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Numerical Analysis on Displacement and Stress Field of LCSG Pile under Vertical Loading

[1]Feng Li, [1]Wang Wei, [2]Zhou Aizhao, [3]Chi Xuchao and [4]Li Zhi
[1]School of Civil Engineering, Shaoxing University, 312000, Shaoxing, China
[2]College of Civil Engineering and Architecture, Jiangsu University of Science and Technology, 212003, Zhenjiang, China
[3]Melbourne School of Design, Melbourne University, 3010, Victoria, Australia
[4]Shanghai Underground Space Architectural Design and Research Institute, 200032, Shanghai, China

Abstract: Concrete pile is widely used as one effective foundation type to strengthen soft soil in geotechnical engineering. Several special cross-section concrete piles are introduced and their defect of poor drainage ability is put forward. Concept of one concrete-gravel composite pile, namely long-concrete short-gravel pile (LCSG pile), is presented in terms of its material composition, bearing mechanism and drainage behavior. What's more, FEM analysis on the working behavior of the LCSG pile under vertical loading is conducted by using Midas software. Distributions of displacement and stress field of soil around the LCSG pile are mainly discussed. The numerical results show that (a) LCSG pile can make good use of engineering materials to gain good working ability, (b) Increasing the length of outer gravel body can effectively achieve lowering the values of displacement and redistribute the Major Principal Stress (MPS) adjacent to LCSG pile and (c) End grouting is very conducive to reduce the magnitude and gradient of the displacement field and the MPS field. The above research results are available to related engineering design.

Key words: Concrete pile, gravel, displacement, stress field, numerical analysis

INTRODUCTION

Concrete pile is widely used to treat and strengthen soft soil foundations in geotechnical engineering because of its big bearing capacity and small settlement (Wang *et al.*, 2012). With the more and more complicated geology condition, however, modern geotechnical engineering gives rise to new challenges more than bearing capacity and settlement, for example, horizontal stability and soil quick condition (Chen *et al.*, 2011; Huo, 2012). In order to deal with such challenges, lot's of effort has been devoted to this subject and several concrete piles with special cross-section have been proposed. Ring section pile, namely PCC pile, shown as in Fig. 1a, was developed by Liu, professor of Hohai University and this technology has been used to many railway foundations (Mahfouz, 2011; Liu *et al.*, 2003, 2007, 2009a, 2012). This pile can make good use of shaft friction force offered by inner and outer concrete surface. Currently, Y-shaped section pile, developed by engineer Lu, was one extensively used kind special-shaped concrete pile in China (Liu *et al.*, 2009b) and cross section

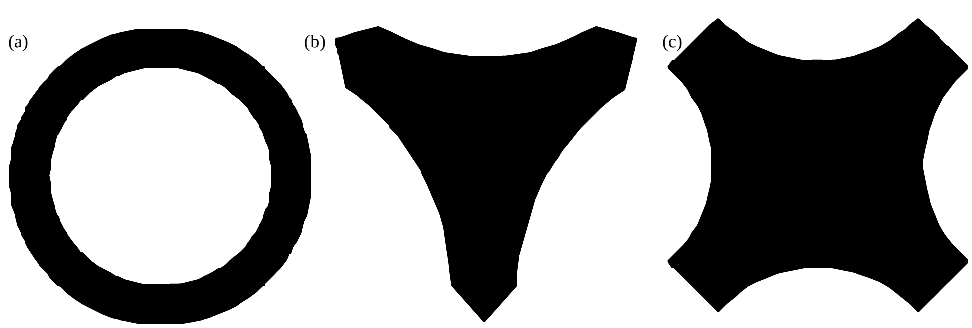

Fig. 1(a-c): Several special section piles (a) Ring section pile, (b) Y-shaped section pile and (c) X-shaped section pile

Corresponding Author: Wang Wei, School of Civil Engineering, Shaoxing University, 312000, Shaoxing, China

of this pile is shown as Fig. 1b. X-shaped section pile was invented by geotechnical institute of Hohai University which transforms its cross section to inverted arch from arch (Lv *et al.*, 2012), shown as in Fig. 1c. Compared to traditional concrete pile, above mentioned three special piles differ greatly on section behavior. With same cross section area, their circumferences and moment of inertia are much bigger than that of traditional ones which enable these piles to have better working property and broaden their application scope.

It should be noted that, many current improving methods, including PCC pile, Y-shaped pile and X-shaped pile, are mainly focused on loading transfer behavior of pile, however, attention to drainage and consolidation of the soil is not paid enough. Classic soil mechanics has proved that shortening drainage distance and speeding up internal draining process of soft soil are also good and practical ones.

To this end, the development of a new type of concrete pile with good vertical bearing capacity, horizontal anti-deformation ability and convenient drainage path, is in great need of geotechnical engineering (Wu *et al.*, 2013). This study introduced one fresh concrete-gravel composite pile, namely long-concrete short-gravel pile (LCSG pile) which can satisfy the above discussed requests. We further discussed the distribution of displacement and stress around the LCSG pile subjecting to vertical loading by FEM simulating.

GEOMETRICAL DESCRIPTION AND WORKING MECHANISM

LCSG pile consists of three parts of inner concrete body, outer gravel body as well as cement-grouted end, shown as in Fig. 2, with cross section (Wu *et al.*, 2013). Geometrical relations among the three parts and their performances are as follows:

- The inner concrete body is the core body of the LCSG pile, with diameter of d, length of L. Main function of this part is to balance and transfer up vertical loading to materials around or beneath pile, including soil and gravel
- The outer gravel body is with diameter of D = 1.41 d, length of x which is less than L, resulting one ratio k = x/L which ranges from 0-1. The case of x = 0 means the disappearance of the outer gravel body while the case of x = 1 denotes that the outer gravel body has same length to the inner concrete body. Key function of the outer body is both to strengthen horizontal stiffness and vertical bearing capacity of the LCSG pile and to give effect to drainage path for the soft soil which can enable the foundation to speed up its own consolidation and reduce its surface settlement
- The cement-grouted end which is not necessary to the pile, has same diameter to the outer gravel body. It, if pile has it, would contribute greatly to control displacement field and optimize stress field of the soil around the LCSG pile

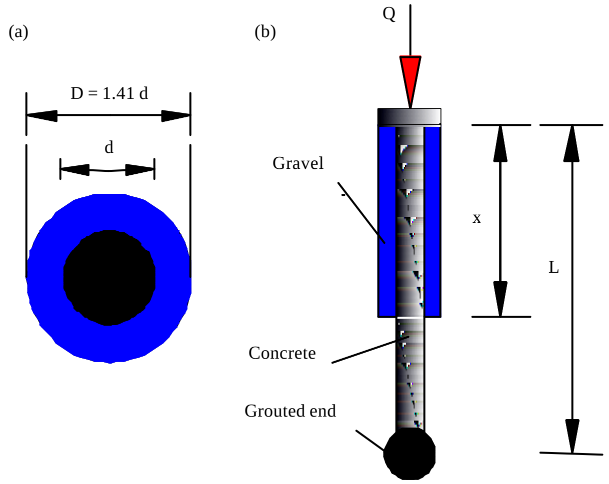

Fig. 2(a-b): General geometrical description of the pile (a) Cross section and (b) Profile section

FEM SIMULATION

Calculating parameter and FEM mesh: During this numerical simulation, the inner concrete body is designed as with 400 mm diameter, 16 m length; the diameters of outer gravel body and cement-grouted end are both 560 mm. Calculating boundary is designed as 8×8×24 m which is divided into 45161 elements and 47668 nodes.

Soil around pile is modeled by solid element, assuming to obey Mohr-Coulomb criterion; pile is modeled by linear elastic element. The cross section mesh and three-dimensional FEM grid are shown as Fig. 3 and 4, respectively.

Working conditions: In order to understand properly the behavior of LCSG pile, 12 cases are elaborated to simulate complicated working conditions according to different k = x/L and grouted end, listed as Table 1. All the cases are simulated by Midas software.

DATA ANALYSIS

Typical displacement field: According to the data derived form FEM computation, vertical displacement field of soil

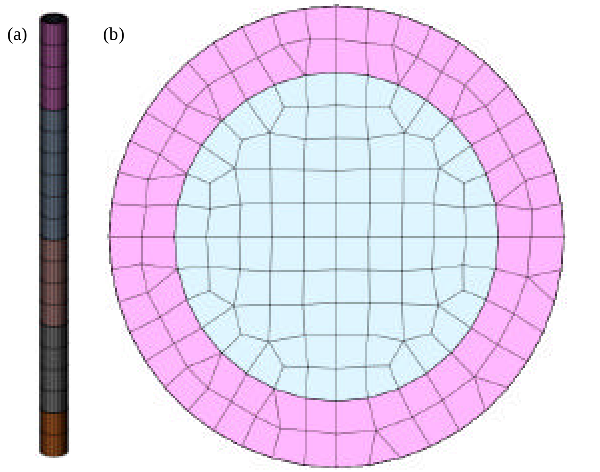

Fig. 3(a-b): FEM grid of LCSG pile (a) Longitude mesh and (b) Cross section

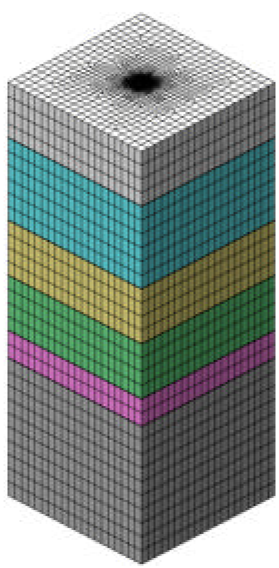

Fig. 4: Three-dimensional FEM grid of all calculating area

Table 1: Designed parameters of different cases

Case	x	L	k	Grouted end
1	0.0	16	0.0	Yes
2	3.2	16	0.2	Yes
3	8.0	16	0.5	Yes
4	10.2	16	0.7	Yes
5	14.4	16	0.9	Yes
6	16.0	16	1.0	Yes
7	0.0	16	0.0	No
8	3.2	16	0.2	No
9	8.0	16	0.5	No
10	10.2	16	0.7	No
11	14.4	16	0.9	No
12	16.0	16	1.0	No

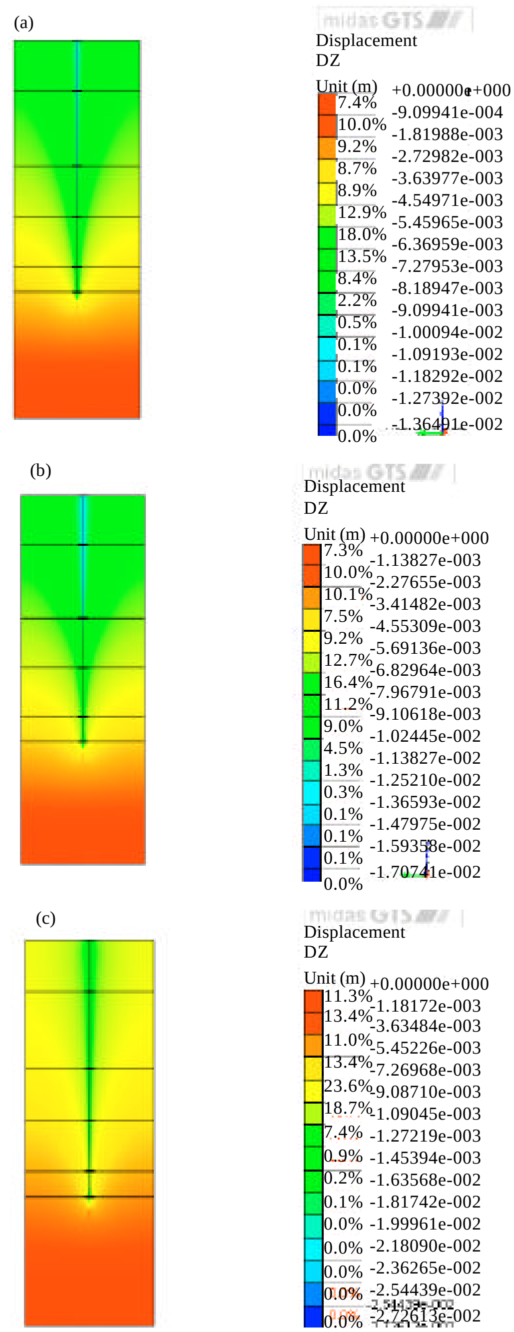

Fig. 5(a-c): Typical displacement field of end-grouted pile (a) Case 1: End grouting and k = 0, (b) Case 3: End grouting and k = 0.5 and (c) Case 6: End grouting and k = 1.0

around pile with typical working conditions under failure condition are demonstrated as Fig. 5 and 6, where Fig. 5 is for LCSG with end grouting while Fig. 6 is for without end grouting.

Fig. 5 and 6 show that:

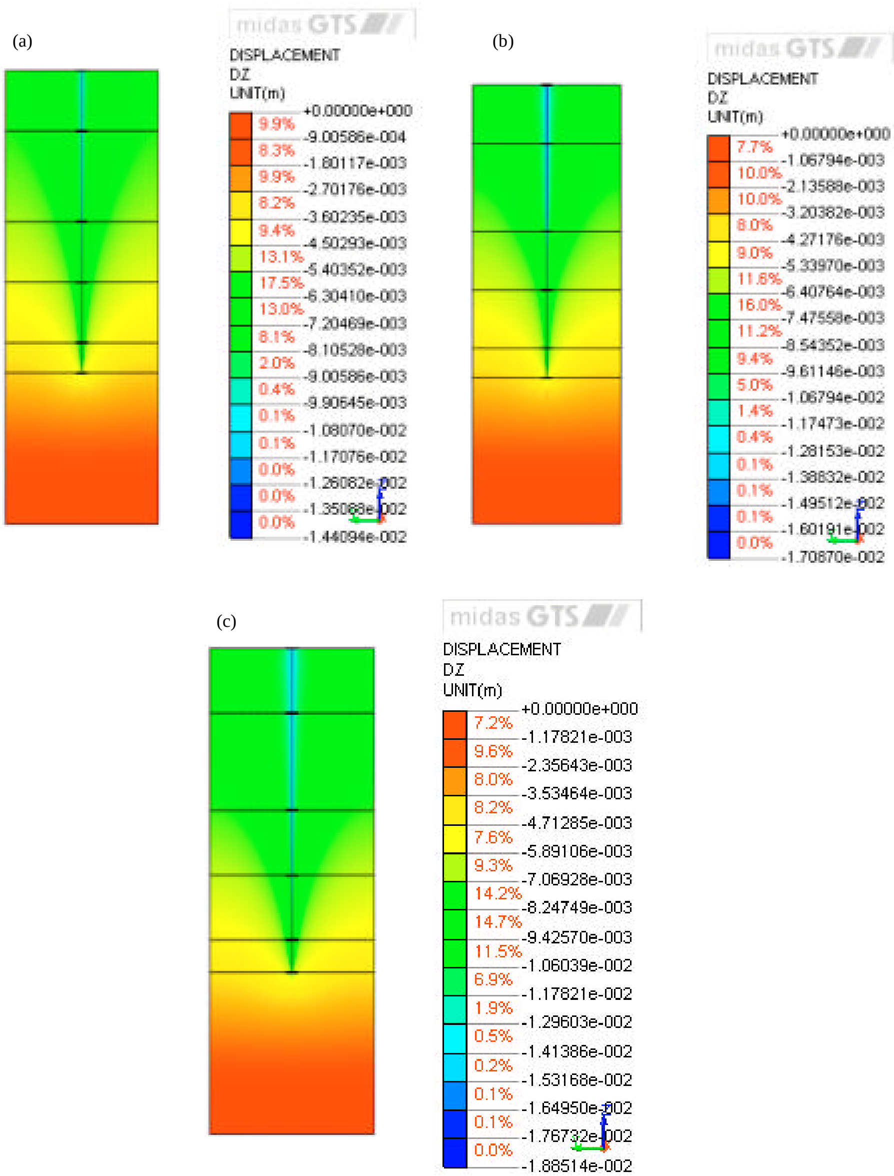

Fig. 6(a-c): Typical displacement field of none end-grouted pile (a) Case 7: No end grouting and k = 0, (b) Case 9: No end grouting and k = 0.5 and (c) Case 12: No end grouting and k = 1.0

- Generally, the value of displacement decreases from the biggest one at top side to the smallest one which is almost equal to zero at the bottom area which well fit the classic soil mechanics
- As to the soil at the fixed depth along the pile, the smaller the distance away from the pile, the bigger the displacement
- Whether grouted at end or not, increasing k, namely increasing the length of outer gravel body, can effectively give rise to the lowering value of displacement field which clearly manifests the importance of outer gravel body
- No mater what the parameter k is, end grouting can develop smaller magnitude and gradient of the displacement field which is conducive to control total settlement and differential settlement of foundation

Typical major principal stress field: At the same time, Major Principal Stress field (MPS field) of soil around pile

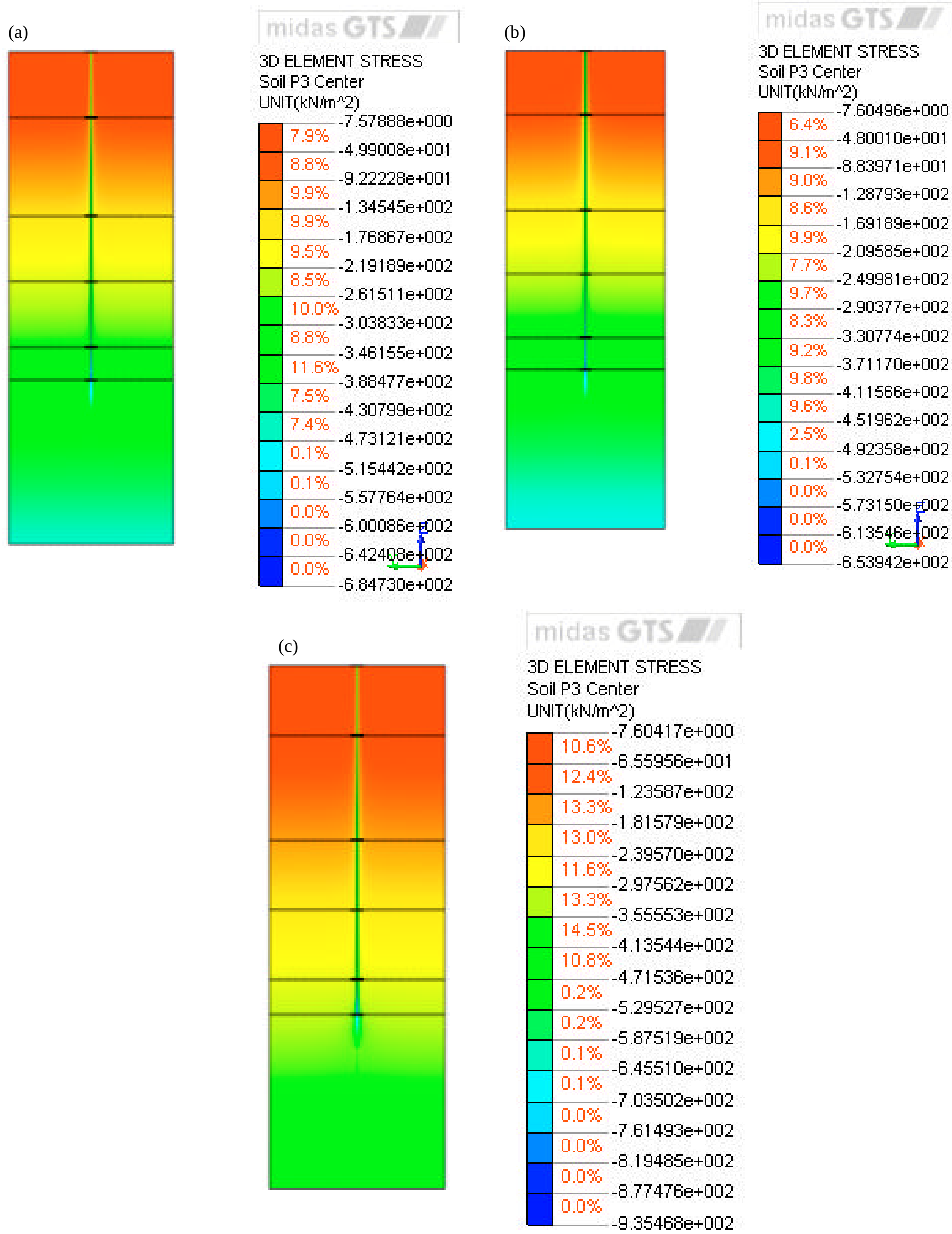

Fig. 7(a-c): Typical displacement field of end-grouted pile (a) Case 1: End grouting and k = 0, (b) Case 3: End grouting and k = 0.5 and (c) Case 6: End grouting and k = 1.0

is also to foundation safety. Typical MPS field with key working conditions under failure condition are demonstrated as Fig. 7 and 8, where Fig. 7 is for LCSG with end grouting while Fig. 8 is for without end grouting.

Fig. 7 and 8 show that:

- Broadly, the value of the MPS increases from the smallest one at top side which is almost equal to zero, to the biggest one at the bottom area. It should be noted that this vlaue is bigger at a small area around the pile end because of stress conceration and penetrating effect at that place
- As to the soil at the same depth, the smaller the distance away from the pile, the bigger the MPS
- Whether grouted at end or not, increasing k can also result a significant redistribution of MPS field which present the undisputable positive action of outer gravel body

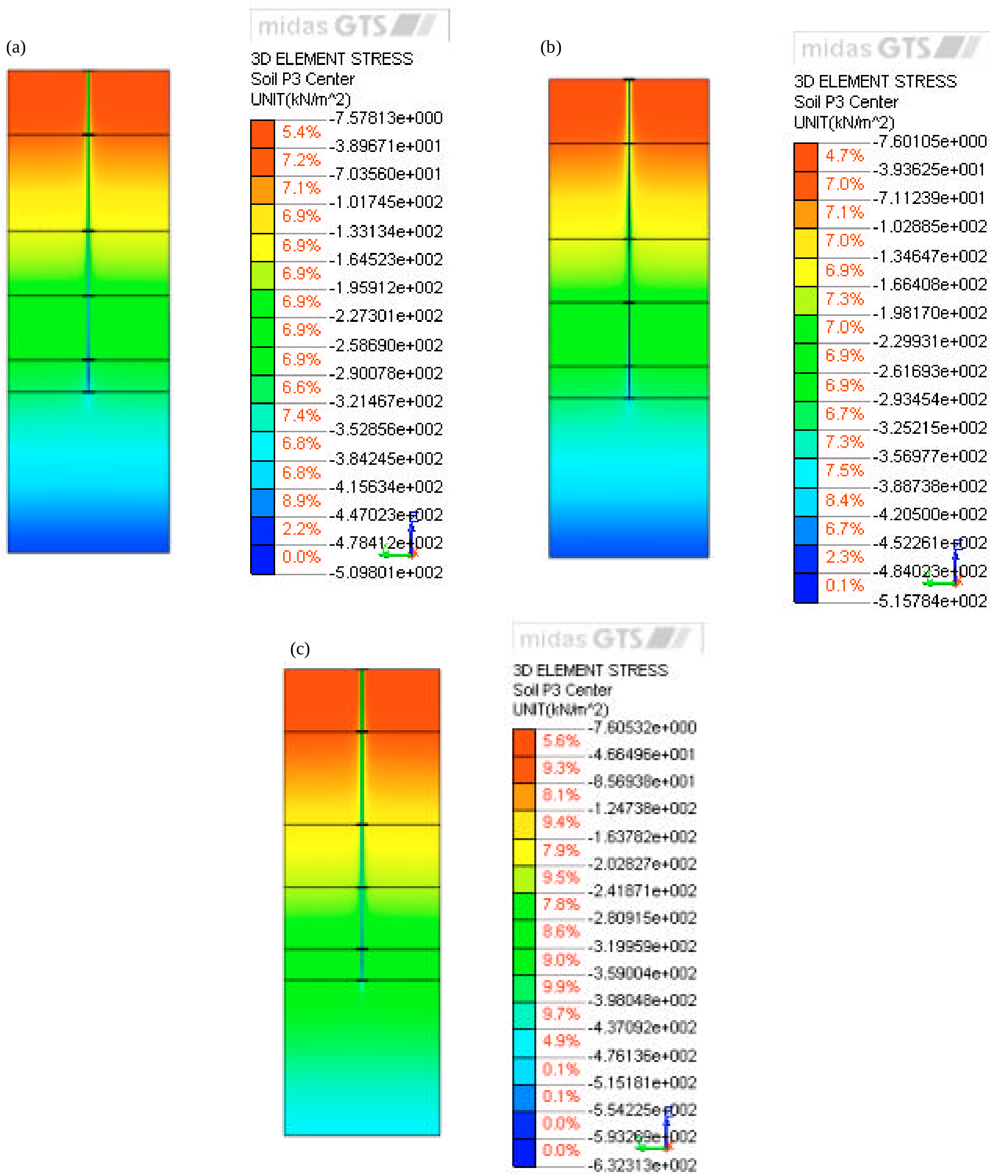

Fig. 8(a-c): Typical displacement field of none end-grouted pile (a) Case 7: No end grouting and k = 0, (b) Case 9: No end grouting and k = 0.5 and (c) Case 12: No end grouting and k = 1.0

- No mater what the parameter k is, the smaller magnitude and gradient of MPS field can be derived from end grouting which is beneficial to foundation, too

CONCLUSION

Through numerical analysis of the LCSG pile, we can make some meaningful conclusions and the major elements are as following:

- The LCSG pile, consisting of the inner concrete body, the outer gravel body and the cement-grouted end, can take full advantage of its own materials to gain good engineering behavior
- The value of displacement of the soil around pile taper off from the biggest at top side to the almost zero at the bottom area while the MPS increases from the almost zero at top side to the biggest at the bottom area

- At the fixed depth, the magnitudes of both the displacement and the MPS decrease with bigger distance from the LCSG pile
- Increasing the length of outer gravel body can effectively lower the values of displacement and redistribute the MPS of soil adjacent to LCSG pile
- End grouting can produce smaller magnitude and gradient of the displacement field and the MPS field which is conducive to total safety of foundation

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