# Influence of Shear Strength of Soil on Stresses in Footing-A Review

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**ABSTRACT**

Shear strength characteristics of soil beneath the footing play a salient role on the stresses developed in the footing. In the design of foundation, it is imperative to analyse the stresses developed in it to prevent failures. Estimation of the influence of shear strength of underlying soil and flexural rigidity of footing on the shear force and bending moment developed in the foundation is necessary for effective determination of stress. Unlike conventional experimental methods, numerical analysis using Finite Element Method based geotechnical software like PLAXIS, FLAC, MIDAS etc. enables the analysis of foundations with complex stress characteristics. Finite Element Method (FEM) is a numerical analysis procedure that provides approximate solutions to various problems associated in the field of geotechnical engineering. This paper critically reviews the current literature on numerical methods to investigate the influence of shear strength of supporting soil on the structural forces developed in a footing. The relevance of the present approach to the concept of shear strength analysis is scrutinised by various numerical simulation analysis software.

**Keywords:** Shear Strength, Flexural Rigidity, Finite Element Method, Foundation

## 1 INTRODUCTION

Deformation pattern and the stresses developed in a loaded footing are influenced by the shear strength of supporting soil which affects the structural characteristics of a loaded member. Numerical methods are a promising technique to investigate the shear strength and deformation of the supporting soil and enhance facile structural analysis. Numerical simulation in geotechnical engineering is a complex structural analysis technique that develops simpler and feasible approaches for various structures having a complicated geometrical analysis or complex loading conditions. A traditional and generalized experimental technique often impairs the efficient and economical analysis of structures thereby, highlighting the relevance of constitutive modelling methods so as to achieve the required accuracy of solution. Numerical analysis of stress and deformation involves various continuum methods (Finite Difference Method, Finite Element Method, Finite Volume Method etc.) and dis-continuum methods (Discrete Element Method, Discrete Fracture Network Method etc.). However, only a few researches and literatures have been conducted in particular to examine the validation and reliability of these numerical analysis developments in geotechnical engineering (Schweiger, 2002). This paper critically analyses the current literatures on these numerical approaches in order to investigate the relevance of various computational techniques by analysing the influence of shear strength of underlying soil and flexural rigidity of footing on the structural properties of a footing.

## 2 NUMERICAL SIMULATION OF SHEAR STRENGTH OF SOIL

Determination of shear strength of underlying soil on the structural properties of a footing is an integral component considered in the design of foundations. Considering its significance, the concept of shear strength is widely adopted by geotechnical engineers in the analysis of bearing capacity of foundations, construction of



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highway and airfield pavements, stability analysis of slopes and embankments and the like. Foundation characteristics are often harnessed when subjected to extreme loading conditions and impairs the stability of the structural components of a building in direct contact to the soil mass. Various numerical analysis oriented researches in the field of geotechnical engineering has revealed the successful and facile analysis of foundations with complex stress characteristics (Akhtarpour, 2016).Conventional methods of geotechnical analysis may be cumbersome and unmanageable when subjected to adverse loading conditions(Schweiger, 2002), as a result of which these numerical simulation software act as a productive tool to perform stress-strain analysis in geotechnical applications. The applicability and hypothesis of various strength theories in geotechnical engineering by numerical simulation has been examined in different literatures.

## 2.1 STRESS ANALYSIS IN SOIL STRUCTURE INTERACTION

Soil structure interaction in geotechnical perspective is a complex analysis which emphasis on the influence of the soil on structural movement and vice versa. This concept is widely analysed in various applications such as stability analysis of foundation, seismic activity, structural displacement, ground displacement and the like. Various researches regarding a detailed mechanical interpretation using numerical analysis on soil structure interaction have been conducted orienting the same in order to analyse the contact characteristics between soil and structure (Chang Qiang et al, 2019).

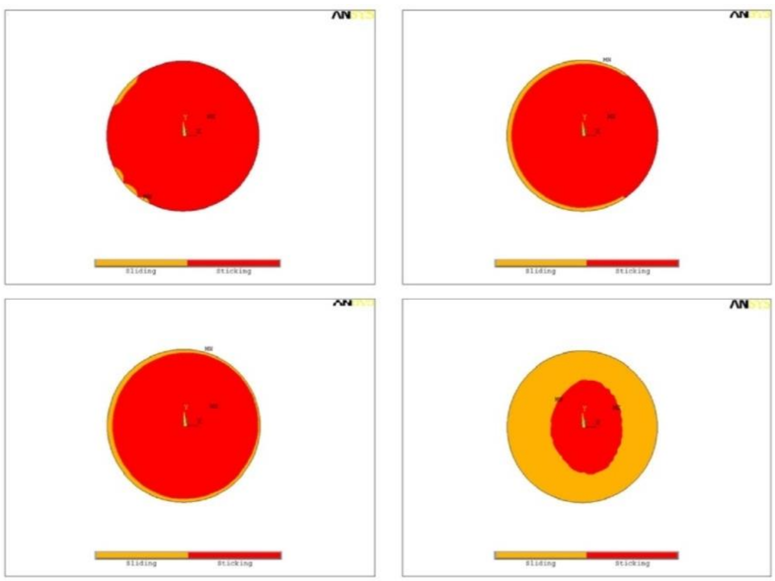

Figure 1. Contact surface shear failure development cloud (Chang Qiang et al, 2019)

In contrast to conventional methods, (Chang Qiang et al, 2019) adopted a numerical simulation method of finite element analysis to study the shear strength of contact surface and the corresponding deformation characteristics. The contact surface element method was adopted by developing a relation between the contact plane and the contact surface thereby analysing its mechanical properties under external loading conditions. A cuboidal concrete structure (70 cm width and 40 cm height) was placed in contact with a cylindrical soil specimen (50 cm diameter and 40 cm height) subjected to normal stress conditions of 100, 200, 300, 500 and 1000kPa. Numerical simulation using the ANSYS finite element software revealed a nonlinear behaviour in the contact characteristics. The contact surface developed two shear stress regions and the shear stress distribution cloud of the contact surface showed a non-uniform trend at its left, middle and right nodes. A general increase in the shear stress distribution was also observed with an increase in shear displacement until a specified limit after which a stable shape was obtained. Further the contact surface damage mechanism was observed to be formed gradually from the edge to the internal part of the contact cloud. Figure 1 indicates the contact surface shear failure development cloud formed when subjected to varying normal stresses. The modelled specimen was also analysed using the ABAQUS finite element software and it was observed that the contact surface shear stress and shear displacement developed a hyperbolic model. A linear trend in shear strength characteristics of the contact surface was obtained and ascertained satisfactory adherence to the principal theory of Mohr-Coulomb strength criterion. Thus, the results obtained on adopting numerical simulation using the ANSYS and ABAQUS software revealed an efficient and facile analysis of stresses in soil-structure interaction.

## 2.2 PUNCHING SHEAR FAILURE MECHANISM IN FOOTING

The phenomenon of punching shear is a failure mechanism commonly observed in structural members like slab-to-column or footing-to-column connections wherein the failure action of a concentrated load results in the formation of a shear failure cone (Jiho Moon et al, 2014). Numerous experimental and analytical studies have been conducted to estimate the occurrence of punching shear failure in the case of a concrete flat slab-column connection. In order to analyse the punching shear mechanism in a footing, (Jiho Moon et al, 2014) employed a non linear finite element analysis to determine the enhancement in the strength and ductility properties of a footing upon the insertion of punching shear preventers (PSPs). To undergo the study experimentally, four punching shear preventers (PSPs), shaped in the form of a cone with two sizes (500x100x200) and (700x200x250) were inserted into the footing, inclined at an angle of 45˚. Five large scale square shaped test footings were modelled with the dimensions of 2400 mm side length and 500 mm depth, with the axial load applied at the centre of the footing.

Test results were analysed on considering various parameters such as strength characteristics, relation between applied load and strain, vertical displacement, formation of crack pattern at the middle section of the specimen etc. Results obtained indicated the effectiveness of PSPs in preventing adequate punching shear failures in the footing due to appropriate redistribution of the applied load to the reinforcing bars, the major reason being the isolation of shear cracks on placing the PSPs at the zone of compressive strut. Further, finite element analysis was adopted using ABAQUS software wherein, the concrete footing was modelled using 8-node solid elements and PSP was modelled using 4-node shell elements. Values equivalent to the test results were obtained on conducting the same specifying the accuracy of the experimental tests. Figure 2 indicates the finite element model for the test specimen.

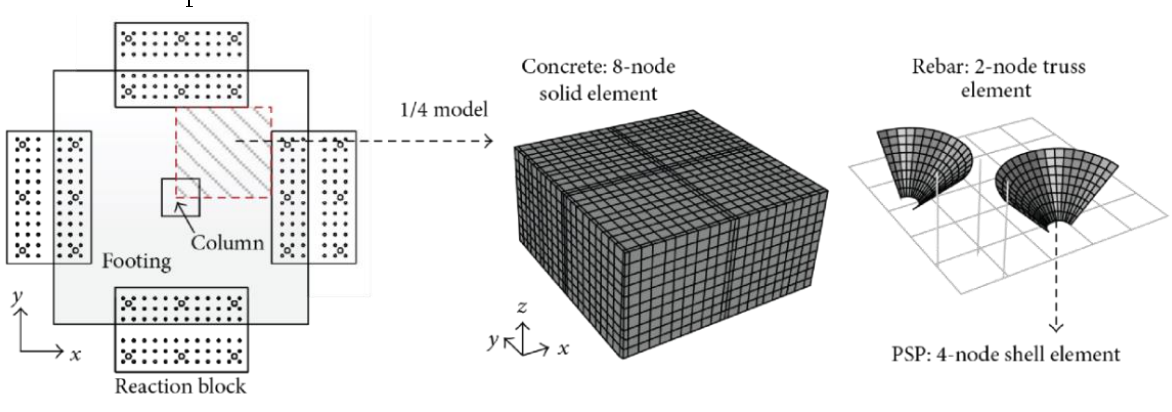


Figure 2: Typical finite element model for the test specimen
(Jiho Moon et al, 2014)

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Analysis results also indicated that considerable enhancement in strength properties and ductility of the footing with PSPs could not be obtained on varying the dimensions of PSP such as size, thickness etc. The results analysed were further verified with conventional codal equation such as ACI design equation and it was observed that a reduction in strength by 14% was obtained on adopting the equation in comparison to the obtained value. Thus, the variation in the structural properties of a footing when exposed to punching shear can be effectively analysed on adopting numerical analysis.

### 2.3 INFLUENCE OF SHEAR STRENGTH OF SOIL ON STRUCTURAL PROPERTIES OF FOOTING

(Mohamad, 2019) has conducted a study on the effect of soil and bedrock conditions below the footing on the footing behaviour. Footings are structural elements that transmit column or wall loads to the underlying soil below the structure. They are designed in a manner so that the transmission of the load to the soil won't exceed the safe bearing capacity of soil, to control the excessive settlement of the structure to a tolerable limit, to attenuate differential settlement, and to forestall sliding and overturning. In the associated literature, the structural response and behaviour of the square footing was analysed by conducting a numerical modelling on adopting a finite element analysis software, PLAXIS 2D.

The different conditions considered to analyse the structural response of footing are (1) Various bedrock depths ,D = 4m to 20m under the footing at horizontal bedrock slope ($\theta = 0°$); (2) Various friction angles ($\Phi$) for all bedrock depths at horizontal bedrock slope ($\theta = 0°$); (3) Different bedrock slopes ,$\theta = 11.3°$ to $70.3°$ at depths, D = 8m & 16m; (4)Different friction angles ($\Phi$) for various bedrock slopes at depth D = 8m; (5) Different coefficient of elasticity (E) for various bedrock slopes at depth, D = 8m. PLAXIS 2D has been developed specifically for the analysis of deformation and stability in geotechnical engineering projects. The structural analysis by PLAXIS 2D in the research, involved investigating displacements, stresses, and shear strains.

The results obtained shows that the utmost horizontal displacements, stresses, and shear strains below the footing with different friction angles, different bedrock slopes and different bedrock depths have significant effect on the footing behaviour due to the presence of larger and smaller amount of soil below the footing which results in an increasing and decreasing pattern of soil stresses below the footing (Mohamad,2019).The horizontal displacements, stresses, and shear strains under the footing have the foremost effect on footing behaviour with increasing coefficient of elasticity at varying bedrock slopes; this can be due to the increasing soil stresses below the footing and its effect on the footing behaviour. When increasing friction angle at varying bedrock slopes, the utmost horizontal displacements, shear strains, and stresses below the footing decrease. This is because of the increasing soil granules friction with one another that result in a control over the frictional resistance of soils along with the conventional effective stress. The analysis of horizontal displacements, shear strains, and stresses were also executed effectively using the PLAXIS 2D software. Hence, the software adopted for the analysis of various parameters associated with the bed rock and soil conditions was proved to develop accurate results as compared to conventional methods.

## 3 ANALYSIS OF STRUCTURAL PROPERTIES OF BEAM USING PLAXIS SOFTWARE

PLAXIS is a finite element program that performs analysis of deformation and stability in the realm of geotechnical engineering projects. Soil is a multiphase material with properties which can vary with a changing environment. In order to examine these complex soil conditions, PLAXIS is given features to deal with hydrostatic and non-hydrostatic pore pressure within the soil and to analyse aspects dealing with complex geotechnical structures. One of the most important issues in geotechnical and structural field is modelling the soil and structure set (soil-structure interaction). In the research executed by (Akhtarpour, 2016), soil mechanic software for numerical modelling which has both geotechnical and structural modelling features, are in priority and the performance of PLAXIS software in soil-structure interaction was analysed. First its performance on beam analysis results with different support condition were analysed and compared with classic structural analysis methods' results. Then building frames were modelled and analysed by PLAXIS and ETABS.

Validation of software is done by modelling one span beam, considering beam with simple support condition and beam with double cantilever support condition. Different loading condition including load concentrated at the mid-span and distributed loading were also considered. Classic structural analysis equations were used for the comparison of settlements and moment values. Comparison of results of PLAXIS with the values obtained from classic equations for maximum settlement and maximum moment of the beam with different support condition and different loadings were done. Figure 3 shows the moment under distributed load of double cantilever beam and Figure 4 shows the settlement under distributed load of double cantilever beam obtained from PLAXIS.

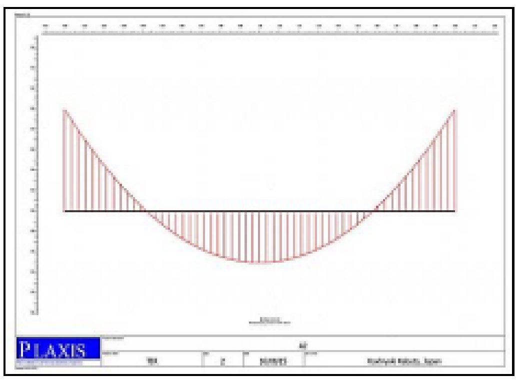


Figure 3. Moment under distributed load of double cantilever beam (PLAXIS)

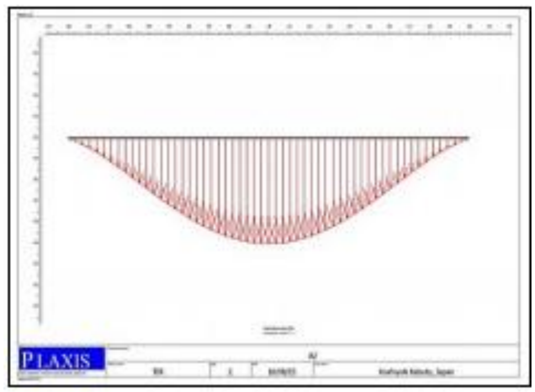


Figure 4. Settlement under load of double cantilever beam (PLAXIS) (Ali Akhtarpour and Mahbubeh Mortezaee 2016)

Slight variation in values can be seen by comparing the results of the software with classical equations of structure, for both types of beams and different support conditions; so efficiency of software to analyse beams is confirmed.

After assurance about the software performance in one-span beam modelling, a building frame was modelled and the results were compared with ETABS data. The properties of frame including bending moment of frame components, shearing force of frame components and deformations were analysed.

- The bending moment at different nodes of frame derived from PLAXIS and ETABS are shown in Figure 5.

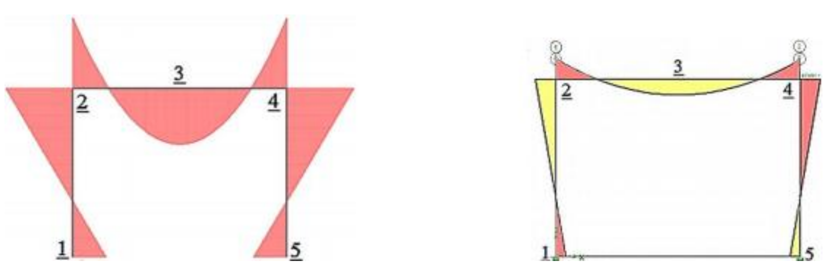


Figure 5. Bending moment at various nodes of frame (PLAXIS and ETABS) (Ali Akhtarpour and Mahbubeh Mortezaee 2016)

- The shear force of frame components obtained from both software is shown in Figure 6.

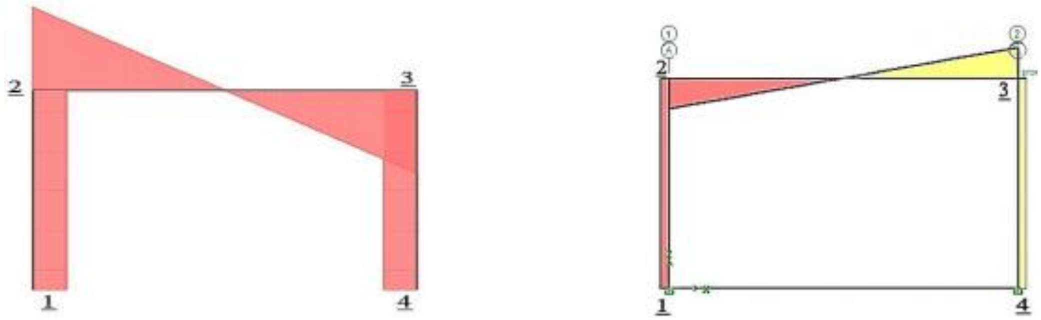


Figure 6. Shear Force of frame components (PLAXIS and ETABS) (Ali Akhtarpour and Mahbubeh Mortezaee 2016)

- The frame deformation derived from PLAXIS and ETABS software is shown in Figure 7.

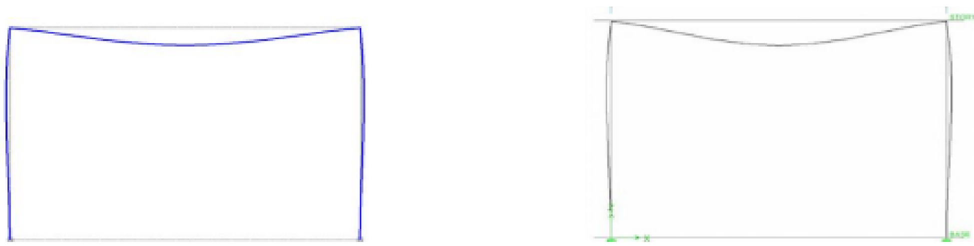

Figure 7. Frame deformation (PLAXIS and ETABS) (Ali Akhtarpour and Mahbubeh Mortezaee 2016)

Thus, with reference to the study adopted by (Akhtarpour, 2016), the results obtained by PLAXIS geotechnical software in modelling of structural frames based on theoretical equation of structural analysis and ETABS software show good agreement. By studying the results, it can be concluded that PLAXIS has the capability to analyse beam and building frames. The researches regarding the analysis of structural properties of footing by PLAXIS were limited. Based on the study employed by (Akhtarpour, 2016), it can be concluded that PLAXIS has the ability to analyse structural properties of footings which further need investigation in order to widen the scope of the software.

## 4 ANALYSING VARIATION IN FLEXURAL RIGIDITY OF FOOTING

Analysis of structural degradation of a footing is imperative to work out the structural response of a footing to external impact and further, to validate the service lifetime of a structure (Feng, 2018). Additionally to numerically analysing the shear characteristics of a soil on the stresses in the footing, the numerical simulation of the flexural response of a foundation is required to adequately determine various structural conditions. This category of foundation and its design depends upon the magnitude of the masses and therefore the variety of strata which support it (Schweiger, 1998).

(Haider, 2011) adopted a research to analyse the effect of flexural rigidity and soil modulus on linear static analysis of under structure. A raft foundation is basically an extended slab resting on the soil that extends over the foundation of the building; thereby providing support to the building and transferring its weight to the bottom of the building. In structures carrying heavy superimposed loads involving closely spaced columns or other supports, a substructure is often adopted especially when the soil bearing capacity is low(Daniel, 2010).The mentioned literature was adopted to examine the effect of flexural rigidity, modulus of subgrade reaction, bending moment, shear forces, and deflection on a typical raft. Here the soil was considered to be homogeneous and elastic. The essential principle considered during this research was the uniform thickness of the mat foundation.

Flexural rigidity may be revealed by reconfiguring the mat foundation in numerous ways which implies reconfiguring the thickness of the mat below the columns. With the rise of raft thickness, differential settlements are often decreased and also the maximum moment may be increased. The analysis methods are rigid beam analysis (conventional method) and Non-rigid or Elastic method. Rigid beam analysis is the simplest method and is employed when the settlements are small. The Discrete element method includes Finite Difference Method, Finite Grid Method (FGM) and Finite Element Method (FEM). Finite element analysis is the most accurate way of analysing the raft. In the associated literature, the accuracy of the traditional rigid method was estimated by comparing its result to the more accurate finite element analysis. The software used for the research was Slab Analysis by the Finite Element method software "SAFE". The analysis executed using the software SAFE revealed its ability to convert the object-based model into a finite element model.

The subsequent conditions used for investigating the effect of flexural rigidity were; d=0.5 m, L=6.0 m, column load = 1.0 MN, column dimensions: 0.4 m x 0.4 m, modulus of subgrade reaction for the supporting soil (k) = 80 MN/m3, modulus of elasticity for the raft material = 21 GPa and also the thickness (t) is variable. During this research, the distribution of soil pressure at different thickness like 0.4 m,0.6 m,0.8m,1.0m was considered by drawing different graphs with distance on X-axis and soil pressure on Y-axis(Haider, 2011). Modulus of subgrade reaction is the reaction pressure sustained by the soil sample. This may be determined by conducting a test or by employing a Winkler model. During this work, the effect of soil modulus was investigated by ranging the modulus of subgrade reaction from 60 MN/m3 to 120 MN/m3 and fixing all the opposite parameters for the identical typical and symmetric groundwork. Further, the following parametric conditions were used for the investigation of modulus of subgrade reaction. d=0.5 m, L=6.0m, column load = 1.0 MN, column dimensions: 0.4 m x 0.4 m, modulus of elasticity for the raft material = 21 GPa, thickness (t) = 0.6 m and also the modulus of subgrade reaction for the supporting soil (k) is variable.

The results obtained from this research indicated that the flexural rigidity (thickness) of the mat foundation has an influence on the pressure distribution of the soil, especially at sections under columns, and for the raft adopted in the present research. An absolutely noticeable condition is that the soil pressure distribution is far from being planar when the raft thickness is 0.4 m. However, when the thickness reaches 1.0 m, the pressure distribution approaches the planar profile assumed using the conventional rigid method. By decreasing the raft thickness from 1.0 m to 0.4 m; the utmost deflection under columns was increased to a percentage which is almost equivalent to the change within the thickness. The negative bending moment undergo changes within the raft rigidity than the positive bending moment. Thus, with reference to the research conducted by (Haider, 2011), a general conclusion can be derived on the efficiency of the software to research the effect of flexural rigidity by varying the thickness and thereby analysing the effect of structural properties on footing.

## 5 CONCLUSION

This paper focussed on critically analysing the relevance and effectiveness of numerical analysis with reference to researches orienting various geotechnical aspects. The analysis was conducted by studying the effect of various geotechnical parameters on the stresses of the footing. The research conducted to validate the capability of numerical analysis were limited. Based on the referred literature reviews, it can be concluded that numerical

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analysis has the ability to analyse the influence of shear strength of underlying soil and flexural rigidity of footing on the stresses in a footing. However, further investigation with respect to various factors is necessary in order to widen the scope of numerical analysis and to understand its relevance.

## How to Cite this Article:

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