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Relation between wall displacement and reinforcement for reinforced retaining wall

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ABSTRACT: From previous studies and results of field tests by the authors, the allowable wall displacement for design of reinforced retaining walls was defined. In addition, two dimensional elasto-plastic FEM analyses for the prototype retaining wall with stiff reinforcement were carried out to determine the optimum reinforcement considering the allowable wall displacements.

1 INTRODUCTION

The current design methods for reinforced retaining wall being employed are based on the theory of rigid-plasticity that takes no account of wall displacement and deformation of reinforcing material in backfill. It does not correspond with a real phenomenon. For instance, Rowe et al. collected measured tensile forces of reinforcements of actual reinforced retaining walls and showed that the measured values of tensile forces in reinforcement are smaller than those by the current design when the wall is stable (Rowe & Ho, 1992).

To obtain a rational solution to this structure, it is needed to clarify the relations among the displacement of wall, the tensile force in reinforcement, the earth pressure acting on the wall, and the frictional force between reinforcement and soil. These relations were observed in the series of centrifuge model tests (Kawamura & Okabayashi, 1998a) and its simulation analysis (Kawamura & Okabayashi, 1998b). In these papers, it was recommended that the strain level of the backfill material had to be restricted, and that the wall displacement should be prescribed as the design parameter, to be able to determine the amount of the reinforcement rationally.

In this study, two dimensional FEM analyses were carried out for models by applying gravitational force. The relation between the wall displacement and the amount of optimum reinforcement will be discussed.

2 ALLOWABLE WALL DISPLACEMENT FOR THE RETAINING WALL REINFORCEMENT

The relationship between the wall height and the wall displacement of the reinforced retaining wall by the centrifuge model tests and actual measurements, are shown in Figure 1. The results of centrifuge model tests and the simulations are the values at failure and the others are the values when the walls are stable.

The data at the failure state were plotted for the centrifuge model tests and simulation analyses, in Figure 1, and the data at the construction works and immediately after the construction were plotted in the same figure. It is recommended that the wall displacement is limited within the wall displacement immediately after the construction to maintain the small stress level and the wall stability. The maximum wall displacement at failure is approximately H/60 and the wall displacement after construction is approximately H/150. Therefore, it seems that the safety factor is about 2.5.

H/150 is reasonable as the allowable wall displacement, as this number is a little bigger than the values by field measurement in 112 fields by Ogawa (Ogawa1993) and the other measured values are also within this range.

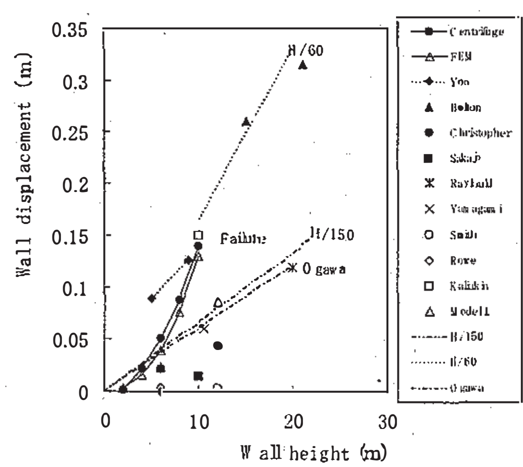

Figure 1. Wall height and wall displacement.

3 FEM ANALYSES FOR THE RITEINING WALL

Figure 2 shows an example of analytical model for model 4. In these analyses, it is assumed that the reinforcement and the facing are elastic, and the backfill is Elasto-plastic. In the elasto-plastic constitutive equation, plastic softening was considered. In plane strain analyses, the reinforcement was simulated as a continuous sheet with an equivalent thickness (rigidity equivalent). The self weight analyses by the backfill are performed. The material constants of the reinforced retaining wall are shown in Table 1.

Joint elements shown in Figure 3, between facing and soil, and between reinforcement and soil were employed for the discontinuity. Material constants of the joint elements are shown in Table 2. In Table 2, ψ is dilatancy angle, Ks is the shear modulus of rigidity (kPa), Kn is the normal modulus of rigidity (kPa), and ϕ is the angle of shear resistance. These properties were obtained by the FEM inverse analysis in which the Centrifuge model tests were simulated (Kawamura & Okabayashi, 1998). Figure 4 shows the cases to be studied, in which model 0 is unreinforced one. The heights of retaining wall, H, for each case are 6.0 and 12.0m. The length, L, of the reinforcement laid in the backfill varies in L/H, which are 0.1875, 0.375, 0.5625, and 0.75. The spacing, h, varies in h/H which are 0.125,0.25,0.33 and 0.5.

Figure 5 shows the calculated lateral displacement of the wall for each model. The lateral displacement of the wall decreases as length of the reinforcement becomes larger, and as the spacing of the reinforcement becomes smaller. The calculated maximum lateral displacement of the wall occurred at the middle height of the wall.

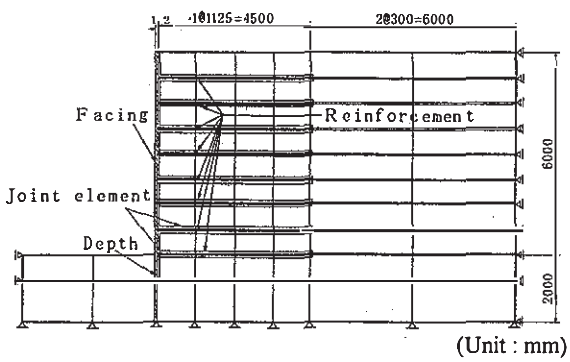

Figure 2. FEM model for model 4

Table 1. Material properties.

	Elastic Modulus E (kpa)	Poisson's Ratio ν	Unit weight γ (kN/m³)	C (kpa)	φ (°)
Wall face	2107000	0.2	23.52	—	—
Reinforcement	21600000	0.3	77.03	—	—
Backfill	19600	0.3	15.5	0	35

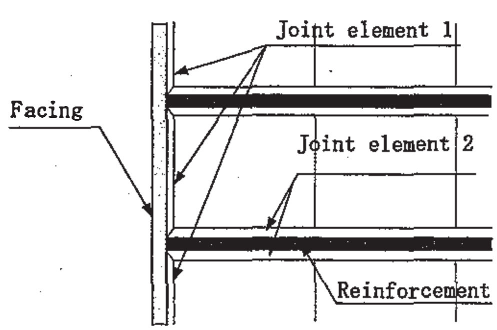

Figure 3. Place of joint element.

Table 2. Properties of joint element.

	Ks (kpa)	Kn (kpa)	φ (°)	ψ (°)
Facing/soil	100000	10000	10	10
Reinforcement/soil	100000	100000	10	10

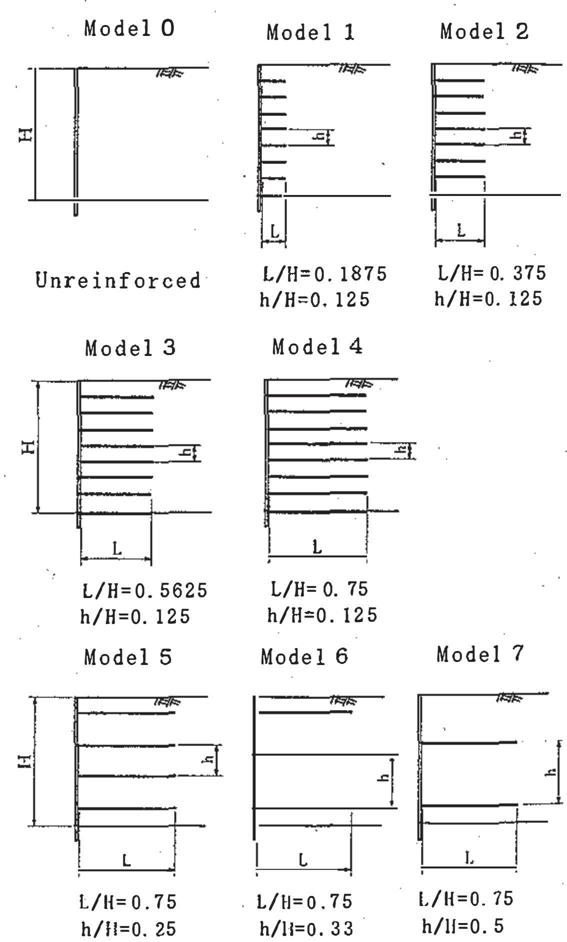

Figure 4. Models.

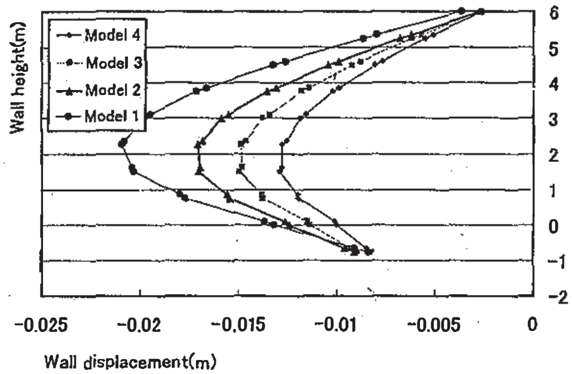

Figure 5. Wall displacement.

3.1 *Relation between the wall displacement and the length of the reinforcement.*

The maximum wall displacements resulted from the reinforcement in the case of h/H=0.125 are plotted in Figure 6, for the length of reinforcement in the backfill. The maximum wall displacement ,δ_{max}, and the length of reinforcement L, are nondimensionalized by the wall height. In this figure the dotted line indicates the allowable wall displacement.

The relation between the maximum wall displacement and the length of reinforcement is like a hyperbola and the maximum wall displacement decrease, as the length of reinforcement becomes larger. And the values of maximum wall displacement vary by the difference of the wall height. From Figure 6 all calculated values are within the allowable displacement incase of H=6m, and it is understandable that all cases require the longer reinforcement than Model 2 in case of H=12m.

3.2 *Relation between the wall displacement and spacing of reinforcement*

Figure 7 shows the relation between the dimensionless maximum wall displacement, δ_{max}/H, and the dimensionless spacing of reinforcement, h/H, in the case of L/H=0.75.

The dimensionless maximum wall displacement by the reinforcement of backfill becomes larger as the spacing becomes larger. And the values of maximum wall displacement changed according to the wall height. From Figure 7, all calculated values are within the allowable displacement incase of H=6m, and it is understandable that making the spacing of reinforcement closer than Model 6 in case of H=12m.

3.3 *Relation between the reduction ratio of the earth pressure and the length of the reinforcement.*

The reduction of earth pressure resulted from the reinforcement are evaluated by reduction ratio, which is proposed by (Ogisako et al., 1988). The reduction ratio of the earth pressure, *Rp*, is expressed by the following equation

$$Rp = 1 - Pg / P_0 \qquad (1)$$

in which P_0 is resultant force of Rankin's active earth pressure acting on the wall in the unreinforced earth structure, and *Pg* is that of earth pressure resulted from the analysis with reinforced soil backfill, as shown in Figure 8.

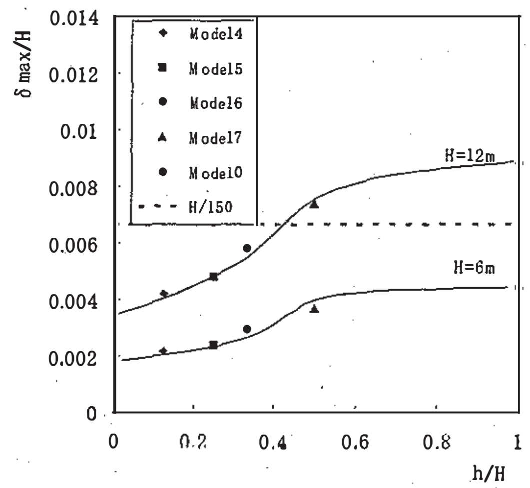

Figure 6. Wall displacement and length of reinforcement.

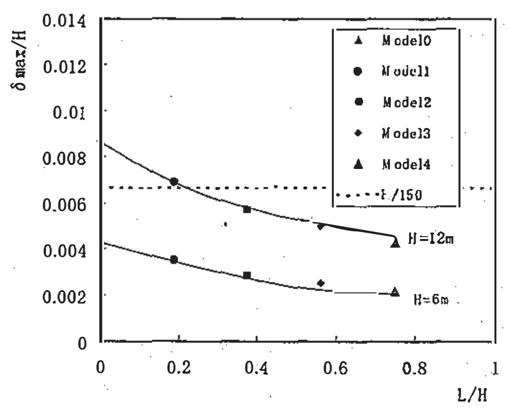

Figure 7. Wall displacement and spacing of reinforcement.

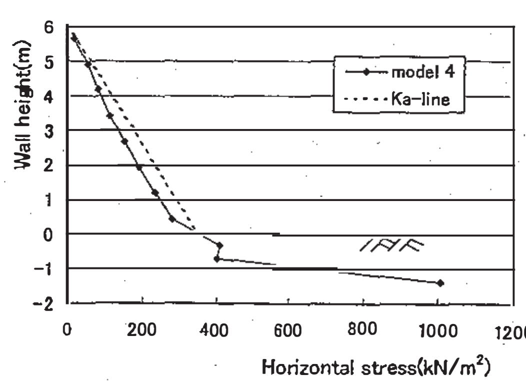

Figure 8. Reduction of earth pressure (h/H=0.125).

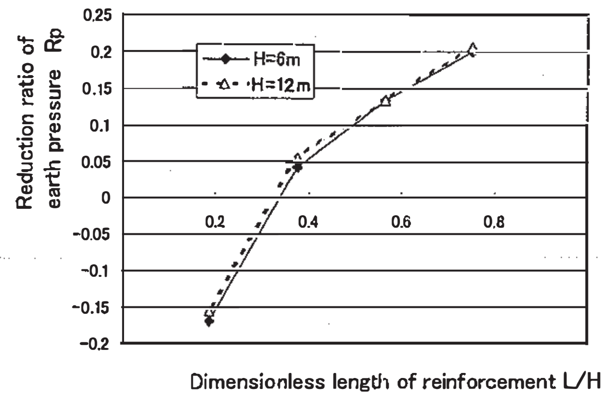

Figure 9. Reduction ratio and L/H (h/H=0.125).

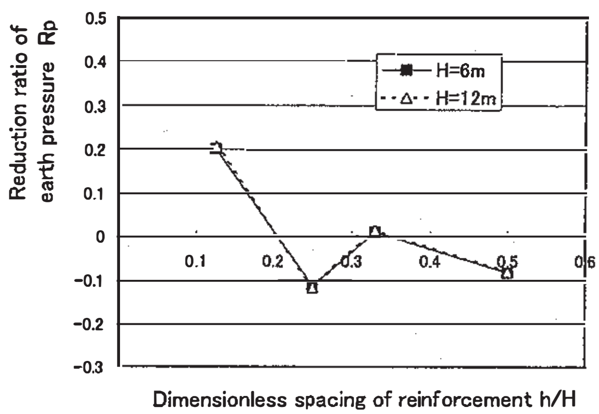

Figure 10. Reduction ratio and h/H (L/H=0.75).

Reduction of earth pressures resulted from the reinforcement in the case of h/H=0.125 are plotted against the dimensionless length of the reinforcement in the backfill in Figure 9. The reduction ratio of the earth pressures decreases gradually as the length become larger, and the reduction ratio of the earth pressure has the almost same values of the wall height independently.

3.4 *Relation between the reduction ratio of the earth pressure and spacing of reinforcement*

Figure 10 shows the relation between the reduction ratio of earth pressure and dimensionless spacing of the reinforcement in the case of L/H=0.75. The reduction ratio of the earth pressure decreases rapidly as the spacing becomes larger, and the reduction ratio of the earth pressure has the almost same values independently of the wall height.

In case of dimensionless spacing of the reinforcement h/ H=0.25, the reduction ratio of earth pressure becomes negative. It can be supposed that the increment of earth pressure due to the reduction of wall displacement is larger than that of the earth pressure reduced by the reinforcement.

From these results the earth pressure acting on the wall is changed according to the condition of the wall deformation, and tensile force acting on the reinforcement.

4 CONCLUSION

As the results, the followings were made clear.

1. From the results of author's model tests, FEM analyses, field tests and prototype experiments with regard to the displacement of a reinforced retaining wall, H/150 is considered as an allowable displacement for a stable state.
2. The dimensionless maximum wall displacement by the reinforcement of backfill decrease, as the length of reinforcement becomes larger. And it becomes larger as the spacing becomes larger.
3. The values of maximum wall displacement changes different due to the difference of the wall height.
4. The reduction ratio of the earth pressure decreases gradually as the Length becomes larger. And it decreases as the spacing becomes larger.
5. The reduction ratio of the earth pressure has the almost same values independently of the wall height.
6. In this paper, the deformation due to self weight of the backfill was analyzed. The consideration of the surcharge and other external lodes and the verification by experiment are necessary.

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