EARTHQUAKE BEHAVIOR OF CONCRETE-BLOCK RETAINING WALL AND EFFECT OF SIMPLE REINFORCEMENT METHOD

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SUMMARY:

This paper presents the shaking table test of real scale concrete-block retaining wall for the confirmation of behavior at earthquake and a development of the simple reinforcement method. The test specimen made fill-up ground in the steel box (6x3x2.5m), piled up the concrete-block (strength 18N/mm^2, hexahedron 400x350x250mm), and made the retaining wall. In the experiment, Case1 is the dry masonry of un-coursed. Case2 is the wet masonry of un-coursed. Case3 is the dry masonry of coursed. Case4 is the simple reinforced dry masonry of coursed (a connecting each concrete-block surface by a sheet iron (t=3mm,w=50mm)). In each case, an earthquake excitation with 100gals～1000gals and a random excitation with 20gals peak acceleration were carried out. The earthquake behavior of the test specimen was different according to the difference of the integrity of the retaining wall. The wet masonry concrete-block retaining wall showed the solid body behavior by having been integrated by concrete. The simple reinforcement concrete-block retaining wall confirmed no collapse even if it transformed by reinforcement.

Keywords: Shaking table testing, Full-scale, Retaining wall, Reinforcement method, Dynamic behavior

1. INTRODUCTION

In the earthquake of Japan, the damage of an old masonry retaining wall and an old concrete block retaining wall is reported. It is important to understand the behavior at earthquake of the retaining wall where the earthquake-resistant is not clear in devising the method of the seismic retrofit and the reinforcement method of the retaining wall. When an old masonry retaining wall and an old concrete block retaining wall are reinforced, it becomes restructuring. However, bearing of costs is large, and because it also takes time, it is not easily enforceable. In this report, it reports on the outline of real scale shaking table test executed of the dry masonry retaining wall. The research purpose is a grasp of the behavior at earthquake of the retaining wall and a confirmation of the reinforced effect of a simple reinforcement method. The dry masonry retaining wall and the wet masonry retaining wall and the simple reinforcement dry masonry retaining wall were used for the experiment.

2. OUTLINE OF EXPERIMENT

Fill-up ground was made in the steel box, the retaining wall concrete-block was piled up, and the test specimen was made. Externals of the retaining wall concrete-block (design strength 18N/mm^2, 400x350x250mm: width, depth, and height) used to experiment and the steel box (6x3x2.5m: width, depth, and height) are shown in Photo1. The outline of the surface of the retaining wall of the test specimen is shown in Fig.1. The experiment was executed to four kinds of test specimens. Table 1 shows the test specimen list.

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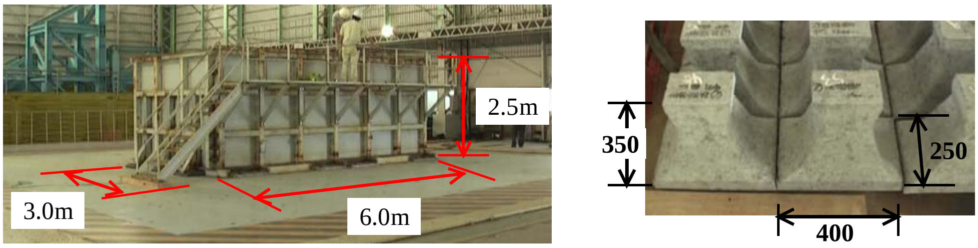
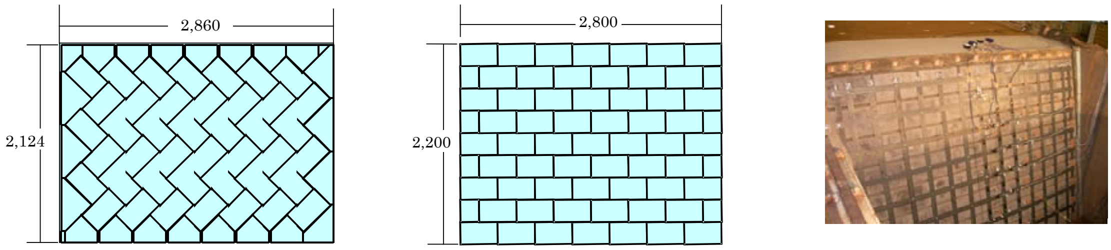


Steel Box Concrete-block

Photo1 Outline of steel box and concrete-block



Un-coursed masonry Coursed masonry Simply reinforced masonry

Fig.1 Outline of retaining wall surface

Table1 List of specimen

Test Case	Type	
Case1	Un-coursed Masonry	Dry Masonry
Case2		Wet Masonry
Case3	Coursed Masonry	Dry Masonry
Case4		Simple Reinforced Dry Masonry

Case1 is the dry masonry retaining wall of un-coursed masonry (the retaining wall block was only piled up). Case2 is the wet masonry retaining wall of un-coursed masonry (the back of the retaining wall was integrated by concrete). Case3 is the dry masonry retaining wall of coursed masonry (the retaining wall block was only piled up). Case4 is the simply reinforced dry masonry retaining wall of coursed masonry.

In the simply reinforcement method of Case4, the method of connecting each retaining wall concrete-block with iron plate (w=50mm,t=3mm) for reinforcement with the bolt was used. The anchor for fixation was set the center of retaining wall concrete-block, and after the retaining wall had been made, the iron plate for reinforcement was connected with the retaining wall concrete-block with the bolt.

The Edosaki sand (natural water content 14.1% and densities 2.69g/cm^3 of the soil particle) was used for the material of fill-up ground. Fig.2 shows the grain size distribution curve of the Edosaki sand. Fill-up ground was made by compaction of which five times were the frequencies of the compaction. A further thickness was assumed to be 25cm. The non-woven fabric made of the polypropylene was set up on the steel box frame side for the friction reduction of the earth tank frame side and fill-up ground. Because neither the inside measurement size nor the size of the retaining wall of the earth tank were completely corresponding, the non-woven fabric the styrene foam and made of the polypropylene was set up in the space between the retaining wall and the steel box. The horizontal angle degree of the retaining wall was about 70 degrees in Case1&Case2, and about 68 degrees in Case3&Case4.

The outline of the measurement is shown in Fig.3. Accelerometer, earth pressure cell, load cell, and displacement gauges were set up. The marker for the subsidence and the deformation measurement was arranged on the surface of fill-up ground. To become a condition that the retaining wall fundamental portion doesn't move in the direction of the front side, the beam was set up between the retaining wall base and the steel box frame.

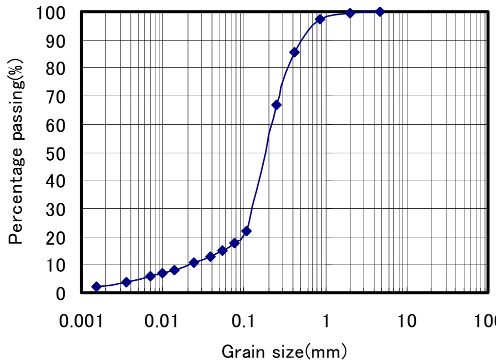


Fig.2 Grain size accumulation curve of Edosaki sand

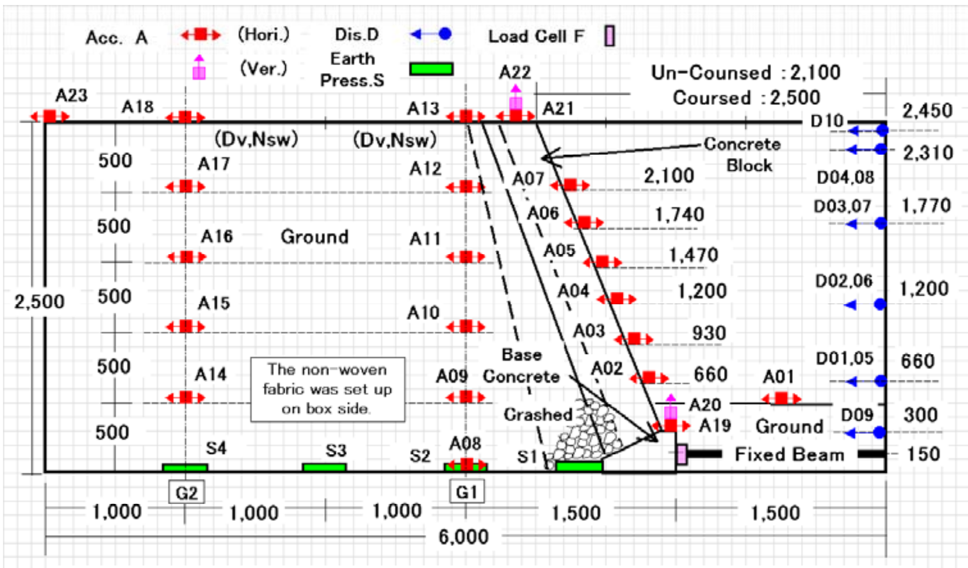


Fig.3 Outline of measurement

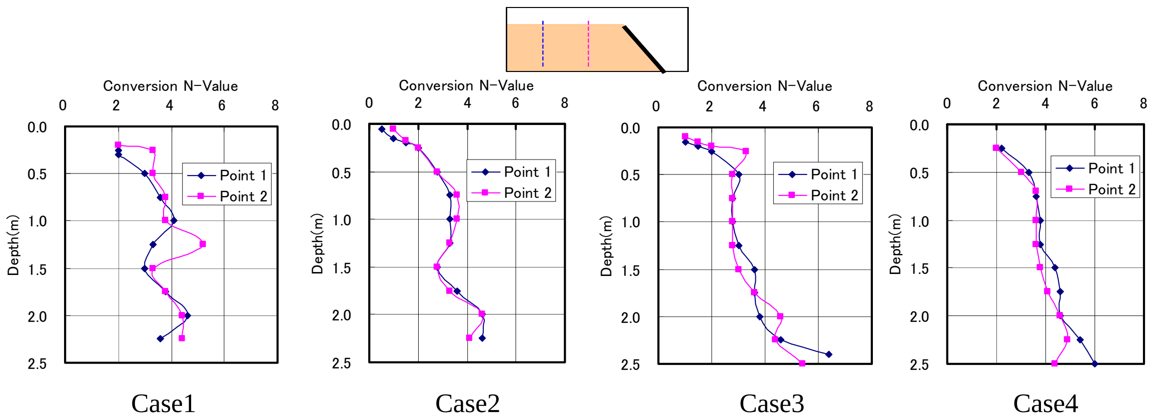


Fig.4 Distribution of conversion N-value (weight sounding test result)

The distribution situation of conversion N-value of fill-up ground is shown in Figure-4. Conversion N-value was calculated from the weight sounding test result. It is thought the almost uniform ground though a few differences are seen in the surface part and the bottom.

In each case, an earthquake excitation with 100gals, 200gals, 400gals, 818gals (orignal max. level) and 1000gals peak acceleration and a random excitation with 20gals peak acceleration were carried out. A NS component acceleration record at GL-32m depth at Port Island, Kobe during 1995 Hyougoken-nanbu earthquake was used in earthquake excitation.

3.OUTLINE OF EXPERIMENTAL RESULT

3.1 Earthquake excitation

In input maximum acceleration 100gals～400gals, each test specimen was not able to confirm a large deformation and the subsidence from externals. In the input maximum acceleration 818gals, the difference of the test specimen behavior by the occurrence of a deformation of the retaining wall and a ground surface crack etc. was confirmed. It reports on the final situation of each test specimen as follows.

3.1.1. Case1 （the dry masonry retaining wall of un-coursed masonry）

In the input maximum acceleration 818gals, a parallel crack to the retaining wall was generated on the surface of the fill, and the unbridgeable gulf was seen between retaining wall concrete-blocks. And, the permanent set was confirmed to the retaining wall intermediate portion.

Fig.5 shows the responsive wave shape of accelerometer and the load cell in the input maximum acceleration 818gals. A08 is the acceleration of the bottom of steel box, A13 is the ground surface acceleration and A21 is the retaining wall top acceleration. The load cell responsive wave shape shows the harmony of two retaining wall load cells that set up the base and the front side. In the acceleration response waveform of A13 and A21, the shape wave of the pulse-like is seen. It is thought the influence of the unbridgeable gulf between retaining wall concrete blocks. Fig.6 shows the response displacement waveform of the retaining wall top and the displacement distribution situation of the retaining wall. The retaining wall displacement showed a straight displacement distribution from the lower side to the top. The permanent set was about 50mm in the retaining wall intermediate portion. It is judged that it collapsed from 50mm the permanent set on the function. Next, it excited by the input maximum acceleration 1000gals, and the final situation of the test specimen was confirmed. In the input maximum acceleration 1000gals, the number of ground surface cracks increases, and the width of the crack has extended. And, the concete-block in the upper part of the retaining wall collapsed being pushed out to the fill of the back of the retaining wall. Photo2 showed the appearance of the retaining wall collapsed in the input maximum acceleration 1000gals.

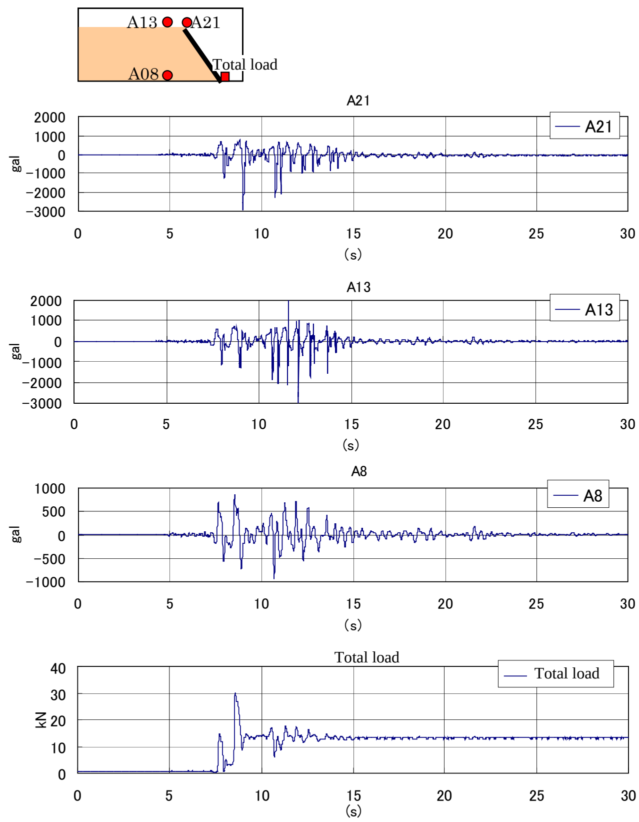


Fig.5 Case1 response wave (Max. 818gals)

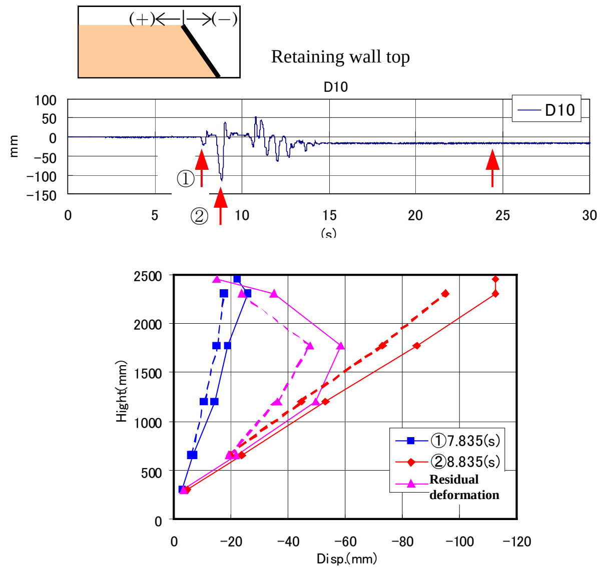


Fig.6 Displacement distribution of retaining wall Case1 (Max. 818gals)

Photo2 Collapsed final situation of Case1 (Max. 1000gals)

3.1.2. Case2 (the wet masonry retaining wall of un-coursed masonry)

In the input maximum acceleration 818gals, the crack was generated on the surface of the fill and the retaining wall inclined at a front side. And, the back ground inclined, subsided along with inclining forward of the retaining wall, and the horizontal moved.

Fig.7 shows the response displacement waveform of the retaining wall top and the displacement distribution situation of the retaining wall. The permanent set showed a straight displacement distribution. Next, the maximum acceleration 1000gals were input.

In the input maximum acceleration 1000gals, the width of the crack on the surface of the fill extended, and the entire retaining wall rotated around the base of the retaining wall. The retaining wall had been displaced to about 6mm in the lower part and about 25mm in the upper part to front side respectively. It is thought that Case2 showed behavior in the solid body because it has integrated by the backfill concrete.

3.13. Case3（the dry masonry retaining wall of coursed masonry）

In the input maximum acceleration 818gals, the crack is generated on the surface of the fill in parallel to the retaining wall, and the space between blocks has extended in a part of retaining wall concrete-blocks. Finally, the back fill moved, and the intermediate portion of the retaining wall was deformed. And, the concrete block of the intermediate portion of the retaining wall fell forward and the retaining wall has collapsed. Photo4 showed the appearance of the retaining wall decay.

Fig.9 shows the response displacement waveform of the retaining wall top and the displacement distribution situation of the retaining wall. Fig.9 showed the displacement distribution of 13.725(s) immediately before decay of the retaining wall. It is understood that the deformation of the lower part of the retaining wall was rapidly advanced immediately before decay.

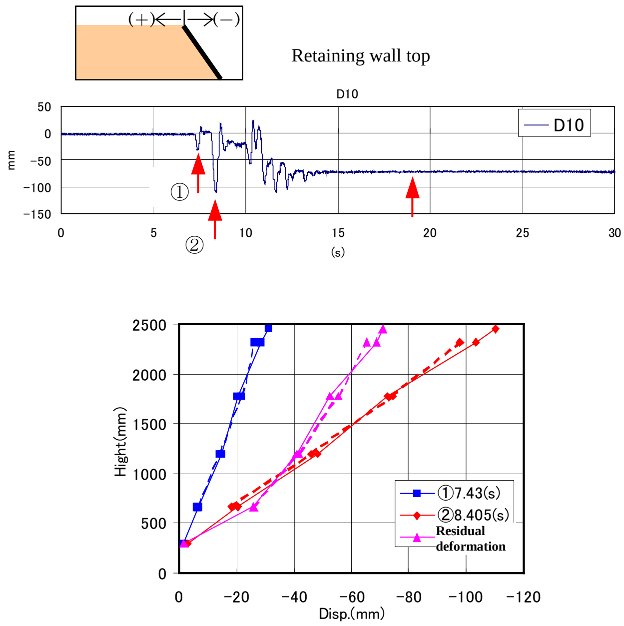


Fig.7 Displacement distribution of retaining wall Case2 (Max. 818gals)

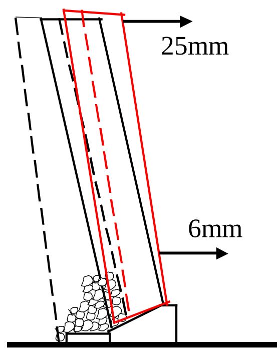


Fig.8 Final situation of Case2 (Max. 1000gals)

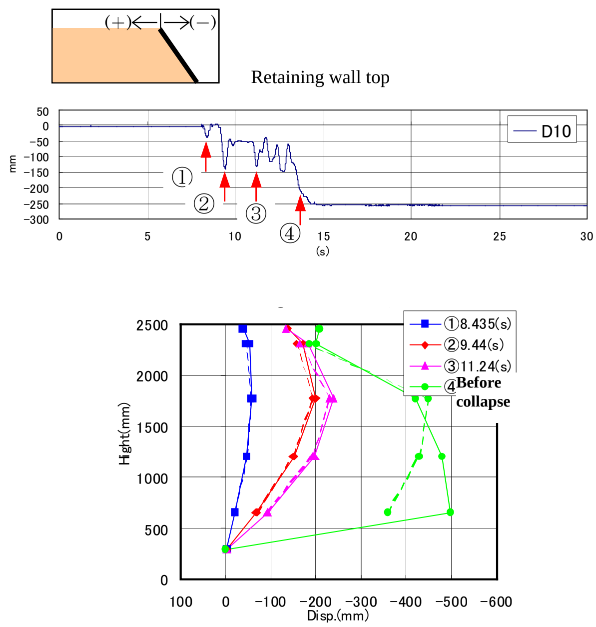


Fig.9 Displacement distribution of retaining wall Case3 (Max. 818gals)

Photo3 Collapsed final situation of Case3 (Max. 818gals)

3.14.Case4 (the simply reinforced dry masonry retaining wall of coursed masonry)

In the input maximum acceleration 818gals, the crack was generated on the surface of the fill in parallel to the retaining wall. And, the tendency that a part of retaining wall concrete-block moved to a front side and the space between blocks broadens was seen. However, the retaining wall showed almost united behavior because it connected between concrete blocks with the reinforcement externals iron plate.

Fig.10 shows the response displacement waveform of the retaining wall top and the displacement distribution situation of the retaining wall. The displacement distribution of the retaining wall extended around the interlayer, and a final permanent set was about 60mm in the intermediate portion. Next, the maximum acceleration 818gals were input again for the final situation confirmation of the test specimen. The final situation was shown in photo5. In the re-input of the maximum acceleration 818gals, the number of cracks of surfaces of the fill increased and the width of the crack on the surface of the fill extended. And, it was pushed to the fill with the subsidence of the back fill, and the retaining wall moved on the foundation to a front side. However, the retaining wall has not collapsed.

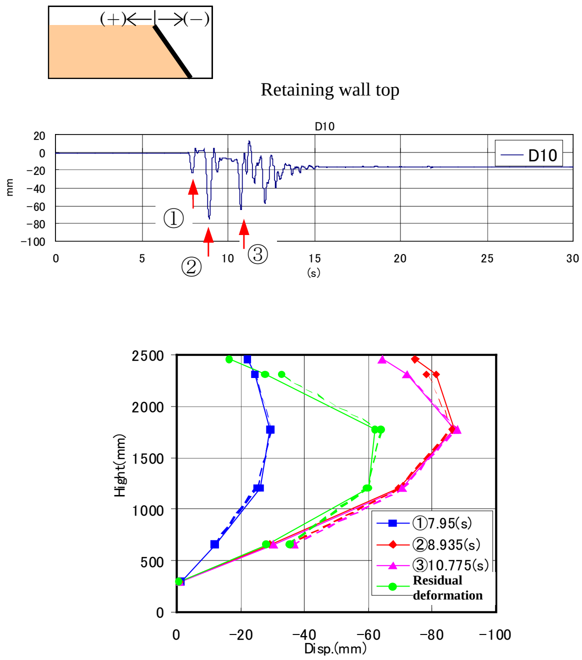


Fig.10 Displacement distribution of retaining wall Case4 (Max. 818gals)

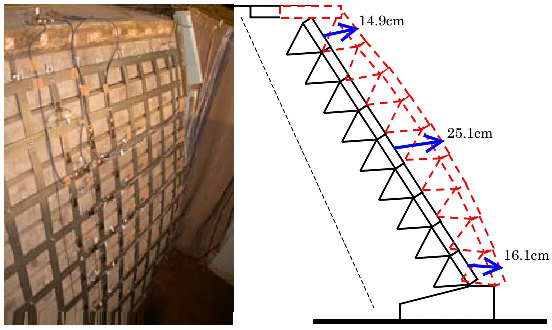


Photo4 Collapsed final situation of Case4 (Re-input Max. 818gals)

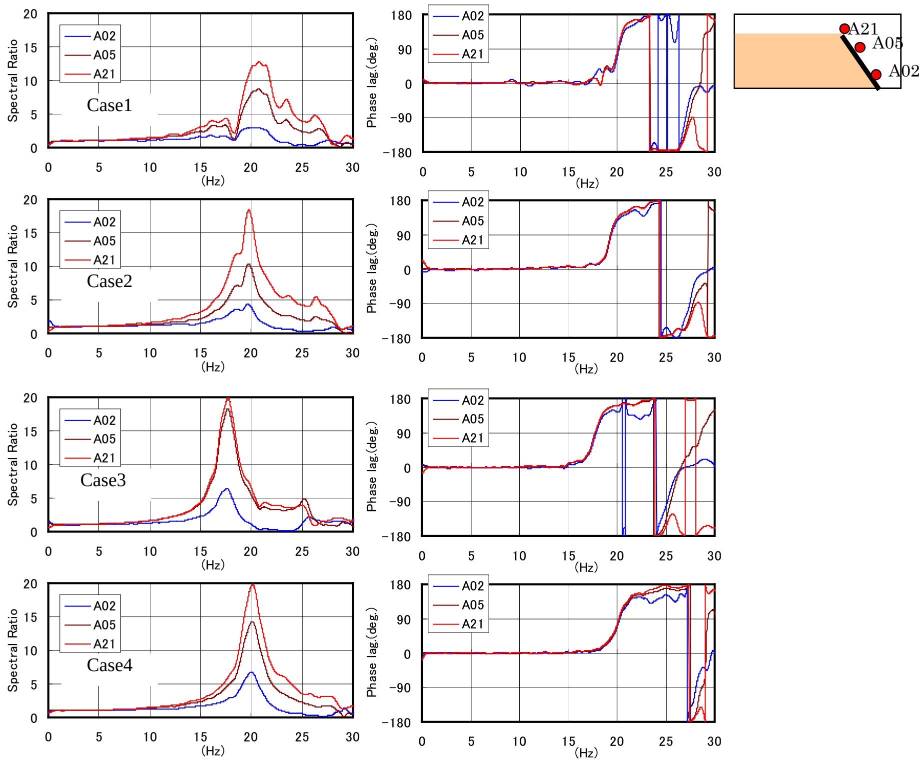


Fig.12 Transfer function of base acceleration (Random Max.20gals)

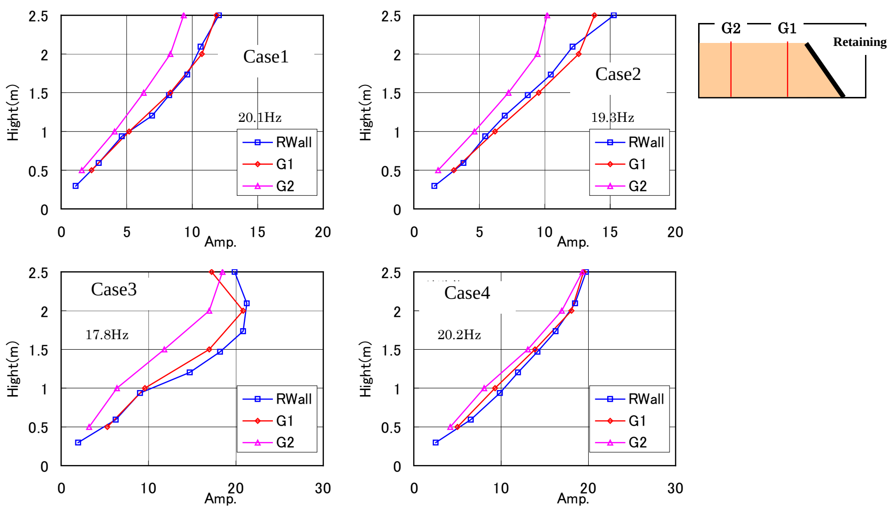


Fig.13 Acceleration modes (Random Max. 20gals)

3.2 Transmission property

The transmission properties of Random wave (Max.20gal) excitation that had been executed before the earthquake ground motion was excited were compared. Fig.12 showed the transfer function of base acceleration that had been obtained from accelerometer on the retaining wall. Fig.13 showed the acceleration mode at natural frequency of fill-up ground (G1, G2) and the retaining wall. 20.1Hz in Case1, 19.3Hz in Case2, 17.8Hz in Case3, and 20.2Hz in Case4 were natural frequencies. Case3 is the lowest natural frequency, and understands the stiffness is low compared with other test specimens. In Case3, the mode line is curved by the upper part of the retaining wall, and it is a little different from other test specimens. In the comparison of natural frequencies of Case1 and Case3, natural frequency of Case1 is higher than natural frequency of Case3, it is thought that the stiffness of retaining wall of the un-coursed masonry type is higher than that of the coursed masonry type. The retaining wall block is diagonally arranged in the un-coursed masonry specification. As a result, the contact length between blocks becomes long compared with the coursed masonry specification, and it is thought that the width of the joint part extends.

4.CONCLUDING REMARKS

The concluding remarks are summarized as follows;

(1) In each case, an earthquake excitation with 100gals～818gals and 1000gals peak acceleration. Case 1, the retaining wall deformed at 818gals and collapsed at 1000gals. Case2, the retaining wall inclined at 1000gals. Case3, the retaining wall collapsed at 818gals. Case4, the retaining wall deformed at 818gals and moved to a front side at re-input 818gals.

(2) The vibratory behavior of the test specimen was different according to the difference of the integrity of the retaining wall concrete-block. The wet masonry concrete-block retaining wall showed the solid body behavior by having been integrated by concrete. The simple reinforced concrete-block retaining wall confirmed no collapse even if it transformed by reinforcement.