Design improvements for expansion of a roadway on a thick layer of soft soil

Un projet d'amélioration pour l'élargissement d'une autoroute sur une argile molle

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ABSTRACT: Expansion of a roadway on a soft soil can cause settlement of the existing road during embankment construction due to the consolidation characteristics of the soft soil. Many problems related to construction and maintenance, such as deterioration of the surface, decreased safety, and decreased structural stability, could affect the existing road. This scenario is especially true if the roadway foundation is a thick layer of soft soil. Therefore, the characteristics of the soil layer should be considered in the design and construction of the roadway expansion. In this study, the expansion of the second branch of the Namhae Expressway was selected as the target site because the expressway is constructed on a soft soil layer approximately 53 m thick. The original design plans were reviewed, problems were discussed and solutions to the problems were proposed.

RÉSUMÉ : L'élargissement d'une autoroute sur un sol d'argile sensible risque d'entraîner des tassements pour les voies actuelles pendant le remblayage sous l'effet de la compression des sous-sols argileux. D'importants problèmes liés à la construction et à la maintenance sont posés : dégradation de la surface, instabilité structurelle, insécurité des usagers. Le scénario présenté s'avère particulièrement important lorsque le sous-sol de l'autoroute en question est constitué d'une couche épaisse de sol argileux. Il faut donc tenir compte des caractéristiques du sol pour le projet d'élargissement de l'autoroute. Dans cette étude, nous prendrons comme exemple le cas de l'autoroute Namhae dont la seconde voie repose sur une couche argileuse atteignant 53m d'épaisseur. En examinant son plan de construction original, on étudiera les problèmes posés et on suggérera diverses solutions.

KEYWORDS: deep thick soft soil, roadway expansion, settlement, construction, design.

1 INTRODUCTION

Stress can exist at a point in a soil not only because of loading above the point by a superstructure but also by loading on adjacent points. For saturated clay, this stress can result in consolidation due to dissipation of excess pore water pressure. Localized nonuniform settlement can cause unevenness and cracking in the road and cracks in a superstructure. To minimize the likelihood of this problem occurring, it is best to apply a uniform embankment preload to the entire roadway area. In a road-widening project, however, it is difficult to accomplish this because of the need to divert traffic and comply with the construction schedule.

Recently, the traffic on the second branch of the Namhae Expressway has been approaching the traffic capacity of the roadway because of the increase in national income and increased desire for leisure. Severe traffic jams have diminished the comfort of drivers and the operating speeds of vehicles on the expressway. Expansion of the roadway from 4 lanes to 8 lanes is in progress because of the expansion of SOC (social overhead capital) and the economic growth of the country (Korea Expressway Corporation, 2008a; 2008b; 2008c).

As part of the original design for this project, embankment construction was planned after removal of the existing road and installation of vertical drains. Differential settlement might not be a problem if sufficient time were available for consolidation of the soil after construction of the embankment. However, differential settlement could occur because the overconsolidation ratio of the soil and the load history of the expanded and existing portions of the roadway are different. In addition, PBD (plastic board drain) are to be installed after removing the soil of the existing road. This installation may be difficult because of the resistance of granite material, such as crushed stone and gravel, used in the exiting roadway construction. The strength of the soil could also be reduced by disturbance during the installation of the PBD.

The original design plans call for expanding the roadway from 4 to 8 lanes by banking soil on the existing road and raising the longitudinal grade of the roadway. However, settlement of more than 2 m, and in some locations up to 5.4 m, was expected because the construction section of the second branch is located on soft soil up to 53 m thick. As an alternative, embankment construction after removal of the existing road and improvement of the underlying soil was planned. However, this strategy was also expected to be complicated and time-consuming. Moreover, this construction was expected to cause settlement in the surrounding area due to disturbance to the soil under the existing roadway that had been stable for more than 30 years. Consequently, complaints about damage to nearby farmlands, factories and houses were anticipated.

Expansion of a roadway typically involves diversion of traffic. Expansion of a roadway on a soft soil could cause settlement of the existing road during embankment construction due to the consolidation characteristics of the soft soil. Many problems related to construction and maintenance, such as deterioration of the surface, decreased safety, and decreased structural stability, could affect the existing road. This scenario is especially true if the roadway foundation is a thick layer of soft soil.

Accordingly, design and construction methods need to be identified to minimize the problems that can occur during construction of the expansion and minimize the expenditures associated with such problems, including future maintenance costs. This paper outlines the problem of designing and constructing the expansion of the second branch of the Namhae Expressway and suggests solutions to the problems involved.

2 STRIBUTION OF SOFT SOIL ON THE PROJECT SITE

Construction of the expansion of the second branch of the Namhae Expressway is in progress. The project has been divided into four construction zones (A, B, C and D). The distribution of soft soil in each zone is as follows (Korea Expressway Corporation, 2008d; 2008e; 2008f).

In zone A, which has a total length 6.40 km, soft soil is present at thicknesses in the range of 0.0~15.4 m in a segment 890 m in length, from station 5+110 to station6+000. According to the results of the boring investigation, the soft soil consists of clayey silt and silty clay. Zone B has a total length of 5.50 km and is located across the Joman River (5+140 to 5+500). The soft soil is present at thicknesses in the range of 2.0~50.8m throughout zone B, except between stations 0K+000 and 1K+000. Zone C is located across the W. Nakdong River (6K+160) and Pyeonggang Creek (8K+080 to 8K+230) and has a total length of 3.56 km. This section also has soft soil present at thicknesses in the range of 2.0~53 m. In the area of the W. Nakdong River, sandy soil is present to a depth of 10~12 m due to sedimentation from the river, and soft clay soil is present below the sandy soil. In zone D, soft sandy soil is present at thicknesses of 2.9~11.4 m, and soft clay soil is present at thicknesses of 8.0~25.2 m. The soft clay soil consists of clayey silt or silty clay.

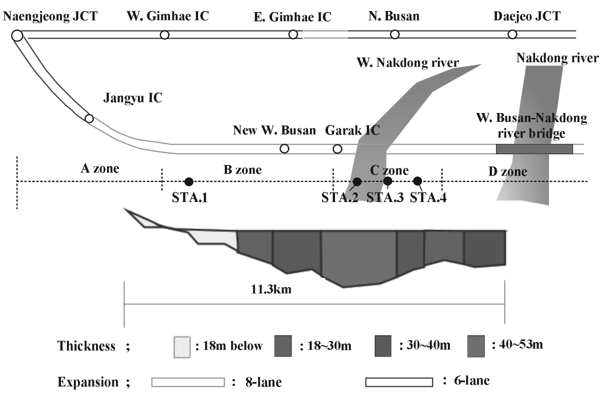


Figure 1. Route map of expansion construction for the second branch of the Namhae expressway and distribution of soft soil along the route.

3 THE ORGINAL DESIGN

Most of the new construction zones were planned to be expanded bordering the existing road in the direction of Naengjeong, except for a portion of the zones in which the horizontal alignment was to be adjusted. An accelerated consolidation method was applied to satisfy the requirement of 10 cm of allowable residual settlement. PBDs were selected as the vertical drain type to be used in the consolidation acceleration. For horizontal drainage, fiber drains were to be used in parts of zones C and D where sandy soil is present in the upper layer. In the remainder of the zones, a crushed stone mat was to be used for drainage.

For the existing road, prefabricated vertical drains (PVD) were installed along 1.2 km of the roadway, equivalent to 6% of the total length 19.6 km when it was constructed in May of 1978 (Korea Expressway Corporation, 1982). Long-term and continuous consolidated settlement occurred in the remainder of the zones because an embankment was built during the operation of the road after constructing MAT using sand and gravel and crushed stone. Thus, the construction method below was designed for and applied to the existing road because it was thought to be an economical method of ensuring the long-term stability of the roadway, allowing residual settlement by removing the existing soil, installing vertical drains for consolidation acceleration and preloading with counterweight fill.

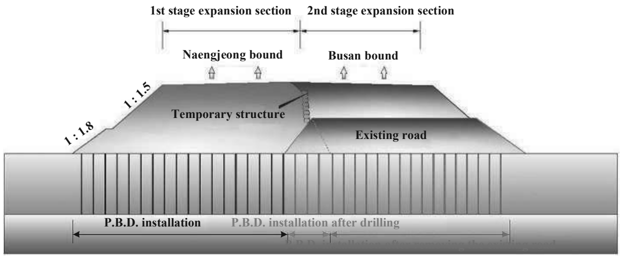


Figure 2. Overview of original design of road expansion.

4 EXAMINATION OF PROBLEMS WITH THE ORIGINAL DESIGN

4.1 *Low constructability and increased costs*

According to the original design, an improvement method should be applied to the soft soil after removing the soil under the sting road. When constructing the existing road, only a part of the sections improved with paper drains, and the remainder of the sections banked using sand, gravel, and crushed stone on the lower part without vertical drains being installed. The sand, gravel and crushed stone rested on the lower part of the natural soil during construction and use of the road. Thus, these objects pose obstacles to the installation of vertical drains under this expansion construction.

Therefore, it is expected that the constructability would be very poor because of the difficulty of removing the settled crushed stone and transport the soils removed from the existing roadbed. It is also expected that the costs would be increased by the need to transport and dispose of the waste asphalt concrete resulting from removal of the existing road. Examination of the cores reveals that the thickness of the asphalt concrete at an abutment is 1~1.5 m, due to repeated overlays of the pavement necessitated by settling of the soil over a long period of time.

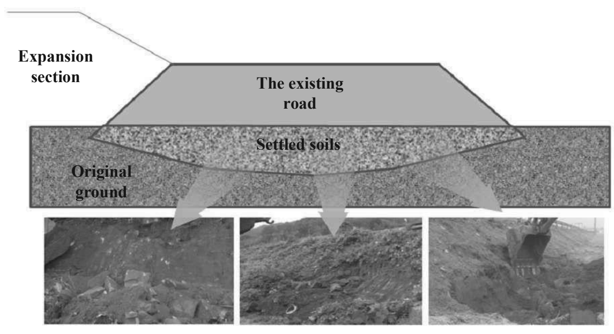


Figure 3. Results of field survey of the existing road.

4.2 *Problems of PBD construction on the existing Road*

Typical PBD construction is not expected to be possible because of resistance from the crushed stone and other coarse materials in the existing roadbed. Thus, special drilling and excavation are necessary, but these activities will delay construction and increase costs. If the existing roadbed soil is completely removed, the stability of the soil may be disrupted by PBD construction. If a drilling PBD method is applied on the slope of the existing road, it is expected that construction will be delayed due to the additional time required for construction processes such as drilling and filling the drilled hall.

4.3 *Shortage of time for construction*

In the initial stage of construction, it was impossible to start the improvement of the soft soil on time because of civil complaints and delays in obtaining agreements for purchasing land. Multi-phase construction work such as "PBD construction after removing the existing road" may reduce the time available to improve the soft soil. For example, in the case of the Namhae line, on which construction was completed in 1996, it was expected that it would take 24 months to improve the soft soil in two sections of expansion and existing roads. However, it took more than 24 months just to improve the soft soil in the expansion section. Thus, at that time, the construction plan was modified to reduce the time spent improving the soft soil of the existing road (Korea Expressway Corporation, 2006).

4.4 *Allowable residual settlement*

For the construction of the expansion of the second branch, 10 cm of allowable residual settlement was applied equally, in spite of the great differences in the depths of the soft soil in the different zones. However, the problems and phenomena vary depending on the conditions of the soft soil. If the 10 cm standard is applied equally to all zones, it may produce an inefficient effort. For example, it is necessary that more than 98% of the consolidation occur during the construction period to satisfy the 10 cm residual settlement requirement, based on the assumption that the thickness of the soft soil is 50 m and the total settlement is 450 cm, applying Terzaghi's consolidation theory. In this situation, the cost and time required to improve the soft soil are excessive.

The road design manual clearly states that "For a road, it can be applied 10 cm as the residual settlement after pavement, but it should be appropriately applied by considering the factors such as the purpose of use, importance, ground characteristics, construction period, constructability and economic feasibility, etc." Accordingly, the standard needs to be adjusted.

5 IMPROVEMENTS IN DESIGN

5.1 *Establishment of improvement direction*

The original design was made to satisfy a grade of 0.5% and for traffic to be diverted during construction of the expansion, so that in both directions (to Busan and to Naengjeong), where the soft soil is present, the longitudinal grade could be raised and the road could be widened. To satisfy the 10 cm residual settlement requirement within 1,500 days (the construction time allowed), the soil of the existing road was to be removed, the soft soil improved and counterweight fill applied after banking. This design approach poses many problems. For example, long-term settlement can be induced by raising the longitudinal grade, dividing the median strip bilaterally and counterweight filling (banking), as well as not treating the existing road. Thus, improvements to the plan are needed to solve these problems.

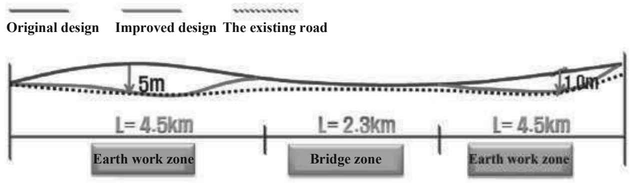
Table 1. Improvements in design.

Original design	Improved design
Removing the embankment of the existing road + PBD + preloading	Non-improvement of the existing road + Preloading
⇒ Satisfy the residual settlement requirement during the construction period	□ Inducing long-term settlement
Upward adjustment of the longitudinal grade and connecting the two alignments	Controlling the upward adjustment of the longitudinal grade and dividing the median strip bilaterally

5.2 *Improvement factors*

5.2.1 Lowering the longitudinal grade

To minimize the settlement due to overburden load on none improved existing road, the embankment height was adjusted by changing the standard for the minimum slope (from 0.5% or more to 0.3% or more) given in the Manual and Guideline for Standards of Road Structures stipulated by the Ministry of Construction and Transportation (2003). Additionally, the embankment height was changed to be similar to the longitudinal grade of the existing road by changing a bridge type (from passing below to passing above) that crosses the main line and adjusting the height of the bridge to provide sufficient overhead clearance.



How to adjust	Descriptions	Applicable length	Remark
Change the way to cross a bridge	Underground rigid frame bridge ⇒ Pedestrian bridge	1.0km	- 5m
Adjustment of minimum Longitudinal slope	0.5% ⇒ 0.3%	4.5km	- 1m
Adjustment of passing extra height of bridge	Secure the minimum overhead clearance	3.5km	- 0.8m

Figure 4. A plan to adjust the longitudinal grade.

5.2.2 Change in the standard for allowable residual settlement

Disregarding the initial soil conditions (the depth of the soft soil), the design standard for uniformly applied allowable residual settlement is 10 cm. However, this standard was changed based on the depth of the soft soil, as shown in Table 2.

Table 2. Design criteria for allowable residual settlement.

Thickness of soft soil	Allowable residual settlement	Degree of consolidation
10 m below	10 cm	90% above
30 m below	20 cm	
30 m above	30 cm	

5.2.3 Line separation

To minimize damage due to differential settlement induced by the different loading histories of the soil in each direction, installation of a green belt 3~6 m wide on the median strip and line separation for each direction were suggested. For the existing road, an overlay was applied to match the finished grade with a slight adjustment of the longitudinal grade. The soil underneath the existing road was not improved.

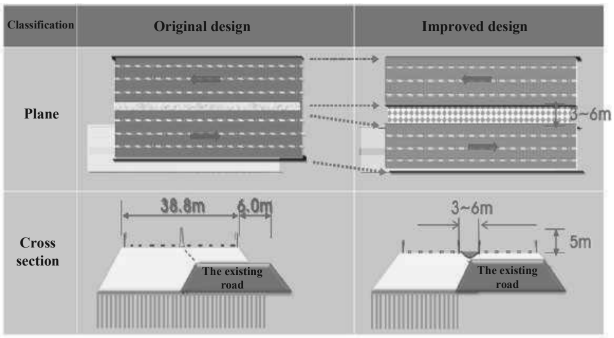


Figure 5. A plan for the road separation.

5.3 *Feasibility of improvement factors*

5.3.1 Constructability aspect

Reducing the number of construction steps from six to one makes it possible to reduce the time required for construction by more than 10 months. This reduction in construction time offsets the delays due to land purchases, civil complaints, etc. at the initial stage of this project.

The improved plan does not require disposal of soils and pavement materials removed from the existing road. The constructability would be improved because the sequence of work activities is not limited and issues such as the difficulty of PBD installation by drilling on the slope of existing road can be avoided.

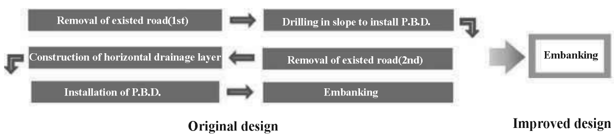


Figure 6. Simplification of construction phases.

5.3.2 Economic aspects

If PBD is installed in the soil of the existing road, additional expense is involved in drilling or removing the gravel and crushed stone underneath the existing road. In addition, a cost for disposal of the asphalt concrete is also incurred. However, the improved plan would result in a decreased net volume of the embankment and length of drainage material and consequently a decrease in the construction cost.

5.3.3 Stability aspects

If PBD is installed to improve the soil under the existing road, it is expected that a coupled settlement will occur near adjacent roads, railways, farmland, facilities, and other structures due to the soil settlement. The improved plan does not involve improvement of the soft soil of the existing road and consequently protects the stability of structures located near the existing road.

6 CONCLUSIONS

This study was conducted to develop improved design and construction methods for expansion of a roadway on a deep layer of soft soil. The project that was the focus of this study was the expansion of the second branch of the Namhae Expressway. The original design plans were reviewed, problems were discussed and solutions for the problems were proposed.

With the improved plan, it does not necessary to dispose of soil and asphalt concrete removed from the existing road. The constructability of the project would be improved because the sequence of work activities is simplified and issues related to the difficulty of installing PBD by drilling on the slope of the existing road can be avoided.

The improved plan reduces the construction cost. Installation of PBD beneath the existing road would involve additional costs for drilling or removing gravel and crushed stone underneath the existing road. In addition, there would be a cost for disposal of the waste asphalt concrete.

If PBD is used to improve the soil under the existing road, it is expected that coupled settlement will occur near adjacent structures due to the soil settlement. The improved plan does not involve improvement of the soft soil of the existing road and consequently protects the stability of structures located near the existing road.

7 ACKNOWLEDGEMENTS

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