Research on filling scheme and deformation properties of wide subgrade of foamed lightweight soil on soft ground

Faru Zhang*, Deguang Yang, Liujun Zhang

CCCC First Highway Consultants Co., Ltd., Xi’an 710075, Shaanxi, China

*Corresponding author e-mail: 1450312182@qq.com

Abstract. The wide subgrade on soft soil ground has the significantly different transverse settlement curve characteristics and the location of the maximum asymmetrical transverse settlement compared with ordinary subgrade. Especially when the subgrade filled with materials of different densities, the synergism deformation of ground-subgrade-pavement and the pavement structure stress become more complex. Combining with the engineering example, the settlement deformation characteristics of wide subgrade adopting the different filling scheme and the stress distribution of pavement structure are analyzed. Results show that the settlement curve of wide subgrade has a shape of flat middle with steep sides, and the maximum transverse asymmetrical settlement locates in close to the shoulder position. The maximum stress within the pavement structure is also in close to the shoulder position. Regarding the wide subgrade composed of main road and relief road, the post-construction settlement can be greatly reduced when both roads are filled with foamed lightweight soil.

1. Introduction

In general, when a new highway is built on soft soil ground, its roadway width is 25m, and the shape of settling curve is proximity to parabola or cosine curve along the cross-sectional direction. With rapid development of communication, the road widening engineering of highway and urban main roads appear continuously in recent years. Besides, it is also very common that the road is broadened into an eight-lane highway or even more lanes in the same section. As for this wide foundation, the characteristic of its settling curve differ significantly from the normal foundation, and the research on this aspect is seldom mentioned before.

The compatible deformation about ground-subgrade-pavement is very complex, some studies have demonstrated that differential settlement of soft soil foundation is more likely to cause the early destructive phenomena occurred in pavement [1-2]. In order to convenient to follow for designers, the influence of additional stress of pavement structure does not take into account in our regulation of pavement design [3-4], which is caused by the different settlement of embankment. However, some experimental investigations mainly use the finite element method to simulate complex pavement stress effects caused by the settlement of subgrade [5-6].

In this paper, based on engineering examples, characters of consolidation settlement curve in the pre-period, the design period and after construction have be analyzed and contrasted in great detail. Besides, in order to reveal settlement characteristics of wide subgrade and stress response properties of
pavement deformation, using finite element method to calculate the stress caused by lateral different settlement of embankment in pavement.

2. Project profile
This supporting project is an urban expressway, the width of main road is 46.4m, the width of side roads is 21m, and the total width of subgrade has reach 88.4m. The filling is higher, which is located in part of freeway on soft foundation, and the relevant measuring parameter about foundation soil layer, as shown in Table 1.

| Number | Bottom deepness (m) | Density (g/cm³) | Allowable value of beating capacity (kPa) | Quick direct shear test | Coefficient of consolidation (×10⁻⁴ cm²/s) | Compression modulus(MPa) | Geologic description |
|--------|---------------------|----------------|------------------------------------------|------------------------|------------------------------------------|--------------------------|---------------------|
| 1      | 2.1                 | 19.0           | 180                                      | 16.80                  | 12.70                                    | 30                       | 30                  | Silty Clay, plastic |
| 2      | 13.1                | 16.0           | 50                                       | 8.64                   | 6.84                                     | 20                       | 20                  | Silt, flexible plastic |
| 3      | 15.0                | 19.1           | 180                                      | 0.00                   | 16.10                                    | 70                       | 70                  | Medium sand, saturation |
| 4      | 22.0                | 20             | 500                                      | 30.7                   | 15.1                                     | 50                       | 50                  | Strongly weathered   |

The original design about soft soil subgrade as follows: soil-rock mixtures are used to fill the subgrade, and cement piles are used to treat foundation. Among these cement piles, the pile diameter is 0.5m, pile length is 14.5m, the distance between piles is 1.6m. When the height of embankment reaches 6m, the data of settlement observation shows that settling rate of subgrade and settlement are large, as shown in Figure 1. Therefore, this paper puts forward two new design models because it can be inferred from these datas that settlement after construction can not satisfy the request.

![Figure 1. Settlement curve](image-url)
In the first scheme, foamed lightweight soil is used to fill main routes, and soil-rock mixtures are still used to fill side roads. In the second scheme, main routes and side roads both use foamed lightweight soil to fill. Compared with the second scheme, the amount of foamed lightweight soil is relatively less and economical in the first scheme, but its fill loads in the relief roads are still large. However, embankment loads would be markedly reduced in the second scheme, and scheme No.1 is advantageous from the point of controlling the subsidence. In order to ensure whether both two schemes can meet requirements and select optimal scheme, characteristics of wide subgrade adopting the different filling schemes, change rules of differential settlement and the stress distribution of pavement structure are analyzed contrastively, the best design scheme is proposed in the end.

Some parameters in calculating of design as follow: the density of fillers is 21 kN/m³, the density of asphalt concrete is 24 kN/m³, and the density of foamed lightweight soil is 6.3kN/m³.

3. The comparison of stability and settlement curve
In this paper, the stability and settlement curve of different filling schemes are analyzed by Liheng Geological Structure Designing [8], calculation charts about cross-section(1/2) of these three schemes, as shown in Figure 2~4.

Figure 2. Schematic diagram of cross-section (1/2) of original scheme

Figure 3. Schematic diagram of cross-section (1/2) of scheme No.1

Figure 4. Schematic diagram of cross-section (1/2) of scheme No.2
As can be seen from these figures, great changes have taken place in original scheme and change schemes. For example, the stability safety coefficient is 1.20 both in original scheme and scheme No.1, and the slip circles of original scheme and scheme No.1 are both located in side roads, but the stability safety coefficient of scheme No.2 is 1.54. This illustrates that no increase in safety stock of side roads if soil-rock mixtures are still used to fill side roads, but the safety coefficient could dramatically improve when side roads is filling with foamed lightweight soil in scheme No.2.

The settlement curves during preloading period, subsidence for 15 years, and settlement after construction as shown in Figure 5~6, and Figure 7 shows the settlement curves during preloading and subsidence for 15 years on another subgrade with the wide is 29.5m. It can be seen from Figure 5~7, there are striking differences in characters of settlement curves between the wide subgrade and the constant width subgrade, the settlement curve of wide subgrade has a shape of flat middle with steep sides in Figure 5~6, but the settlement curve of 29.5m width subgrade exhibits a parabola relationship. It is obvious to see from Figure 5, settling spots exists in two sides and middle part of the subgrade, which are located roughly 2m of the shoulder on side roads. The reason for this is that, foamed lightweight soil is used to fill the main route and soil-rock mixtures are used to fill the side roads, which led to the weight of subgrade fillers on the main route is greater than the weight of subgrade fillers on the side roads [7]. There is no doubt that sudden change of settling is harmful to the force of pavement structure, which create a stress concentration that can cause crack initiation during the usage of pavement.

It is also clear to know from Figure 5~6, the amount of settlement after construction is 0.702m and the total settlement is 2.474m in original scheme, the amount of settlement after construction is 0.586m and the total settlement is 1.669m in scheme No.1, the amount of settlement after construction is 0.294m and the total settlement is 1.645m in scheme No.2. Through calculation and analysis known that the total settlement decreases significantly, but the amount of settlement after construction is no big change in scheme No.1 compared with the original scheme. This means that using foamed lightweight soil to fill the main route is really helpful to reduce subgrade settlement in any period. However, when soil-rock mixtures are used to fill side roads, the additional settlement of the main route is fall behind compared with filling rate, which is caused by subsidiary stress on the main route. Therefore, scheme No.1 cannot meet the design requirements of settlement after construction, but scheme No.2 can meet the design requirements.

![Figure 5. Settlement in preloading period and 15years](image-url)
4. The analysis of structural stress and pavement deformation

In order to study the effects of settlement after construction upon pavement structure with three different schemes, calculating differential settlement and internal stress of pavement by building finite element models [8], as shown in Figure 8, and main parameters about the model listed in Table 2.

![Figure 8. Structure of the finite element model](image)

![Table 2. Main parameters of FEM mode](image)

| Structure Properties | Road surface | Roadbed | Road subbase | Foamed lightweight soil subgrade | Earth-rock mixture subgrade |
|----------------------|-------------|---------|--------------|---------------------------------|-----------------------------|
| Materials            | Asphalt     | The water stability gravel | Aggregate | Foamed lightweight soil | Soil+aggregate |
| Density (t/m³)       | 2.4         | 2.4     | 2.1          | 0.63                            | 2.1                         |
| Constitutive model   | Linear elastic | Linear elastic | Linear elastic | Linear elastic | Linear elastic |
| Elasticity modulus (MPa) | 1200     | 1500    | 300          | 500                             | 150                         |
| Poisson ratio        | 0.25        | 0.25    | 0.35         | 0.2                             | 0.2                         |

The displacements and stress under three schemes can be obtained by these models and main parameters, take scheme No.1 as the example, its vertical displacement nephogram as shown in Figure 9, the horizontal stress nephogram as shown in Figure 10, and settlement of pavement structure of three schemes can be seen in Figure 11.
As can be seen from Figure 13, the horizontal settlement on pavement and the trends of change of post-construction settlement of embankment are basically similar under different schemes, especially the settlement curve of scheme No.1 is coincidence with the original. This shows that it would not reduce the post-construction settlement and the settlement in service life of pavement due to the effect of attached load, when foamed lightweight soil is used to fill the main route but soil-rock mixtures are still used to fill side roads.

The column diagram of maximum asymmetrical settlement on the main route and side roads of three schemes as shown in Figure 12. As you can see in the Figure 5, the maximum settlement of scheme No.1 is located in 10m away from the subgrade centre, but the maximum settlement of scheme No.2 is located in the centre of subgrade. This shows that the filler of side roads has a remarkable impact on additional settlement of the main route when soil-rock mixtures all are used to fill side roads.

In the original scheme, cross slope rate of the main route is 0.17%, and cross slope rate of side roads is 0.26%. In the scheme No.1, cross slope rate of the main route is 0.16%, and cross slope rate of side roads is 0.26%. As for scheme No.2, cross slope rate of the main route is 0.06%, and cross slope rate of side roads is 0.20%. Research proves that, landscape orientation differential settlement in original scheme is actually close to scheme No.1 although settlements after construction are larger, as shown in Figure 6.

In addition, column diagram of maximum press stress within pavement of three schemes can be shown in Figure 13, and column diagram of maximum tensile stress within subbase of three schemes
can be shown in Figure 14. From Figure 13, the maximum tensile stress decreases in the order of original scheme, scheme No.1, and scheme No.2, but the difference of these schemes is not too big, mainly because the landscape orientation differential settlement on the main route is smaller. This reason that have also led to the maximum tensile stress within subbase is rather small for any type of scheme, as shown in Figure 14.

On all these counts, compared with original scheme and scheme No.1, scheme No.2 has the following advantages: 1) the post-construction settlement is the smallest, 2) the uneven settlement of pavement is the smallest, 3) the pavement stress is also the smallest. Therefore, there is no doubt that the scheme No.2 is the best scheme.

5. Conclusion
(1) There is a significant difference in settlement curve shape between wide subgrade and common subgrade. The settlement curve of wide subgrade cannot be achieved by parabola and cosine curve fitting, and the settlement curve of wide subgrade has a shape of flat middle with steep sides, the maximum transverse asymmetrical settlement locates in close to the shoulder position.
(2) The maximum stress within the pavement structure is also in close to the shoulder position, which led to the uneven settlement and pavement stress of wide subgrade are large.
(3) Regarding the wide subgrade composed of main road and relief road, the post-construction settlement can be greatly reduced when both roads are filled with foamed lightweight soil.
Acknowledgments
This work was financially supported by CCCC First Highway Consultants Co., Ltd fund.

References
[1] SHA Qing-lin. Premature damage and its preservative measures bituminous pavement on expressway [M]. Beijing: China Communications Press, 2001.
[2] WANG Xin-qi, LIU Yu-min. Influence of soft ground settlement on asphalt concrete pavements [J]. China Municipal Engineering, 2001(1): 27-29.
[3] JTG D50—2006 Specifications for design of highway asphalt pavement [S]. 2006.
[4] ZHANG Jia-fan, ZHANG Hui-mei. Additional stress in pavement structure due to asymmetrical settlement of soft subgrade [J]. Journal of Chang’an University(Natural Science Edition), 2003, 23(3): 21-25.
[5] LIAO Gong-yun, HUANG Xiao-ming, YANG Qing-gang. Adaptability of different asphalt pavement structures on soft ground with differential settlements [J]. Journal of Highway and Transportation Research and Development, 2007, 24(4): 34-38,46.
[6] DENG Wei-dong, HUANG Xing-qiang, CHEN Bo, et al. Nonlinear FEM analysis of influence of asphalt pavement under non-homogenous settlement of roadbed [J]. China Journal of Highway and Transport, 2004,17(1): 12-15.
[7] ZHU Wei-dong, ZHANG Chao-jie, ZHANG Ying-ying, et al. Analysis on settlement curve pattern of soft marine sedimentfoundation and its impacting factors [J]. Water Resources and Hydropower Engineering, 2013, 44(7): 59-63.
[8] YAN Ming-xing, WANG Jin-chang. Application of ABAQUS finite element software in pavement structural analysis [M]. Hangzhou: Zhejiang University Press, 2016.