

# Analysis of Soil-Structure Interaction Mechanisms on Integral Abutment Bridge

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**Abstract** - Bridges constructed with joints are identified as conventional bridges. These joints are usually found in the abutment and piers, providing spaces between the abutments or piers, and the longitudinal beams or slabs. Bridges constructed without joints are known as integral bridges. The present research work includes the analysis of 3D numerical model with 5 m-high abutments, 40 m span length and 15 m length pile foundation with 0.85 m diameter in the integral bridge using the finite element analysis software MIDAS CIVIL (2011) that simulate the behaviors of integral abutment bridges to assess the soil-structure interaction between the pile and soil. In addition, this work evaluates and validates the suitability of integral abutment bridges for different types of foundation soil by a parametric study under the static loading conditions. In order to be a balanced research in terms of a multidisciplinary study, this research analyzed key facts and issues related to soil-structure interaction mechanisms with both structural and geotechnical concerns. Moreover, the study established an explanatory diagram on soil-structure interaction mechanisms thermal movements in integral abutment bridges.

**Key Words:** Integral abutment; Semi-integral abutment; Transition slab; soil-structure interaction; durability; conceptual design.

## 1. INTRODUCTION

Integral bridges are characterized by monolithic connection between the deck and the substructure. This rigid connection allows integral bridges to act as a single unit in resisting thermal and brake loads. The stability of integral bridge is depending on the foundation soil. Therefore foundation soil is most important play role in design of superstructure and substructure of integral bridge. The Soil-Structure Interaction (Terzaghi and Peck, 1967) has become an important role in the stability assessment of structural engineering related problems such as massive constructions on soft soils i.e. nuclear power plants, concrete and earth dams. Buildings, bridges, tunnels and underground structures may also require particular attention to be given to the account of SSI effect. For the assessment of SSI in the different field situations such as if a lightweight flexible structure is built on a very stiff rock foundation, a valid assumption is that the input motion at the base of the structure is the same as the free-field earthquake motion and if the structure is very massive and stiff, and the foundation

is relatively soft, the motion at the base of the structure may be significantly different than the free-field surface motion. For a better performance of an integral bridge, the effect of SSI should be accounted in the analysis.

All of the civil engineering structures involve some type of structural element which is in direct contact with soil. To estimate the accurate response of the superstructure it is necessary to consider the response of the soil supporting the structure and is well explained in the soil structure interaction analysis. Many attempts have been made to model the SSI problem numerically, but have been found that the soil nonlinearity, and foundation interfaces, application of boundary element makes analysis more complex and computationally costlier.

Several research have concluded on the complex soil structure relationship in integral bridges constitutes the major challenge to engineers in designing and predicting the behavior of integral bridges in use with the account of SSI effect. The post construction flaws of integral bridges are fundamentally of a geotechnical nature, not structural (Horvath, 2005). Faraji (2001) says that a major uncertainty in the analysis of integral abutment bridges is the reaction of the soil behind the abutment, next to the foundation piles, and described the handling of the soil-structure interaction in the analysis of integral abutment bridge as problematic. Several of the challenges associated with the integral bridge design can be ascribed to the attempt of managing the effect of the soil-structure interaction (Terzaghi, 1936b) caused by the abutment displacement, or the attempt of controlling the abutment displacement that cause the soil structure interaction. Two significant consequences of the displacement induced soil- structure interaction have been identified. These are the development of increasing earth pressure behind the abutment in the backfill and irregular surface or subsidence of the bridge approach.

A finite element based 3-D model is developed using the FEM theory (Reddy, 1993) and try to incorporate the above discussed issues to enhance the stability of integral bridge.

## 2. MODELLING

Finite element modeling of integral bridge have 40m span length, 5 m-tall abutments and 15 m height pile foundation in the bridge using the finite element analysis software MIDAS CIVIL commercial software that simulate the

behavior of integral abutment bridges to assess the soil-structure interaction between the pile and different type of soil i.e. dense sand, medium sand, stiff clay and soft clay. The step by step modeling procedure is discussed in the following sub sections.

### 2.1 Geometry Modelling

In the finite element modeling, the basic geometries of integral bridge, abutment, pile foundation and deck etc. are developed with the help of MIDAS CIVIL commercial software. Firstly we modelled the main girder as a line element with 40 m length with 3.5 m spacing c/c. The abutment is design as a thick plate with 10.5 m wide and 1.2 m thickness. The pile is modelled also as a line element with length of 15 m. The complete geometry of integral bridge is represented by Fig -1.

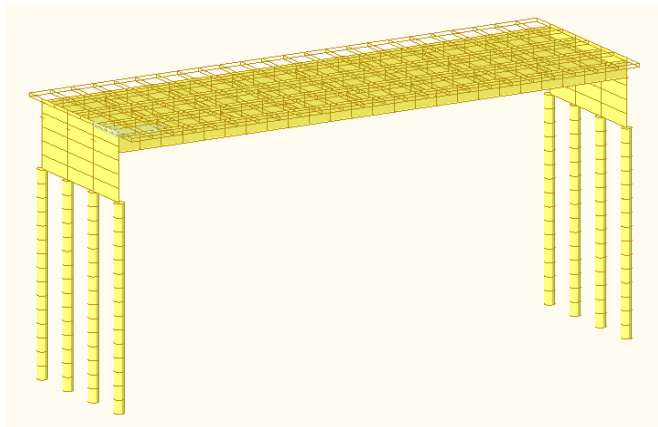


Fig -1: Geometry of integral bridge

### 2.2 Properties of Super and Sub Structure

The assignment of the sections and material properties of all four developed finite element models are given through the option of assignment material properties as inbuilt in the software itself. The generic properties of concrete grade M40 are considered in the analysis and isotropic behavior of concrete material is considered for the analysis. Steel properties followed general steel elasticity parameters within elastic strain below the yield stress limits. Parameters for steel and concrete, like modulus of elasticity, poisons ratio etc. are presented in the Table -1. The concrete is used for the construction for pile foundation, abutment and deck of integral bridge. Here the steel is design as per IS: 800:2007 and concrete is design as per IS: 456:2000.

Table -1: Concrete and Steel material properties

S.N.	Properties	Concrete	Steel
1.	Grade	M40	Fe540
2.	Young's Modulus (kN/m <sup>2</sup> )	3.1622e+007	2.05e+008

3.	Poisson's ratio	0.2	0.3
4.	Coefficient of thermal expansion	1.000e-005/°c	1.200e-005/°c
5.	Weight density (kN/m <sup>3</sup> )	23.6	76.98
6.	Mass density (kN/m <sup>3</sup> )	2.407	7.85
7.	Damping ratio	0.05	0.05

The four types of soil properties are considered for the analysis to assess the soil structure interaction behavior and these properties for four types of soils (dense sand, medium dense sand, stiff clay and soft clay) are listed in the Table -2.

Table -2: Foundation material properties

Soil	Dense sand	Medium dense sand	Stiff clay	Soft clay
$\gamma_{\text{usat}}$ (kN/m <sup>3</sup> )	20	19	18	17
$\gamma_{\text{sat}}$ (kN/m <sup>3</sup> )	21	20	19	18
$\gamma_w$ (kN/m <sup>3</sup> )	9.81	9.81	9.81	9.81
$\gamma$ (kN/m <sup>3</sup> )	11.19	10.19	9.19	8.19
$\phi$ (deg)	35	29	-	-
$K_0$	0.38	0.42	0.61	0.63
$C_u$ (kN/m <sup>2</sup> )	-	-	80	40
$k$ (kN/m <sup>3</sup> )	15000	10000	9500	4500

### 2.3 Loading on Super and Sub Structure

To apply load on the integral bridge we need to create load in the load module. To carry out loading we need to choose the step "Loading" generated in the step module. Step type was selected as pressure under static load category. Top surface of main girder had chosen for region of applied load. Distribution of load was chosen as uniform distribution. Various load acts on the integral bridge i.e. self-weight wet. concrete load, parapet load, earth pressure load, temperature load and live load. The live load is taken 35kN/m which is safe load for AA class vehicles as per IRC code standard. Parapet load is applied on both longitudinal edge nodes of the main girder of bridge as 10kN/m.

### 3. RESULTS

The following result obtained from the analysis of integral bridge by FEM software is discussed in the following sub sections.

### 3.1 Vertical Displacement of Pile Foundation

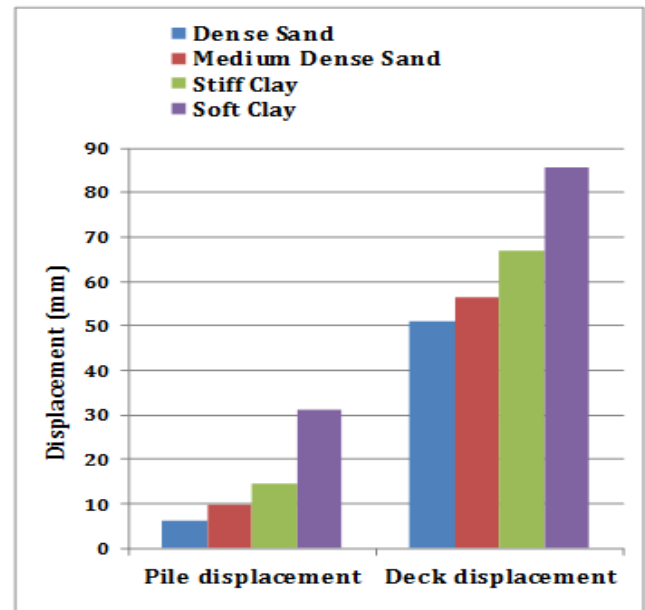
The results obtained from the finite element analysis for the estimation of vertical displacement (i.e. in z-direction) of friction pile (group pile) model in dense sand, medium dense sand, stiff clay and soft clay are approximately 6.3 mm, 9.9 mm, 14.7 mm and 31.0 mm respectively. According to the Indian code of practice (IS: 2911, Part 4, 1985) the total permissible settlement of pile foundation is 12.0 mm, unless a value different from 12.0 mm is specified depending upon the nature and type of structure. The vertical displacement in dense sand and medium dense sand are found under permissible limit as per IS code. The vertical displacement of pile in stiff clay is found approximately same as permissible limit but the vertical displacement of pile in soft clay is very large approximately 2.5 times of permissible limit which is cause for failure of structure. The vertical displacement of pile foundation of integral bridge is represented by Table -3.

### 3.2 Vertical Displacement of Main Steel Girder

As per IS: 800:2007, the permissible height of steel girder is 2500 mm for 40 m length steel girder bridge. The steel girder has 1.6 m height and its flange has 80 mm thick hence the total height of steel girder is 1820 mm which is under permissible limit as per IS: 800: 2007. The permissible deflection of steel girder is L/600 according to the Indian code of practice (IS: 800: 2007). Therefore the permissible deflection of steel girder for 40 m steel girder is 67.0 mm. The estimated vertical displacement of a steel girder of integral bridge in dense sand, medium dense sand, stiff clay and soft clay are 50.9 mm, 56.6 mm, 67.0 mm and 85.6 mm respectively. The results indicated that, when the stiffness of soil is decreases from dense sand to soft clay, the vertical deflection of girder is increases. These results shows that the deflection of girder of bridge is depend on section properties of girder, steel properties of girder, loading condition and length of girder also depends on soil properties of pile foundation. The vertical displacement of pile foundation of integral bridge is represented by Table -3.

**Table -3:** Vertical displacement of pile foundation and steel girder of integral bridge

Type of soil	Vertical Displacement of pile foundation	Vertical Displacement of Steel Girder
Dense sand	6.3 mm	50.8 mm
Medium dense sand	9.9 mm	56.5 mm
Stiff clay	14.7 mm	67.0 mm
Soft clay	31.0 mm	85.5 mm



**Fig -2:** Vertical displacement of pile foundation and steel girder of integral bridge in different type of soil

### 3.3 Bending Moment and Combined Bending Stress of Pile Foundation

In the pile foundation, the maximum positive (sagging) bending moment in Y-direction is obtained in soft clay and minimum positive (sagging) bending moment is obtained in dense sand. The magnitude of maximum negative (hogging) bending moment in pile foundation is decrease from dense sand to soft clay because the stiffness is decrease from dense sand to soft clay.

The magnitude of combined negative bending stress in pile foundation is increase from dense sand to soft clay which is max in soft clay and min in dese sand. The bending moment in Y-direction and combined bending stress are represented by Table -4.

**Table -4:** Bending moment and bending stress behavior of pile foundation in integral bridge

Description	Type of model	Bending moment (kN-m)		Bending stress (kN/m <sup>2</sup> )
		+ve	-ve	
Pile Foundation behavior of integral bridge	Dense sand	1703.8	789.4	32689.9
	Medium Dense sand	2083.4	718.1	38953.9
	Stiff clay	2548.9	616.8	47501.4
	Soft clay	2600.2	524.5	46624.2

#### 4. CONCLUSIONS

The results obtained from the analysis, the vertical displacement estimated in dense sand and soft clay are 6.3 mm and 31.1 mm respectively. The maximum permissible deformation of group pile as per IS: 2911, Part 4, 1985 is 12.0 mm. The vertical displacement of pile in dense sand and medium sand is under permissible limit but in soft soil, vertical displacement of pile foundation is over permissible limit.

The vertical displacement of deck slab in integral bridge supported with abutment and friction pile foundation in the dense sand, medium dense sand, stiff clay and soft clay are estimated as 50.0 mm, 56.0 mm, 67.0 and 85.6 mm respectively. The maximum permissible deformation of deck slab for 40 m span in integral bridge as per IS 800:2007 (2007) is 67.0 mm. The results indicated that, the vertical displacement of deck slab of bridge model in dense sand, medium sand and stiff clay are under limit but in soft clay vertical displacement of main girder is 85.6 mm which is greater than as compare to the permissible limit of IS code (IS: 2911, Part 4, 1985) therefore the soft clay is not safe for design.

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