Design and Construction of a Reinforced Retaining Wall

Y.Nakamura[1], Y.Ohne[2], K.Narita[2], S.Hanagata[3], S.Imayama[3] and K.Maegawa[4]
[1]AICO co. ltd., Togo, [2]Dept. of Civil Eng., Aichi Inst. of Tech., Toyota
[3]Wakachiku Construction co. ltd., Nagoya, [4]Shirataka Kogyo co. ltd., Fukui

Synopsis

A newly developed reinforced retaining wall, the arch wall, consisting of a discontinuous wall of concrete segments and a reinforced earth with steel tie rods is discussed in this paper. The design and construction procedures of the arch wall are first reviewed by introducing an actual earth fill construction with a wall protection of 9m high. The behavior of the wall is then studied by analyzing the data of stress transmission along tie rods, the earth pressure acting on the wall and movement of the wall observed in the field. The design value of earth pressure and the concept of earth reinforcement in the fill are again reviewed to propose a proper standard for the arch wall construction.

Keywords

slope protection work, reinforced earth, earth fill, anchor, earth pressure

1. Introduction

Recent development of geosynthetic and concrete products has brought about various types of reinforced earth and slope protection works, through extensive ideas on the mechanism of reinforcement and capabilities for different usage of the product. In addition to usual requisites for mechanical and economical conditions, another aspects of design have been taken into consideration from viewpoints of sight and scenic beauty. The arch wall, here to be presented in this paper, is one of slope protection works recently developed, in which arch-shaped concrete wall segments are piled up along the front face of an earth fill, together with reinforcement work by burying steel tie rods and end anchor plates in the fill. Precise and intensive discussions are still required on the mechanism of earth pressure and earth supporting systems of such discontinuous walls, in order to propose more comprehensive and reliable design method founded on a theoretical background.

This paper concerns a newly developed reinforced retaining wall, the arch wall, consisting of a discontinuous wall of concrete segments and a reinforced earth with steel tie rods and anchor plates. Some important issues to be noticed in the design and construction of the arch wall are first reviewed by introducing an actual project of land development where an earth fill is constructed with a wall protection of 9m high and 92m wide, about 580m^2 in area. The behavior of the wall is then studied by analyzing the data of stress transmission along tie rods, the earth pressure acting at wall face and horizontal and vertical movement of the wall observed in the field. Discussions are further made on the design value of earth pressure and the concept of earth reinforcement in the fill to establish a proper standard for the arch wall.

2. Design of arch wall

2.1 Structure of arch wall

Reinforced retaining walls in general have an advantage to form a steep slope protection along the front face of a fill by utilizing composite structural actions between wall segments, reinforce materials and fill materials. A sketch of the arch wall is presented in Figure 1. It is characterized by arch-shaped concrete wall segments piled up alternately along the front face of an earth fill and steel tie rods with end anchor plates connected to the back of the segments and buried deep in the fill for earth reinforcement. The arch wall has several advantages of ensuring a large resisting force against pulling-out of tie rod with a relatively small displacement of the anchor plate, reducing earth pressure acting on the wall due to the arching action produced by the shape of wall segment, and of its wide application for various fill materials from sandy to cohesive soils. Planting in spaces made between wall segments becomes to be another characteristic aspect of the wall from a viewpoint of sight and scenic beauty.

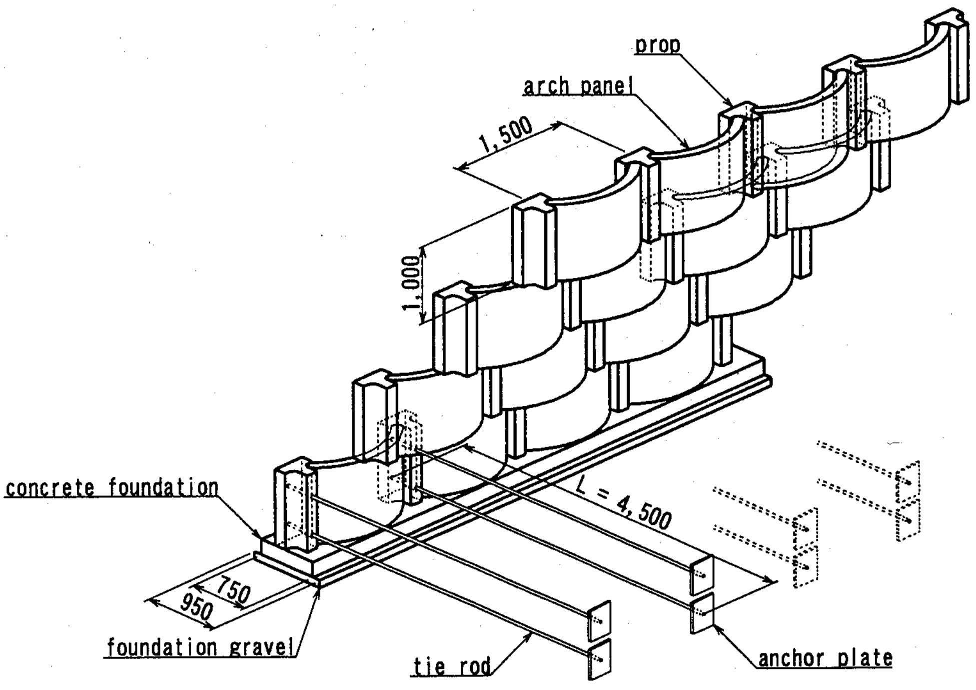

Figure 1 Key sketch of arch wall

2.2 Design of arch wall

The design concept of the arch wall is founded on an basic idea that the resistance force against pulling-out of tie rods should be balanced with the earth pressure acting on the wall to ensure slope stability of the fill. Stability of the wall and earth fill is then checked up in terms of the following three items: i.e., ① stability in individual reinforced wall segments, where calculation is done for the tension force in tie rods required to withstand pulling-out forces induced by the earth pressure acting on the wall, ② overall stability as a reinforced wall structure, where safety evaluation is done for overturning, horizontal sliding and bearing capacity in an ordinary design of a retaining wall and also for a sliding failure of the reinforced fill behind the wall, and ③ structural strength of wall segments, where check is done for wall structure to have sufficient strength and stiffness against earth pressure. In the item ①, earth pressure acting on the wall is calculated, regarding it as a vertical wall, as shown in Figure 2. The earth pressure p_i acting at the i-th tie rod located at the depth z_i from the crest of the wall is then expressed in the following form.

$$p_i = K_A \gamma (z_i+H_2) + qK_A \tag{1}$$

where K_A is the Coulomb's coefficient of active earth pressure with an assumed angle of wall friction of $\delta=2/3\ \phi$. The influence of a surcharge load q which rests on the crest cover extra-fill of the thickness H_2 is taken into account as an increase in earth pressure over the range of the wall below the point Q, at which a line of 1 on 2 starting from the end point of the surcharge intersects the wall. By eliminating friction between tie rod and the surrounding soil, the tension force T_i of the i-th tie rod which is required to balance with the above earth pressure p_i is calculated, by denoting the height and the width of the wall associated with the i-th tie rod as ΔH_i and ΔL_i, as follows;

$$T_i = p_i \cdot \cos \delta \times \Delta H_i \times \Delta L_i \tag{2}$$

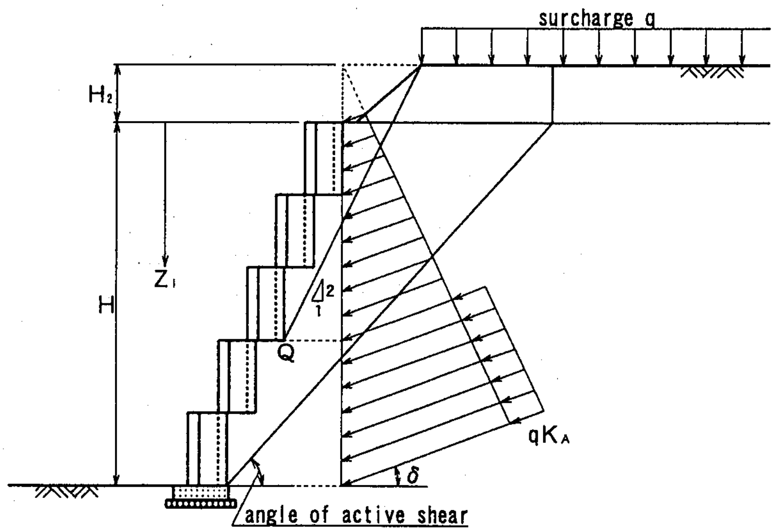

Figure 2 Calculation of earth pressure on arch wall

3. Construction of arch wall

In a project of land development, an earth fill was constructed with the arch wall protection of 9m high and 92m wide. A standard construction sequence of the arch wall is reviewed in the flow chart presented in Figure 3. The main process is composed of foundation treatment, drainage, base construction, and iteration sequence of setting of wall segment, burying of tie rod and anchor plate and placement of fill material. In this project, clayey gravel (GC) was taken in the site as a fill material, and it was placed by use of a 2-ton weight bulldozer in spreading and a 2-ton weight vibration roller to compact in the degree of compaction over 90% of the maximum dry density. A small size tamping roller was also used for compaction within a narrow area near the wall.

Setting of the arch wall during construction are shown in photo 1.

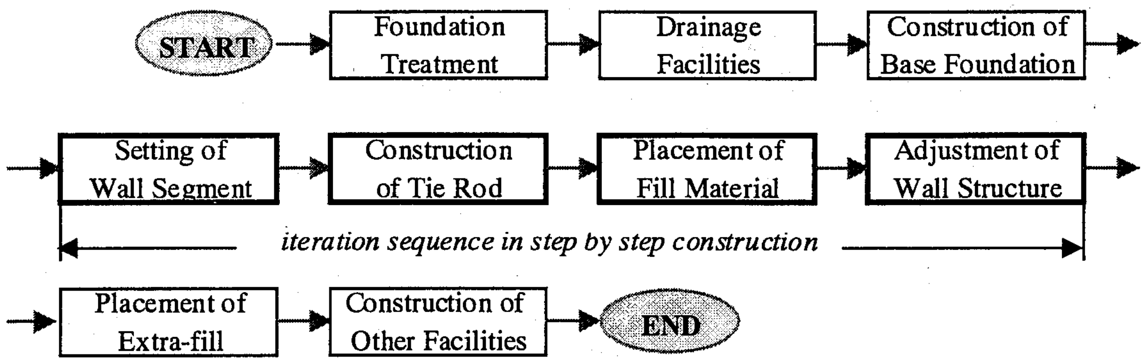

Figure 3 Construction sequence of arch wall

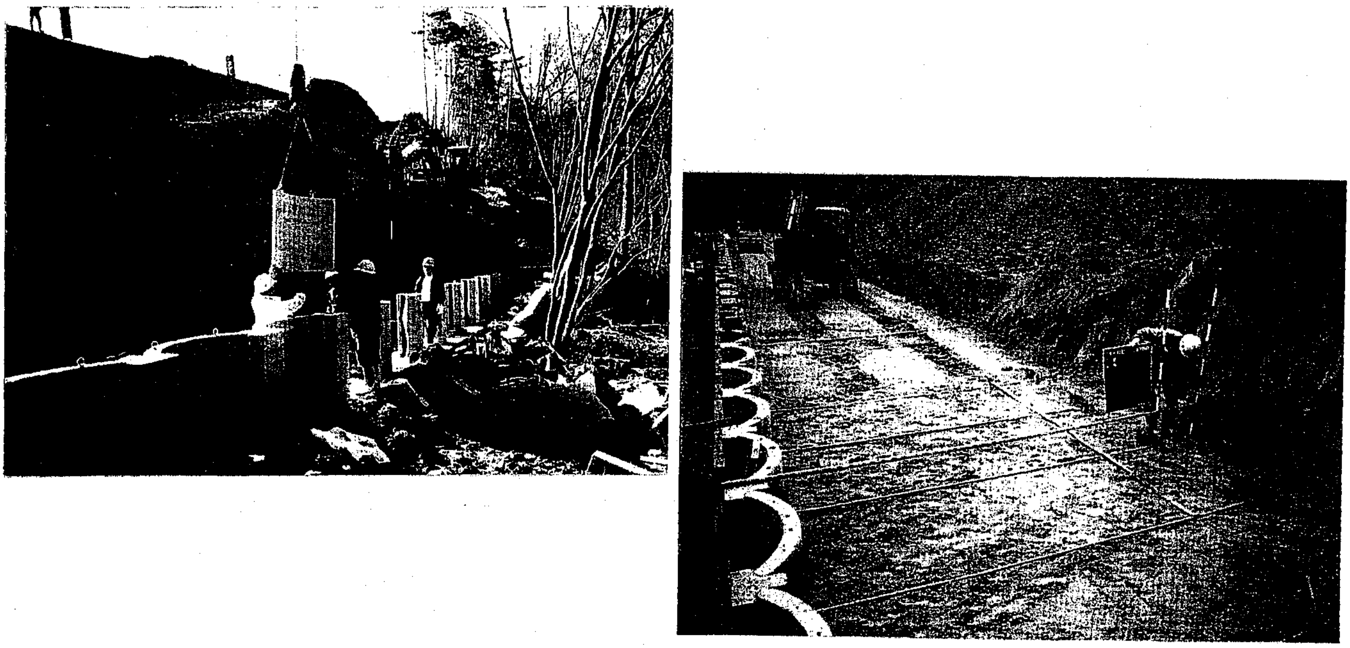

Photo 1 Setting of arch wall

4. Behavior of arch wall

A cross-sectional view of the arch wall construction and instrumentation of measuring system is illustrated in Figure 4. In order to study behavior of the wall during construction, stress transmission along tie rods was measured at every other rod, from 1st to 9th rod from the base concrete, by setting four strain gauges on a steel rod. The axial force T_i in the i-th rod is obtained by multiplying the measured strain ε_i by the Young's modulus E and the cross sectional area A_i of the rod, as $T_i=EA_i\varepsilon_i$. Also measured were the earth pressure at the face of the lowest wall segment, with a load cell, and the horizontal and vertical movement of the top point of each wall segment by surveying. Wall displacement was recorded in this time after construction of the 5-th wall segment.

Variations of the measured values with time of the axial forces in tie rods and those of horizontal and vertical displacement at the top of wall segments are presented in Figure 5, together with the time history of fill and wall construction. Tension is positive in the axial force, and settlement and lateral deflection towards the wall are taken as positive in the vertical and horizontal displacement, respectively. As mentioned above, wall displacement was measured after completion of the 5-th wall segment, and consequently displacement records at the 1-st through 5-th wall segments do not include deformation to be developed by self weight of the fill up to that level.

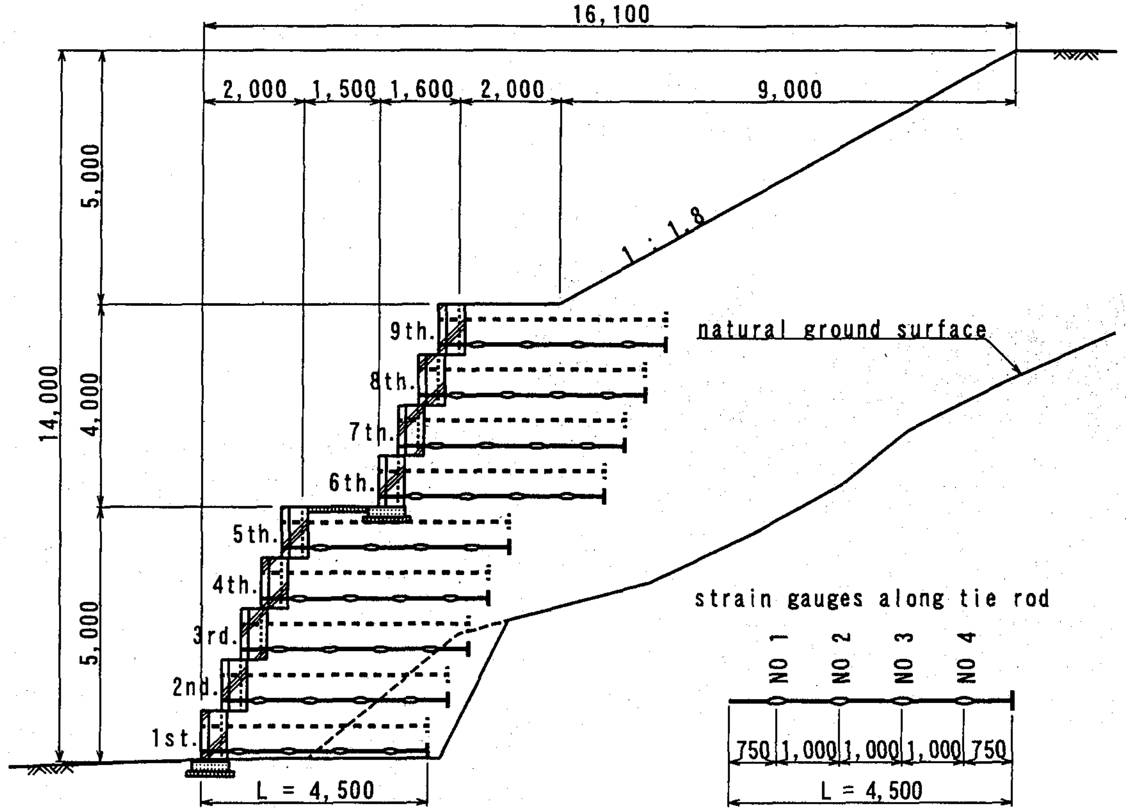

Figure 4 Cross sectional view of arch wall construction

At each tie rod in Figure 5(a), the axial forces measured at four points along the rod are compared with the value of the allowable axial force calculated in the design. It is recognized that most of the axial forces measured in tie rods vary in the range from 12% to 64% of the allowable value, except for the 6th rod where the ratio reached to 87%. In the 1st to 3rd rods, fluctuation of the axial force is characterized by an initial sharp increase after setting of the wall segment and a successive gradual decrease during fill placement. This is considered to be caused by local stress concentration produced by running of a heavy compaction roller, because these tie rods were buried in a narrow space cut off in the natural ground, as shown in Figure 4.

Distributions of the axial force along tie rods and displacement vectors of the points on the wall face are drawn in Figure 6 at three representative times of ①, ② and ③ indicated in Figure 5. It is seen that the measured values of the axial force on the whole show uniform distribution along a tie rod regardless of its location and the time elapsed. This suggests that the frictional resistance between a tie rod and the surrounding soil is negligible as assumed in the design and that the resisting force of an end anchor plate against pulling-out of tie rod is transmitted uniformly in the fill and is in a good balance with the earth pressure acting on the wall.

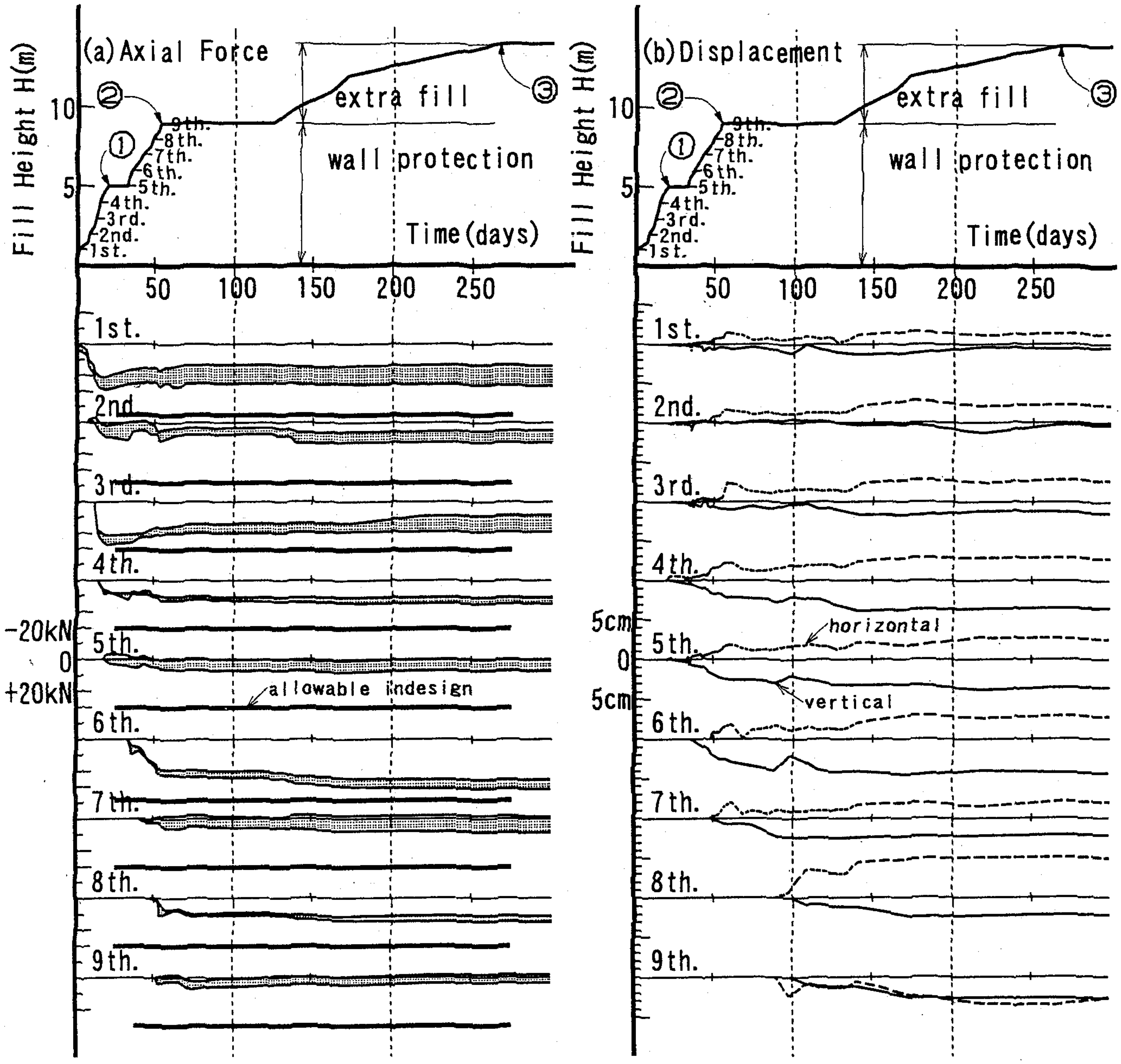

Figure 5 Time histories of wall behavior

Concerning deformation of the wall, the horizontal displacement is almost the same in magnitude in the lower part of the wall, from 1-st to 5-th segments, which signifies a uniform lateral deflection of the wall due to the overburden surcharge effect of the upper part of the fill. A rough indication of overturning movement of the wall is recognized in the upper part of the wall, rotating towards wall side with its axis at the toe. This assures, together with a uniform deformation of the lower wall, movement in a body of reinforced rigid wall as assumed in the design.

The measured values of the axial force in tie rods are compared at the time ③ with the calculated ones in Figure 7, where distributions of the latter T_i in the fill are drawn by use of Eqs.(1) and (2), taking material parameters as γ=20kN/m^3 and ϕ=30° (K_A=0.297), for two cases of wall height, H=5m and 9m. The reason why two cases are considered in the comparison is due to the fact that the arch wall was constructed not in a body but in major two parts with an intermediate comparatively wide berm. It is obvious in the lower

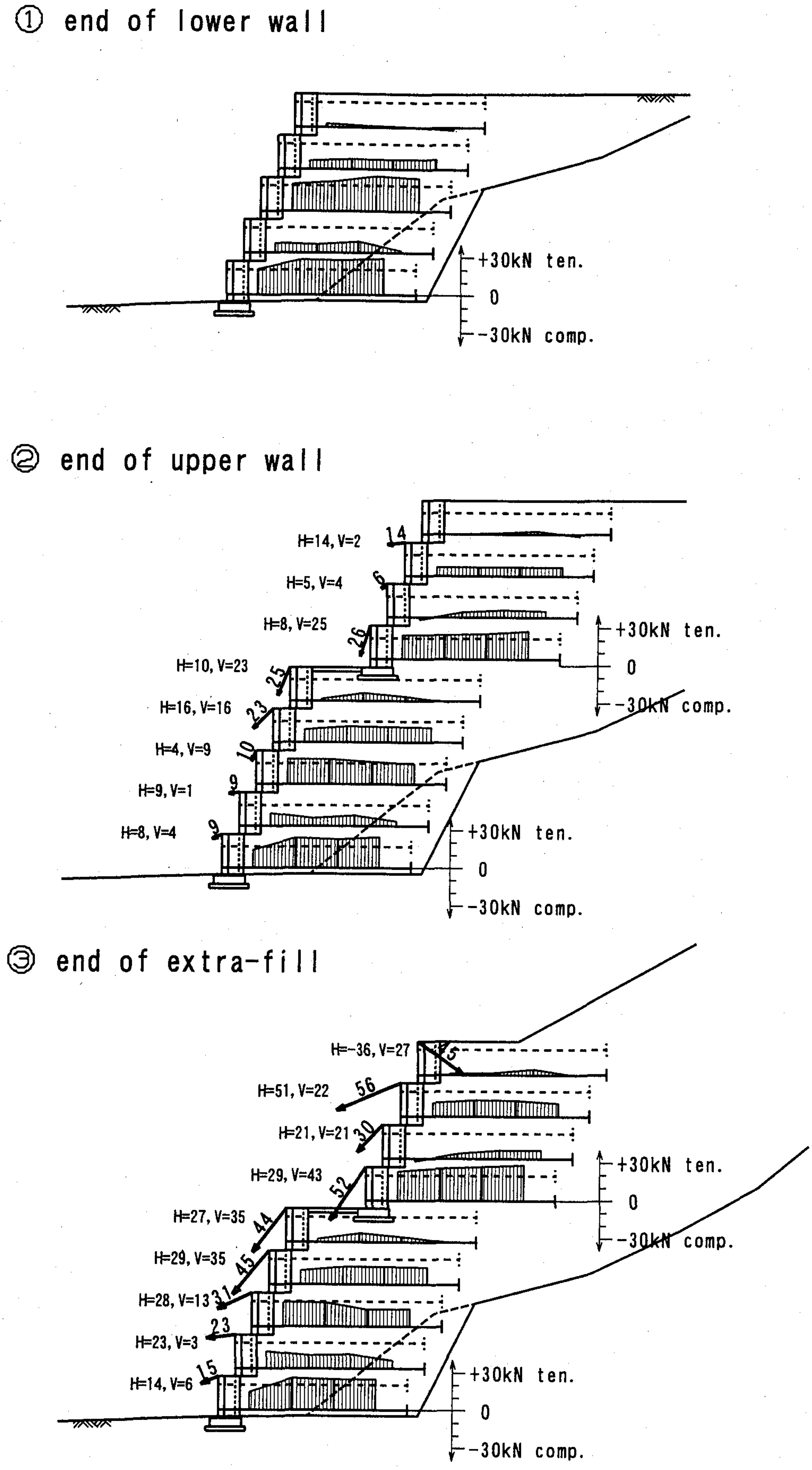

Figure 6 Tie rod axial force and wall movement

part of the wall, 1-st to 5-th tie rods, that the measured values are fairly small as compared to those calculated for the full height H=9m, but they are a little larger than those for the lower height H=5m. This is supposed to be caused by the fact that the weight of the upper fill could not be transmitted directly as an overburden load due to the presence of the wide berm on the crest of the lower fill. In the upper part of the wall, 6-th to 9-th tie rods, a roughly good correspondence is attained between the measured and calculated values, which suggests that Eqs. (1) and (2) can be used effectively in the evaluation of earth pressure and tie rod force in the design of such a discontinuous wall as the arch wall.

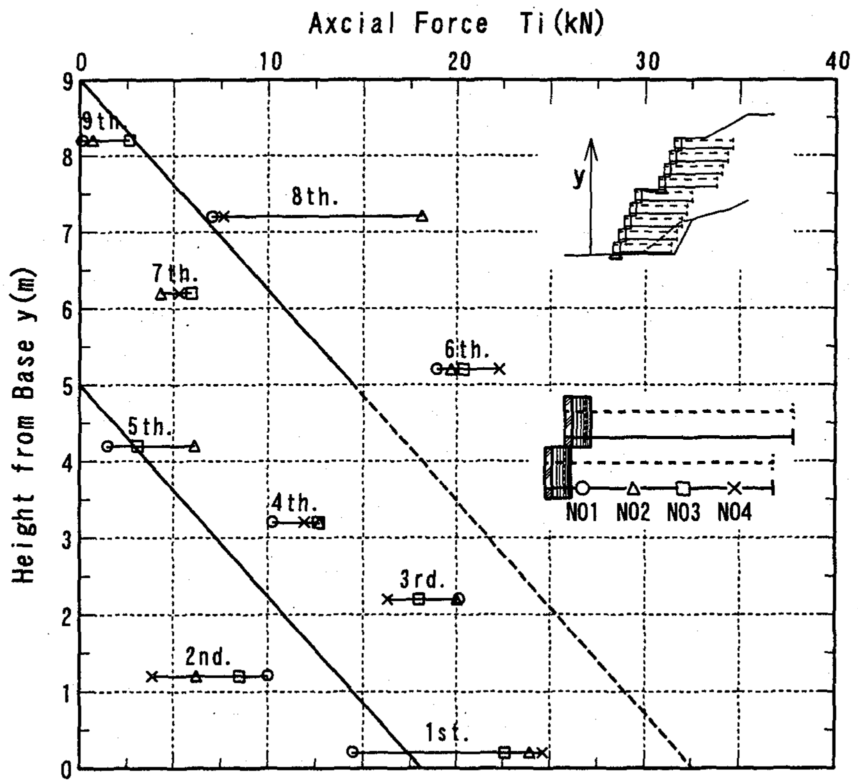

Figure 7 Comparison with design value

5. Conclusion

Concluding remarks drawn from the present study are summarized as follows;

1) Measurement of wall displacement in the field assured a movement in a rigid body of the reinforced wall as assumed in the design.

2) The axial force showed uniform distribution along a tie rod regardless of its location and the time elapsed, which suggests that the resisting anchor force against pulling-out of tie rod is in a good balance with the earth pressure acting on the wall.

3) A roughly good correspondence was attained between the measured and calculated values of the axial force in tie rods, which points out that the proposed design method of calculation is effective for such a discontinuous wall as the arch wall.

References

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