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Journals, Poland, Directory of Research Journals

International Journal of Earth Sciences and Engineering

www.cafetinnova.org

ISSN 0974-5904, Volume 09, No. 04

August 2016, P.P.1429-1433

Settlement Analysis of Widening Subgrade in the Highway Considering Technology Parameter of Composite Foundation

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Abstract: In the highway widening engineering, clay foundation is often treated by composite foundation. Considering pile length, pile distance and elastic modulus factors of composite foundation, settlement and level displacement deformation after old subgrade widening is analyzed by finite element. It is resulted that ground additional settlement, additional level displacement of foundation surface and level displacement of new subgrade slope toe are reduced with reducing pile distance. There is the critical pile length scope. Beyond this scope, enhancing pile length is not benefiting for reducing subgrade deformation. When elastic modulus of pile is enhanced, reducing trend of the corresponding settlement and level displacement gradually turn to be mild.

Keywords: *Widening subgrade, settlement, level displacement, pile length, pile distance, elastic modulus*

1. Introduction

In the past subgrade widening problem on soft soil foundation is not better solved. As soil constitutive model, loading history and boundary conditions are complex, resolution solution does not satisfy engineering precision need [1-3]. Finite element method can consider consolidation property of soil, nonlinear stress-strain relationship, complex boundary condition and loading condition and is widely applied in the geotechnical engineering [4-6]. ADNIA finite element software is used to analyze deformation after old subgrade widening considering different pile length, pile distance and elastic modulus factors. By virtue of establishing finite element model of old subgrade, new subgrade and foundation, ground additional settlement and additional level displacement of subgrade are studied.

2. Establishing Finite Element Model

Subgrade widening model of soft soil foundation and its reinforcement of Jing-Gang-Ao highway are simulated. Dual 4-driveway is widening to dual 8-druveway by symmetry on both sides. Original 4-driveway top road surface width is 26m. Both sides are widening by 8m new subgrade. 42m dual 8-druveway road width of new subgrade is established. Subgrade height is 5m. Slope grades of new and old subgrade are 1:1.5. According to the actual prospecting data and soil experiment, foundation layers of simulating area are divided into three layers: the first one is 4.5m thickness slurry clay layer; the second one is 7.5m thickness silt layer; the third one is 11.5m thickness silty clay layer. Computing model is shown in Fig.1. According to fly ash experiment and information parameters of soil layer is shown in table 1.

Model grid meshing is shown in Fig.2. In the element analysis, 4-node plane strain element in the old subgrade and 4-node plane strain triangle element in the widening subgrade are adopted. Considering effect scope, foundation computing depth is double as foundation depth. According to symmetry of widening subgrade, half of subgrade is simulated [7-8]. Left boundary is symmetrical axle and vertical direction is free and level direction is restricted. Vertical and level directions of below boundary are restricted and drained. Vertical direction of right boundary is free and its level direction is restricted and undrained. Vertical and level direction of upper boundary is free and drained [9-10].

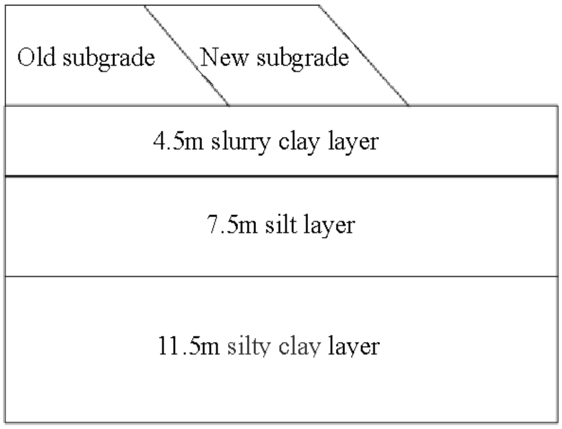

Fig.1: *Chart of computing section*

Table 1: *Material parameter*

Soil layer	Density ρ/kg·m^{-3}	Poisson's ratio ν	φ /°	c /kPa
Old subgrade	2000	0.3	28	30
Slurry clay	1700	0.34	20	10
silt	2000	0.3	16	22
Silty clay	1900	0.3	18	12
New subgrade	2000	0.3	28	30
Pile	/	0.2	/	/

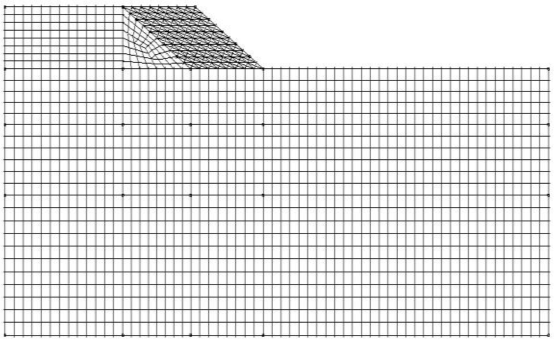

Fig.2: *Grid meshing of model*

3. Technology Parameter of Composite Foundation Effect on the Settlement of Widening Subgrade

3.1. Pile Distance Effect

Considering pile distance effect, pile length and elastic modulus of pile are assumed to be the same and pile distance changes. Pile distance is 1.5m, 2.0m, 2.5m and 3.0m respectively. Vertical settlement contours caused by foundation treatment in the four different pile distance are shown in Fig.3, Fig.4, Fig.5 and Fig.6.

By virtue of Fig.3, Fig.4, Fig.5 and Fig.6, maximum vertical settlement is basically focused on the shoulder of the new road. With increasing pile distance, scope of maximum vertical settlement of the widening subgrade ascends.

In case of different pile distance, ground additional settlement, additional level displacement of foundation surface and additional level displacement of new road slope toe are shown respectively in Fig.7, Fig.8 and Fig.9.

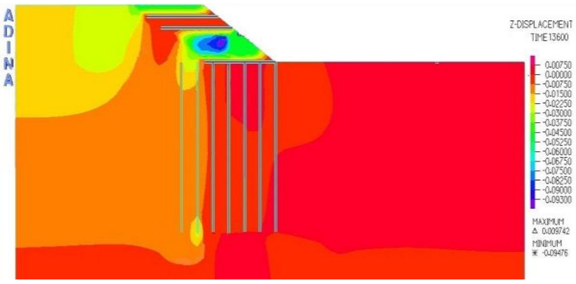

Fig.3: *Vertical settlement contours in the 1.5m pile distance*

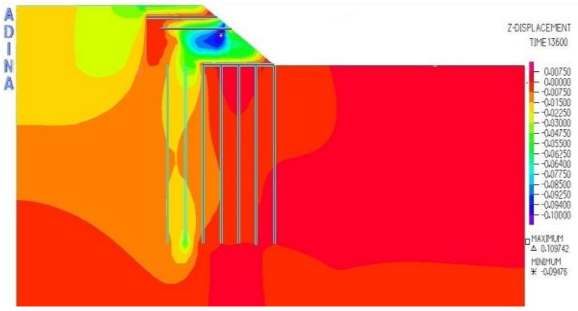

Fig.4: *Vertical settlement contours in the 2.0m pile distance*

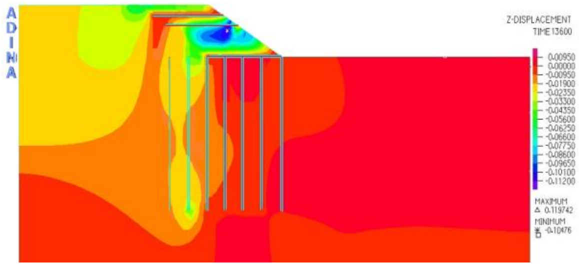

Fig.5: *Vertical settlement contours in the 2.5m pile distance*

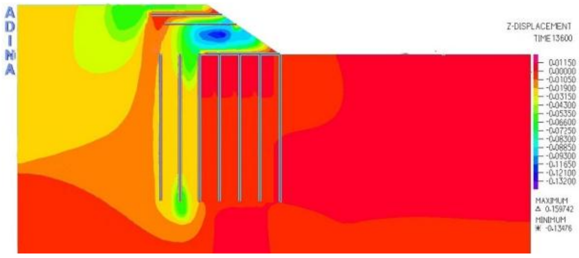

Fig.6: *Vertical settlement contours in the 3.0m pile distance*

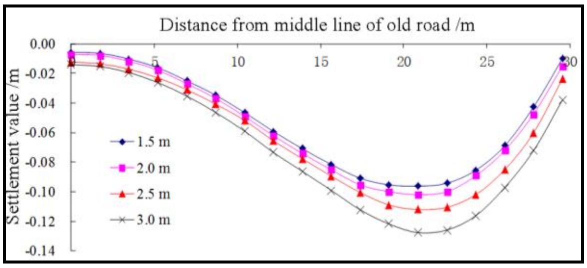

Fig.7: *Ground additional settlement considering pile distance*

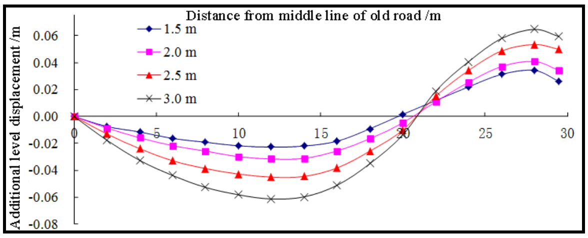

Fig.8: *Additional level displacement of foundation surface considering pile distance*

In case of Fig.7, ground additional settlement of broaden subgrade seem like long ladle and maximum settlement appear at the shoulder of the new road. The settlement of broaden part is larger than one of old subgrade. With increasing pile distance, the settlement of the new and old subgrade enlarges. But increasing scope is small. It is intended that there is critical pile distance. Beyond this critical pile distance, further increasing pile distance has little effect on the load distribution.

From Fig.8, level displacement direction of the old subgrade is inside and level displacement direction of the new subgrade is outside. Old road slope toe is dividing point of altering displacement direction. With increasing pile distance, dividing point appears at outside trend. The maximum lateral displacement of new subgrade appears at new road slope toe. With increasing pile distance, ground level displacement also increases.

According to Fig.9, the level displacement of new road slope toe firstly enlarges, and then reduces slowly. Level displacement is not large in the 0~25m scope. It is intended that pile distance has little effect on the level displacement. Maximum level displacement of the every pile distance appears at 6.7m underground and does not change with pile distance.

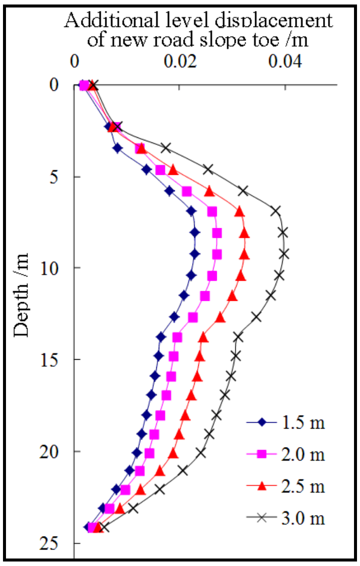

Fig.9: *Additional level displacement of new road slope toe considering pile distance*

3.2. Pile Length Effect

Considering pile length effect, pile distance and elastic modulus of pile are assumed to be the same and pile length changes. Pile length is respectively 12m, 15m, 18m and 21m. Considering pile length, ground additional settlement, additional level displacement of foundation surface and additional level displacement of new road slope toe are shown respectively in Fig.10, Fig.11 and Fig.12.

From Fig.10, with increasing pile length, maximum settlement reduces and the extent of reducing is weak. In the same 1.5m pile distance, maximum settlement of load appears at the shoulder of the new road.

According to Fig.11, changing trend of additional level displacement after subgrade enlarging is the same as pile distance. Dividing point of altering displacement direction is also old road slope toe. With increasing pile length, additional level displacement reduces obviously. It is intended that pile length is obvious at resisting level displacement.

In case of Fig.12, in the same pile length, the level displacement of new road slope toe firstly enlarges, and then reduces slowly. Maximum level displacement appears at 8.0m underground and level displacement appears no clearance at 25m underground. With increasing pile length, Maximum level displacement of new road slope toe changes obviously.

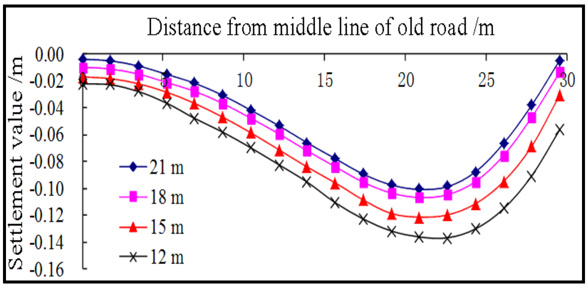

Fig.10: *Ground additional settlement considering pile length*

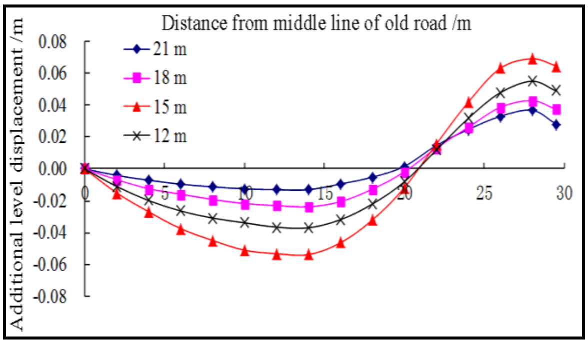

Fig.11: *Additional level displacement of foundation surface considering pile length*

3.3. Pile Elastic Modulus Effect

Considering elastic modulus of pile effect, pile distance and pile length are assumed to be the same and elastic modulus of pile changes. Elastic modulus of pile is respectively 5GPa, 10GPa, 15GPa and 20GPa.

Displacement of pile top consists of pile end settlements and pile compression deformation. Compression deformation depends on member elastic modulus and compressive stress applied on the member. When compressive stress is fixed, elastic modulus is unique factor of affecting compression deformation of the member.

Considering pile elastic modulus, ground additional settlement, additional level displacement of foundation surface and additional level displacement of new road slope toe are shown respectively in Fig.13, Fig.14 and Fig.15.

According to Fig.13, pile obviously controls ground additional settlement. When pile is 15m length and elastic modulus is 15GPa, controlling settlement effect is well. From economical view, 15GPa elastic modulus of pile has good economic benefit.

From Fig.14, additional level displacement of the new subgrade and old subgrade increases with reducing modulus of pile. With increasing pile elastic modulus, dividing point appears at outside trend.

In case of Fig.15, maximum level displacement of new road slope appears at 6.9m underground and reduces slowly with the depth. When elastic modulus of pile is larger than 15GPa, elastic modulus of pile has little effect on the additional level displacement.

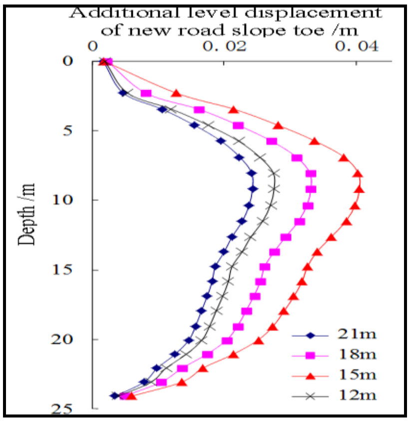

Fig.12: *Additional level displacement of new road slope toe considering pile length*

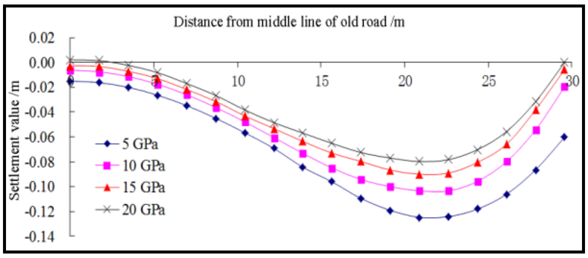

Fig.13: *Ground additional settlement considering pile elastic modulus*

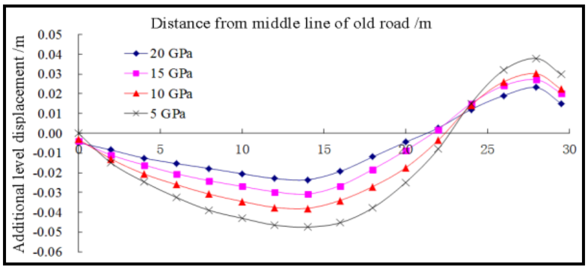

Fig.14: *Additional level displacement of foundation surface considering pile elastic modulus*

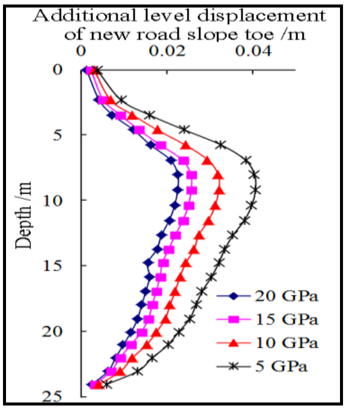

Fig.15 *Additional level displacement of new road slope toe considering pile elastic modulus*

4. Conclusions

By establishing finite element model of old subgrade, new subgrade and foundation, ground additional settlement and additional level displacement of subgrade are studied. It is resulted that:

As pile length and elastic modulus of pile are assumed to be the same, pile distance has some effect on the settlement. When pile distance is reduced, ground additional settlement, additional level displacement of foundation surface and level displacement of new subgrade slope toe are reduced. But reduced extent is different. Pile distance enlargement benefits from capacity developing of soil. But large pile distance enhances settlement of composite foundation and more centralization of pile top stress.

Pile length affect obvious to the additional settlement of ground and level displacement of new subgrade slope toe. Pile length is not better in the length. In the critical pile length scope, enhancing pile length is advantage. Too long pile length is not benefiting for reducing subgrade deformation.

Considering different pile elastic modulus, pile foundation is analyzed. With increasing elastic modulus of pile, additional settlement of ground and level displacement of new subgrade slope toe are reduced.

These conclusions benefit settlement analysis of widening subgrade and evaluate validity of finite element method on subgrade widening.

5. Acknowledgements

The study is supported by National Natural Science Foundation of China (Grant No.51108283, 51178280), Hebei Province Natural Science Foundation (Grant No. E2014210092, E2014210021) and Hebei Province Transportation Department science & technology research item (Grant No.Y2011001). All supports are very gratefully acknowledged.

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