# Mechanically reinforced earth wall using geotube and wire mesh for bridge abutment

Ja Yeon Kim & Kook Hwan Cho
*Seoul National University of Science & Technology, Korea*

ABSTRACT: An approach section on an abutment is located between the soil embankment and the structure, which may cause an uneven surface due to different settlement between the abutment and the soil embankment. This study proposes a new type of wall, which separates the abutment from the backfill material using a mechanically stabilized wall. A new type of keystone which incorporates Geotube and wire mesh is proposed and evaluated. Large-scale laboratory tests were performed to evaluate the behavior of the proposed wall type. The applied load on the surface is 180kN of cyclic loading considering the severe conditions until 2,000,000 times. After cyclic loading, horizontal and vertical displacements of the wall face and vertical earth pressure were measured, the measured values had very small displacements, and the vertical earth pressure on the proposed wall type was much smaller than on the non-reinforced wall. Numerical analyses were performed to investigate the applicability of the proposed keystone type, which incorporates Geotube and wire mesh. The maximum horizontal displacements along GRS wall faces, settlements at the top of pavement and track bed, and tensile forces applied on geotextiles under traffic loads were investigated. The results of the numerical analysis showed that the proposed wall can be used for high-speed railway abutment.

*Keywords: Abutment, Earth Pressure, Transition zone, Geosynthetic Wall, Keystone*

## 1 INTRODUCTION

An approach section on an abutment is located between the soil embankment and the structure, which may cause an uneven surface due to differences in the amount of settlement between the concrete abutment and the soil embankment. Backfill material for the section should satisfy the following two requirements. Firstly, the soil behind the abutment should be able to provide running stability and ride comfort while traffic is passing. The difference in stiffness from concrete abutment to backfill soil within a short distance should not be significant. Specifications for highway and high-speed railway require that the backfill material may be mixed with cement or selected gravel [KRNA 2014]. To achieve the above requirement, the relative density of the backfill material should be 95% or more [Tang 2012].

Secondly, an abutment should be designed to resist the horizontal earth pressure from backfilled material. According to the design specifications, earth pressure on the abutment is assumed to be active earth pressure, which is generally close to the minimum earth pressure [KRNA 2014]. When a relative density of 95% or more is achieved on the backfill material for required traffic supporting stiffness, the earth pressure applied on the abutment is close to the passive earth pressure, as shown in Figure 1[Chen and Fang 2008].

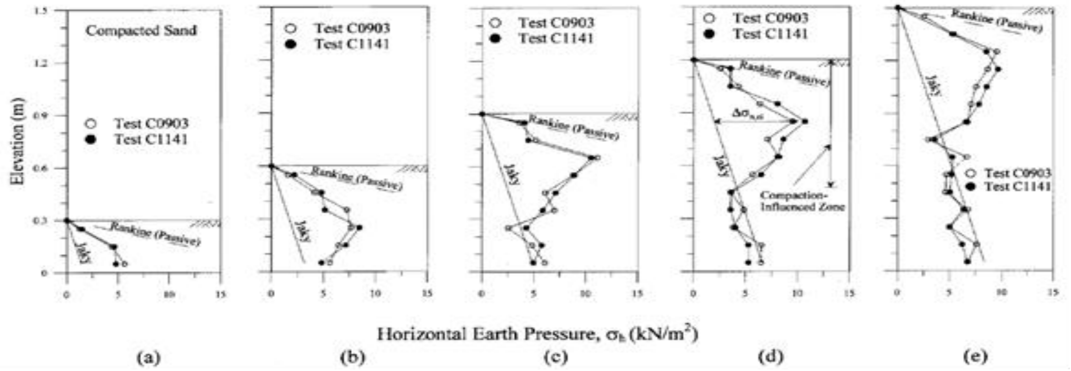


Figure 1 Distribution of horizontal earth pressure after compaction [Chen and Fang 2008]

When passive earth pressure is applied on the abutment, the magnitude of the applied pressure is increased to approximately 10 times the design value, which may cause overturn or generate cracks on the abutment. On the other hand, if compaction is not fully performed to avoid damages on the abutment, settlement behind the abutment section may occur, and then cause the other problems mentioned previously. As mentioned earlier, the conflict between traffic support stiffness and applied earth at an abutment approach section is unavoidable [Ishida and Miura 1998].

## 1.1 *Geosynthetic wall*

A number of studies have been performed to assess the behavior of Geosynthetic Reinforced Soil (GRS) wall, ever since those types of wall were proposed. Field tests of segmental block-faced GRS bridge abutments and piers have demonstrated excellent performance characteristics and a very high load carrying capacity [Abu-Hejleh et al 2000]. GRS bridge abutments and piers are easier to construct and more economical than their conventional alternatives—reinforced concrete gravity and semi-gravity earth retaining walls. According to J.G. Zornberg et al. [2003], the length of geotextile for reinforcement should be at least 70% of abutment height. The minimum length of geotextile should be more than 35% of abutment height according to Kim [2014]. Watanabe et al. [2002] performed a shaking table test and determined that cement-mixed backfill material could improve the stability of the abutment. Yang, et al. [2009] constructed an abutment wall and geosynthetic reinforced wall for separating two walls, and measured earth pressure on a high-speed railway line in China for more than 18 months. The measured earth pressure on the abutment is less than pas-sive earth pressure, and the stability of the wall has been increased over time.

Geosynthetic walls can have many different types of wall face, including wrapping, concrete panel and/or concrete blocks [Jonathan and Wu 1994].

## 1.2 *Proposed keystone wall using geotube and wire mesh*

When GRS wall is applied, the geosynthetic used for wall face should be firmly fixed by using pin to keystone, wrapped-face, etc. All wall face types should satisfy the requirements of dynamic stability, protecting fine grain soil drain, sufficient water drainage, and aesthetic effects. When concrete block type is used for GRS wall face, the cost of the wall face would be approximately 20% of total construction cost. If, however, concrete abutment and GRS wall are used together, the GRS wall face is not exposed, and the aesthetic requirements do not need to be satisfied. This study is intended to enhance the economic feasibility of keystone using Geotube and wire mesh, and to prove the adaptability through verification of the process via laboratory tests and numerical analysis. Geotube an be fabricated by filling the soil into geotextile in tube form to prevent fine grain soil from being drained and help it maintain mechanical stability, as shown in Figure 3. Wire mesh can be used to maintain it in tube form for short & long-term mechanical stability, and prevent creep deformation.

When fabricating a keystone using Geotube and wire mesh, the reduction in material cost compared with using a typical concrete block is estimated as only 40%. The proposed Geotube and wire mesh type wall needs a concrete wall in front of the GRS wall. However, the dimensions of the concrete wall and number of pile foundations (if needed) can be reduced, since the earth pressure on the wall is minimized. Figure 2 shows the process of applying Geotube and Geotube with wire mesh for the keystones proposed in this study.

(a) Compact soil in Geotube (b) Compact soil in wire mesh with Geotube
Figure 2 Keystone installation procedures of proposed method

## 2 LARGE SCALE LABORATORY CYCLIC LOAD TESTS

### 2.1 *Loading equipment and test pit*

A large–scale laboratory load test was carried out to evaluate the stability of the proposed wall-face type. The laboratory test pit is 21m in length (L), 4.5m in width (W) and 4m in height (h). The test GRS walls were designed and constructed based on the specifications for GRS walls. RLS (Railway Loading System) located at Korea Railroad Research Institute, which can simulate moving loads of up to 1,500kN using 12 actuator loading axles.

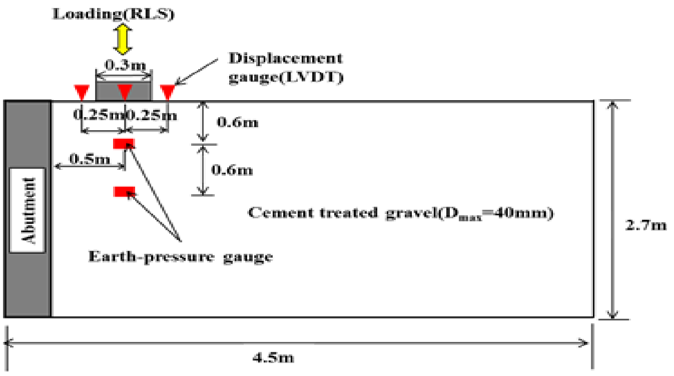
The applied load on the surface of each wall was 180kN, which was estimated through the following procedure. Load transferred from track used for high-speed railway design is 0.1 MPa according to KRL-2012(Korea Rail Load-2012) specification. Since the area of loading plate is 0.54m$^2$(0.3m (W) x 1.8m (L)), the applied load is 59kN. To consider severe conditions, the applied load is assumed to be 3-times larger than design load, which is the maximum load taking dynamic effect on transition zone behind abutment into account. The 2,000,000 times cycling load were applied after static loading to stabilize initial test condition.

### 2.2 *Tested wall types and measurement information*

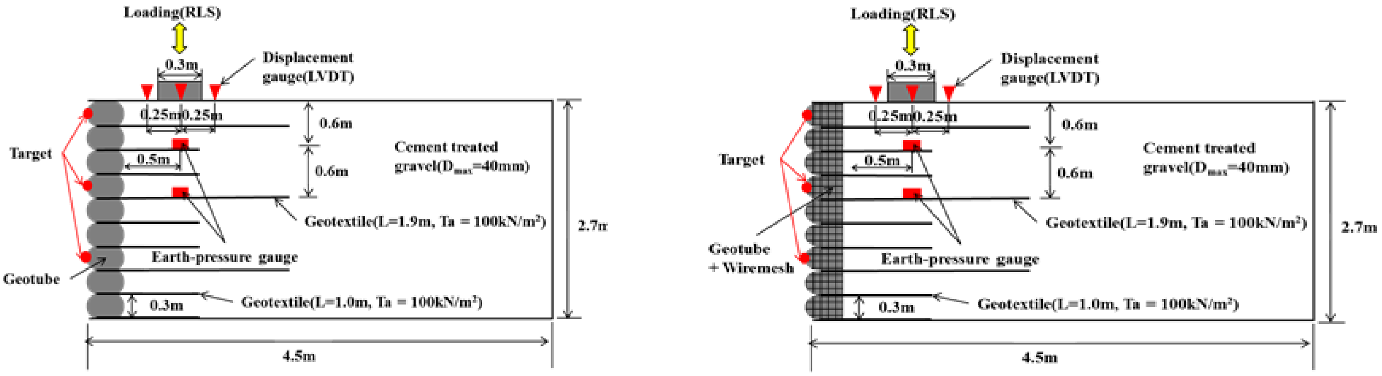
Figure 3 shows the cross-sections of each abutment wall and each approach section, with or without geosynthetic reinforcement types of wall, respectively. The dimensions of all testing walls are 4.5m in length, 3.0m in height, and 3.0m in width. Earth pressure gauges were installed at the depths of 0.6m and 1.2m horizontally to measure vertical earth pressures while traffic load is applied.

Three displacement gauges (LVDT) were also installed on the surface, as shown in Figure 3.

The wall face type of Geotube is model A, as shown in Figure 3(b), and the wall face type with wire mesh and Geotube is model B, as shown in Figure 3(c). No concrete abutment wall was built for models A & B in order to measure the movement of wall face in the vertical and horizontal directions. Geotextile used in this study is PET mat type, and has a maximum tensile strength of 100kN/m, unit weight of 2.0kN/m$^3$, and a Poisson's ratio of 0.2.



(a) Cross-section and sensor locations for non-reinforced wall



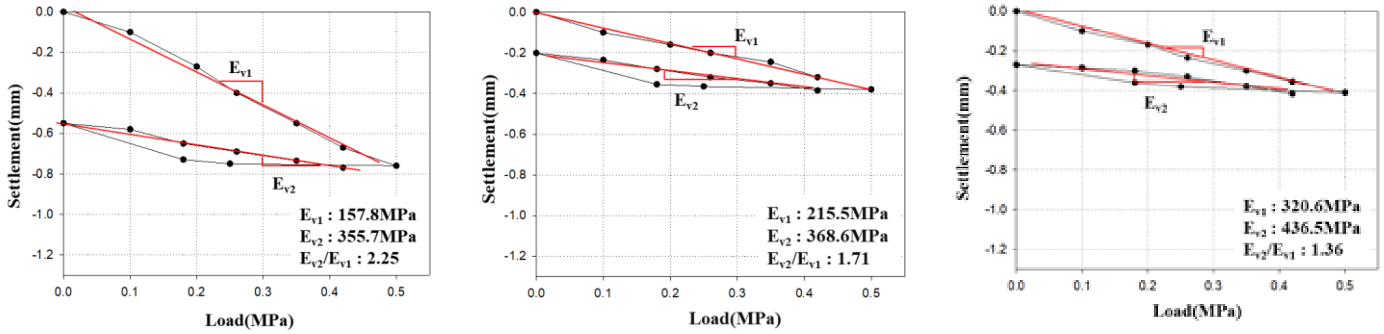
(b) Cross-section and sensor locations for Geotube GRS wall (Model A)

(c) Cross-section and sensor locations for Geotube with wire mesh GRS wall (Model B)

Figure 3 Cross-section and sensor locations for test walls

## 2.3 *Laboratory test results*

Mixed aggregate with a maximum gravel size of 40mm and 3% of cement of aggregate weight was used for fill materials. To evaluate the degree of compaction, a repeated cyclic plate loading test followed by DIN (Deutsche Industrie Normen) 18 134, which is typically used for high-speed railway construction specifications to measure soil stiffness after compaction, was performed on every 30cm compacted layer. Figure 4 shows one of the measured test results from each of the different types of wall and the procedure to estimate deformation coefficients called $E_{v1}$ and $E_{v2}$, respectively. As shown in Figure 4, the stiffness of compacted soil reinforced by geotextile is higher than that of non-reinforced soil.



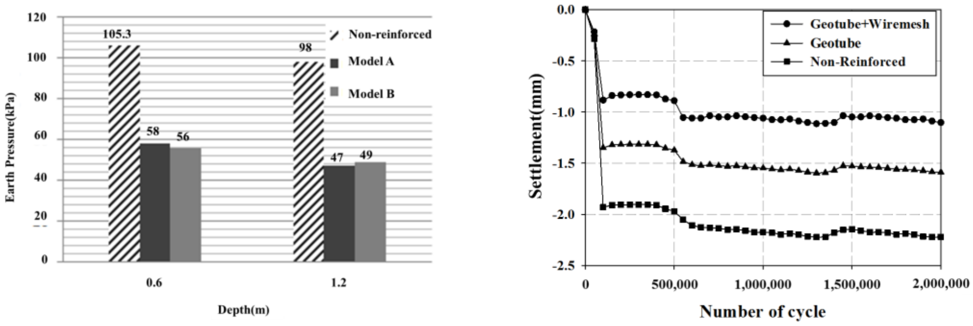
(a) Non-reinforced wall

(b) Model A - Geotube wall

(c) Model B - Geotube with wire mesh wall

Figure 4 Cyclic plate loading test results for compacted layers

Figure 5 shows the comparisons of maximum measured vertical earth pressure at depths of 0.6m and 1.2m after cyclic loading. The results show that only 50% ~ 60% of vertical earth pressures were applied compared with soil that was not reinforced by geotextile. The reduction in vertical earth pressure can be attributed to the redistribution of applied load, to a wider area caused be geotextile reinforcement.

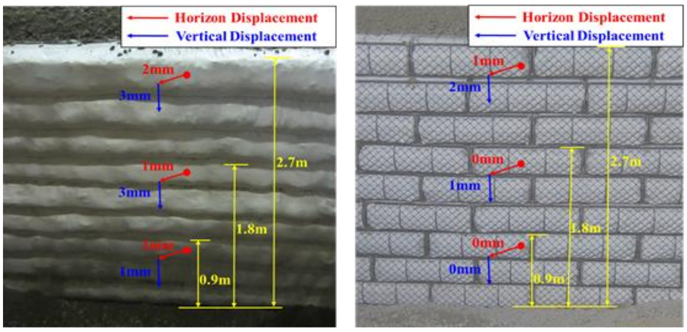


(a) Vertical earth pressures under cyclic loading

(b) Settlements under cyclic loading

Figure 5 Vertical earth pressures and settlements under cyclic loading

Wall face displacements of each type of wall were measured to investigate the influence of compaction during construction and after cyclic loading using an Electro-optical Distance Measuring Device. The measurement targets were installed at heights of 0.9m, 1.8m, and 2.7m from the bottom as shown in Figure 6. Model A has an irregular surface, while in contrast model B has a much regular shape of face. The final deformations of each wall model are presented in Figure 6, which shows not much of different deformations, though model B yields slightly less deformations.



(a) Model A (b) Model B

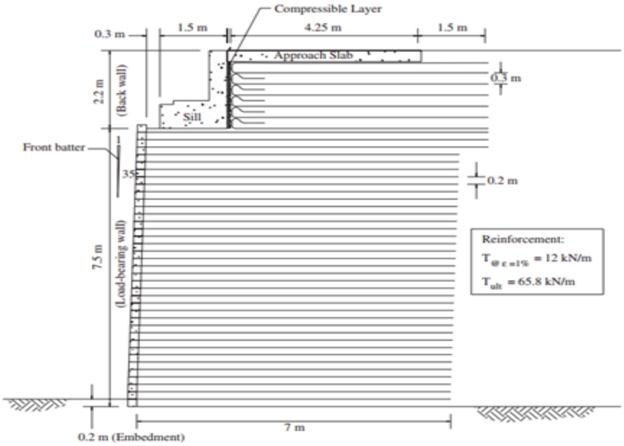
Figure 6 Face shape and displacement of Model A & B

# 3 NUMERICAL ANALYSIS

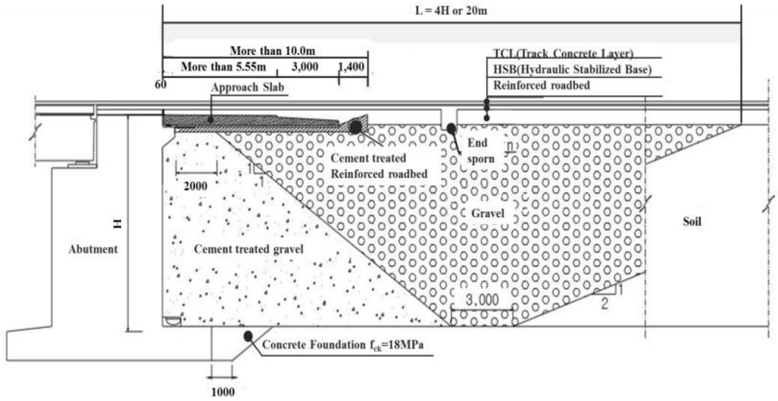
## 3.1 *Numerical modelling*

Numerical analyses were performed to evaluate the applicability of the proposed wall type of model B, which used wire mesh and Geotube for wall face. A typical cross-section of the GRS wall for highway is presented in Figure 7(a). Since the design specification for high-speed railway using GRS wall is not set yet in South Korea, the design procedure for GRS walls also follows FHWA specifications. The applied load, however, follows the Korean high-speed railway design specification. Figure 7(b) shows a typical cross-section in transition zone behind abutment as specified in South Korea for high-speed railway.

A finite element analysis program called MADAS GTS NX was used for numerical analysis. Figure 10 shows the finite element modeling for high-speed railway. The earth retaining wall was examined under two-dimensional (plane strain) conditions, which is consistent with normal de-sign assumptions [NCMA 1996]. The wall height was assumed to be 10m because the maximum height of an abutment wall for an embankment in high-speed railways in South Korea is 10 m, with the exception of some special cases. A sandy soil is modeled between the abutment wall and the GRS wall, since the shape of the concrete abutment wall is not vertically straight, which is designed for supporting approach slab, as shown in Figure 8. The properties of the sand are assumed to be compacted by the railing method. The length of modeling is 40m, which is 4 times the wall height, to minimize the boundary effect from the embankment located behind the abutment. The boundary conditions of modeling were fixed on horizontal and vertical directions at the bottom, and free on vertical and fixed on horizontal directions on the embankment side.



(a) Highway GRS abutment in FHWA specification [Helwany et al 2012]



(b) High-speed railway specification for abutment in South Korea [KRNA 2014]

Figure 7 Schematic diagram of abutments for highway and high-speed railway

As mentioned in Figure 7 above, the abutment for high-speed railway needs a transition zone. Therefore, the modeling of the high-speed railway structure has a transition zone behind the GRS wall with gravel properties as shown in Figure 8. Total three loading cases were applied for high-speed railway modeling, since loading zone of 220 kN/m in 3m lengths is needed within 80 kN/m loading for trainload modeling. Therefore, the higher load of 220 kN/m was applied at three different locations, as shown in Figure 8. Among three loading cases, the numerical analysis results from the loading case 2 gives the maximum wall displacement, vertical settlement, and tensile force in geotextile.

Approach slab of high-speed railway modeling was assumed to be 10m in length. The track bed of high-speed railway modeling was assumed to be a concrete slab track, which consists of Track Concrete Layer (TCL) and Hydraulically Stabilized Base (HSB). Geotextile was modeled as a one-dimensional element that can take only tensile force. The keystone was modeled as a soil element surrounded by a one-dimensional element used for geotextile. The properties of geotextile with wire mesh surrounding keystone can be determined through the procedure for composite material using equation 1. The thickness of Geotube is 3.0 mm, and the diameter of wire mesh is 8.0 mm with a mesh size of 0.15m*0.15 m. The calculated tensile strength of the composite material of Geotube and wire mesh is 102kN/ $m^2$.

$$T_a = (A_1 \cdot T_{a1} + A_2 \cdot T_{a2}) / (A_1 + A_2) \qquad (1)$$

where $T_a$ = Tensile strength of the composite material, $A_1$ = Area of the material 1 (48$m^2$), $A_2$ = Area of the material 2 (0.21 $m^2$), $T_{a1}$ = Tensile strength of the material 1 (100 kN/ $m^2$), $T_{a2}$ = Tensile strength of the material 2 (490 kN/ $m^2$)

Material properties used in numerical modeling were summarized in Table 1. The results of numerical analyses for highway and high-speed railways were discussed with a focus on the horizontal displacement of the wall face and GRS, settlement of backfill material, and axial force on geotextile under loading conditions for high-speed railway.

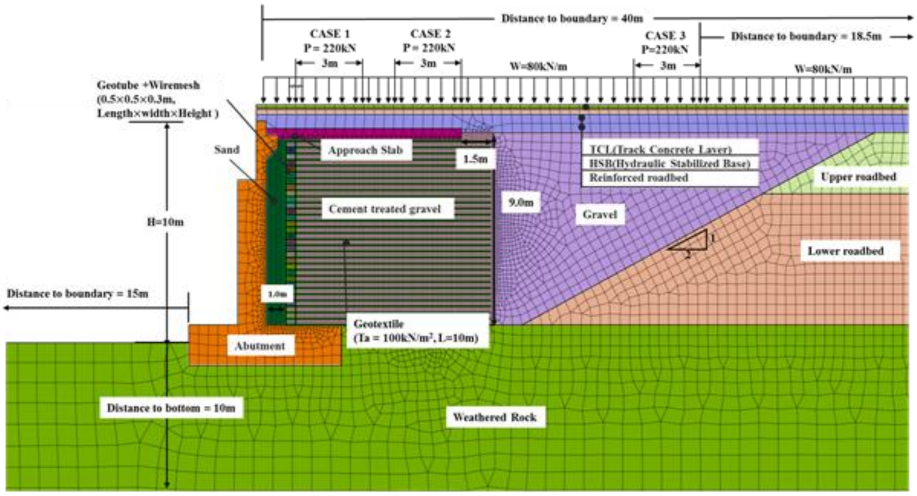


Figure 8 Modeling of abutments for high-speed railway

Table 1. Model properties [Choi 2016]

| Material | Model | Unit weight (kN/ m$^3$) | Cohesion (MPa) | Friction angle(°) | Elastic Modulus (MPa) | Poisson's ratio |
|---|---|---|---|---|---|---|
| Abutment | Elastic | 24 | - | - | 24,000 | 0.2 |
| Approach Slab | | 24 | - | - | 20,000 | 0.21 |
| TCL | | 21 | - | - | 30,000 | 0.21 |
| HSB | | 21 | - | - | 10,000 | 0.21 |
| Sand | Mohr-Coulomb | 18 | - | 25 | 60 | 0.33 |
| Weathered rock | | 20 | 20 | 40 | 100 | 0.2 |
| Reinforced roadbed | | 20 | - | - | 160 | 0.21 |
| Cement treated gravel | | 21 | 50 | 40 | 120 | 0.2 |
| Gravel | | 20 | - | 40 | 80 | 0.25 |
| Upper subgrade | | 19 | - | 35 | 80 | 0.3 |
| Lower subgrade | | 19 | - | 25 | 60 | 0.33 |

## 3.2 *Results of numerical analysis*

Figure 9 shows horizontal displacement on the face along the depth of the GRS wall. Figure 9 shows the maximum horizontal displacement on the high-speed railway wall, which is 0.85mm displacement at 5.0m in height from the bottom of GRS wall. According to the numerical analysis, the proposed wall system, which is Geotube and wire mesh combined with a type of keystone, can be used for abutment of high-speed railway with sufficient stability.

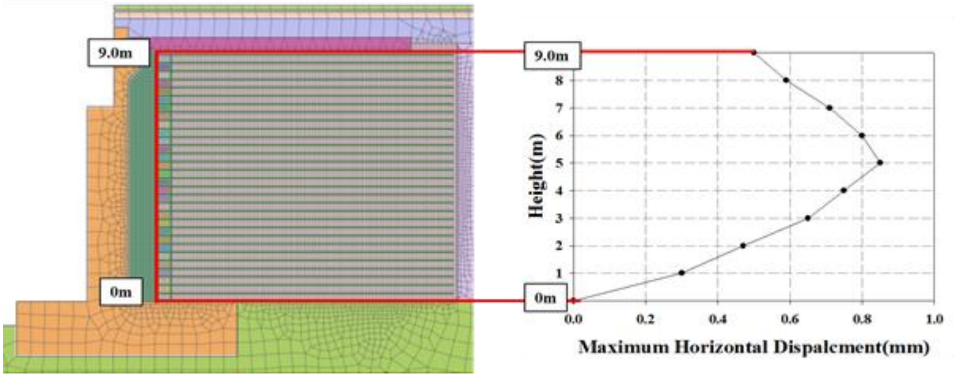


Figure 9 Numerical analysis results of face displacement

Figure 10 shows the settlement on the surface of each GRS wall under highway and high-speed railway loading cases. The maximum settlement occurred at the embankment section, which has the lowest stiffness in modeling. The amounts of settlement are very small, and within the allowable settlement range defined in the specifications.

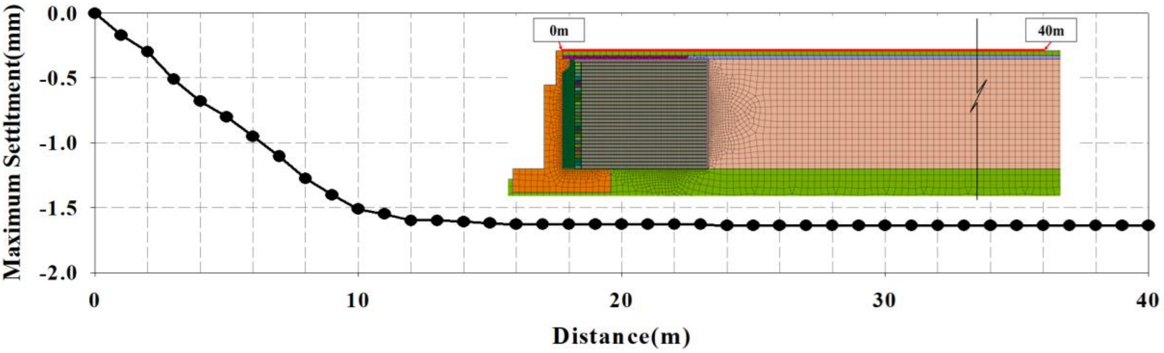


Figure 10 Numerical analysis results of vertical settlement

Figure 11 shows the comparison of the axial force in each geotextile along the wall, which is the maximum axial force for 23kN/m on high-speed railways. The maximum force applied on geotextile along the length is within 4 ~ 5m from the keystone, and the top layer of geotextile takes the maximum load in each case. The maximum axial forces applied on high-speed railway wall cases are 36kN/m. There is barely any residual axial force in geotextiles after loading, to the extent that it can be considered negligible. The maximum tensile force applied on geotextile is 36kN/m, which is less than the long-term allowable strength of 43kN/m, indicating that the proposed wall has no stability problems.

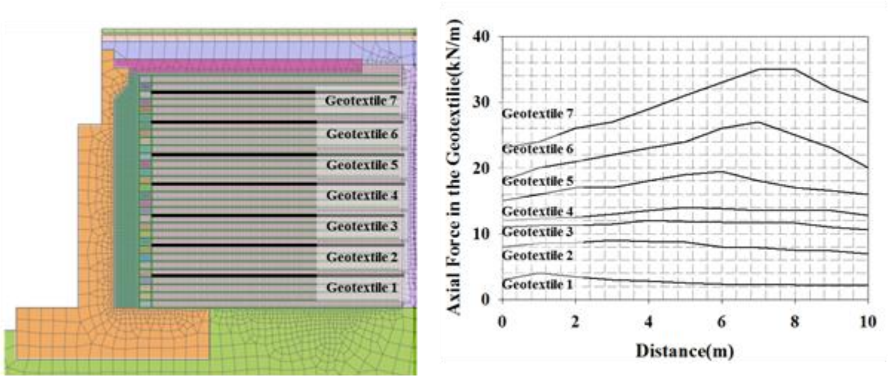


Figure 11 Numerical analysis results of axial forces in the geotextile

## 4 CONCLUSION

This study proposes a new type of wall for high-speed railway abutment, since there is a mismatch in the design concepts of being stiff enough to support traffic loading and having minimal earth pressure applied on abutment. The mismatch in concepts can lead either to settlement problems behind the abutment, or damages or overturns the abutment wall during construction, because of the severe compaction stress. In order to resolve the mismatch, this study proposes the separation of abutment and backfill material using GRS walls. A new type of keystone which incorporates Geotube and wire mesh is proposed and evaluated.

Large-scale laboratory tests were performed to investigate the behavior of the proposed wall type. Two types of walls were tested: Geotube GRS wall, and Geotube and wire mesh combined GRS wall. The measured values had very small displacements, and verified the stability of the proposed wall type.

Numerical analyses were performed to investigate the applicability of the proposed keystone type, which consisted of Geotube and wire mesh for keystone. A concrete abutment wall combined with GRS walls for high-speed railway was modeled using FEM program. The maximum horizontal displacements along GRS wall faces, settlements at the top of pavement and track bed, and tensile forces applied on geotextiles under traffic loads were investigated. The results of the numerical analysis show that the proposed wall can be used for high-speed railway abutments.

## ACKNOWLEDGEMENT

This research was supported by a grant (18CTAP-C129708-02) from National Transport Technology Promotion Research Program funded by Ministry of Land, Infrastructure and Transport of Korean government

## REFERENCES

Korea Rail Network Authority (KRNA), Korea Rail design criteria manual, 2014.

Tang, Haiwei. Analysis of Highway Vehicle Jumping at Bridge-head between Pavement and Abutment of Express Highway, Computer Distributed Control and Intelligent Environmental Monitoring, International Conference, Pages 131-136, 2012

Tsang-Jiang Chen, Yung-Show Fang, M.ASCE. Earth Pressure due to Vibratory Compaction, Journal of Geotechnical and Geoenvironmental Engineering, Vol. 134, 2008, pp. 437–444.

Makoto Ishida, Shigeru Miura. Track Deformation Characteristics and Vehicle Running Characteristics Due to Settlement of Embankment behind the Abutment of Bridges, RTRI Report Vol 12. No. 3, 1998

Abu-Hejleh, N., Wang, T., Zornberg, J.G., Performance of geosynthetic - reinforced walls supporting bridge and approaching roadway structures. ASCE Geotechnical Special Publication No. 103, Proceedings, Geo-Denver 2000, Denver, CO, pp. 218–243.

Jorge G. Zornberg, Naser M. Abu-Hejleh,, Victor Elias, Jim Watcharamonthein, Design Assessment of the Founders/Meadows GRS Abutment Structure, Paper No. 03-3268,Transportation Research Board CD ROM, 2003

Kim, D.S. Stability Evaluation of Reinforced Subgrade with Short Geogrid for Railroad During Construction, Jounal of Korean Geosynthetics Society Vol.13 No.4 2014, pp. 11 ~ 20

Watanabe, K, AA Balkema, Tateyama, M., Yonezawa, T., Aoki, H., Tatsuoka, F., Koseki, J. Shaking table tests on a new type bridge abutment with geogrid-reinforced cement treated backfill. In: Proc. 7th International Conf. on Geosynthetics, Nice, vol.1, pp.119-122. 2002

Guangqing Yang, Baojian Zhang, Peng Lv, Qiaoyong Z. Behaviour of geogrid reinforced soil retaining wall with concrete-rigid facing, Geotextiles and Geomembranes Vol. 27, Issue 5, pp. 350–356. 2009

Jonathan T.H.Wu. Design and construction of low cost retaining walls, Colorado Transportation Institute and the Colorado Department of Transportation U.S. Forest Service University of Colorado at Denver. 1994

DIN 18 134. Determining the deformation and strength characteristics of soil by the plate loading test, Deutsches Institut für Normung e.V., Berlin. Beuth Verlag GmbH, 10772 Berlin, Germany, 2001

Sam Helwany, Jonathan Wu, Philip Meinholz. Seismic Design of of Geosynthetic-Reinforced Soil Bridge Abutments with Modular Block Facing, Contractor's Final Report for NCHRP Project 12-59 (01), National Cooperative Highway Research Program, 2012

National Concrete Masonry Association (NCMA), Design Manual for Segmental Retaining Walls. Second Ed. NCMA, Herndon, VA, USA. 1996

Won-Il, Choi. Stress Release zone Characteristics and Reinforcement around Sub-structure Constructed by Non-open Cut Method under Railway, Graduate School of Railway Seoul National University of Science and Technology Doctoral thesis, 2016