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# Behavior of Bridge Abutment Foundation in Mixed Ground Condition

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**Abstract.** Bridges are prime components of transportation network. Subsoil conditions, water table depth and seismicity have crucial impact on the foundation part of a bridge abutment which may mainly consist of pile or open foundation. Hence, it is necessary to study the effect of soil-structure interaction of bridge foundation under seismic force. To study the non-linear behavior of bridge abutment and its foundation, different sets of soil models with various seismic forces have been developed by using FEM based software for a typical bridge abutment foundation. To gain an insight into the seismic response of abutment foundation, its geometrical profile has been further modelled for both pile and open foundations. Different surrounding subsoil conditions (soft soil, weathered rock, etc.) provide variation in safe bearing capacity, ground settlement, stability factor, etc. The results of the present study show that the factor of safety of the bridge abutment gradually increases by 4-12% and ground settlement decreases by 6-16% when ground condition changes from medium to stiff clay followed by weathered rock. Ground settlement increases by 30-135% when seismic zone changes from zone-III to zone-IV with higher PGA, even for same soil condition.

**Keywords:** Bridge Abutment; Mixed Ground Condition; Seismic condition; Ground settlement.

## 1 Introduction

Transportation network plays a very vital role in economic growth of fast developing country like India. Railways and roads have always played a very key role in transportation network system [1]. Amongst transportation systems, bridges are essential components for both rail and road networks [2]. As per conventional approach, a reinforced concrete abutment foundation is to be analyzed by considering the foundation to be rigid [3]. It is fact that this is quite simplify assumption for the design, but it cannot capture the exact representation of the subgrade soil [4]. Therefore, it is better to model the foundation as flexible through its length and to model the subgrade soil by providing closely spaced springs [5]. These springs considered are calculated from the general concept of modulus of subgrade reaction. The different ground soil conditions (medium clay, stiff clay etc.) provide varying safe bearing capacity, ground settlement, etc. [6].

Soil-structure interaction under different seismic loads is a vastly non-linear phenomenon. This non-linear behavior plays very important role in the entire structural response [7].

In this paper, the behavior of bridge abutment and its foundation have been studied in detail under different surrounding subsoil conditions (soft soil, weathered rock, etc.) by varying water table and seismic condition (seismic zone III and zone IV). As a part of parametric study, various sets of numerical models have been further developed based on Finite Element Method (FEM) to study the non-linear behavior of bridge abutment with both pile and open foundations. Considering variation in soil and rock layer, six different types of ground conditions have been considered for six different FEM models in this parametric study. The outcomes of model analyses: factor of safety, ground settlement, bending moment and shear force, have been assessed for all six FEM models.

## 2 Model of the Case Study:

In the present paper, different sets of parametric study have been conducted by developing various numbers of models in 2D MIDAS GTS NX software (MIDAS IT Co., Ltd., 2020) for varying subsoil condition, water table and seismicity. Abutment foundation geometrical profile has been further re-modelled for both pile and open foundation. Geometrical profile of embankment cross section along with abutment and soil/rock layers are shown in Fig. 1.

A model view from FEM models of bridge abutment for both pile and open foundation are shown in Fig. 2.

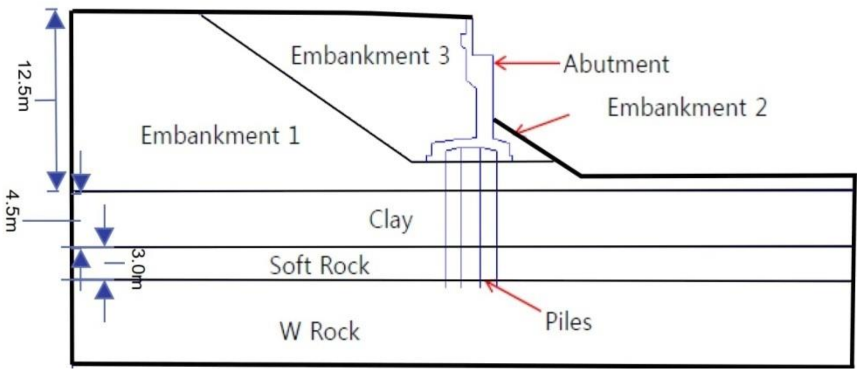
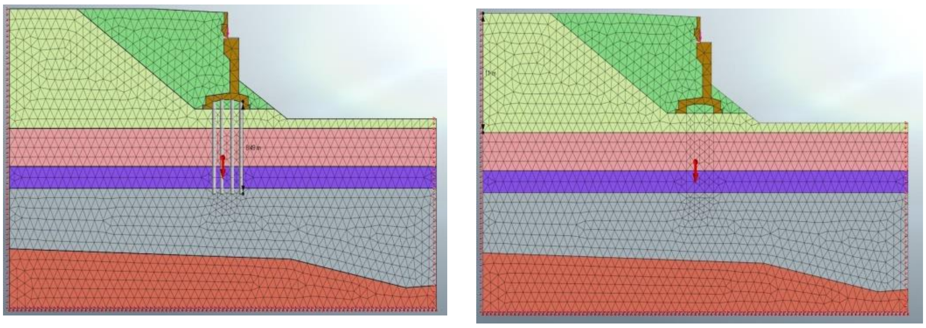



**Fig. 1.** Geometrical profile of embankment cross section including abutment, soil, and rock layers.

As per sequence of construction of the bridge abutment, embankment has been subdivided in three zone which is already shown in Fig.1. Embankment ground conditions with Geotechnical parameters are shown in Table 7.



A. Bridge abutment with pile B. Bridge abutment with open foundation

**Fig. 2.** A model views from FEM models of bridge abutment for both pile and open foundation.

In ground conditions, soil layers followed by two different rock layers have been considered for present parametric study. Considering variation in type and property of soil and rock layer, six different types of ground conditions have been considered for six different FEM models. Ground conditions with geotechnical properties of six different FEM models, i.e., FEM Model-1, FEM Model-2, FEM Model-3, FEM Model-4, FEM Model-5, and FEM Model-6 are tabulated in six tables, i.e., Table 1, Table 2, Table 3, Table 4, Table 5, and Table 6 respectively.

**Table 1.** Ground conditions with Geotechnical parameters of FEM Model-1.

| **Ground Condition** | **Soil Type** | **C (Avg.)** kN/m$^2$ | **Φ' (Avg.)** deg | **Y (Avg.)** kN/m$^3$ | **E' (Avg.)** MPa | **ν' (Avg.)** |
|---|---|---|---|---|---|---|
| Stratum-I | Medium sandy clayey silt | 50 | 20 | 18.5 | 12.5 | 0.30 |
| Stratum-II | Soft /highly weather rock | 200 | 32 | 22.0 | 150 | 0.25 |
| Stratum-III | Weathered Rock | 450 | 35 | 24.0 | 300 | 0.20 |

**Table 2.** Ground conditions with Geotechnical parameters of FEM Model-2.

| **Ground Condition** | **Soil Type** | **C (Avg.)** kN/m$^2$ | **Φ' (Avg.)** deg | **Y (Avg.)** kN/m$^3$ | **E' (Avg.)** MPa | **ν' (Avg.)** |
|---|---|---|---|---|---|---|
| Stratum-I | Medium sandy clayey silt | 50 | 20 | 18.5 | 12.5 | 0.30 |
| Stratum-II | Soft /highly weather rock | 200 | 32 | 22.0 | 150 | 0.25 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Stratum-III | Weathered Rock | 600 | 35 | 24.0 | 400 | 0.20 |

**Table 3.** Ground conditions with Geotechnical parameters of FEM Model-3.

| **Ground Condition** | **Soil Type** | **C (Avg.)** kN/m$^2$ | **Φ' (Avg.)** deg | **Y (Avg.)** kN/m$^3$ | **E' (Avg.)** MPa | **ν' (Avg.)** |
|---|---|---|---|---|---|---|
| Stratum-I | Medium sandy clayey silt | 50 | 20 | 18.5 | 12.5 | 0.30 |
| Stratum-II | Soft/highly weather rock | 250 | 32 | 22.0 | 180 | 0.25 |
| Stratum-III | Weathered Rock | 450 | 35 | 24.0 | 300 | 0.20 |

**Table 4.** Ground conditions with Geotechnical parameters of FEM Model-4.

| **Ground Condition** | **Soil Type** | **C (Avg.)** kN/m$^2$ | **Φ' (Avg.)** deg | **Y (Avg.)** kN/m$^3$ | **E' (Avg.)** MPa | **ν' (Avg.)** |
|---|---|---|---|---|---|---|
| Stratum-I | Stiff sandy clayey silt | 75 | 20 | 19.5 | 14.5 | 0.30 |
| Stratum-II | Soft/highly weather rock | 200 | 32 | 22.0 | 150 | 0.25 |
| Stratum-III | Weathered Rock | 450 | 35 | 24.0 | 300 | 0.20 |

**Table 5.** Ground conditions with Geotechnical parameters of FEM Model-5.

| **Ground Condition** | **Soil Type** | **C (Avg.)** kN/m$^2$ | **Φ' (Avg.)** deg | **Y (Avg.)** kN/m$^3$ | **E' (Avg.)** MPa | **ν' (Avg.)** |
|---|---|---|---|---|---|---|
| Stratum-I | Medium sandy clayey silt | 50 | 20 | 18.5 | 12.5 | 0.30 |
| Stratum-II | Soft/highly weather rock | 250 | 32 | 22.0 | 180 | 0.25 |
| Stratum-III | Weathered Rock | 600 | 35 | 24.0 | 400 | 0.20 |

**Table 6.** Ground conditions with Geotechnical parameters of FEM Model-6.

| **Ground Condition** | **Soil Type** | **C (Avg.)** kN/m$^2$ | **Φ' (Avg.)** deg | **Y (Avg.)** kN/m$^3$ | **E' (Avg.)** MPa | **ν' (Avg.)** |
|---|---|---|---|---|---|---|
| Stratum-I | Stiff sandy clayey silt | 75 | 20 | 19.5 | 14.5 | 0.30 |
| Stratum-II | Soft/highly weather rock | 250 | 32 | 22.0 | 180 | 0.25 |
| Stratum-III | Weathered Rock | 600 | 35 | 24.0 | 400 | 0.20 |

The basic difference in ground conditions with geotechnical parameters between Model-1 and Model-2 are in the rock parameters of Stratum-III. The difference between Model-1 and Model-3 are in the rock parameters of Stratum-II. The difference between Model-1 and Model-4 are in the soil type/parameters of Stratum-I. In model-5, there are changes in the rock parameters of Stratum-II and Stratum-III, whereas changes in the soil/rock type and parameters of all three strata are in Model-6.

**Table 7.** Embankment Ground conditions with Geotechnical parameters.

| **Ground Condition** | **Soil Type** | **C (Avg.)** kN/m$^2$ | **Φ' (Avg.)** deg | **Y (Avg.)** kN/m$^3$ | **E' (Avg.)** MPa | **ν' (Avg.)** |
|---|---|---|---|---|---|---|
| Embank-ment | Medium sand | 15 | 29 | 18.0 | 40 | 0.30 |

## 3 Analysis and Presentation of Results:

Different sets of numerical models of 1.0m x 1.0m mesh size have been developed in 2D MIDAS GTS NX software (MIDAS IT Co., Ltd., 2020) to understand the non-linear behaviour of bridge abutment and its foundation during varying ground conditions. Peak Ground Acceleration (PGA) value of 0.24 and 0.36 for two different seismic zones (zone III and zone IV as per IS-1893) have been further applied in the present FEM model to understand the seismicity behaviour of bridge abutment and its foundation. To notice the effect of water table, existing FEM model has been further have been developed by considering water profile below the embankment.

As outcomes of present FEM model analysis, factor of safety, ground settlement, bending moment and shear force have been estimated for all six FEM models. Factor of safety values of the bridge abutment for both pile and open foundation for all six different FEM models have been presented in Table 8A and Table 8B respectively.

**Table 8A.** Factor of safety values of the bridge abutment with pile foundation.

| **Model-1** | **Model-2** | **Model-3** | **Model-4** | **Model-5** | **Model-6** |
|---|---|---|---|---|---|
| 3.456 | 3.484 | 3.528 | 3.600 | 3.581 | 3.900 |

**Table 8B.** Factor of safety values of the bridge abutment with open foundation.

| **Model-1** | **Model-2** | **Model-3** | **Model-4** | **Model-5** | **Model-6** |
|---|---|---|---|---|---|
| 1.614 | 1.612 | 1.598 | 1.626 | 1.607 | 1.631 |

Ground settlement values of the bridge abutment for both pile and open foundation for all six models have been presented in Table 9A and Table 9B respectively.

**Table 9A.** Ground settlement values of the bridge abutment with pile foundation.

| **Model-1** (mm) | **Model-2** (mm) | **Model-3** (mm) | **Model-4** (mm) | **Model-5** (mm) | **Model-6** (mm) |
|---|---|---|---|---|---|
| 35.946 | 35.54 | 35.77 | 33.923 | 35.37 | 33.137 |

**Table 9B.** Ground settlement values of the bridge abutment with open foundation.

| **Model-1** (mm) | **Model-2** (mm) | **Model-3** (mm) | **Model-4** (mm) | **Model-5** (mm) | **Model-6** (mm) |
|---|---|---|---|---|---|
| 85.536 | 84.812 | 85.184 | 74.694 | 84.465 | 73.618 |

Bending moment and Shear force values of the bridge abutment with pile foundation for all six different FEM models have been presented in Table 10A and Table 10B respectively.

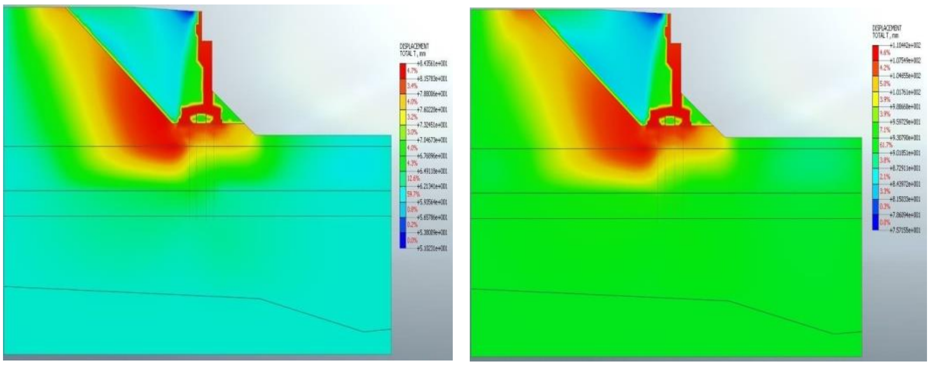
**Table 10A.** Bending moment values of the bridge abutment with pile foundation.

| **Model-1** (kN-m) | **Model-2** (kN-m) | **Model-3** (kN-m) | **Model-4** (kN-m) | **Model-5** (kN-m) | **Model-6** (kN-m) |
|---|---|---|---|---|---|
| 230.65 | 229.12 | 241.81 | 207.69 | 239.98 | 216.57 |

**Table 10B.** Shear force values of the bridge abutment with pile foundation.

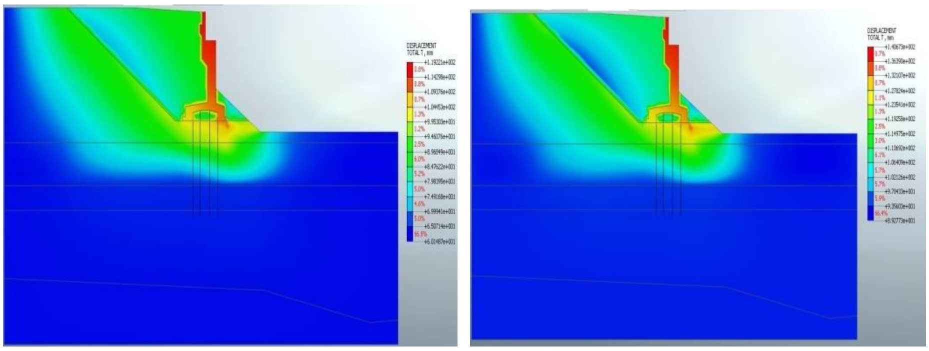
| **Model-1** (kN) | **Model-2** (kN) | **Model-3** (kN) | **Model-4** (kN) | **Model-5** (kN) | **Model-6** (kN) |
|---|---|---|---|---|---|
| 68.74 | 60.96 | 68.63 | 83.26 | 60.59 | 75.57 |

Ground settlements of the bridge abutment with **pile foundation** for PGA value of 0.24 (for zone-III) and 0.36 (for zone IV) are shown in Fig. 3. Ground settlements of the bridge abutment with **open foundation** for PGA value of 0.24 (for zone-III) and 0.36 (for zone IV) are shown in Fig. 4. Ground settlements and bending moment values of the bridge abutment with pile foundation for water profile below the embankment are shown in Fig. 5.



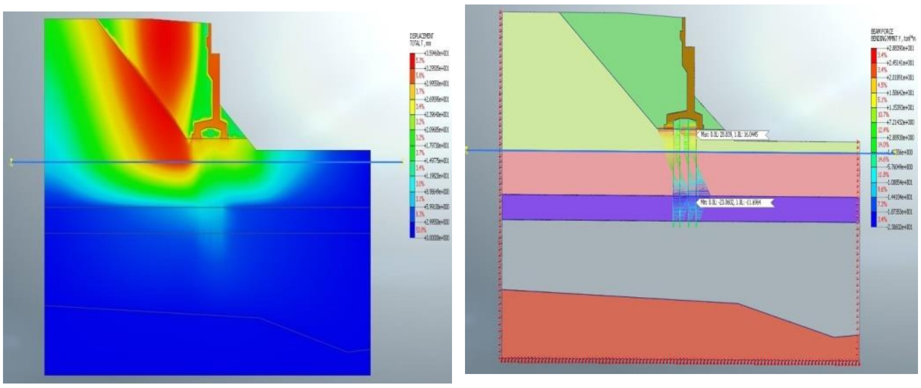
A. PGA value of 0.24 (for zone-III) B. PGA value of 0.36 (for zone-IV)

**Fig. 3.** Ground settlements of the bridge abutment with **pile foundation** for PGA value of 0.24 (for zone-III) and 0.36 (for zone IV).



A. PGA value of 0.24 (for zone-III) B. PGA value of 0.36 (for zone-IV)

**Fig. 4.** Ground settlements of the bridge abutment with **open foundation** for PGA value of 0.24 (for zone-III) and 0.36 (for zone IV).



A. Ground settlement of the bridge abutment B. Bending moment of the bridge abutment

**Fig. 5.** Ground settlements and bending moment values of the bridge abutment with pile foundation for water profile below the embankment.

## 4 Discussions on results:

From the results shown in the Table-8A, it can be noted that factor of safety values of the bridge abutment with pile foundation gradually increases by 4-12% when ground condition changes from medium to stiff clay followed by weathered rock. From the results shown in the Table-8B, it is observed that factor of safety values has variation less than 1% for the bridge abutment with open foundation.

From the results shown in the Table-9A and Table-9B, it is clear that ground settlement value decreases by 6-8% in pile foundation and by 14-16% in open foundation when ground condition changes from medium to stiff clay.

Table-10A shows bending moment value decreases by 6-11% in bridge abutment with pile foundation when ground condition changes from medium to stiff clay whereas Table-10B shows shear force value increases by 9-17%.

The diagram of Fig.3 shows that ground settlement of the bridge abutment with pile foundation increases by 30-135% when seismic zone changes from zone-III to zone-IV with higher PGA, even for same soil condition whereas the diagram of Fig.4 shows that ground settlement of the bridge abutment with open foundation increases by 18-40% when seismic zone changes from zone-III to zone-IV.

The diagram of Fig.5 shows the ground settlement and bending moment values of the bridge abutment with pile foundation having no significant variation between the case of water profile below the embankment and case with no water table. However, factor of safety value of the bridge abutment with pile foundation decreases slightly (around 10%) for the case of water profile below the embankment.

## 5 Conclusions:

In the present paper, the behaviour of bridge abutment and its foundation has been studied under varying subsoil, water table and seismic condition. Different sets of parametric study have been conducted by developing various numbers of FEM models for bridge abutment with both pile and open foundation. Following conclusion can be drawn from the current study's analysis and results:

- Factor of safety of the bridge abutment gradually increases with gradual improvement of ground condition. Factor of safety values of the bridge abutment with pile foundation gradually increases by 4-12% when ground condition changes from medium to stiff clay. In the case of bridge abutment with open foundation, values have no significant variation (around 1%).
- Ground settlement of the bridge abutment gradually decreases with gradual improvement of ground condition. Ground settlement value decreases by 6-8% in the case of bridge abutment with pile foundation and by 14-16% in the case of bridge abutment with open foundation when ground condition changes from medium to stiff clay.
- With the change of ground condition from medium to stiff clay, bending moment value decreases by 6-11% in bridge abutment with pile foundation whereas shear force value increased by 9-17%.
- With the change of seismic zone from zone-III to zone-IV, ground settlement of the bridge abutment with pile foundation increases by 30-135% even for same soil condition whereas ground settlement increases by 18-40% in the case of bridge abutment with open foundation.
- Factor of safety of the bridge abutment with pile foundation decreased by 10% for the case of water profile below the embankment. However, ground settlement and bending moment values of the bridge abutment with pile foundation having no

significant variation between the case of water profile below the embankment and case with no water table.

Outcomes of the present case study may be useful to the practicing engineers as a reference for similar situations.

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