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A Field Study and Dynamic Finite Element Analysis of Railway Retaining Structures Damaged by the Hyogoken-Nambu Earthquake (1995)

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A FIELD STUDY AND DYNAMIC FINITE ELEMENT ANALYSIS OF RAILWAY RETAINING STRUCTURES DAMAGED BY THE HYOGOKEN-NAMBU EARTHQUAKE (1995)

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ABSTRACT

The seismic damage to embankments and retaining walls caused by the Hyogoken-nambu Earthquake (1995) was reviewed, rather focusing on railway structures. Nearly eight kilometers of damaged retaining structures were divided into five structural types, such as gravity-type walls, leaning-type walls, embankments, geo-textile-reinforced earth walls, and reinforced concrete walls, and into three categories of the damage, such as collapse, tilt, and crack. It was observed that the damage to gravity-type and leaning-type walls was greater than that to embankments, geo-textile-reinforced earth walls, and reinforced concrete walls, when they are lower than five meters. But some leaning-type walls higher than seven meters remained un-collapsed. In a smaller limited section, damage analyses of stone masonry walls of gravity type were carried out including undamaged ones. The percentage of heavy damage to stone masonry walls with slopes was nearly twice larger than that without slopes. Moreover, two-dimensional dynamic non-linear finite element analyses were performed on a gravity-type wall, a leaning-type wall, and a geo-textile-reinforced earth wall. As the results, it was pointed out that the gravity-type and leaning-type walls developed slide or gap against the backfill. But the geo-textile-reinforced earth wall developed tension in the reinforced material and it prevented the wall from leaning or sliding.

INTRODUCTION

Immediately after the Hyogoken-nambu Earthquake, a research committee on the Great Hanshin-Awaji Earthquake Disaster was established in the Kansai Chapter of Japan Society of Civil Engineers. This committee consists of eight sub-committees and the Sub-committee No. 2 concerned about Soils and Foundations. It was established under chairmanship of Professor T. Matsui of Osaka University to investigate seismic damage, to study the mechanism of the damage, and to make suggestions on the aseismic design method, concerning on ground, earth structures, and foundations. The sub-committee made 286 pages of report in Japanese. In this sub-committee, a group for highway and railway retaining structures reviewed the seismic damage on embankments and retaining walls.

This paper is a summary of some findings in this group rather focusing on railway retaining structures, with some additional information. It was observed that the damage to these structures on alluvial fans tended to be smaller than that on other deposits, but geometrical and geological conditions of the ground surface could not be related to the degree of damage. This paper first describes damage and restoration works on these retaining structures, followed by statistically analyzing damaged ones in relation to the height and with-or-without slopes. Finally, dynamic finite element analyses are conducted in order to elucidate seismic response difference due to the types of retaining structures.

CLASSIFICATION OF RETAINING STRUCTURES AND THE DAMAGE

Damaged retaining structures were divided into five structural types, such as gravity-type walls, leaning-type walls, embankments, geo-textile-reinforced earth walls (GRW), and reinforced concrete walls (RCW). Gravity-type walls withstand earth pressure with their own weight and bearing capacity. Leaning-type walls cannot stand by themselves, and therefore they need backfill in order to keep "leaning." Embankments have no retaining walls. GRWs consist of soils reinforced by layered geo-textiles and wall with bending rigidity. RCWs support backfill earth pressure with their wall rigidity and bearing capacity. Therefore, the concrete wall should have bending rigidity usually reinforced by re-bars. L-shaped retaining walls fall into this type.

The degree of damage was divided into three categories, such as collapse, tilt, and crack. Cracks in a retaining wall are internal damage, while tilting of a wall is external damage. But it should be noted that collapse of retaining structures would happen both internally and externally. Fig.1 shows

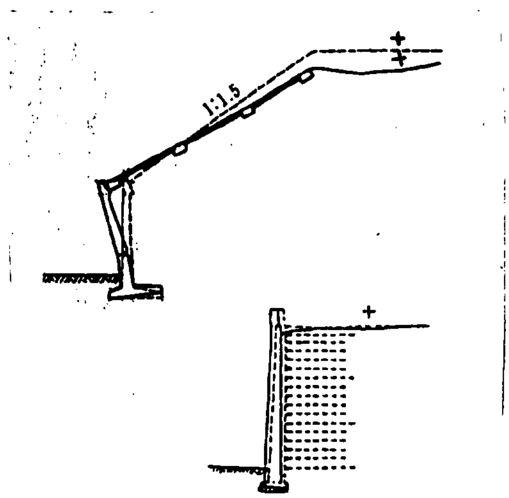


Fig.1. Collapse of RCW (above) and tilt of GRW (below)

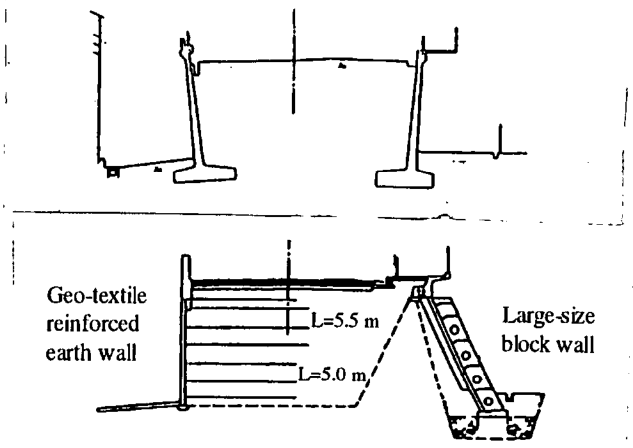


Fig.2. Restoration of a highway embankment: before (above) and after (below)

some examples of combination of structural type and degree of damage. That is, the above figure shows an example of collapse of RCW, and the below an example of tilting of GRW.

RESTORATION EXAMPLES OF DAMAGED RETAINING STRUCTURES

Restoration of damaged retaining walls of a municipal highway was conducted, using a geo-textile-reinforced earth wall and a large-size block wall, as shown in Fig.2.

Collapsed retaining walls of Hankyu Railways are shown in Fig. 3. As for the restoration, the damaged walls were removed, the railway tracks were temporarily supported by staging, then a U-shaped concrete wall was constructed, and finally air-mortar was poured into the space inside the U-shaped wall.

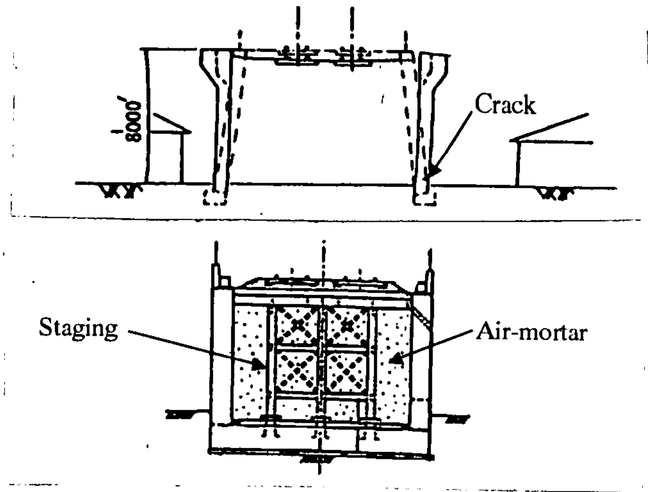


Fig.3. Restoration of a Hankyu Railways leaning-type wall: before (above) and after (below)

ANALYSIS OF DAMAGED RAILWAY RETAINING STRUCTURES

In a severely damaged area of seven in the seismic intensity scale of the Japan Meteorological Agency, three railway lines run east-to-west connecting Osaka and Kobe. About 8.5 kilometer section was chosen for damage analysis, and the damaged retaining structures investigated amounted to be 7984.7 meters in length (Nagayama *et al* 1998). The structural type had been judged by staffs in charge of the rapid reconstruction, so some gravity-type walls seemed to be miss-classified as leaning-type walls. Figure 4 shows the variation of damaged length with their height for the five types of retaining walls. From this figure, the followings are observed;

- Damage to embankments, GRWs, and RCWs was smaller than that to gravity-type or leaning-type walls,
- RCWs suffered internal damage but had no external damage, and
- Gravity-type walls of higher than 5 meters tend to collapse but leaning-type walls of higher than 7 meters remained tilted without collapse.

In a smaller limited section, all stone masonry retaining structures including non-damaged ones were analyzed, and the damage ratio was calculated. The retaining structures in this section were composed from stone masonry wall, stone masonry wall with protruded crown, and stone masonry wall with slope as shown in Fig.5. Figure 6 shows that the damage ratio of stone masonry wall with slope is twice greater than that without slope. The ratio of collapse in stone masonry wall with protruded crown is nearly twice greater than stone masonry wall. But even if tilted structures are included to the collapsed, the damage ratio with protruded crown does not change so much. From this figure, it is suggested that in the

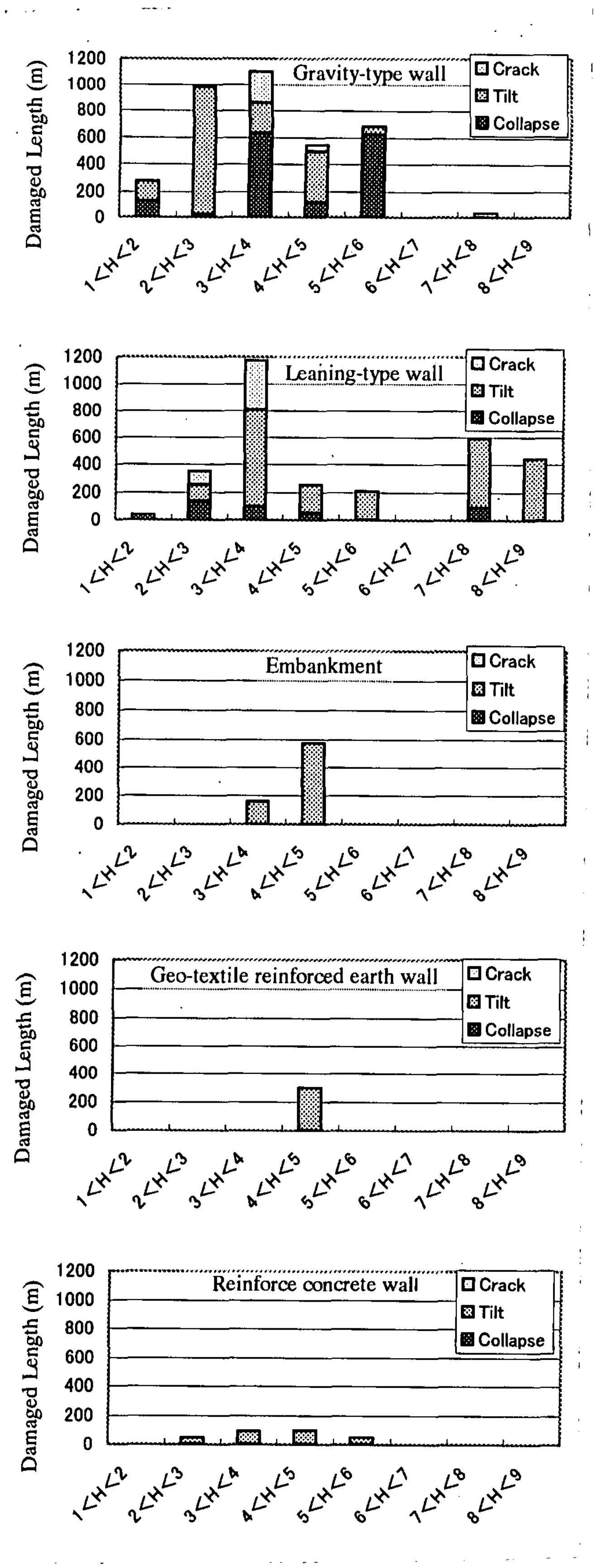


Fig.4. Degree of damage according to the height H (m) and type of retaining structures

applied aseismic design of retaining walls with slope, seismic active earth pressure can be estimated to be too small. Figure 7 shows the assumed slope for calculating seismic earth pressure in the applied seismic design. The shaded triangular soil mass over the assumed slope is considered to slide during earthquake, and neglected in the calculation of seismic earth pressure. This underestimation of seismic earth pressure may contribute to the large ratio of collapse. Moreover, some other factors such as slope protection works might accelerate the damage.

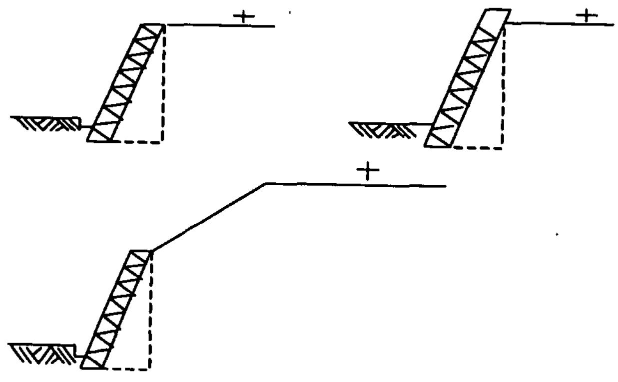


Fig.5. Three structures compared: stone masonry wall (above left), stone masonry wall with protruded crown (above right), and stone masonry wall with slope (below)

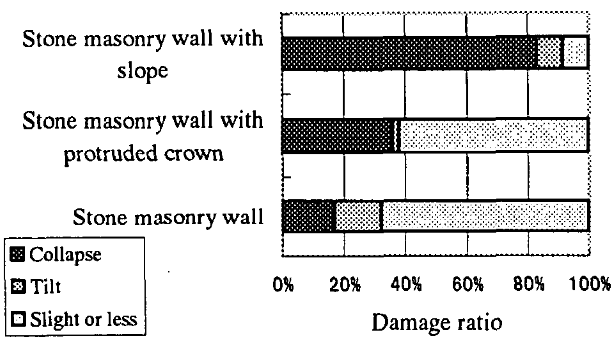
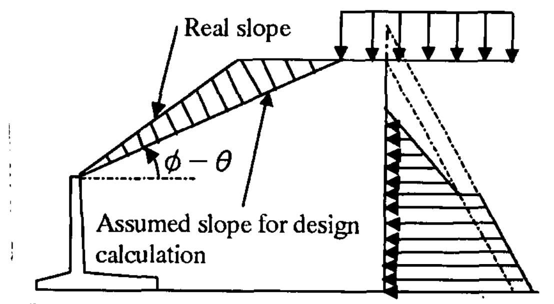


Fig.6. Damage ratio of stone masonry walls



ϕ =Angle of internal friction, θ =$\tan^{-1}K_h$,

K_h= Horizontal seismic coefficient for design

Fig. 7. Assumption of slope for applied aseismic design of retaining wall with slope

ANALYSIS OF DAMAGED HIGHWAY STRUCTURES

Damage to embankments of national highways was analyzed. Figure 8 shows the relationship between height of embankment and damaged length or damage ratio. The damage ratio is found to become greater as increasing the height of structures (Kunitomi *et al* 1998).

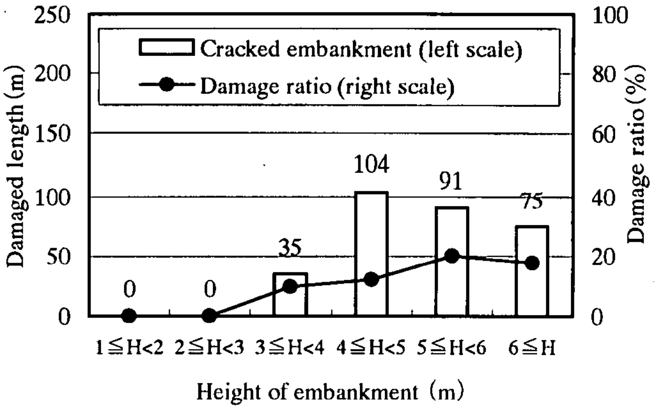


Fig.8. Damage to highway embankment

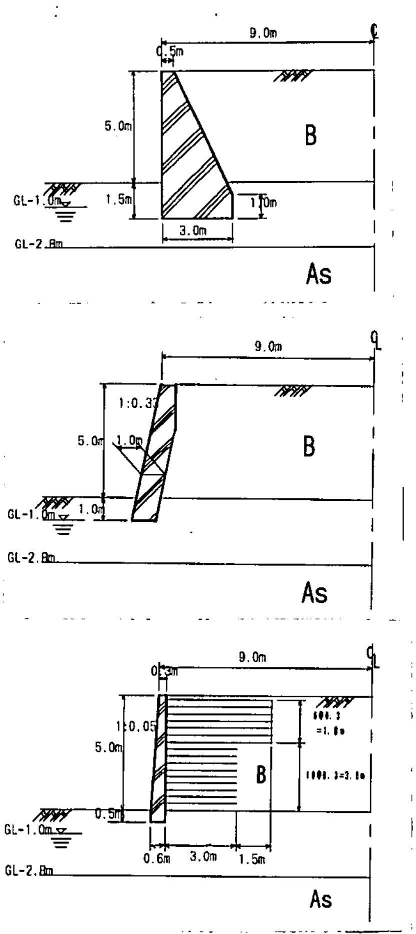


Fig.9. Modeled sections of retaining walls: gravity-type wall (top), leaning-type wall (middle), geo-textile reinforced earth wall (bottom)

DYNAMIC FINITE ELEMENT ANALYSIS OF DAMAGED RAILWAY RETAINING STRUCTURES

Time history response analyses were conducted for a gravity-type wall, a leaning-type wall, and a GRW, each of which has five meters in height, as shown in Fig.9 (Kasai *et al* 1998).

Modeling and waveform

The two-dimensional finite element model has depth of 61.2 meters and extends 56 meters from the wall location to both boundaries as shown in Fig. 10. The lower boundary faces bedrock. Non-linearity of ground stiffness, de-lamination or sliding at the contact face between backfill and wall is considered in the calculation. Soil properties were obtained at the damaged site of the gravity-type wall. As the aim of the analyses is to find some difference in seismic response among these three retaining structures, the same soil properties are used for analyses. The shear wave velocity is 150 meters per second in the backfill, and 100-540 meters per second in bearing layer increasing from surface to bedrock. Backfill soil and the top five-meters layer of the ground follow the elasto-plastic Mohr-Coulomb's criterion. The angle of internal friction for the cohesionless backfill and the top layer are 42.0 and 35.8 degrees respectively. The soils below this layer and concrete walls are modeled as linear materials. Geo-textile material is modeled as non-symmetrical bi-linear spring that resists tension force only.

In order to obtain an input waveform, a pre-calculation was performed. The waveform of earthquake ground motion detected at the location of Kobe University on bedrock surface during the 1995 Hyogoken-Nambu earthquake was applied on the bottom viscous boundary with half space, and a quasi-linear analysis was conducted. The resulting waveform at the upper side of the boundary is used for the present finite element analysis. Figure 11 is the waveform thus obtained.

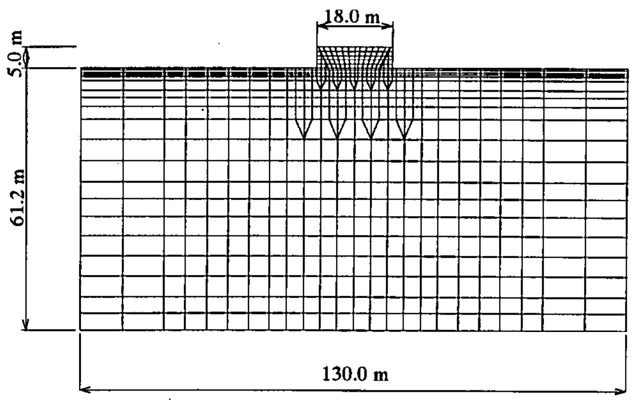


Fig. 10. Finite element model (gravity-type wall)

Calculation is conducted applying this waveform for twenty seconds, and free vibration follows afterwards for ten seconds in order to get the residual displacement.

Results of analysis

Figure 12 shows response of the gravity-type wall and the backfill. The gravity-type walls and the backfill horizontally oscillate in the same phase as shown in the upper figure of Fig.12. But, as shown in the lower figure of Fig.12, the settlement of backfill accumulates from the earlier stage, and the surface of embankment can not hold the original level.

The gravity-type walls develop de-lamination at the contact plane to backfill as shown in Fig.13. This soil-wall slippage displays non-reversible character. This type of relative displacement is also developed in the leaning-type walls.

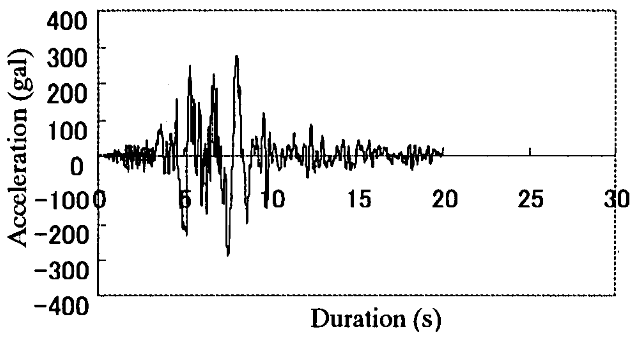


Fig.11. Waveform in acceleration

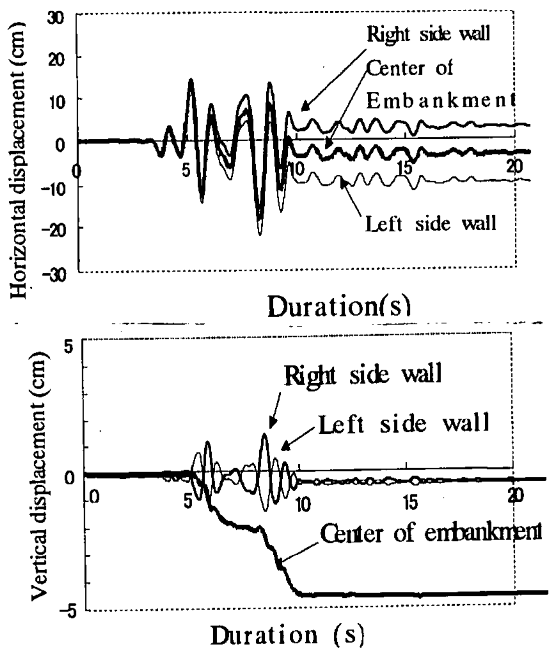


Fig.12. Response of the gravity-type wall and the backfill: horizontal (above) and vertical (below)

Figure 14 shows stress distribution at the contact face between gravity-type wall and backfill. The gravity-type wall develops earth pressure when the whole structure is moving from backfill side to wall side as shown in Fig. 14, but has no earth pressure when moving the other way around. This means that the gravity-type wall suppresses the movement of the backfill.

Figure 15 shows displacement of leaning-type wall at 9.7 seconds. The leaning-type wall does not develop any earth pressure at the contact face with the backfill whether it is moving right or left. It moves as if it was on the side slope of the embankment and toppled after as shown in Fig.15.

Figure 16 shows tension force in the geo-textile and settlement of reinforced embankment. The geo-textile material develops tension force in accordance with the settlement of backfill as shown in Fig.16. The distribution of the tension force in geo-textile does not change so much

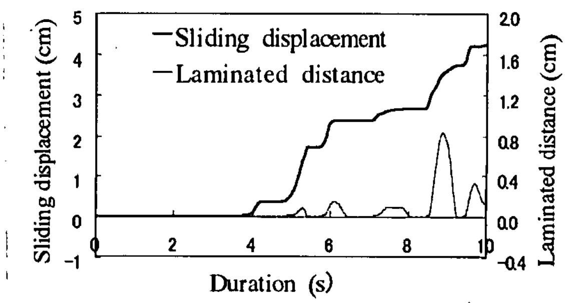


Fig.13. Relative displacement between the gravity-type wall and the backfill

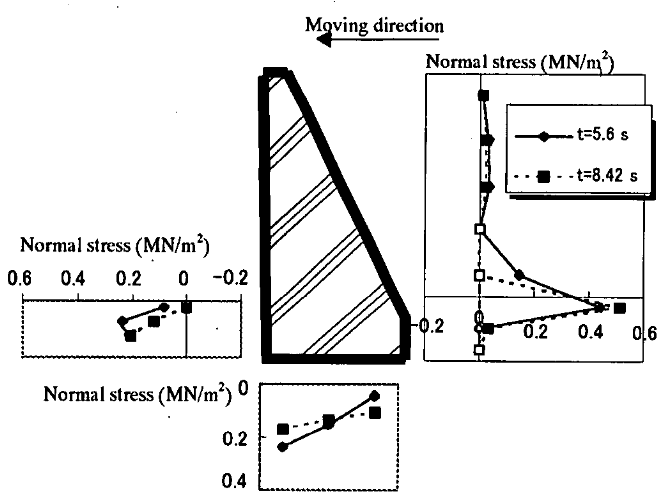


Fig.14. Stress distribution at the contact face between gravity-type wall and backfill

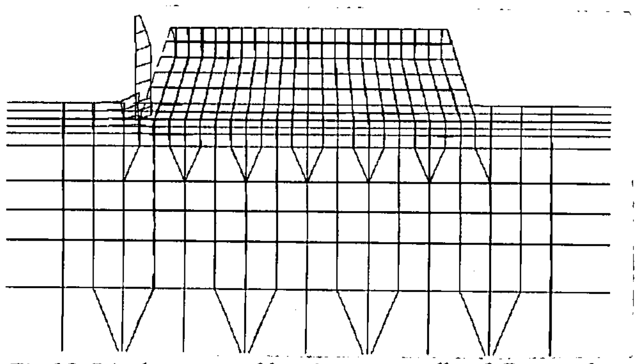


Fig.15. Displacement of leaning-type wall at 9.7 seconds

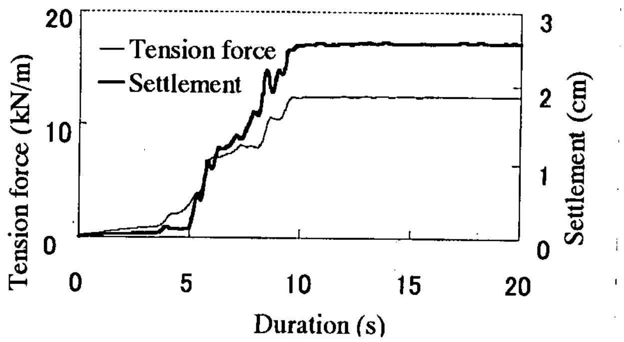


Fig.16. Tension force in the geo-textile and settlement of reinforced embankment

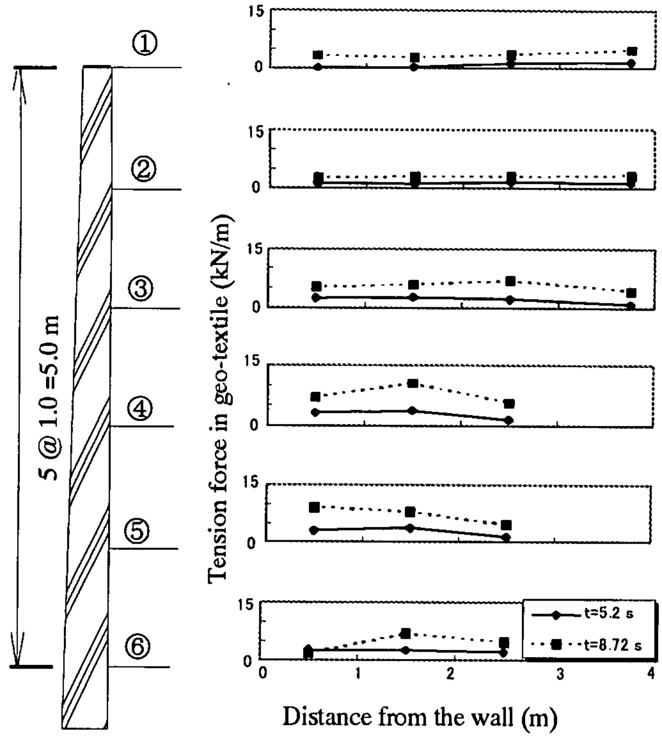


Fig.17. Distribution of tension force in the geo-textile

whether the wall is moving right or left. Therefore, the tension force is not directly caused by the horizontal movement of the wall, but by the settlement of backfill. This tension force suppresses sliding of the wall. Figure 17 shows the distribution of tension force when the whole structure is moving from the left to the right.

CONCLUDING REMARKS

After the Hyogoken-nambu Earthquake (1995), the authors collected data about the damage and restoration methods concerning to embankments and retaining walls of railways and highways. Those data have been categorically analyzed and investigated. Based on the result, dynamic analysis was conducted. In this paper, some valuable information related to the aseismic design method for retaining structures could be presented, rather focusing on railway structures. But some problems are left for further studies. Among them is the mechanism as to why tall leaning-type retaining walls could avoid the collapse.

Aseismic design codes for railway structures were revised in 1999, and the concept of sliding soil mass in the calculation of seismic active earth pressure to retaining walls with slope was abandoned. The necessity of this revision coincides with the findings presented in this paper.

Although this study is incomplete even after six years from the earthquake, the authors believe that the result of this study can make some contributions to readers. The authors owe so much to the persons who took notes of the damage on the site.

REFERENCES

Kasai, H., N. Fukuda, T. Matsui, Y. Nagayama, and K. Sho, [1998]. The seismic behavior and damage mechanism of retaining wall, Proc. the 10th Japan Earthquake Engineering Symposium, Vol. 2, pp. 1569-1574. (in Japanese)

Kunitomi, K., I. Kobayashi, T. Matsui, S. Yamazaki, and I. Yasukawa [1998]. Structural factor analysis of road embankment damages due to Hanshin-Awaji Earthquake, Proc. the 10th Japan Earthquake Engineering Symposium, Vol. 1, pp. 437-442. (in Japanese)

Nagayama, Y., K. Mizobata, K. Kubota, K. Sho, and S. Samata [1998]. Overviews of the damage on railway banking and retaining walls caused by the Hanshin-Awaji Earthquake. Proc. the 10th Japan Earthquake Engineering Symposium, Vol.1, pp. 431-436. (in Japanese)