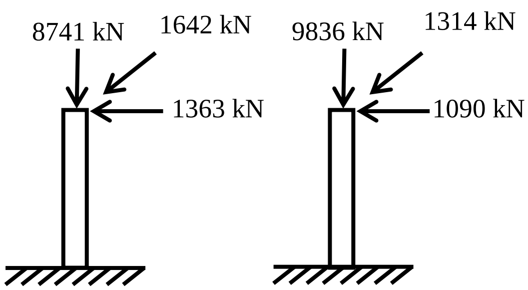
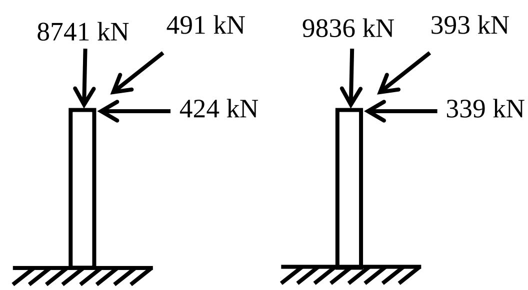
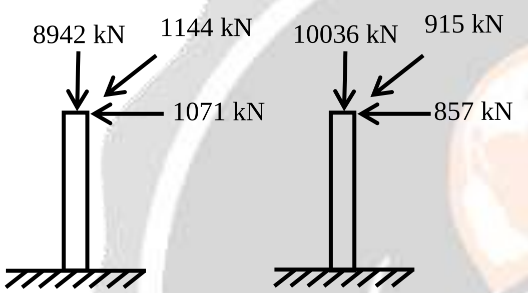
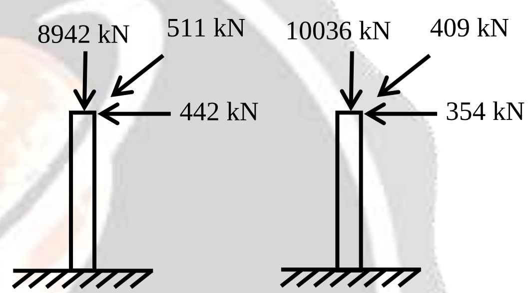
<tr><td>

1.25DL+1.5SIDL+1.5EQ
1.25DL+1.5SIDL+0.5LL+1.2EQ</td><td>

1.25DL+1.5SIDL+1.5EQ
1.25DL+1.5SIDL+0.5LL+1.2EQ</td></tr>
<tr><td colspan="2">Height of Pier – 12 m</td></tr>
<tr><td>FBD</td><td>DDBD</td></tr>
<tr><td>

1.25DL+1.5SIDL+1.5EQ
1.25DL+1.5SIDL+0.5LL+1.2EQ</td><td>

1.25DL+1.5SIDL+1.5EQ
1.25DL+1.5SIDL+0.5LL+1.2EQ</td></tr>
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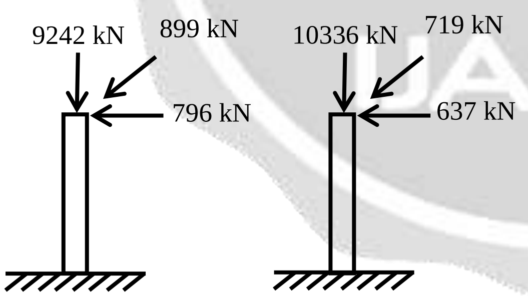
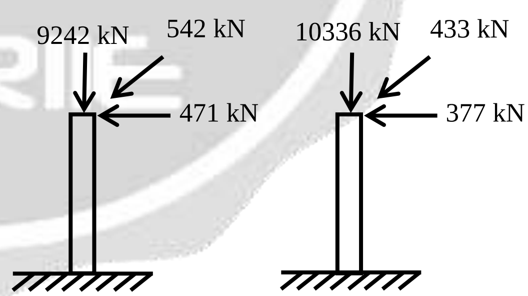
<tr><td>

1.25DL+1.5SIDL+1.5EQ
1.25DL+1.5SIDL+0.5LL+1.2EQ</td><td>

1.25DL+1.5SIDL+1.5EQ
1.25DL+1.5SIDL+0.5LL+1.2EQ</td></tr>
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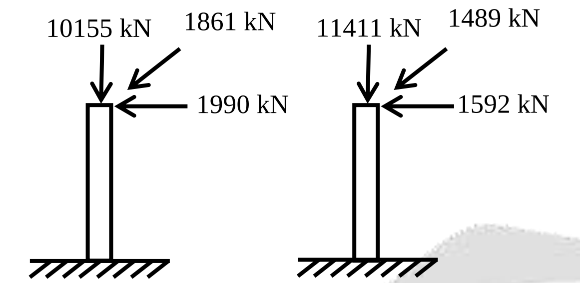
Table -6: Span = 31 m, Square 2m x 2m Pier, Zone- V, Hard Soil

Height of Pier – 8 m

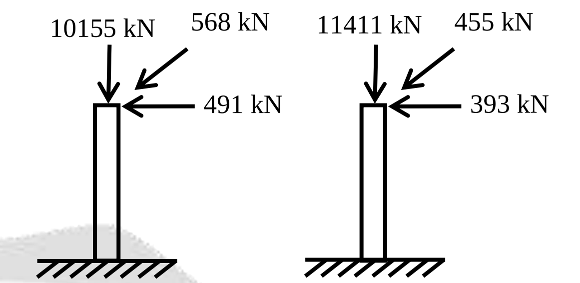
FBD



1.25DL+1.5SIDL+ 1.5EQ

1.25DL+1.5SIDL+ 0.5LL+1.2EQ

DDBD

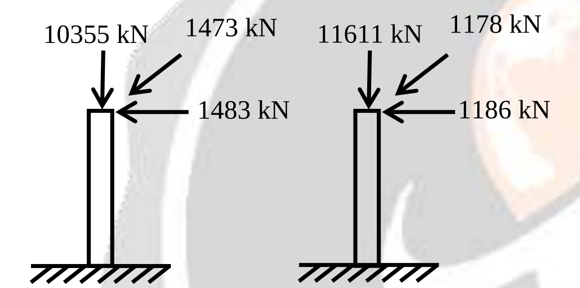


1.25DL+1.5SIDL+ 1.5EQ

1.25DL+1.5SIDL+ 0.5LL+1.2EQ

Height of Pier – 10 m

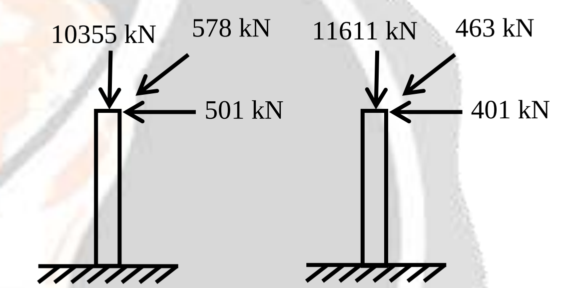
FBD



1.25DL+1.5SIDL+ 1.5EQ

1.25DL+1.5SIDL+ 0.5LL+1.2EQ

DDBD

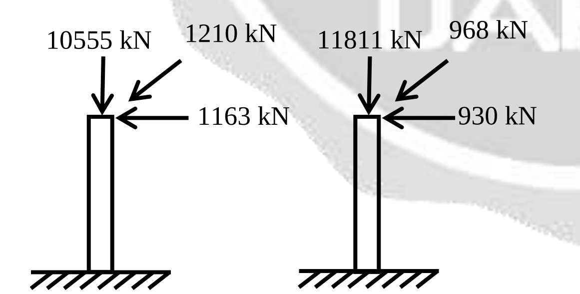


1.25DL+1.5SIDL+ 1.5EQ

1.25DL+1.5SIDL+ 0.5LL+1.2EQ

Height of Pier – 12 m

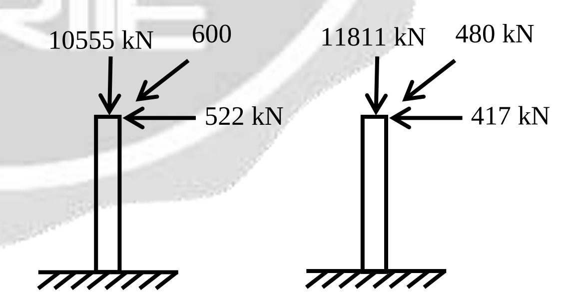
FBD



1.25DL+1.5SIDL+ 1.5EQ

1.25DL+1.5SIDL+ 0.5LL+1.2EQ

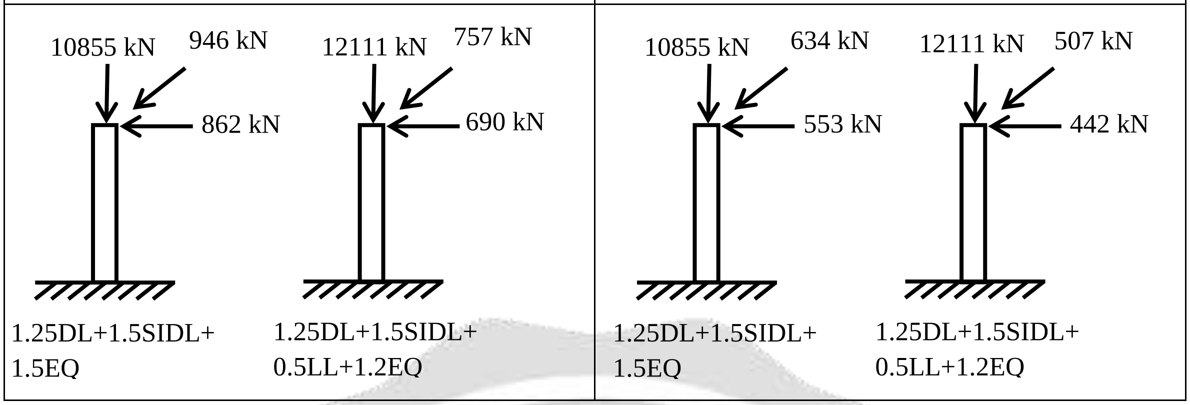
DDBD



1.25DL+1.5SIDL+ 1.5EQ

1.25DL+1.5SIDL+ 0.5LL+1.2EQ

Height of Pier – 15 m	
FBD	DDBD



In this graphical view, the horrizontal arrow is indicate the longitudnal direction and inclined is transverse and other remain is in global gravity force on pier.

5. CONCLUSION

In this paper, reinforced bridge pier of 8m, 10m, 12m and 15m height with 25m and 31m span were analysed using direct displacement based design (DDBD) and traditional forced based design (FBD) method as per RDSO: 2015. It is observed that the difference in the design loading is significant for both square as well as for circular section for all seismic zones, when pier height increas lateral load decreases. The seismic shear of pier by DDBD is less compared to FBD. As DDBD method for pier attrect lesser seismic force compared to FBD, Which results in to saving of material. The work can be extended by detail design of both the methodologies to get accurate result and the same can be implimanted on Multi-Degree-Freedom (MODF) bridge structures by doing performance evaluation of results using pushover analysis and nonliner time historey analysis (NLTHA).

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