SOIL STRUCTURE INTERACTION ANALYSIS FOR INTEGRAL ABUTMENT BRIDGE SYSTEM

by

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SOIL STRUCTURE INTERACTION ANALYSIS FOR INTEGRAL ABUTMENT BRIDGE SYSTEM

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ABSTRACT: Integral Abutment Bridges (IABs) are jointless bridges whereby the deck is continuous and monolithic with abutment walls. Their principal advantages are derived from the absence of expansion/contraction joints, making them the most cost-effective system in terms of construction, maintenance and longevity. It is one of the challenging tasks to achieve the soil structure interaction between the piles and the surrounding soil of the integrated bridge system. In this research paper numerical model is developed using appropriate finite element software for both the basic system with SSI and without SSI and dynamic analysis is carried out to understand the importance of the soil pile interaction in the considered bridge system. The parametric study including different soil types, different type of connections between pile and abutment, effect of water table, different earthquake loading and the results are compared for both the conditions including SSI and without SSI. The main objective of this study to observe the trends in bending moment, deflection in longitudinal girders and in piles subjected to the given dynamic loading. The study concluded that the temperature effects are more significant in case of integral abutment bridges; however the changes in soil properties behind the abutment and around the piles affect significantly the performance of super structure.

INTRODUCTION
Integral Abutment Bridges (IABs) are Joint less Bridges in which the deck slab is continuous and monolithic with abutment walls. This system of bridges is proved to be more cost-effective in terms of construction, maintenance and longevity due to the absence of expansion/contraction joints and joint bearing which is the prime factor increases the maintenance cost as prevent the corrosion of structure due to water seepage through joints (Fig. 1).

Fig. 1 Details of the conventional IAB (Horvath, 2000)
In structural point of view it gives single structural unit increases the degree of redundancy enabling higher resistance to extreme loading like earthquakes [13]. The continuity achieved by this construction results in thermally induced deformations which give more stability to the substructure [2]. In the history of the jointless bridges the Teens Run Bridge (Gallia County, USA) built in 1938 is recognized as the first integral bridge [7] including 13000 integral abutment bridges, of which about 9000 are full integral abutment bridges, around 4000 are semi-integral abutment bridges [8,12,14]. Other than this in Canada, several provinces including Alberta, Quebec, Nova Scotia and Ontario have integral abutment bridges [13]. In the United States overall the model of integral abutment bridges has confirmed to be successful economically in both initial construction and maintenance costs as well as satisfied technically in removing expansion joint problems. However, it does not yet possess a perfect liberty from annual maintenance caused by the bump at bridge approach slabs, decreasing a pavement ride quality for automobiles. Moreover, some maintenance operations for cracks or settlements are required by the excess movements during the winter and summer months. In order to increase
the confidence in the design and construction of Integral Abutment Bridges, it is important and crucial that a comprehensive and exhaustive performance study be implemented \[4,5 \text{ and 9}\].

**Geotechnical Issues with Integral Abutment Bridges:**
There are two commonly encountered problems inherent in the design of integral abutment bridges that are not structural in nature but rather, geotechnical (9, 2000). The cyclic loading of the bridge superstructure due to daily changes in temperature causes the abutments to rotate about the base and translate into the soil, thus developing considerable lateral earth pressure on the abutments. The magnitude of these soil pressures can approach or reach the passive state in the summer when bridge expansion is highest. Passive earth pressures are large in magnitude and may exceed the normally consolidated at-rest state for which an abutment should normally be designed by at least an order of magnitude. Failure to design the abutment for the larger pressures that develop during bridge thermal expansion can cause structural damage to the abutment. Adversely, the cost to properly design the abutment subjected to these higher forces will increase. The failure in the bridges is generally happened due to the ratcheting which build-up of lateral earth pressure as the soil becomes effectively wedged behind the abutment.

Many researchers proposed a solution to this issue like use of compressible illusion and geofoam etc. Using this geofoam configuration would help with both the settlement behind the abutment and the tendency toward ratcheting behaviour[9].
A number of limitations and guidelines have been presented in order to avoid passive pressure, high pile stresses [7].

**Challenges involved with IABs:**
There are a number of limitations in the design of Integral Abutment Bridges owing to two main problems. Although the IAB concept has confirmed to be economical and technically successful in terms of eliminating expansion joint problems, it is not free from problems. Bridges are susceptible due to a complex soil-structure interaction mechanism involving relative movement between the bridge abutments and the backfill, and the piles and adjacent soil. One of the two major problems observed with IABs is the development of lateral earth pressures against the abutments. The other is the void development under approach slabs [9].

**Soil Structure Interaction for Bridge System:**
The interaction between the structures, foundation and soil medium is potential to alter the actual behavior of any structure considerably compared with the fixed base analysis. Since, behavior of the Integral Abutment Bridge is interdependent between its structural components and soil medium, it is vital to determine the relevant parameters of soil to represent its behavior. In general modeling of the structural element i.e. superstructure and foundation piles are rather simple and straightforward compared to soil medium. The complex behavior of soil due to its heterogeneous, anisotropic and nonlinear in force–displacement characteristics need to be accounted for in its modeling. So the properties of soil have to be modeled as spring constants which evaluate the stiffness and flexibility of soil behind substructure (Fig 2).

![Fig. 2 Soil Structure Interaction for IABs](image)
NUMERICAL MODELLING OF INTEGRAL ABUTMENT BRIDGE

In this research paper 3-Dimensional model of a prestressed concrete bridge is developed using finite element software MIDAS CIVIL (V13) for both fixed and spring support with appropriate spring constant in accordance with the soil considered which incorporate the effect of soil structure interaction (Fig 2). The dimension of bridge components is taken as per the AASHTO guidelines (Fig 3, Table 1) and the grade of the concrete is taken as M35.

Fig. 3 Finite element model for IAB system

Table 1 Bridge dimensions considered in present study

<table>
<thead>
<tr>
<th>Bridge Components</th>
<th>Size (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Effective span</td>
<td>36</td>
</tr>
<tr>
<td>Width</td>
<td>10.36</td>
</tr>
<tr>
<td>Deck slab thickness</td>
<td>0.226</td>
</tr>
<tr>
<td>Pile length</td>
<td>15 (HP-10 x 125)</td>
</tr>
<tr>
<td>Abutment (d x t)</td>
<td>5 x 1.2</td>
</tr>
<tr>
<td>Girder</td>
<td>AASHTO guidelines</td>
</tr>
</tbody>
</table>

To capture the real time scenario of soil the heterogeneity soil is considered including the four horizontal stratified zones including medium dense (SAND 1), dense (SAND 2), medium stiff (CLAY 1) and stiff (CLAY 2). The details of the each soil layers each type of soil is described in Fig. 5.

Fig. 5 Details of soil layers considered in present study
The engineering properties of the soils zones is detailed in the table 2. The parametric study is carried out altering these layers and the interaction response is studied (Table 3).

**Table 2** Engineering properties of the soil layer considered in the present study

<table>
<thead>
<tr>
<th>Parameter</th>
<th>SAND1</th>
<th>SAND2</th>
<th>CLAY1</th>
<th>CLAY2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unit Wt. $\gamma$</td>
<td>19</td>
<td>20</td>
<td>18</td>
<td>19</td>
</tr>
<tr>
<td>Unit Wt. $\gamma_s$</td>
<td>20</td>
<td>21</td>
<td>19</td>
<td>20</td>
</tr>
<tr>
<td>Void Ratio, $e$</td>
<td>0.59</td>
<td>0.45</td>
<td>0.76</td>
<td>0.59</td>
</tr>
<tr>
<td>Friction angle, $\phi'$</td>
<td>32</td>
<td>38</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Earth pressure coefficient at rest, $K_0$</td>
<td>0.47</td>
<td>0.38</td>
<td>0.63</td>
<td>0.61</td>
</tr>
<tr>
<td>Cohesion, $C_u$ (kN/m²)</td>
<td>-</td>
<td>-</td>
<td>40</td>
<td>80</td>
</tr>
<tr>
<td>Subgrade Reaction, $K_h$ (kN/m³)</td>
<td>6000</td>
<td>12000</td>
<td>4500</td>
<td>9500</td>
</tr>
</tbody>
</table>

**RESULTS AND DISCUSSION**

The dynamic analysis of the IAB system with multi linear springs is carried out for a Bhuj ground motion and the response of the integrated system is estimated in the form of displacements at the pile and an abutment location (Fig 6). The response is calculated for both with and without considering the interaction effect for all possible analysis cases. The typical deflection profile of IAB for critical load combination is shown in Fig. 7.

The rotation at the pile head and abutment location is also captured in the numerical analysis (Fig. 8). The soil response is studied against the ground shaking by means of the stresses developed in the linear spring attached at the different nodes of the pile and the backfill locations at the abutment positions. The response of the soil (spring at pile top) is shown in Fig. 9 for all analysis cases of soil structure interaction.

The model included the partial fix condition between pile and the abutment and the extended for both conditions including with and without SSI. The dynamic analysis is carried out for a Bhuj (2001, PGA 0.31g) ground motion and the critical load combination including dead load, live load, wind load, footpath load, parapet load, thermal load and ground shaking is applied at the surface level to simulate the earthquake in the numerical model. The displacement profile has been studied for the pile and abutment location in all principal directions for all analysis cases. The stresses response is studied in terms of bending and axial pile stresses and soil behaviour against the dynamic loading is predicted in terms of the shear stresses in the spring.
Soil Structure Interaction analysis for Integral Abutment Bridge System

Fig. 7 a. Girder b. Pile Displacement in X, Y and Z directions.
a. Girder Rotation in X direction

b. Pile Rotation in X direction

c. Girder Rotation in Y direction

d. Pile Rotation in Y direction

e. Girder Rotation in Z direction

f. Pile Rotation in Z direction

Fig. 8 a. Girder b. Pile rotation in X, Y and Z directions.
The pile drift is estimated at the different position along the pile length to ensure the life safety of the bridge for both fixed base condition and soil structure interaction effect. Fig 10 shows the pile drift observed for all analysis cases.

**RESULTS AND DISCUSSION**

The finite element model has been developed for analyzed for the dynamic loading in the form of earthquake acceleration as a input shaking .The response analyzed for the soil heterogeneity to meet the actual scenario for both the conditions with and without soil structure interaction in analysis. Following are few conclusions drawn from the present study.

**Displacements:** It is found that the displacement for pile and girder follows the same typical profile along each principal direction. In fixed base analysis for both pile and girder shows fewer displacements in all directions. In SSI analysis CASE 4 which includes shows considerably more displacements in X-direction for both pile and girder that other cases and Y and Z direction displacements is found to be almost same. CASE 3 proves to be a good combination for least displacement.

**Rotation:** Girder rotations against the dynamic loading are found to be negligibly small with comparison of the pile head rotation. It concludes that the IAB system with fixed connection between pile and abutment creates negligibly small rotational moment in the superstructure. Rotations observed to be more in all the cases which includes the soil structure interaction effect than compared to the fixed base analysis of the IAB system.

**Soil behaviour:** With the hysteresis obtained from the analysis which includes the soil structure interaction effect the shear stresses developed in all analysis cases are within the permissible range and among all cases of analysis CASE 3 shows the less shear stress.

**Pile Drift:** The pile drift is estimated at the different position along the pile length and it has been observed that fixed base analysis shown the fixed base analysis shows the least drift as compared to the SSI analysis. In soil structure interaction analysis all cases shows the drift within the safe limit i. e. less than 2 %.

**REFERENCES**


