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EFFECT OF SOIL STRUCTURE INTERACTION ON RESPONSE REDUCTION FACTOR FOR PIER OF SKEW BRIDGE

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ABSTRACT

Bridges are inevitable structures which plays an important role in the development of the country. The bridge design should be strong, economical and safe during earthquake. In the present study, pier of skew bridge is analyzed using FEM based software MIDAS Civil. For the analysis of the pier, displacement controlled nonlinear static pushover analysis method is used. The primary aim of the study is to compare Response Reduction Factor with and without consideration of soil structure interaction on pile foundation as per Applied Technology Council (ATC – 19). After comparison, it is observed that base shear has been decreased up to 20% and time period increases up to 14% while considering soil structure interaction.

Keywords: *Skew Bridge Pier, Response Reduction Factor, Push Over Analysis, Soil Structure Interaction.*

I. INTRODUCTION

Bridges are important structures built to span without closing the way underneath like valley, road or water for purpose of providing passage over the obstacle. In recent days, skew bridges have increased considerably for highways and railways to meet the serval requirements like man-made obstacles and interaction in the mountain terrains. In case of seismic events, it is essential to design skew reinforced bridge for safe transportation.

Majority of structures include sub-structures which are in direct contact with the soil. When lateral forces like earthquake exert on these systems, neither the structural displacements nor the ground displacements, are free of each other. From past studies, it should be concluded that seismic demand of bridge component pier depends on the structure inelasticity and soil structure interaction. Strength differential and suitable inelastic deformation can only be achieved by the provision of suitable response reduction factor.

Ansari and Agarwal [1]carried out study of response reduction factor based on the two different methods moment-curve method for single cantilever pier and pushover analysis for simply supported bridge supported on two piers with the flexible and fixed condition, using SAP2000. They observed reduction of the aspect ratio as response reduction factor increases. Ezz El Arab [2] analyzed soil structure interaction on nonlinear static pushover analysis for the short span existing RCC bridge using the different type of soil and concluded that base shear and displacement decrease with the SSI. Aswathi and Jayalekshmi [3] carried out soil SSI with the different cross section of pier, height and observed that increase in height increases displacement and shear value based on the cross-section.

II. OBJECTIVE OF STUDY

To design a safe foundation, substructure as well as super structure knowing well that actual behaviour of bridge during the external force may change if soil structure interaction effect is not considered in the analysis. The main objectives of the study are,

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- To determine response reduction factor for Skew Bridge Pier.
- To compare response reduction factor without SSI and with SSI for the bridge pier.

III. VALIDATION OF WORK

Validation of work done with the findings of Swami and Panchal [4]. They carried out work on the displacement and bending moment of different pier with the different soil conditions. The results of bending moment and displacements of pier-1 computed are shown in the Table 1.

Table:

Table 1 Comparison results of Displacement and Bending Moment

Displacement and Bending Moment for loose soil		**Unit**	**Swami & Panchal (2018)**	**Result of present study**	**% Error**
Pier-I	Longitudinal Displacement	mm	6.69	6.70	0.14
	Vertical Displacement	mm	0.93	-0.920	1.07
	Transverse Displacement	mm	-4.79	-4.78	0.20
	Bending Moment	kNm	925.1	926.1	0.10

IV. RESPONSE REDUCTION FACTOR FORMULATION

The response reduction factor is used to decrease the elastic force demand to the design force demand in a particular component of structure. It gives an indication level of over strength and ductility that any structure should have. Consequently, the structure should be designed for much lower force. This *R*-factor mainly depends on the three-factor which is over strength, ductility and redundancy factor. According to ATC-19 [5], the *R* factor mathematically expressed as,

$R = R_S \times R_R \times R_\mu$

where Rs = Over-strength factor

$R\mu$= Ductility factor

R_R = Redundancy

V. BRIDGE DESCRIPTIONS

The Existing Railway Over Bridge (R.O.B) in Bhavnagar is chosen for this research. The structure is of single span simply supported reinforced skew bridge of length of 37.2m. The carriageway width is 13.4m with three lanes of traffic. The structural steel plates girders are used to support RC deck slab. The depth of fixity is given in the piles as per IS-2911 [6]. MIDAS Civil is used to build the finite element model of skew bridge substructure with pile foundation as shown in Figure 3. The plan of skew bridge and section of pier as shown in Figures 1 and 2.

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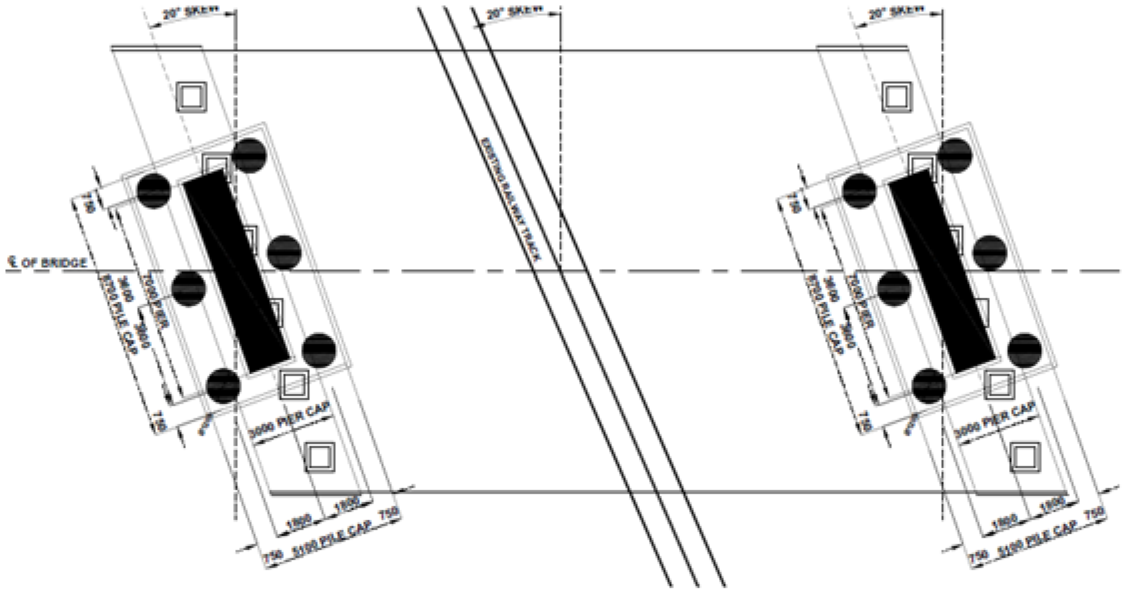

Figure 1. Plan of skew bridge

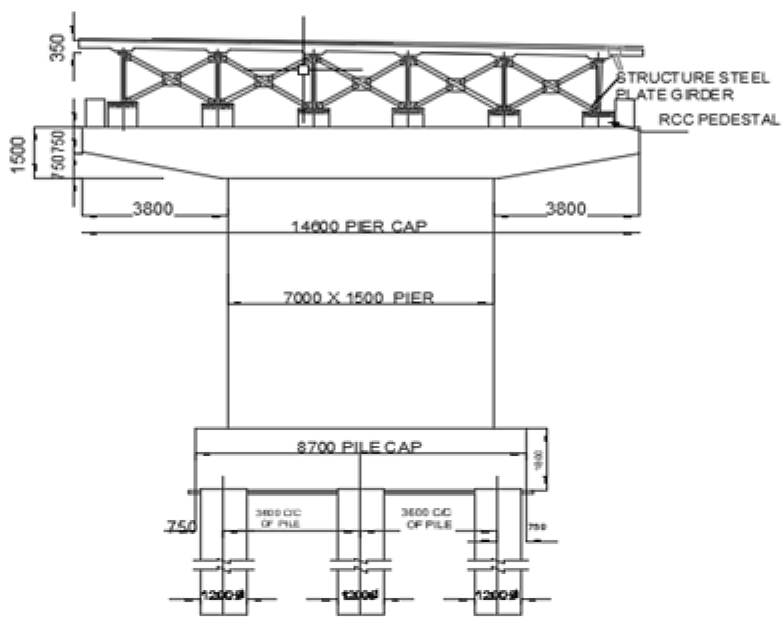

Figure 2. R. O. B Bent cross section

Table:

Table 2 Geometric details of the bridge

Geometrical details	
Pier	7 m × 1.5 m
Pier cap	14.6 m × 1.5 m
Skew angle	20^o
Pile length	25 m
Pile Diameter	1.2 m
Pile cap	8.7 m × 3 m
Pier height	9.2 m
Concrete grade	M-45
Grade of steel	Fe-500
IRC loading	Class AA &A

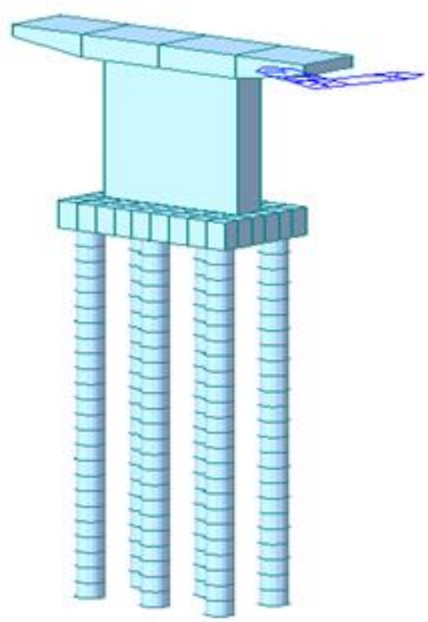

Figure 3. Midas civil substructure model

Dynamic analysis as Response spectrum is done to analyze the actual behaviour of structure and static analysis is also performed for self-weight and live load based on the empirical formula and calculation as per IRC- 6 code [7]. Total load taken on the structure is given in Table 3.

Table:

Table 3 Loads on the substructure

Loading condition	**Loading value**
Dead Load	558.68 kN
Longitudinal moment	896.76 kNm
Transverse moment	3893.439 kNm

VI. SOIL STRUCTURE INTERACTION (SSI) WITH PILE FOUNDATION

In structure design, pile foundation settlement is calculated without consideration of the influence of soil structural stiffness. Interaction effect is ignored to simplify the mathematical model but avoiding the interaction between soil and structure may result in a design that is not safe. In the present study, spring stiffness for the pile foundation MIDAS Civil equation given by Broms [8-10] has been used, which is expressed below in Tables 4 and 5.

Table:

Table 4. Expressions for stiffness of equivalent soil spring

Soil spring stiffness (Mode)	For Sand soil	For clay soil
Lateral	$P_u = A_\gamma X[C_1 + C_2 + C_3 - C_4]$ $C_1 = \dfrac{K_O X \tan\emptyset` \sin\beta}{\tan(\beta - \emptyset`)\cos\alpha}$ $C_2 = \dfrac{\tan\beta}{\tan(\beta - \emptyset`)}(D + X\tan\alpha\tan\beta)$ $C_3 = K_O X \tan\beta\,(\tan\emptyset` \sin\beta - \tan\alpha)$ $C_4 = K_a D$ $\alpha: \emptyset`/2$ $\beta: 45° + \emptyset`/2$	$P_u = D[3s_u + \gamma X + J c_u/D]$
	$P_u = P_u \times A$ $P_m = P_m \times A$ $P_k = P_k \times A$	
Vertical	$K_{tan} = D \times K_O \times \gamma \times X \times \tan\emptyset`$	$K_{tan} = D \times (1 - \sin\emptyset`) \times \gamma \times X \times \tan\emptyset`$

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"Notes: *Pu* = Ultimate soil resistance per unit length, *X* = Depth below soil surface, *D* = Pile Diameter, *ko* = Coefficient earth pressure at rest, *ka* = Active earth pressure, Ø` = Angle of internal friction of sand, *Su*= Undrained shear strength, *Ca*= Undrained cohesion, *J*= Empirical Constant, *γ*= Unit weight of soil"

Table:

Table 4 Constants for Lateral spring stiffness

$Y_u = \frac{3D}{80}$ $Y_m = \frac{D}{60}$ $Y_K = \left(\frac{DP_m}{k_1 X Y_m^{1/n}}\right)^{n/(1-n)} S$	$P_m = P_u \frac{B}{A}$ $P_k = \left(\frac{X}{D}\right) k_1 Y_k$ $n = \frac{P_m(Y_u - Y_m)}{Y_m(P_u - P_m)}$
Notes: *A*, *B* = Adjutants Empirical factor = 0.88, 0.55, k_1= Relative Density	

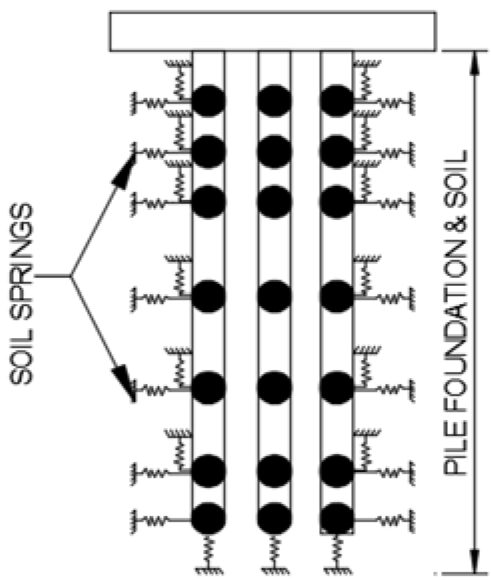

Figure 4. Spring represent interaction between soil and pile

The complicated behaviour of soils due to its properties and Non-linear force-deformation characteristics need to be accounted for the modelling. Hence, the properties of the soil are modelled as spring constant which evaluates flexibility and stiffness of soil behind the structure. At every regular interval soil profile shown in Figure 5. Spring is given which is equal to soil reaction support for the layered soil properties as per Table 6.

Table:

Table 6. Properties of soil layer Idealization

LAYER NO.	SOIL PROPERTIES		
	γ (kN/m^3)	Φ	C (kg/cm^2)
1	18.3	8	0.50
2	19	6	1.02
3	20	10	1.08
4	20.8	20	1.08
5	20.4	32	0
6	20.4	6	1.48
7	20.4	6	1.48
"Notes: Φ = Friction angle; C = Cohesion value; γ= Unit Weight of soil"			

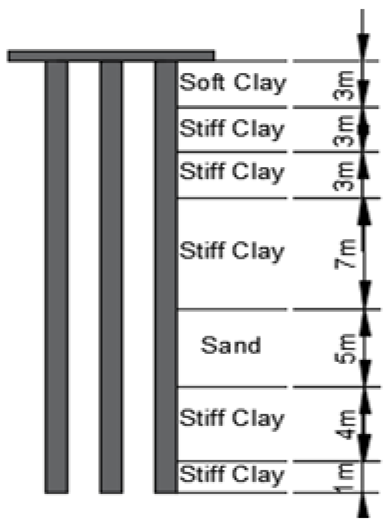

Figure 5. Idealized Soil profile for Bent Piles

The soil adjacent to pile modeled linear elastic spring represented as linear and multilinear spring support in finite element software MIDAS Civil [8,9] as shown in Figure 6. Stiffness constants and force deformation vary at the death of the pile are shown in below Figures 7 and 8.

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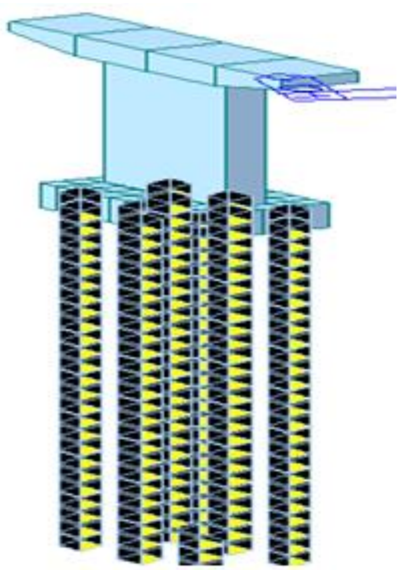
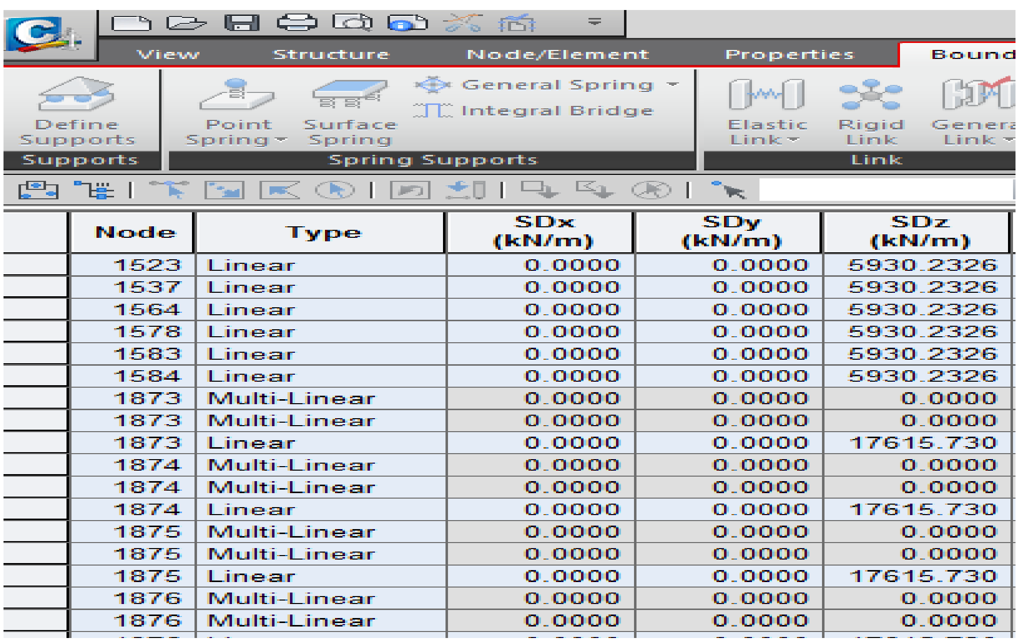


Figure 6. Pile spring support modeled in MIDAS Civil



Node	Type	SDx (kN/m)	SDy (kN/m)	SDz (kN/m)
1523	Linear	0.0000	0.0000	5930.2326
1537	Linear	0.0000	0.0000	5930.2326
1564	Linear	0.0000	0.0000	5930.2326
1578	Linear	0.0000	0.0000	5930.2326
1583	Linear	0.0000	0.0000	5930.2326
1584	Linear	0.0000	0.0000	5930.2326
1873	Multi-Linear	0.0000	0.0000	0.0000
1873	Multi-Linear	0.0000	0.0000	0.0000
1873	Linear	0.0000	0.0000	17615.730
1874	Multi-Linear	0.0000	0.0000	0.0000
1874	Multi-Linear	0.0000	0.0000	0.0000
1874	Linear	0.0000	0.0000	17615.730
1875	Multi-Linear	0.0000	0.0000	0.0000
1875	Multi-Linear	0.0000	0.0000	0.0000
1875	Linear	0.0000	0.0000	17615.730
1876	Multi-Linear	0.0000	0.0000	0.0000
1876	Multi-Linear	0.0000	0.0000	0.0000

Figure 7. Linear spring in Midas Civil

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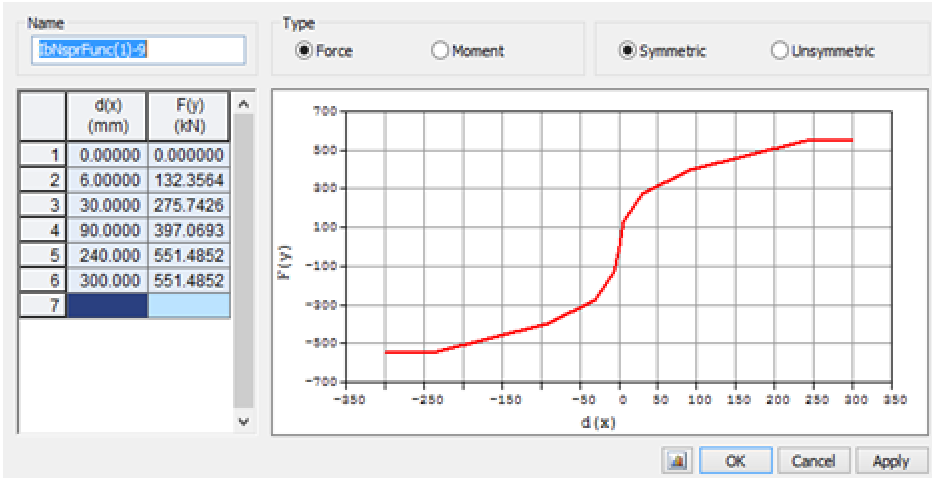
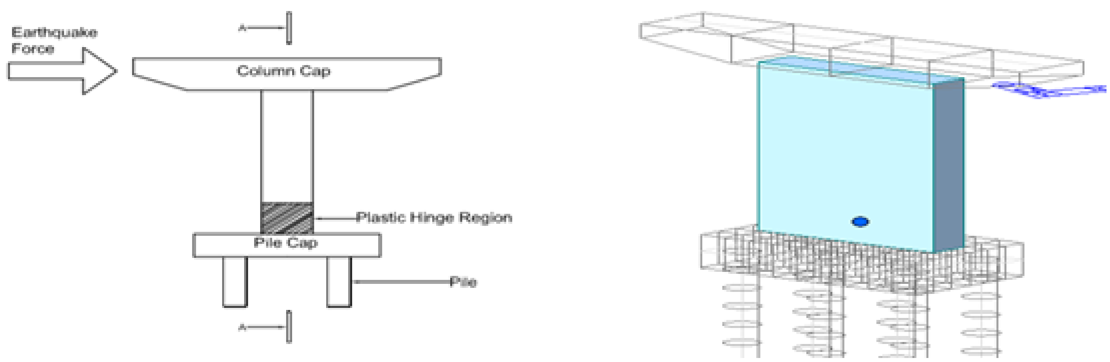


Figure 8. Force deformation function -Multilinear spring

VII. PUSHOVER ANALYSIS

A Pushover analysis (static nonlinear) is a method in which the amount of the structural lateral load gradually increases with the distribution of load along the height of new or existing structures. It is displaced till the maximum displacement is reached or the structure collapses. In this investigation, nonlinear static analysis is performed for the pier using the finite element software, MIDAS Civil. The non-linear behavior of the pier is simulated using Axial Force-Moment (P-M) interaction. The hinge property like Moment-rotation(M-θ) taken for this analysis according to FEMA-356 [11]. Also, the P-Δ effect is considered during the pushover analysis to get the actual response of the structure. Displacement control method is applied to the pushover analysis. Here, it is essential that the plastic hinges are considered as per IRC-114 [12] for single pier hinge at bottom only which shown in below Figure 9.



(a) Hinge location given in IRC-114 *(b) Hinge formation*

Figure 9 Hinge Location

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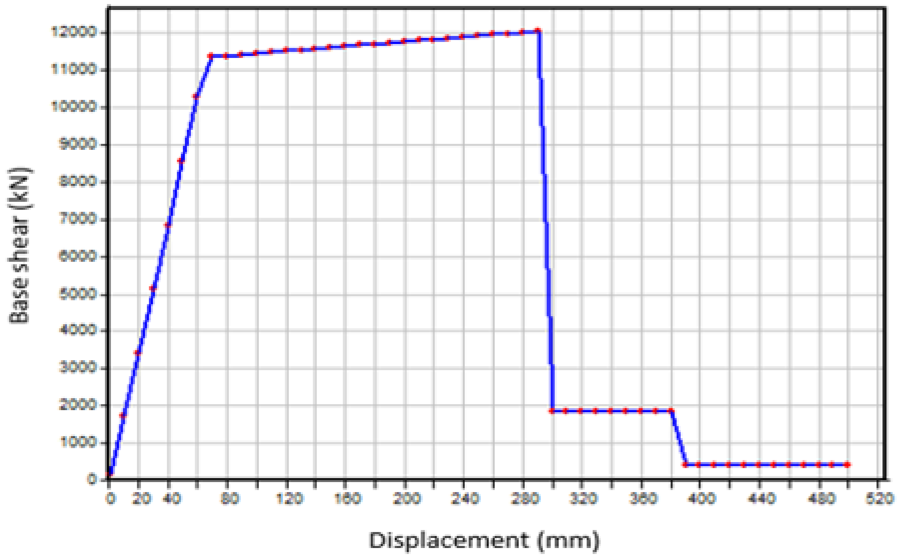

Figure 10 Pushover Curve without SSI

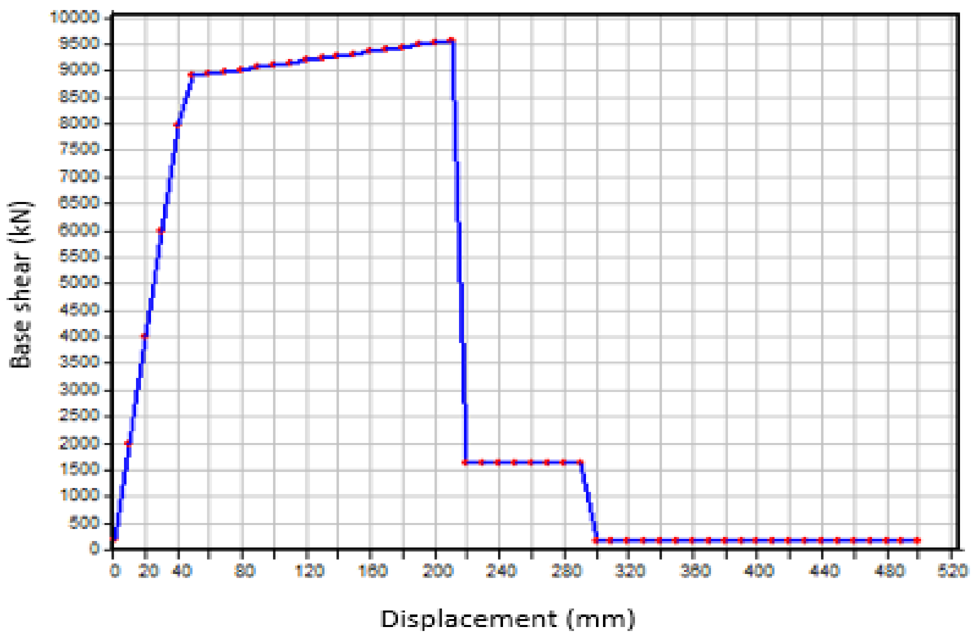

Figure 11. Pushover curve with SSI

- **Evaluation of *R* factor for without SSI**

1. **Over Strength Factor:**
   Maximum Base Shear (V_0) = 12051.2 kN (From pushover curve)
   Design Base Shear (V_d) = 6000 kN (As per IS-1893 [13] calculation)
   Using strength factor equation as per ATC-19 [5],

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$$R_S = \frac{V_O}{V_d} = \frac{12051.2}{6000} = 2.00$$

2. **Ductility Factor:**

Ultimate Displacement(Δ_m) = 292.96 mm (From pushover curve)
Yield Displacement (Δ_y) = 70 mm (From pushover curve)
Ductility ratio (μ) = $\frac{\Delta m}{\Delta y} = \frac{292.96}{70} = 4.18$
Using the equation of ductility factor, derived by Miranda and Bertero as per ATC-19 [5],

$$R_\mu = \left\{\left(\frac{\mu - 1}{\emptyset}\right) + 1\right\}$$

Where $\emptyset = 1 + \frac{1}{12T - \mu T} - \frac{2}{5T} e^{-2(\ln(T) - 0.2)^2}$ (For medium soil)
T= 0.681478 seconds (From MIDAS Civil model)
R_μ = 3.02

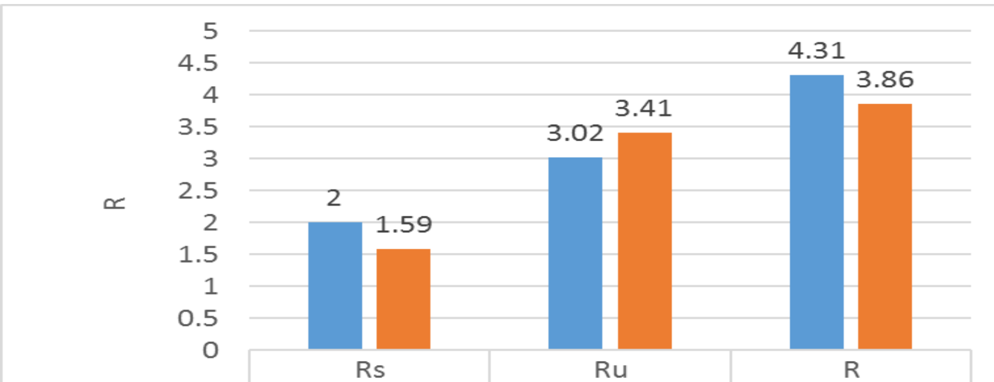
3. **Redundancy Factor:**

R_R= 0.71 (From ATC-19)
Response reduction factor $R = R_S \times R_R \times R_\mu$
$= 2.00 \times 3.02 \times 0.71 = 4.31$

VIII. RESULTS AND COMPARISONS

From the analysis carried out the results are obtained and presented in Figures 12-14. The following are observed.

1. The skew bridge pier with soil structure interaction shows almost 11% more ductility factor and over strength factor 20% less.
2. Overall, response reduction factor decreases almost 12% with soil structure interaction.



	Rs	Ru	R
Without SSI	2	3.02	4.31
With SSI	1.59	3.41	3.86

Figure 12 Comparison of R factor and it's components without & with SSI

3. As can be seen in the Figures 13 and 14, there is a variation of base shear and time period. Base shear decreased 20% and time period increased 14%. This variation is seen in the layered soil because flexibility of soil is introduced when soil structure interaction is incorporated in the analysis. Hence, SSI plays an important role and helps in a substantial strengthening of new or the existing bridges.

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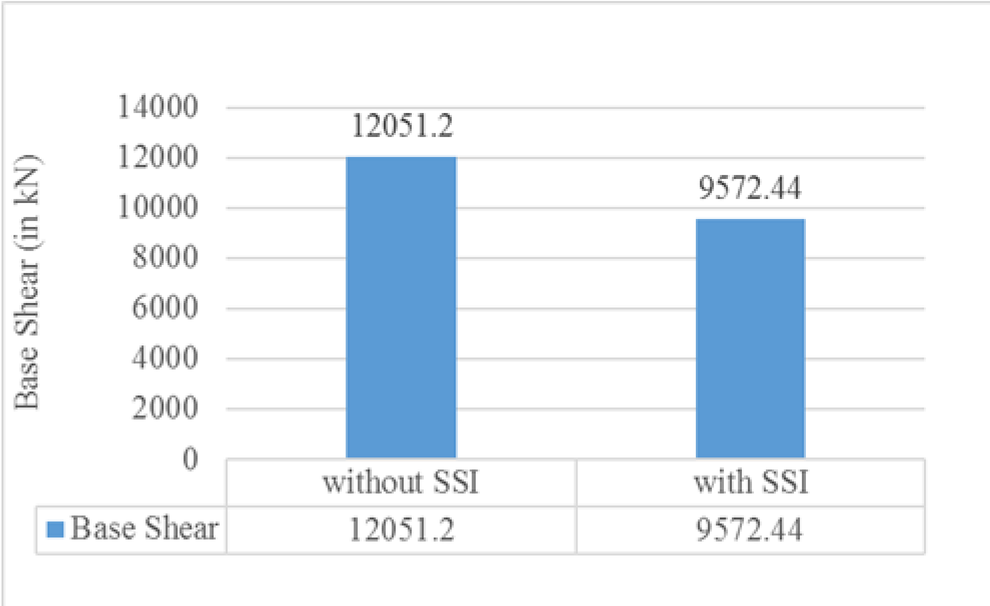

Figure 13 Comparison of base shear without & with SSI

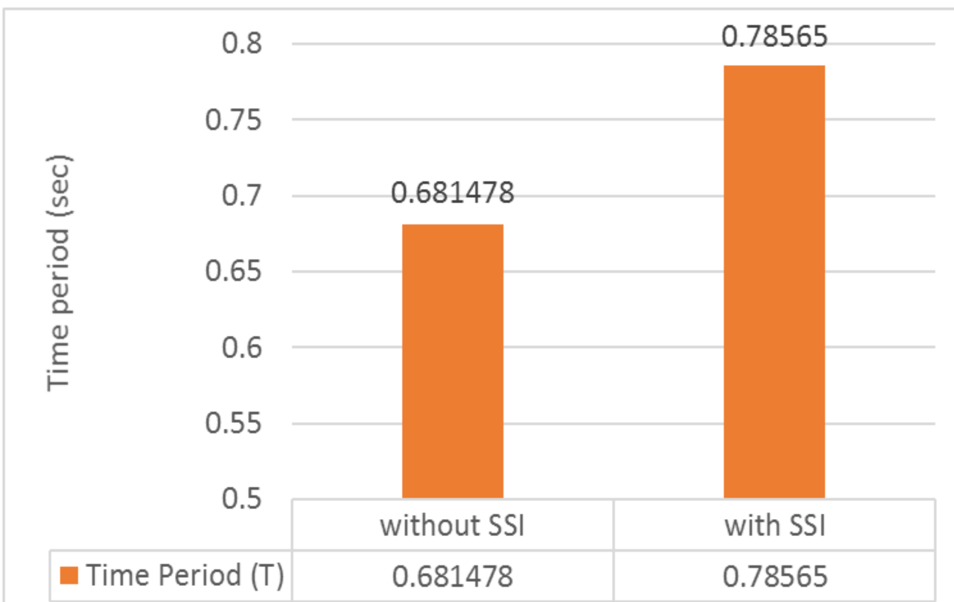

Figure 14 Comparison of the Time period without & with SSI

IX. CONCLUSIONS

In the present study, according to ATC-19 Response reduction factor of skew bridge pier is evaluated with and without considerations of soil structure interaction. The conclusions drawn from the study are summarized as below.

1. When the SSI is considered the response reduction factor is decreased and the actual *R* factor is arrived for the existing skew bridge pier.
2. Contribution of the over strength factor (*R*s) to the *R* factor is reduced and ductility factor (*R*μ) is increased with the SSI.

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3. The system is more flexible resulting in less base shear and more time period, when the effect of SSI is considered.

REFERENCES

1. *M. I. Ansaria, P. Agarwal (2014) "The Evaluation of R-Factor for Bridge Pier in Indian Context", 3rd International Conference On Emerging Trends in Engineering & Technology, New Delhi.*
2. *I. M. Ezz El-Arab (2017) "Soil-Structure Interaction Effects on PushoverAnalysis of Short Span RC Bridges", Open Journal of Engineering, Vol. 7, pp. 348-361.*
3. *Aswathi M and Jayalekshmi (2018) "Effect of Soil Structure Interaction on Seismic Response of Bridges with Pile Foundations", International Research Journal of Engineering and Technology, Vol. 5, pp. 2915-2919*
4. *Swami M. and Panchal B. (2018) "Parametric study on the effect of soil-structure interaction on bridge piers" International Research Journal of Engineering and Technology Vol. 5, pp. 1855-1859*
5. *ATC 19 (1995), "Structural Response Modification Factors Report", Applied Technology Council, Redwood City, California, USA.*
6. *IS 2911-1-1 (2010), Design and construction of pile foundations - code of practice, part 1: concrete piles, section 1: driven cast in-situ concrete piles [soil and foundation engineering], India.*
7. *IRC 6: (2014), standard specifications and code of practice for road bridges, Loads and Load Combinations, Indian Road Congress.*
8. *Broms, B. B. and Ingleson, I. (1971). "Earth pressure against the abutments of rigid frame bridge", Geotechnique, The Institution of Civil Engineers, London, U.K. Vol. 21, pp. 15-28.*
9. *MIDAS soft (2013). Midas Civil: Integrated Solutions system for the bridge and civil Engineering. MIDAS INFORMATION TECHNOLOGY CO., Ltd.*
10. *Civil, M.I.D.A.S., (2005). Online Manual. MIDAS Information Technology Co., Ltd*
11. *FEMA 356 (2000), "Prestandard and commentary for the seismic Rehabilization of Buildings" Federal Emergency Management Agency, Washington, USA.*
12. *IRC SP 114 (2018), Guidelines for Seismic Design of Road Bridges, Indian Road Congress, New Delhi.*
13. *I.S. 1893 (2016), "Indian Standard Criteria for Earthquake Resistant Design of Structures Part-1, General Provisions, and Buildings", Bureau of Indian Standards, New Delhi, India.*