Parametric study on effect of soil-structure interaction on bridge piers

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Abstract - *In the analysis of the bridges, the base usually is considered to be fixed neglecting the effect of soil and foundation flexibility. Hence, actual behaviour of structure cannot be assessed without considering soil structure interaction (SSI) effects. SSI effects depend upon many dynamic properties of soil. During earthquake, dynamic properties of soil change the seismic response of structure. The interaction among structure, their foundation and the soil media below foundation alter the actual behaviour of structure considerably than what is obtained from consideration of structure alone. Thus, a reasonably accurate model for SSI system with computational validity, efficiency and accuracy is required in improved design of bridges. Bridges being lifeline structures, it should be designed with at most care and accuracy so that during disaster it should remain functional. In the present study, RCC slab beam type bridges are modelled and variation due to SSI effect is assessed by varying height of piers and the soil type. SSI effect is introduced by modelling the soil as linear and multi-linear spring support given to pile foundation. Non-linear time history analysis is carried out. Bridge response with and without consideration of soil structure interaction is obtained in terms of displacements and bending moments.*

***Key Words*: Bridge pier, soil structure interaction.**

1. INTRODUCTION

Soil structure interaction is an important parameter which should be considered for the analysis of structures like bridges. The studies have been done for the analysis of the effect of soil structure interaction on bridges. Effect of SSI on the fundamental vibration periods of seismic-isolated bridges with a heavy superstructure and light substructures was found to be negligible. However, it was observed that SSI may significantly affect the periods at higher modes of vibration, which are related to the vibration of the substructures. For seismic-isolated bridges with light superstructures and heavy substructures, including the SSI in the seismic analysis was found to have a notable effect on bearing seismic forces and especially displacements. This effect was more pronounced for softer foundation soil conditions. Moreover, for such bridges including SSI in the seismic analysis was observed to have a remarkable effect on the substructure reactions regardless of the foundation soil stiffness [1]. Significant influence of soil pile interaction was observed on tower base shear response in the transverse direction. The response is much higher as compared to that of the bridge with fixed tower base when the soil is soft to medium. As the stiffness of the soil strata increases the effect of SSI diminishes. Inclusion of SSI is essential for effective design of seismically isolated cable-stayed bridges, specifically when the towers are very much rigid and the soil condition is soft to medium [2]. The SSI effects have been found to vary with varying height of the pier, type of soils and seismic severity zones. This study has indicated that in some cases, especially for soft soil, the base shear values for flexible footing are more than that of fixed base [3]. Studies observed that considerations of SSI in the analysis of isolated bridges is warranted when the stiffness of the supporting soil medium is less than 10 times the stiffness of isolation bearings. The SSI affects the bearing displacements at the abutment and ignoring these effects will underestimate the design displacement at abutment, which may be crucial from the design point of view [4].

2. PARAMETRIC STUDY

For the evaluation of effects of soil structure interaction on bridges RCC Slab-beam type bridges are modelled in MIDAS CIVIL. Three types of actual soil conditions as mentioned below is considered for analysis. The effects of SSI are analysed by varying height of pier and by changing the type of foundation soil conditions. SSI effects are modelled as pile spring support in which soil is modelled as linear and multi-linear spring support given to pile. For fixed base condition fixed support applied to pile by evaluation depth of fixity of pile as suggested by IS 2911. Nonlinear time history analysis is carried out by time history of “El Centro Site, 1940” earthquake. Loads and Loads combinations are taken as per IRC 6.

3. MODEL DESCRIPTION

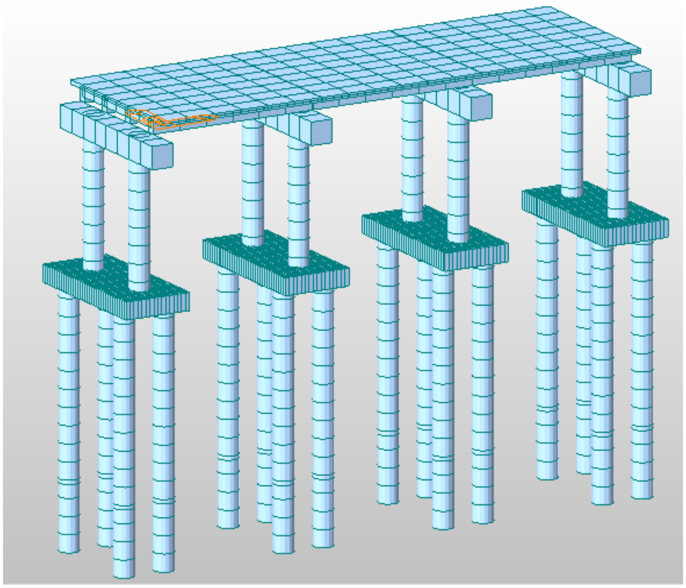
Three span simply supported RCC slab beam Type Bridge is modelled in MIDAS CIVIL. The geometric dimensions are as follows:

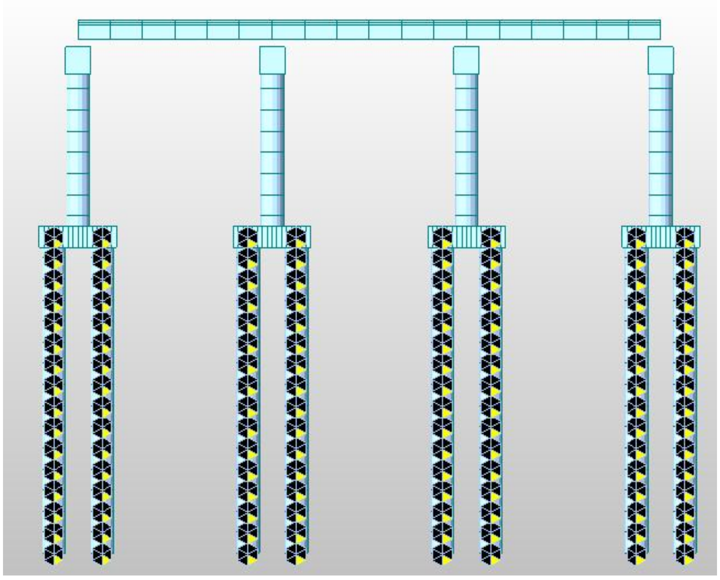
Table-1: - Geometric parameters

Span Length	10 m
Thickness of Slab	250 mm
Longitudinal girder	500 mm x 800 mm
Cross Girder	300 mm x 500 mm
Diameter of pier	1.2 m
Pier cap	1.3 m x 1.3 m
Diameter of pile	1.2 m
Number of pile	4
Depth of pile	15 m
Thickness of pile cap	1 m
IRC vehicle	Class AA and Class A
Concrete grade	M 30
Reinforcement	Fe 500
Thickness of wearing coat	80 mm (γ = 22 kN/m^3)
Pier height	7m, 9m, 11m, 13m

Table-2: - Soil Parameters

depth (m)	"N" Value			specific weight (kN/m^3)			angle of repose		
	Soil 1	Soil 2	Soil 3	Soil 1	Soil 2	Soil 3	Soil 1	Soil 2	Soil 3
1	7	14	8	15	18.25	15.3	29	32	27
2	7	14	8	15	18.25	15.3	29	32	27
3	8	14	8	15	18.25	15.3	29	32	27
4	9	14	8	15.89	18.25	15.3	29	32	27
5	18	20	8	16	18.25	16.28	30	32	27
6	18	20	17	16	18.25	16.28	30	32	27
7	18	20	17	16	18.25	16.28	31	32	27
8	18	20	17	16	18.25	17.46	31	32	29
9	25	35	32	16.5	19.42	17.46	27	33	29
10	25	35	32	16.57	19.42	17.46	27	33	29
11	25	41	32	16.57	19.42	17.46	28	33	29
12	25	41	100	16.57	18.34	17.46	28	35	29
13	28	42	100	16.57	18.34	17.46	28	35	29
14	31	42	100	16.57	18.34	18.84	31	35	34
15	31	42	54	16.57	18.34	18.84	31	35	34





4. RESULTS AND DISCUSSIONS

Models with variation of pier height and soil type are analyzed in MIDAS Civil and structural response in terms of vertical, longitudinal and transverse displacements with Bending moments at top and bottom of pier is obtained as follows:

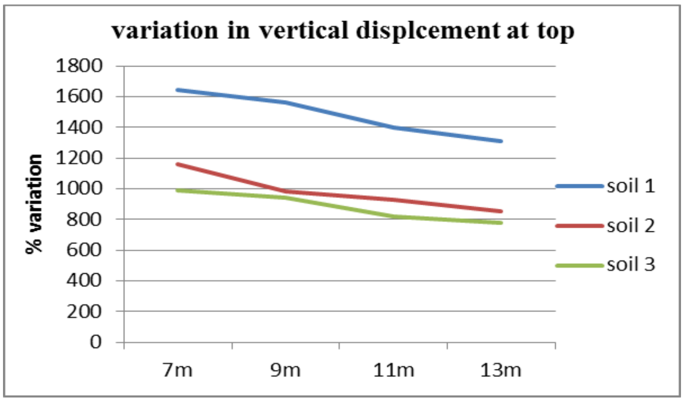
Variation in displacement in vertical, longitudinal and transverse direction with and without consideration of SSI with respect to fixed base condition is found out by following formula:

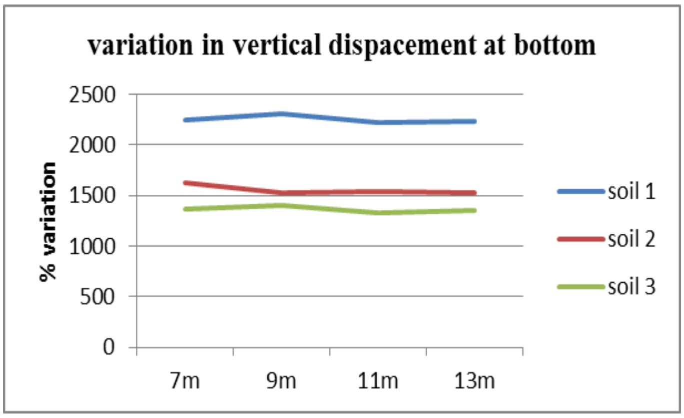
Percentage variation =

$$\frac{(\text{Displacement with SSI})-(\text{Displacement without SSI})}{\text{Displacement with SSI}} \text{ x } 100$$

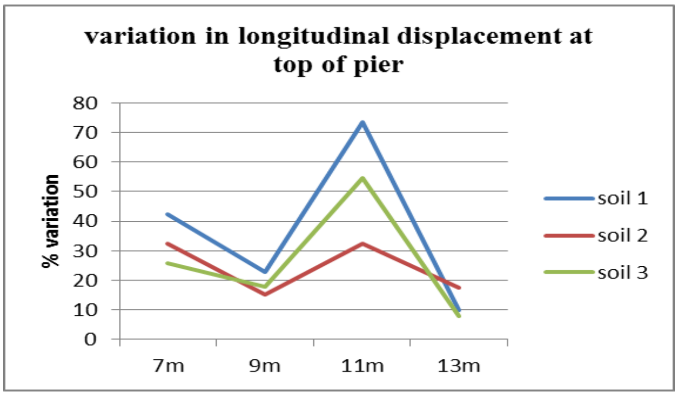
Thus, positive sign indicates value of displacement considering SSI is higher than that of fixed support condition and vice versa.

Variation pattern in vertical displacement at top and bottom of all four above mentioned pier is as follows:

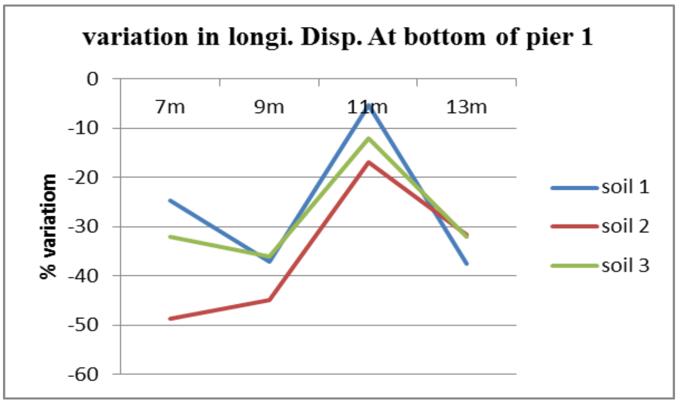


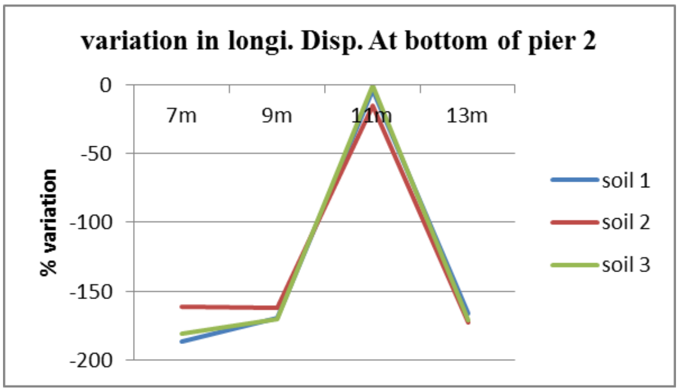


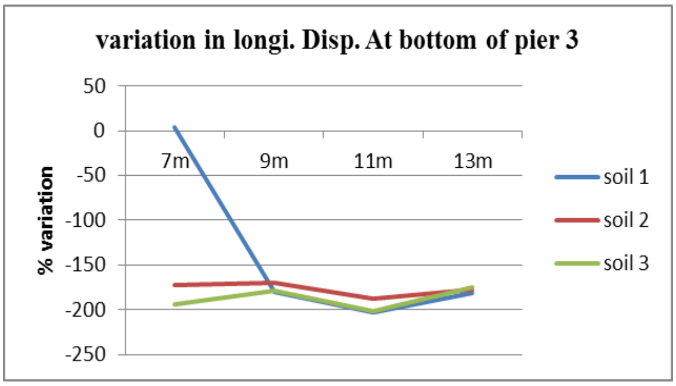
Variation pattern in longitudinal displacement at top all four above mentioned pier is as follows:

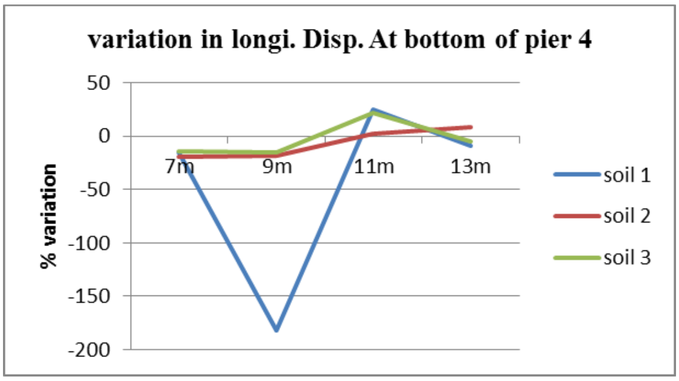


Variation pattern in longitudinal displacement at bottom all four above mentioned pier is as follows:

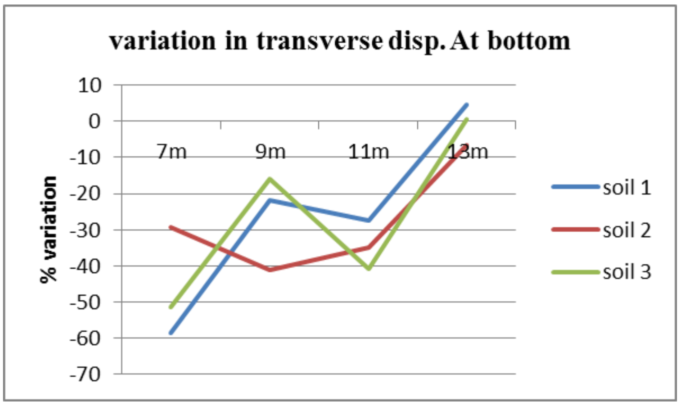








Variation pattern in transverse displacement at top and bottom all four above mentioned pier is as follows:



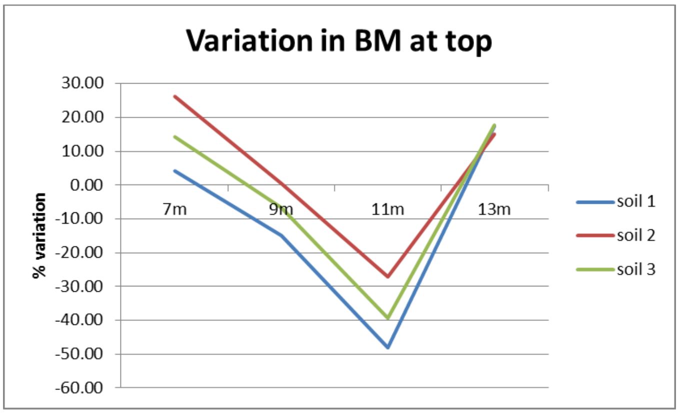
Variation in Bending Moment with and without consideration of SSI with respect to fixed base condition is found out by following formula:

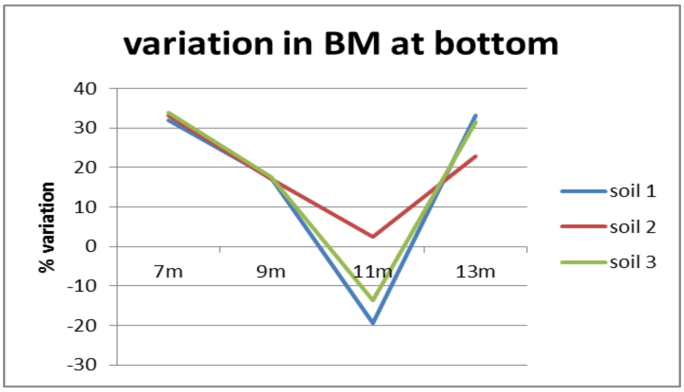
Percentage variation =

$$\frac{(\text{BM without SSI})-(\text{BM with SSI})}{\text{BM without SSI}} \text{x } 100$$

Thus, negative sign indicates value of bending moment considering SSI is higher than that of fixed support condition and vice versa.

Variation pattern in Bending Moment at top all four above mentioned pier is as follows:





5. CONCLUSIONS

- Consideration of effect of soil structure interaction increases the vertical deflection of piers 10-15 times with respect to fixity at top and 20-30 times at bottom of pier. For all three types of soil variation decreases from 7 m to 13 m in top of pier, while at the bottom of pier variation almost remains constant.
- Longitudinal and transverse deflection varies from 0.8 to 2 times with SSI effect which shows the significant variation in deflected shape of pier.
- Variations in longitudinal displacement at top of pier is maximum for pier height 11 m and minimum for pier height 13 m, while at bottom of pier variation pattern changes for all four piers.
- Variations in transverse displacement at top of pier is maximum for pier height 13 m and minimum for pier height 7 m, while at bottom of pier variation is maximum at for per height 7 m and minimum for 13 m.
- Longitudinal and transverse displacement at top of pier is higher considering SSI, while at bottom it is higher considering fixity.
- For pier height 9 m and 11 m, negative variation shows that effect of SSI gives higher results compared to fixity and for pier height 7 m and 13 m fixity results are conservative.
- As soil stiffness increases effect of SSI decreases and vice-versa.
- If SSI effects are ignored, the load estimation may be underestimated.
- As in some cases fixity consideration gives more response, both with SSI and without SSI support conditions should be checked and designed for maximum response.

REFERENCES

[1] M. Dicleli, M.ASCE1; S. Albhaisi; and M. Y. Mansour, A.M.ASCE "Static Soil–Structure Interaction Effects in Seismic-Isolated Bridges" Journal of practice periodical on structural design and construction (February 2005), ASCE

[2] B.B. Soneji, R.S. Jangid "Influence of soil–structure interaction on the response of seismically isolated cable-stayed bridge" Journal of Soil Dynamics and Earthquake Engineering 28 (2008) 245–257, ELSEVIER

[3] R P N Singh, Dr. Hemant Kumar Vinayak "Assessment of soil structure interaction in seismic bridge pier analysis using force and displacement based approaches" SSP--JOURNAL OF CIVIL ENGINEERING Vol. 10, Issue 2, 2015

[4] N.P. Tongaonkar, R.S. Jangid "Seismic response of isolated bridges with soil–structure interaction" Journal of Soil Dynamics and Earthquake Engineering 23 (2003) 287–302, ELSEVIER

[5] Mahir Ülker-Kaustell a, Raid Karoumia, Costin Pacoste "Simplified analysis of the dynamic soil–structure interaction of a portal frame railway bridge" Journal of Engineering Structures 32 (2010) 3692–3698, ELSEVIER

[6] IS: 456-2000, "Code of Practice for Plain and Reinforced Concrete", Bureau of Indian Standards, New Delhi, India.

[7] IS: 1893(part 1): 2002, "Criteria for Earthquake Resistant Design of Structures", part 1-General provisions and buildings, fifth revision, Bureau of Indian Standards, New Delhi, India.

[8] IRC 6: 2014 standard specifications and code of practice for road bridges

[9] 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 [ced 43: soil and foundation engineering.