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Subgrade reaction of Reinforced Earth Wall underneath the facing panel

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ABSTRACT: Typical facing elements of the Reinforced Earth Wall include the use of steel strip reinforcements, steel plate materials, and concrete or steel rod grid panels. The erection of facing components made of steel plate materials or steel rod grid panels may not require concrete foundation. However, the concrete facing panels require a concrete foundation pad to facilitate proper placement of concrete panels and distribute the vertical loads from facing to subgrade soil. Flexible joint materials are installed to allow movements of concrete facing to follow settlement of backfill soil. Some measurement results show that subgrade reaction in the foundation is larger than facing panel weight. Subgrade reaction is used for assessing external stability such as bearing or tilt failure mechanisms. This paper presents a statistical study based on full-scale model tests and some measurements in actual structures. A relationship between subgrade reaction and tensile force in reinforcements has been obtained.

1 INTRODUCTION

Reinforced Earth Walls consist of granular soil, soil reinforcing elements and facing materials. Typical facing elements are made of reinforced concrete panels. Some type of facing elements made of steel plate materials or steel rod grid panels. In these cases, the erection of facing components may not require concrete foundation. The facing elements cannot support vertical loads given that steel plate and a steel grid system behaves as flexible components.

The other hand, the concrete facing panels require a concrete foundation pad to facilitate proper placement of concrete panels and distribute the vertical loads from facing to subgrade soil. A construction procedure using concrete panels is following steps. First, concrete foundation pad is placed. Usual size of foundation is 0.4 m widths and 0.2 m heights.

Concrete facing panels are set on a foundation pad, then backfill is spread and compacted in lifts up to level of strip connecting layer. And reinforcing strips are connected to facing panels with the bolt. It is repeated a cycle of filling and compacting of backfill, connecting strips, setting panels until design height is reached.

Wall surface is divided structure, and flexible joint materials are installed to prevent concrete-to-concrete contact between the concrete facing elements. Therefore, these constitutions allow movements of concrete facing to follow settlement of backfill soil.

It was known that some measuring results of the vertical loads from facing are bigger than self-weight of facing panels. It is important to estimate subgrade reaction of a foundation pad for assessment of external stability such as bearing or tilt failure mechanisms.

Design method of Reinforced Earth wall consists of rupture analysis of soil reinforcement and pull out resistance from embankment of soil reinforcement. And, it is calculated against estimated tensile force of soil reinforcement.

However, this design method is not necessary to estimate reaction underneath facing panels or concrete foundation pad. In conventional design method of Gravity Retaining Wall, subgrade reaction of wall calculates from vertical earth pressure along wall surface, obtain by multiplying horizontal earth pressure by angle of wall friction.

In case of Reinforced Earth Wall, we assume that the horizontal earth pressure may calculate from tensile force of soil reinforcement near the facing panel. Some measurement data of subgrade reaction and of soil reinforcement tensile force, available on 4 structures, which are an actual wall or experimental walls. It is shown below as relation between subgrade reaction and tensile force of reinforcement.

2 GENERAL MEASURING RESULT

The profile of 4 structures with the measurement results of subgrade reaction and tensile force in reinforcing strips is shown. The characteristic of backfill material, which is used for each structure, is shown in Table 1 and the overview of facing panel is shown in Table 2.

Table 1. Characteristic of backfill material.

Name of Fill Material		Field Test(1)	Field Test(2)	Field Test(3)	Load Test	Shaking test	Moving test
Soil particles	Gs	2.737	NA	2.706	3.648	2.721	NA
Grain Size	Gravel (%)	66.8	67.7	55.9	0	0	0
Distribution*	Sand (%)	25.8	20.8	26.3	98.3	81.0	91.6
	Silt (%) } Clay (%)	7.4	11.5	17.8	1.7	15.0	5.4
	Clay (%)					4.0	3.0
Shear Strength	Cohesion (kN/m^2)	NA	NA	NA	Cd=0	C'=0	Cd=2.0
	Angle of shear resistance (deg)	NA	NA	NA	φd=36.6	φ'=34.4	φd=37.8
Construction	Unit weight γt (kN/m^3)		20.2 (Average)		17.5 (Average)	13.4	15.5 (Average)
	Water content w (%)		NA		3.6	4.3	3.4

* Gravel (2–75 mm), Sand (75 μm–2 mm), Silt (5–75 μm) (%), Clay (<5 μm) (%)

Table 2. Type of facing panel.

Type	Nominal dimension (m)	Weight (kg)
Thick type	1.5 × 1.5 × 0.18	950
Thin type	1.5 × 1.5 × 0.1	650
	1.5 × 1.5 × 0.13	750
Small type	1.0 × 1.0 × 0.11	270

2.1 *Field measurement*

This field measurement in an actual wall (Height is 12.75 m) is executed to survey the behavior of the structure, which used thin panels (thickness 0.1 m/0.13 m) or thick panels (thickness 0.18 m). And it compared the difference of the effect for the behavior between using thin panels and using thick panels.

The cross-section is as shown in Figure 1. As for the backfill material, "Field test(1)" is used for the range from the base to 5.25 m high, "Field test(2)" is used for the range from 5.25 m high to 9.75 m high, and "Field test(3)" is used for the range from 9.75 m high to 12.75 m high. Load cell is installed underneath the concrete facing panel at the concrete foundation pad for measuring subgrade reaction. And tensile force in reinforcement strips were measured at behind a wall of all facing panels, above a load cell.

Figure 2 shows the relation between the height of the fill and the subgrade reaction during fill process. The measurement results up to 12.15 m fill height is shown. The subgrade reaction is assumed in which the weight of the facing panel is subtracted from the measurement result with the load call. And it shows as a load for 1 m along wall.

As for the gradient of an increase between subgrade reaction and fill height, thin type panels and thick type panels are the same until 8 m high. But in the thick type, increase of subgrade reaction is less than thin type panels from 8 m high. On the other hand, subgrade reaction of thin type increases in linear with fill height.

Relation with the total tensile force of reinforcing strips and subgrade reaction is shown in Figure 3. As for tensile force of reinforcing strips at the same subgrade reaction, both thick type panels and thin type panels are approximately the same. For maximum value of subgrade reaction, in case of thick type panels, subgrade reaction is 52kN/m and tensile force of reinforcing strips is 138 kN/m. In case of thin type, subgrade reaction is 138 kN/m and tensile force of reinforcing strips is 95 kN/m.

2.2 *Loading test*

The loading test is conducted to understand a behavior of Reinforced Earth wall when the high load surcharge at the wall top of the experimental wall.

The cross-section is as shown in Figure 4. In CASE1 and CASE3, vertical distance between all reinforcements layers is 0.5m. On the other hand, in CASE2, reinforcing strips install 0.25 m in the vertical interval from the top of wall to 1 m depth. A small type is used for the facing panels.

As backfill procedure in CASE2 and CASE3, after completion of load test CASE1, once backfill material is removed from the top of wall to a depth of 2 m, and then reconstruct a experimental wall for next case. As surcharge procedure, the load beam is set on the top of the wall, then the load beam is loaded using a hydraulic jack. In CASE1 and CASE2, a maximum surcharge load is 500 kN/m2, although it is loaded until 1200 kN/m2 in CASE3.

For the filling process, relation with fill height and subgrade reaction is shown in Figure 5. The calculation of subgrade reaction is the same as section "2.1 Field measurement". The subgrade reaction with an increase of fill height is increasing in a linear relation at any

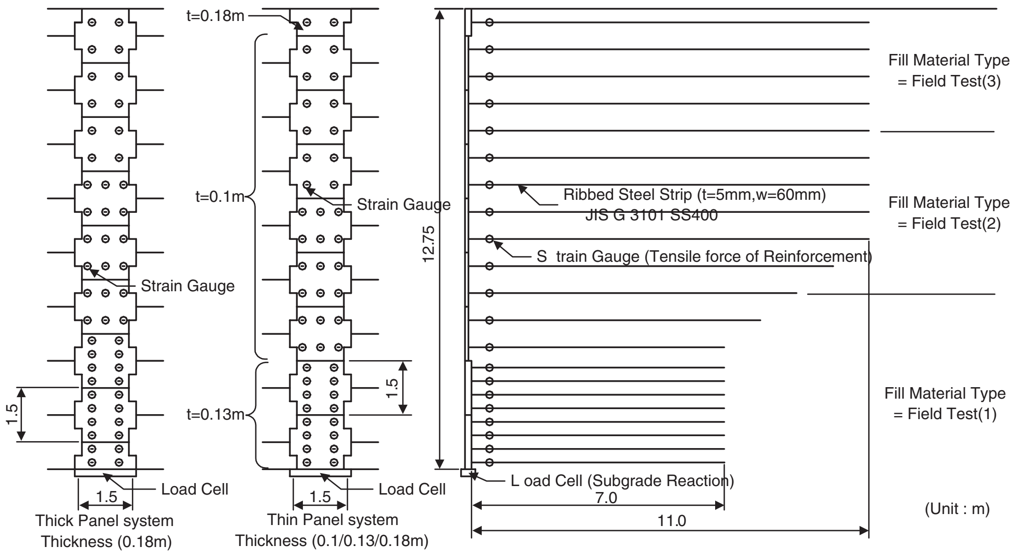

Figure 1. Cross section of actual wall for field measurement.

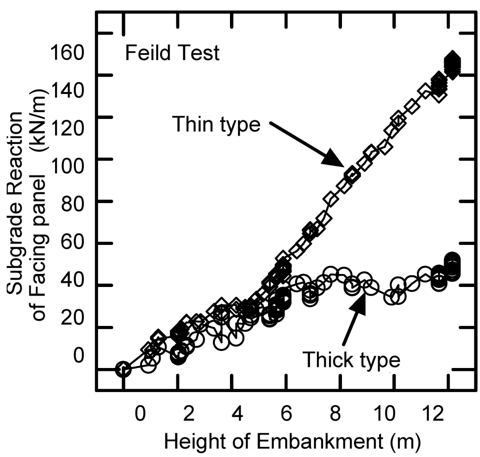

Figure 2. Subgrade reaction versus fill height.

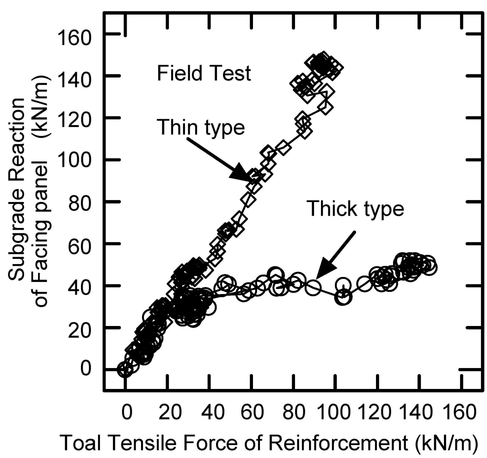

Figure 3. Subgrade reaction versus tensile force.

cases. Relation with the total tensile force of soil reinforcement and subgrade reaction is shown in Figure 6. It shows a direct proportional relationship. For maximum value of subgrade reaction, in CASE1, subgrade reaction is 11 kN/m and tensile force of reinforcing strips is 37 kN/m. In CASE2, subgrade reaction is 12 kN/m and tensile force of reinforcing strips is 39 kN/m. In CASE3, subgrade reaction is 13 kN/m and tensile force of reinforcing strips is 36 kN/m.

As the result of the Loading process, the relationship between a surcharge load and subgrade reaction is shown in Figure 7, and the relation between subgrade reaction and tensile force of reinforcing strips is shown in Figure 8. Data of subgrade reaction and tensile force of strips shows as incremental load during the loading process.

In CASE1, when a surcharge load is 507 kN/m^2, subgrade reaction is 70 kN/m and tensile force of reinforcing strips is 193 kN/m. In CASE2, when a surcharge load is 499 kN/m^2, subgrade reaction is 82 kN/m and tensile force of reinforcing strips is 200 kN/m. The tensile force of reinforcement is measured up to roughly 1000 kN/m^2 in CASE3. When a surcharge load is 450 kN/m^2, subgrade reaction is

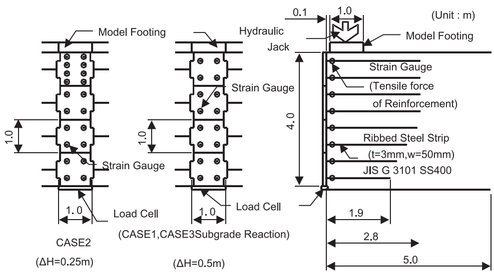

Figure 4. Cross section of experimental wall for load test.

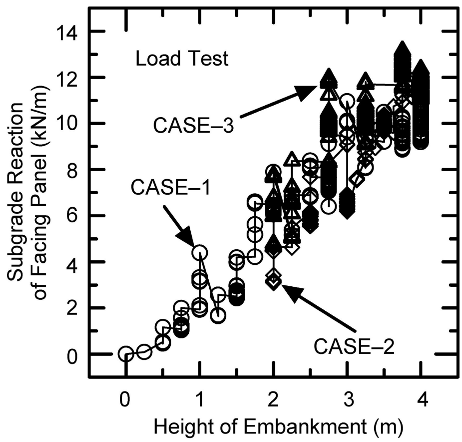

Figure 5. Subgrade reaction versus fill height.

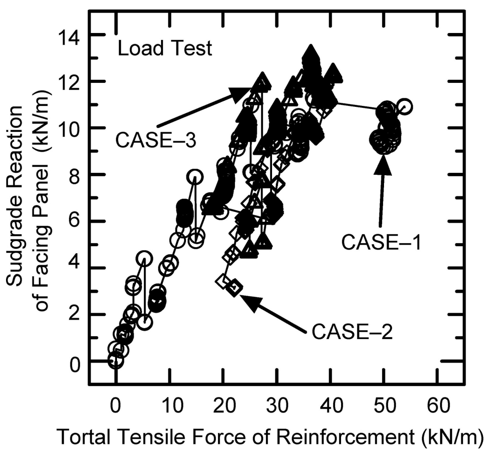

Figure 6. Subgrade reaction versus tensile force.

77 kN/m and tensile force of reinforcing strips is 182 kN/m. and when a surcharge load is 1045 kN/m^2, subgrade reaction is 260 kN/m and tensile force of reinforcing strips is 567 kN/m.

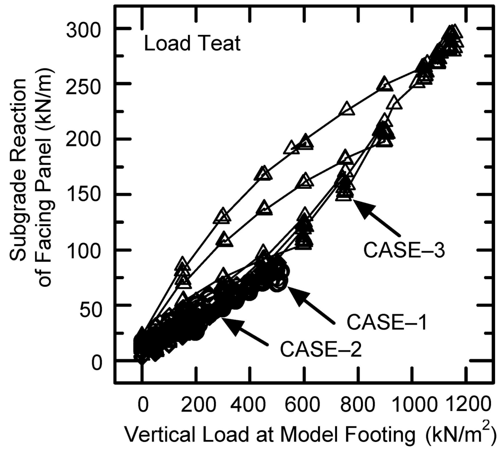

Figure 7. Subgrade reaction versus surcharge load.

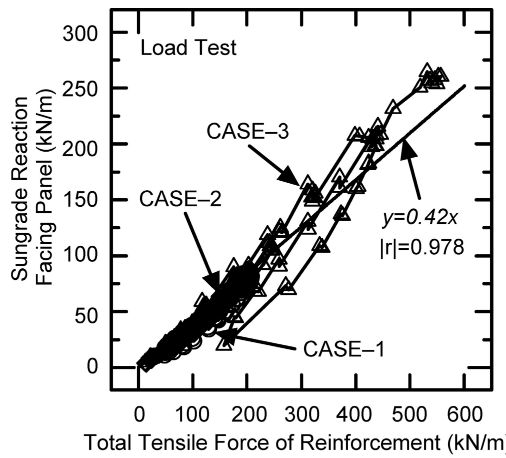

Figure 8. Subgrade reaction versus tensile force.

In Figure 7, which shows relation of a surcharge load and subgrade reaction, the inclination of subgrade reaction is changing in roughly 600 kN/m^2 in a surcharge load.

The other hand, the relation between subgrade reaction and tensile force of reinforcement are an approximately direct proportional relationship in Figure 8. And, a regression equation is estimated "$y = 0.42x$" in linear expression.

2.3 *Shaking test*

This experiment[1] is executed to understand a behavior of Reinforced Earth wall during an earthquake. But in this paper, only the result of the filling process is shown. The cross-section is shown in Figure 9. The facing panel is used thick type panels. Relation with

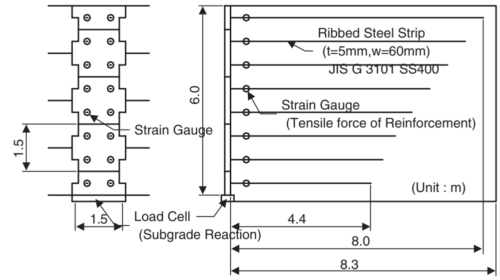

Figure 9. Cross section of experimental wall for shaking test.

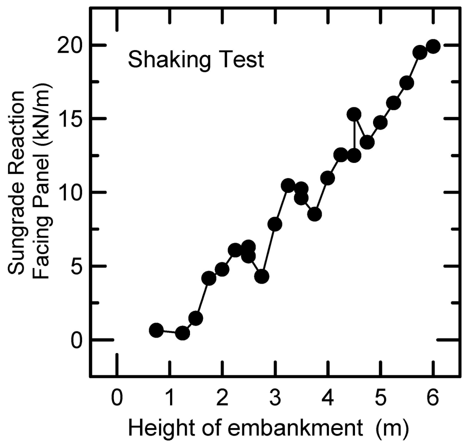

Figure 10. Subgrade reaction versus fill height.

fill height and the subgrade reaction is shown in Figure 10. The subgrade reaction is calculated also the same as case of "2.1 Field measurement". The subgrade reaction is increasing almost linearly with the increase in fill height. Relation with the total tensile force of reinforcing strips and subgrade reaction is shown in Figure 11. It shows also a direct proportional relationship. When subgrade reaction indicates maximum value, subgrade reaction is 20 kN/m and tensile force of reinforcing strips is 65 kN/m.

2.4 *Moving test*

This Moving test is conducted to make out of behavior of Reinforced Earth wall with footing foundation, when footing moved laterally due to its active earth pressure. It is assumed that failure mechanism is sliding mode. The procedure of the footing movement is to gradually loosen the support member, which set at a front of a footing, then a footing foundation move to front of a wall by itself. The cross-section is shown in Figure 12.

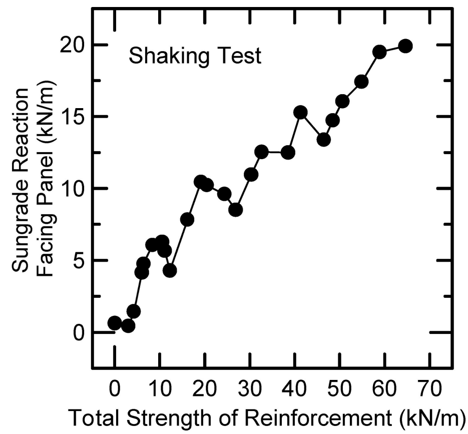

Figure 11. Subgrade reaction versus tensile force.

In CASE1, reinforcement material length is arranged 4 m at all layers to cross an assumed active failure surface, which occurs from the bottom of footing foundation. As for CASE2, the length of reinforcing strips is arranged to be in inside of an assumed failure surface. The load cell measured the vertical load underneath facing panels in 3m of wall-developed length. The measuring position of tensile force is indicated mark "o" in Figure 12. We assume that measured data is representative tensile force in the area with 3.0 m width and 1.0 m heights. Therefore, total tensile force of reinforcing strips is calculated by measured data, which multiplies 12 in this area.

Relation with fill height and the subgrade reaction is shown in Figure 13. The subgrade reaction is estimated by the same way as "2.1 Field measurement". The subgrade reaction increases direct proportional relationship with an increase of fill height. Relation with the total tensile force reinforcing strips and subgrade reaction is shown in Figure 14. It shows also a direct proportional relationship. Tensile force of reinforcing strips in CASE2 is smaller than CASE1 in same subgrade reaction. When the peak value of subgrade reaction is indicated 19 kN/m, tensile force of reinforcing strips is 39 kN/m in CASE1.

In CASE2, when the maximum value of subgrade reaction is indicated 22 kN/m, tensile force of reinforcing strips is 26 kN/m.

Relation with the displacement of the footing foundation and subgrade reaction is shown in Figure 16. Subgrade reaction is almost same up to 20 mm in CASE1 and CASE2. The footing does not move in CASE1 by 18 mm or more, and subgrade reaction is 4.5 kN/m at this point. In CASE2, when the displacement of footing is 15 mm, subgrade reaction indicates 5.9 kN/m. and when the final displacement is 50 mm, subgrade reaction become 11.5 kN/m. Figure 16 shows

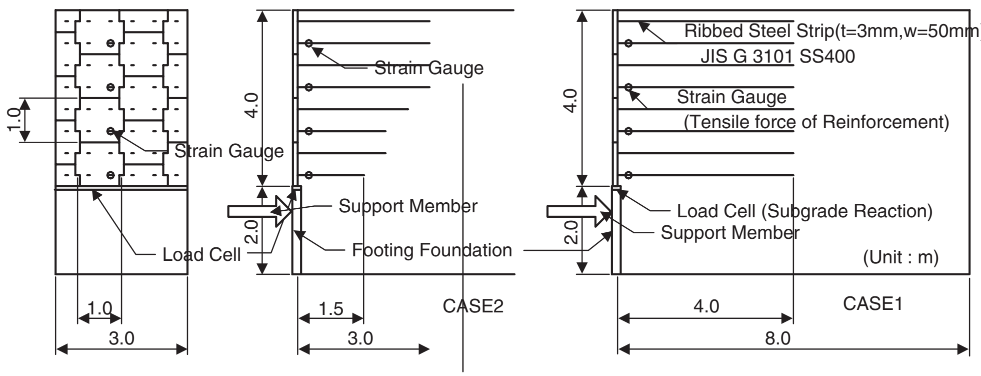

Figure 12. Cross section of experimental wall for moving test.

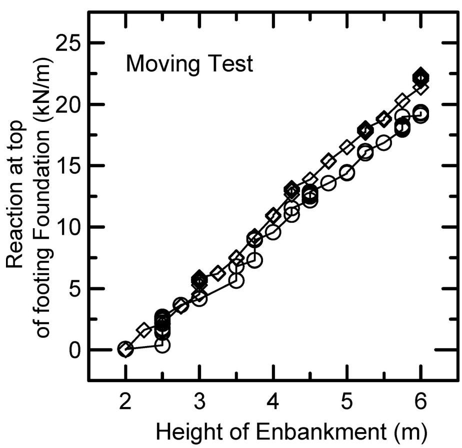

Figure 13. Subgrade reaction versus fill height.

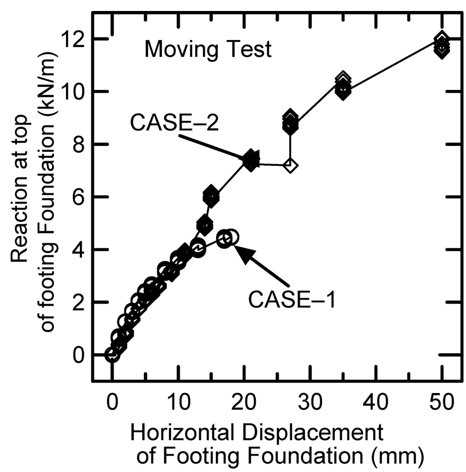

Figure 15. Subgrade reaction versus footing displacement.

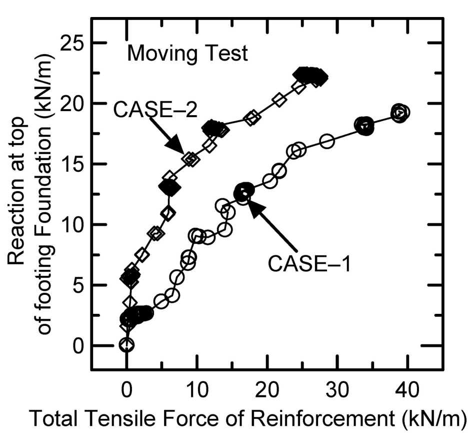

Figure 14. Subgrade Reaction versus Tensile Force.

the relation between the subgrade reaction and the reinforcement tension. In CASE1, the subgrade reaction increases linearly with the tension of reinforcement.

And, a regression equation is estimated "$y = 0.11x$" in linear expression in Figure 16. But, in Case 2, subgrade reaction increases though tensile force of reinforcing hardly increases.

3 RELATION BETWEEN SUBGRADE REACTION AND TENSILE FORCE

The relation between the reinforcement tension and the subgrade reaction is shown in Figure 17 with all data of fill process. When there is measurement data of same fill height, the first measured data is adopted in this graph. The subgrade reaction is proportional relation with a sum of tension of reinforcement. But, it varies

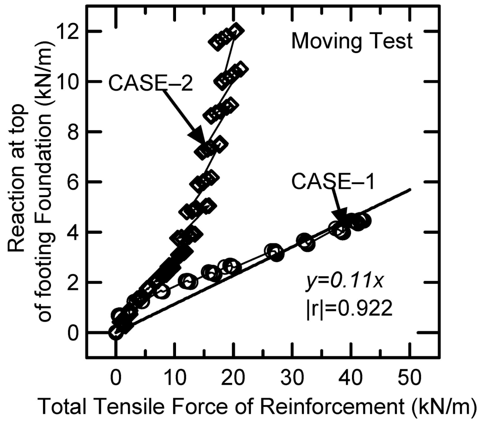

Figure 16. Subgrade reaction versus tensile force.

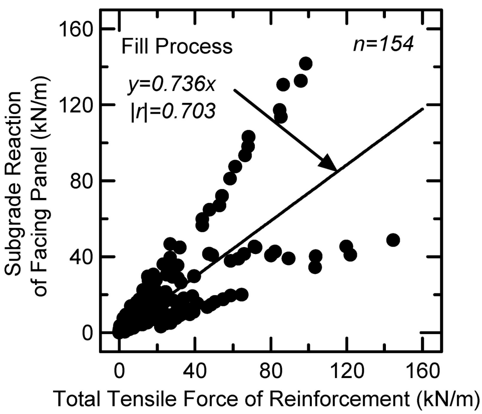

Figure 17. Subgrade reaction versus tensile force.

widely. A regression equation is estimated "y = 0.62x" in linear expression with the use of all data. Therefore, it is calculated that the angle of wall friction is $\delta = 32$(deg), using relation between tensile force of reinforcement and reaction. However, some date indicate that subgrade reaction becomes bigger than the tensile force of the reinforcement. Inclination of regression line is in range from 0.3 to 1.4. At this point, it calculated lateral earth pressure using the formula of Coulomb's active earth pressure with the assumption that the angle of wall friction is $\delta = 0$(deg). Comparison of earth pressure and tensile force is shown in

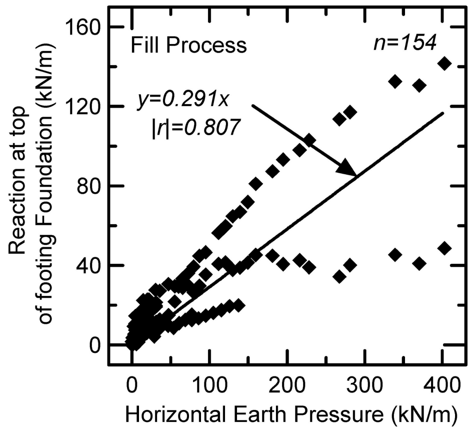

Figure 18. Subgrade reaction versus lateral earth pressure.

Figure 18. At this time, data about the angle of shear resistance is not obtained in the field measurement therefore we assume $\varphi = 35$(deg). With the average, it becomes 0.27 times of the horizontal earth pressure.

4 CONCLUSIONS

1 Subgrade reaction becomes by 0.62 times of the total tensile force of reinforcing strips in a filling process.
2 Subgrade reaction becomes by 0.27 times and the total tensile force of reinforcing strips is 0.44 times the design earth pressure to use Coulomb's earth pressure.
3 The total tensile force of reinforcing strips and the vertical load on a foundation pad has a relation. And tensile force of reinforcing strips and the lateral earth pressure has a relationship too. Therefore it is possible to estimate subgrade reaction from the design earth pressure.

REFERENCES

Futaki, M., Ogawa, N., Sato, M., Kumada, T., and Natsume, S. (1996). "Experiments about Seismic performance of Reinforced Earth Retaining Wall." *Proceedings of Eleventh World Conference on Earthquake Engineering,* ElsevierScience, Ltd. (CD-ROM)