RESPONSE BEHAVIOR OF REINFORCED CONCRETEPILES- IN ROCK-ROCK SYSTEM HAVING SHEAR ZONE

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ABSTRACT

Reinforced Concrete piles are widely used in cases where the desired bearing capacity is not being achieved or large settlements are encountered in the founding strata. The piles are used as load bearing structuresto transfer load through weak rock/ soil to a sound stratum. Generally for light infrastructure projects the load carrying capacity of even a low strength rock is far more than the strength required for construction of their foundation.However, for structures involved in heavy infra projects like hydro-electric power plants, naval industries, defense projects etc., sometimes, the desired ground strength to bear the load of huge structures is not provided by a weak rock mass.This creates a challenging situation to design the foundation. One option is obviously to open excavate and reach the sound rock level, the other option envisages use of pile foundation to transfer the load to sound rock. Large number of projects have been analyzed and executed using pile foundation but all the analysis done so far appear to have simulatedonly homogeneous layersof soil or rock. This usually is not the case as, naturally available weak rock many times contains compressible layers or shear seams.This void creates the scope of the present study. Also, there are various studies available which focus mainly on response of piles under static condition. However, many piling projects, these days are being taken up in highly seismic zones, and this requires use of numerical analysis in order to effectively predict the pile response during earthquakes. This paper presents the response behavior (axial force, bending moment, shear force and displacement) of RC large diameter piles in rock-rock geological formation having shear zone under earthquake loading (pseudo static approach).A 2D FEM model is used to simulate the response of single pile embedded in rock- rock formation consisting of a shear seam under earthquake loads. The superstructure loads that pile would be bearing has been modeled as a block load (heavy load).It is observed that the shear zone does impact the behavior of piles passing through it. The presence of shear seam decreases the axial force in the pile and increases the bending moment and shear force magnitude by an appreciable margin. Hence, while designing a pile foundation through shear zones or compressible zones, higher design provisions than conventional requirement might be taken into account.

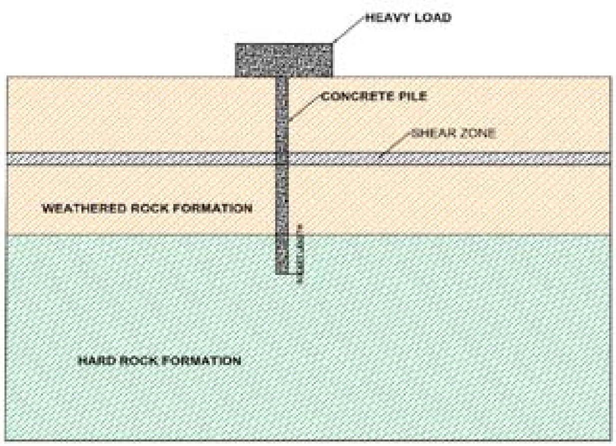


Figure 1 : Typical section (not in scale) of pile embedded in rock-rock formation with shear zone

1. INTRODUCTION

The main objective of any foundation is to provide the desired bearing capacity and stay between allowable settlement. Load transfer mechanisms for piles is necessary to understand for design and analysis. The mechanism of load transfer of piles is different for axial forces than that from lateral forces. In the case of axial (vertical) loads, piles may be looked upon as axially loaded columns; they transfer loads to the ground by shaft friction and base resistance (Salgado, 2008) whereas pile behave as transversely loaded beams in the case of lateral loads.Laterally loaded piles transfer lateral load to the surrounding soil mass by using the lateral resistance of soil. On application of lateral load on pile, a part or whole of the pile tries to shift horizontally in thedirection of the applied load which causing bending, rotation or translation of the pile (Fleming et al.1992, Salgado 2008). The pile presses against the soil in front of it (i.e., the soil mass lying in the direction of the applied load), generating compressive and shear stresses and strains in the soil that offers resistance to the pile movement.

Apart from the load from super structures, pile response are mostly depend on the media in which it is installed no matter what is the load transfer mechanism. Most of the pile foundation analysis considers homogeneous media for load transfer. However, in reality there are number of instances where piles may have to pass through compressible or weak media like shear zones. Therefore, it was felt to study the behavior of the pile passing through intermediate weak/ shear zone. In present study an effort is made to understand its behavior under static and pseudo static conditions of pile embedded in weathered rock and hard rock system as shown in figure1 by 2D Fem analysis.

Analysis of loaded piles can be done by treating the soil surrounding the pile as a continuum. Such an approach is conceptually more appealing than the beamon-foundation approach or the p-y approach because the interaction of the pile and the soil is indeed three dimensional in nature. Research in this direction was pioneered by Poulos(1971a), who treated the soil mass as an elastic continuum and the pile as a strip, which applied pressure on the continuum. He used Mindlin's solution (Mindlin 1936) for horizontal load acting at the interior of an elastic half space and applied a boundary integral technique to obtain pile deflection. The elastic analysis was extended to account for soil nonlinearity in an approximate way by assuming elastic-perfectly plastic soil (Poulos 1972, 1973, Davies and Budhu 1986, Budhu and Davies 1988). A similar boundary element analysis was performed byBanerjee and Davies (1978).Today, the most versatile continuum-based method of analysis available is the finiteelement method. The method can take into account the three-dimensional interaction, and both elastic and nonlinear soils can be simulated by giving inputs of elastic constants (e.g., Young's modulus and Poisson's ratio) or by plugging in appropriate nonlinear constitutive relationships.

2. 2D MODELLING OF PILE

Although piles are a real 3D element there still is a need to model piles in 2D. Reasons could be the interest to observe mostly the global behavior of a structure or to obtain some preliminary results or deformations or structural forces on the piles. Currently, when modeling a pile (row) in 2D, users would have to make use of plate elements and/or node to node beam element. Both however have their own specific possibilities and limitations. The "embedded pile row" element can be used to simulate a row of piles with a certain spacing perpendicular to the model area. The EI and EA properties are smeared and entered per meter width for pile.The embedded piles in 2D basically behave in the same manner as the 3D embedded piles with some limitations. The biggest difference, which also accounts for the 2D vs. 3D behavior, is the stiffness of the line to line interface.

The stiffness of the springs in the 3D line to line interface is set to a high value such that elastic deformations are negligible but not so stiff that numerical problems arise. As a result of this choice all deformations of the pile are a result of elastic/plastic deformations of the soil itself and/or from plastic deformations in the line to line interface.

In a 2D model however this principle no longer works since the soil displacements are no longer a representation of reality but rather an average of the out of plane soil displacement. The latter can be shown by calculation (Sluis, 2012) but can also be explained by realizing that in the 2D model and an equivalent 3D model/reality the same amount of force per m is transmitted to the soil giving the same (average) deformations.

3. BEAM ELEMENTS

Beam elements are two-dimensional elements with three degrees of freedom (x-translation, y-translation and rotation) at each end node. A standard beam element can respond to flexure, axial (compressive or tensile) and shear forces. Beam elements can be joined together with one another and/or the grid. Beam elements are used to represent a structural member, including effects of bending resistance. In RS^2 a Standard Beam liner is made up of a series of "beam elements", corresponding to the edges of finite elements. For a Standard Beam liner you may select one of two different Beam Formulations.Pile element segment is treated as a linearly elastic material with no axial yield. Beams may be used to model a wide variety of supports, such as support struts in an open-cut excavation and yielding arches in a tunnel. Interface elements can be attached on both sides of beam elements in order to simulate the frictional interaction of a foundation wall/pile with a soil or rock. Pile interacts with grid via interface which are shear and normal stiffnesses. These can be assumed as coupling springs which are nonlinear connector and transfer forces and motion between the pile elements and grid at pile element nodes.

4. NUMERICAL MODELLING

A 2D FEM model with rock- rock geological formation (weathered and hard rock)having thin shear seam of 2.0m width in the weathered rock (20m thick)- hard rock formation is being considered under static and earthquake loading (pseudo static). A pile of 26 m length of 2.0m diameter is used with 6 m of socketing in hard rock and a steel block of 10mx5m replicating heavy load is also considered over the pile.For simplicity, a horizontal shear seam is adopted for the study. The study envisages three different cases toobserve and compare the response of pile when driven through shear zone in terms of bending, shear force, axial force and displacement. Following are the three cases considered-

(i) **Case I** : Single pile in rock-rock system is considered without any load is analysed in two stages-

Stage-1 : Static condition (Gravity)

Stage-2 : Pseudo-static condition (earthquake)

(ii) **Case II** : Single pile in rock-rock system with block load over pile

Stage-1 : Static condition (Gravity)

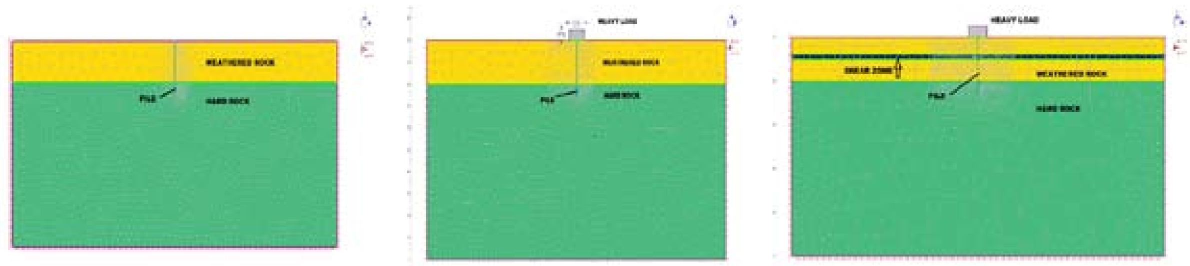
Stage-2 : Pseudo-static condition (earthquake)

(iii) **Case III** : Single Pile in roc-rock system having shear zone with block load over pile.

Stage-1 : Static condition (Gravity)

Stage-2 : Pseudo-static condition (earthquake)

The earthquake coefficients are adopted from highly seismic zone- Zone V to get the maximum response. Direction of earthquake coefficients are from left to right for horizontal excitation and bottom to top for vertical excitation.



Case-I Case-II Case-III

Figure 2 : Typical 2D FEM model showing different cases

4.1 Material Properties

Table 1 : Material Properties

Properties	Hard Rock	Weathered Rock	Shear Zone	Pile	M-C Slip Criteria	Units
Density	26	23	19	25	--	KN/m^3
Young's Modulus	4500	605	100	31622	--	MPa
Poisson's Ratio	0.22	0.25	0.3	0.20	--	--
Cohesion	0.800	0.190	0.015	--	0	MPa
Friction Angle	36	32	25	--	35	deg.
Tension	0.152	0.003	0	--	--	(MPa
Seismic coefficients:	Horizontal acceleration coefficient = 0.24					
	Vertical acceleration coefficient= 0.16					

- **Pile Properties**

Input parameters for pile properties are area (m^2), moment of inertial (m^4), stiffness (MPa), unit weight (KN/m^3) and the out of plane spacing (m). the actual properties are converted to properties which are spread out over the out of plane spacing.The piles are modelled as standard beam element and EI & EA properties were changed to per unit values. The values have to be converted to per unit meter to model discrete pile elements out of plane.

- **Interface Properties**

Soil-structure interaction is described by special developed interface elements, connecting the embedded pile row element and the soil mesh. Along the pile there is a line-to-line interface, represented by springs with numerical stiffnesses, in axial and lateral direction (K_n and K_s). Rock-pile contact is modelled with M-C slip criteria by defining structural interface as Joint-Pile-Joint. Since the results were more sensitive to the interface properties than the modulus of deformation of the rock mass, its condition was carefully adopted.

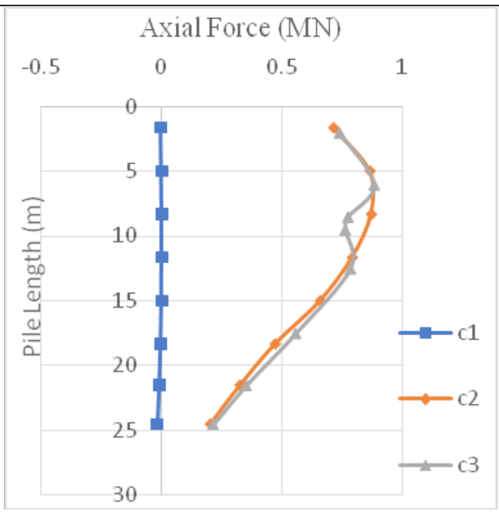
5. ANALYSIS & RESULTS CASES:

Thebehaviour response of piles is closely studied for the above three cases and stages as mentioned. Response in terms of axial force, bending moment, shear force and displacement is only reported other findings in terms of change in stresses and total displacements of the rock mass is not reported in this study. Findings are summarised and presented in graphical form in the subsequent headings as case results-

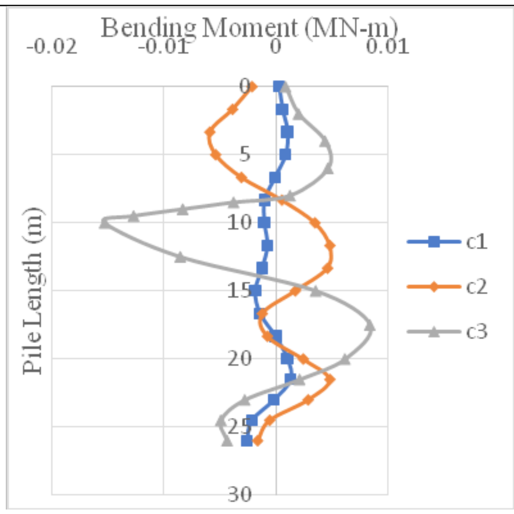
Result Case 1 : Axial force, bending moment, shear force and displacement response of pile in different cases i.e. Case-I, Case-II & Case-III (Figure 3) under static loading.

Result Case 2 : Axial force, bending moment, shear force and displacement response of pile in different cases i.e. C-I, C-II & C-III (Figure 4) under psuedostatic loading.

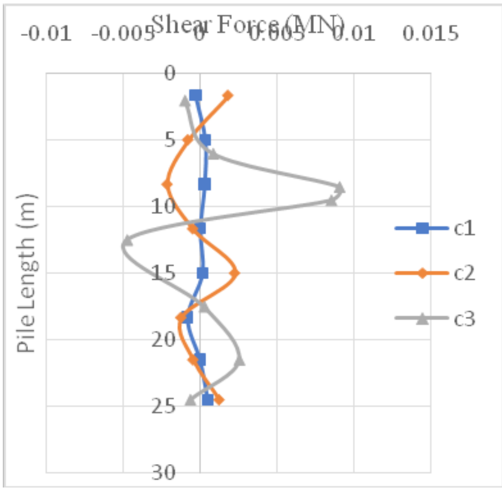
Result Case 1:



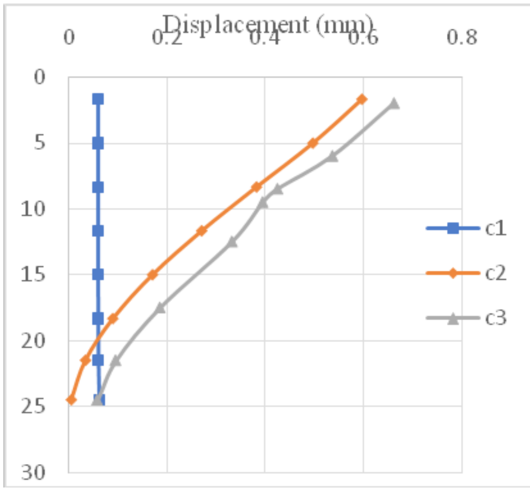
Stage 1 Axial Force along Pile



Stage 1 Bending Moment along Pile



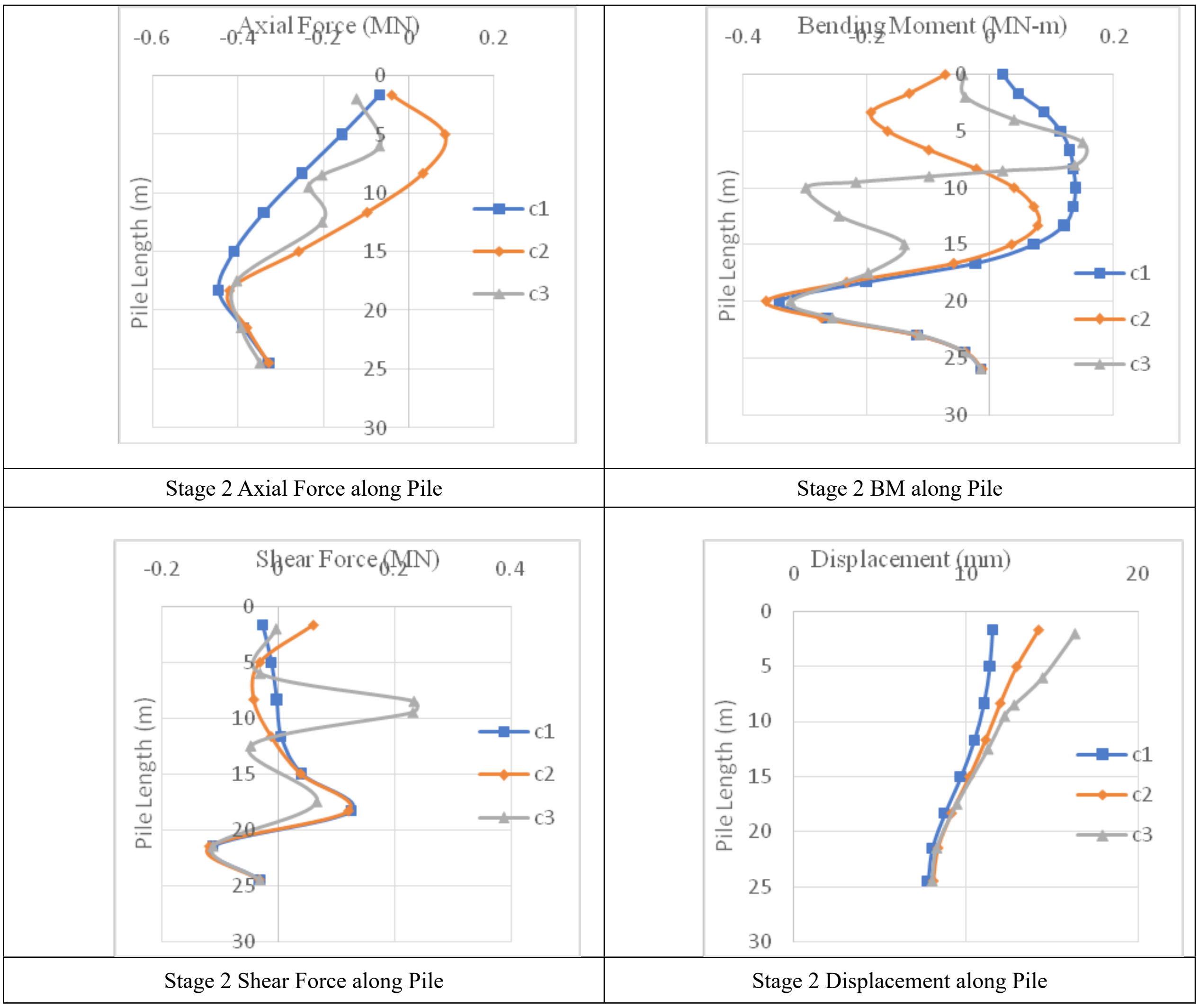
Stage 1 Shear Force along Pile



Stage 1 Displacement along Pile

Figure 3 : Axial Force, Bending Moment, Shear Force and Displacement along pile length for Stage 1 for different cases.

Result Case 2:



Stage 2 Axial Force along Pile

Stage 2 BM along Pile

Stage 2 Shear Force along Pile

Stage 2 Displacement along Pile

Figure 4 : Axial Force, Bending Moment, Shear Force and Displacement along pile length for Stage 2 for different cases.

6. CONCLUSION:

Static Loading Condition

1. Comparison of results between case-I and case-II shows classical response behaviour of piles when put under load in static condition.
2. The axial force increases up to 8m from top and then starts reducing gradually in case-II, reduction in force is approximately 75% which means the load transfer is majorly due to shaft resistance. However, with introduction of shear zone in case-III the axial force capacity reduces (dips) in the range of shear zone and follows a concave type peak.
3. It is likely that the bending moments and shear force will be a maximum at or near rock/shear layer interfaces where there is a significant difference in the stiffness of the layers. It is observed that there is appreciable increase in the magnitude of bending moment (around 3 times) and shear force (around 4 times) at the approximate location of shear zone when compared between case-II and case-III. However, this amplification is also a function of shear zone thickness and load imposed form super structure.
4. In general, it is observed that the shear zone layer reduces the axial force and increases the bending moment and shear force in the pile.
5. Deflection of the pile top increases with the introduction of load under static condition and increases slightly more with introduction of shear zone. This small increase in deflection between case-II & case-III is due to the rock mass movement. It was also observed that the deflection of pile was more responsive to the modulus of deformation of the rock mass than anything else. Deflection profile forms a bulb like pattern for the pile intersection with shear zone in case –III this is possibly due to the lack of lateral support.

Dynamic Loading Condition

6. Axial force is relatively less till 6m from top and increases beyond the shear zone. The magnitudes are less in comparison to static loading condition and that is due to the earthquake loading direction.
7. Bending moment and shear force magnitudes are higher than obtained in static condition and are found to be maximum around shear zone layer only. It is expected that bending and shear force magnitude will increase with the increase in the width of shear seam and under heavy load.
8. Displacements are higher than the static condition which is obvious. Pile bottom shows small displacement of 8mm which is due to the horizontal movement of the rock mass under earthquake loading and firms the fact that the piles under these conditions shall also be designed for lateral loads.

In general, while designing a pile foundation through shear zones or compressible zones, higher design provisions than conventional requirement might be taken into account, especially for the projects located in earthquake prone areas.

7. FUTURE STUDY

2D Fem analysis cases are usually considered to be conservative in the analysis. However, when it comes to discrete pile foundation modelling, 3-dimension model is preferred for close and accurate results. This leaves with the future scope of validating the 2D model results with the 3D model.

The response of a single pile differs from that of a pile placed within a pile group. Each pile in a group, whether loaded axially or laterally, generates a displacement field of its own around itself. The displacement field of each pile interferes and overlaps with those of the adjacent piles; this results in the interaction between piles that also need to be studied.

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