A Dynamic Centrifuge Model Test for the Seismic Strengthening of Existing Embankments by the Reinforcement Bar Inserting Method

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ABSTRACT :

Seismic strengthening of existing embankments for Level II Earthquake Motion has been posed as an issue since the Great Hanshin Earthquake. It is considered as necessary to perform seismic strengthening according to the importance of the embankments. The aim of this report is to inspect economical seismic strengthening measures for existing road embankments. We inspected whether we could achieve mitigation of deformation in Level II Earthquake Motion by casting reinforcing bars, which are effective for general purposes in the existing embankments. We inspected this with a dynamic centrifuge model experiment. We placed the reinforcing bars in certain intervals on the slope side and under the roadbed, and also set bearing pressure plates at the head of the placed reinforcing bars. As a result, the sinking of the embankment was mitigated for Level II Earthquake Motion. Also, it was confirmed that the cracks on the top of the embankment were reduced.

KEYWORDS: ' *experiment, Level II Earthquake Motion, seismic strengthening measures, existing embankment, reinforcing bar, bearing pressure plate*

1. INTRODUCTION

In recent years there have been many major earthquakes in the country. The embankment damage of the Mid Niigata Prefecture Earthquake is still fresh in our minds. There have been 4 major earthquakes in the eastern region of Hokkaido in the past ten-odd years, and the destruction of national highway embankments has affected society seriously. In particular, after the Kushiro-Oki Earthquake in 1993, some areas had to spend up to 44 days to restore damaged embankments (Figure 1).

As there are few alternative routes, damages on the the national highways not only cost restoration fees, but cause a great loss in the society as well. Due to the nature of embankments, they are generally not examined for earthquakes. However, in areas where frequent earthquakes are observed, seismic strengthening measures should be immediately taken for existing embankments.

In this report, we inspected the effectiveness of reinforcing bars, which are easy to use for existing embankments and also economical as seismic strengthening material for Level II Earthquake Motion with a dynamic centrifuge model experiment.

2. CHARACTERISTICS OF EMBANKMENT DAMAGE IN MAJOR EARTHQUAKE

In the Road Earthquake Disaster Measure Handbook, the damage patterns of ground-level embankments are decided according to the form of damage (Chart 1).

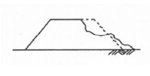
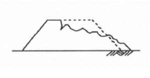
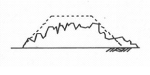
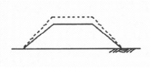
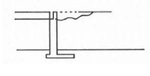
For the damage of embankments in 3 of the major earthquakes of the eastern region of Hokkaido (Kushiro-Oki in 1993, Hokkaido Touhou-Oki, Tokachi-Oki in 2003), the most frequent damage pattern is the damage pattern II, which is a damage pattern of embankments on the ground-level, reaching 80% of all damages.

Damage pattern II is defined as slipping or cracking of embankments, the gap reaching the traffic lane.

Figure 1 shows the road embankment heavily destructed in the Hokkaido Touhou-Oki Earthquake, and this is also a damage pattern II example.

Figure1 National highway embankment damage in the HOKKAIDO TOUHOU-OKI Earthquake

Chart 1 Damage pattern category part

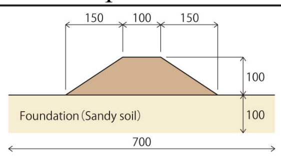
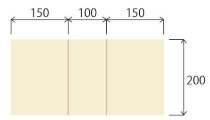
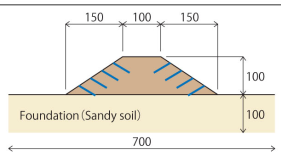
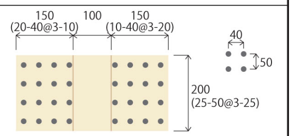
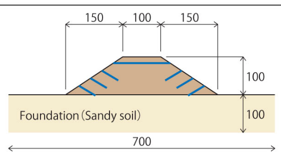
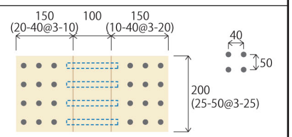
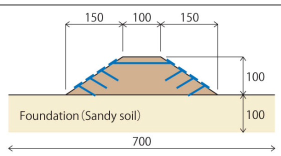
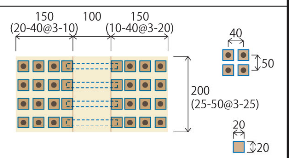
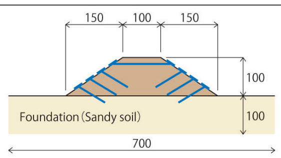
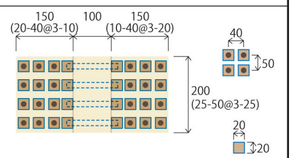
Damage pattern	Damage sample	Damage form
I		Spilling of slope, the gap of damage or cracking does not reach traffic lane and stays within slope
II		Slipping or cracking of embankments, the level gap reaches the traffic lane
III		Damage of foundation, the original form of embankment is not preserved
IV		Equal sinking of embankment, deformation happens with the embankment form preserved to some extent
V		Embankment behind structure sinks or cracks

3. AIM AND MEYHOD OF MODEL EXPERIMENT

We inspected how much reinforcing bar strengthening on embankments can mitigate deformation in earthquakes, with a dynamic centrifuge model experiment.

The list of experiment cases is shown in Chart 2. The embankment material and forms are the same for each experiment. We compared the case with no reinforcing bar strengthening (case 1) and the cases with reinforcing bars cast in the slope side and under the roadbed, with bearing pressure plates set at the head of the bars (cases 2and 3). The model size was on a scale of 1 to 50, and we conducted shake table experiments at the 50G (G= gravitational acceleration) centrifugal acceleration field.

Chart 2 Experiment Case

Case- 1 (No measures)		
Case- 2 (Reinforcing bars in 4 rows ; L=5cm)		
Case- 3 (Reinforcing bars in 3 rows ; L=5cm) (Roadbed bar : 1m under roadbed @5cm)		
Case- 4 (Reinforcing bars in 3 rows ; L=5cm) (Roadbed bar : 1m under roadbed @5cm)		
Case- 5 (Reinforcing bars in 3 rows ; L=8cm) (Roadbed bar : 1m under roadbed @5cm)		

3.1 Model Foundation

In all experiment cases, we created the basic foundation using air pluviation method with dry silica sand, aiming for relative density of Dr = 90%, so that the foundation would be relatively favorable. For the embankment material, we used silica sand and kaolin clay, mixed at a dry ratio of 8:2, regulated with water at optimum moisture content.

The physicality of the embankment material is shown in chart 3. In creating the embankment, the thickness where the sensor was placed was 1 cm, while the other parts were 2 cm, and a small rammer was used for compacting.

For the form of the embankment, we assumed a standard road embankment, and all embankments were 5 cm tall in gravitational field. For the seismic strengthening material, we used stainless spring wire of φ = 1 mm (JIS G 4313, E=1.97x105 N/mm2), the Young's modulus being roughly equivalent to reinforcing bars. In order to obtain the surface friction of reinforcing bars, we polished the surface with an electric file and fixed silica sand with glue.

Case 1 is without reinforcing bar strengthening, and Cases 2 to 5 are with reinforcing bar strengthening. For Case 2 we cast L = 2.5 m (real-size conversion) reinforcing bars (equivalent toφ = 41 mm) from the slope toe towards the top in 4 rows and at 1.5 m intervals, and 4 lines at 2.5 m intervals in the length direction.

For Case 3, the top 3 rows from the slope toe are the same as Case 2, but for the lowest row the reinforcement bars were placed 1m under the roadbed. The length direction is the same as Case 2.

For Case 4, all placements are the same as Case 3, but bearing pressure plates were placed at the head of reinforcing bars.

For Case 5, all placements are the same as Case 4, but the length of reinforcing bars on the slope are L = 4.0 m (real-size conversion, equivalent toφ = 41 mm). Furthermore, general sizes were used as a basis for strengthening material lengths and compact pitch.

Also, past reports were used as reference for the placement of strengthening materials, etc. For measurements, the acceleration responses of the basic foundation and inner embankment were measured by an ultra-small piezoelectric accelerometer, and the sinking of the embankment top was measured by a laser displacement meter (Figure 2).

Chart 3 Conditions of Embankment Material

Item	Value
Embankment Material	Silica sand:kaolin=8:2
Degree of Compaction (%)	85
Density of Soil Particles (g/cm^3)	2.68
Maximum Dry Density (g/cm^3)	1.87
Optimum Moisture Content (%)	10.8
Adhesive Power (kN/m^2)	14
Internal Friction Angle (°)	27.5

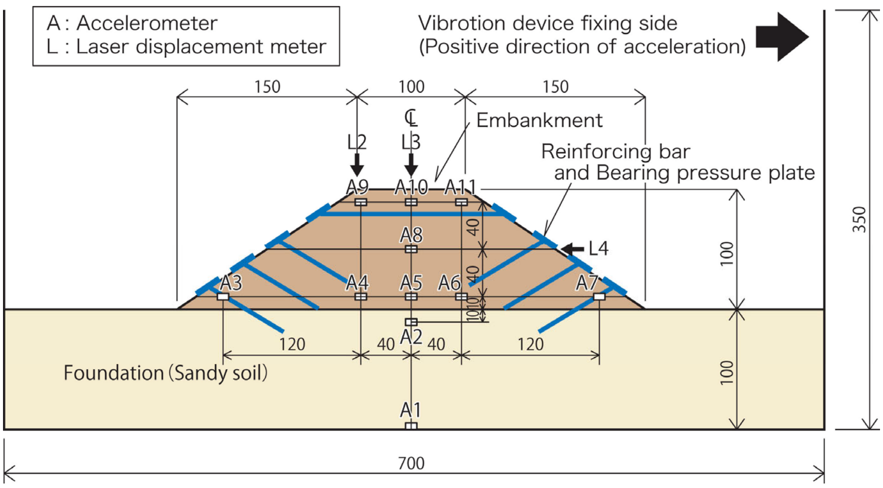


Figure 2 Placement of Measurement Materials

3.2 Vibration Conditions

The acceleration waves were set as sine waves with frequency of 100Hz (real-size conversion: 2Hz), and the vibration time was 0.2 seconds (real-size conversion: 10 seconds). However, due to the efficiency of the vibration device, the actual acceleration waves were not precise sine waves. For Cases 1 to 3, the set acceleration was gradually increased: approximately 50 m/s2 (first vibration, real-size conversion: 100 gal equivalent), approximately 100 m/s2 (second vibration, real-size conversion: 200 gal equivalent), and approximately 250 m/s2 (third vibration, real-size conversion: 500 gal equivalent). However, the actual foundation acceleration (Figure 2 A1) is not the same as the set acceleration, due to the centrifugal device efficiency.

4. RESULTS AND CONCLUSION

4.1 Deformation of Embankment and Foundation

Figures 3, 4,5 and 7 show the top of the embankments after the vibration experiments. In Cases 1 and 3, there were many cracks 1 mm wide and 10 mm deep (real-size conversion: 50 cm) on the top of the embankments, due to the third vibration

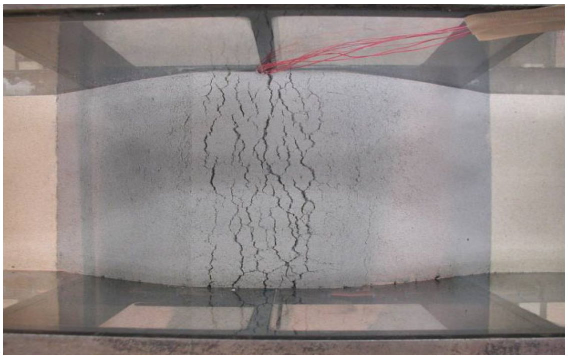


Figure 3 Case1 After Vibration Experiment

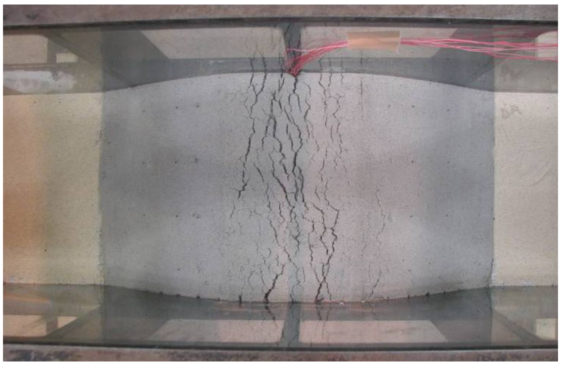


Figure 4 Case3 After Vibration Experiment

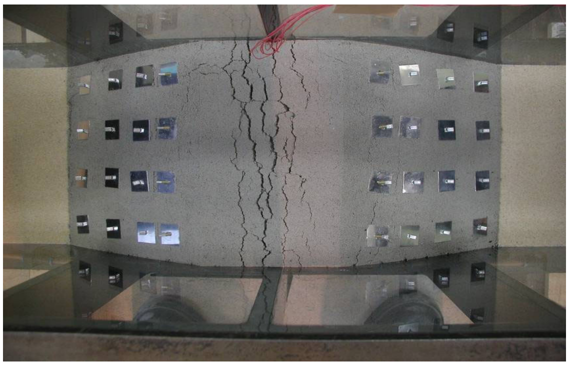


Figure 5 Case4 After Vibration Experiment

Figure 6 Case4 After Vibration Experiment (cross-section)

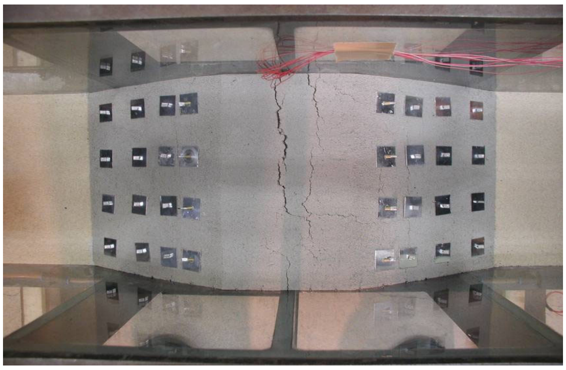


Figure 7 Case5 After Vibration Experiment

Figure 8 Case5 After Vibration Experiment (cross-section)

(Figures 3 and 4). Also, the embankment top condition of Case 2 was similar to Case 1, so it is not shown here.

In major earthquakes in the past, slipping damage was done by ground motion in the cross-direction of the embankment. It was confirmed that cracks occur in the cross-direction.

It can be said that the damage mode of Case 1 is similar to actual embankment destruction (damage pattern II), in Level II Earthquake Motion (Figure 3).

In Case 3, similar cracks were confirmed in the embankment top as Case 1. When comparing the sinking of the embankment top center and L side slope top, of Cases 1 and 3, there was no great difference. It can be said that the seismic strengthening effect of the reinforcing bar placement for Case 3 was small.

In Case 4, bearing pressure plates were placed at the head of reinforcing bars, to better mitigate the deformation of the embankment. Due to the third vibration, an 8 mm sink (real-size conversion: 40 cm) occurred in the center of the embankment top as in Case1.Also, a 6 mm Sink (set acceleration: 30 cm) of the slope top was also confirmed (figures 9 and 10). However, the cracks were concentrated on the top center of the embankment, and there were no cracks on the slope top.

For Case 5, as in Case 4, reinforcing bars were cast in the embankment slope and under the roadbed, and bearing pressure plates were set at the head of the reinforcing bars. The length of the oblique bars was 8 cm (real-size conversion: 4 m), which was 3 cm (real-size conversion: 1.5 m) longer than in Case 4. In this condition, after the third vibration (set acceleration: 500 gal) cracks occurred in the top center of the embankment. However, the cracks were much reduced compared to Cases 1 to 4. Furthermore, there were no cracks at the slope top. Also, the sinking was only 5 mm at the top center of the embankment (real-size conversion: 25 cm) and 4 mm at the slope top (real-size conversion: 20 cm). The sinking was mitigated compared to Cases 1 to 4 (Figures 9 and 10).

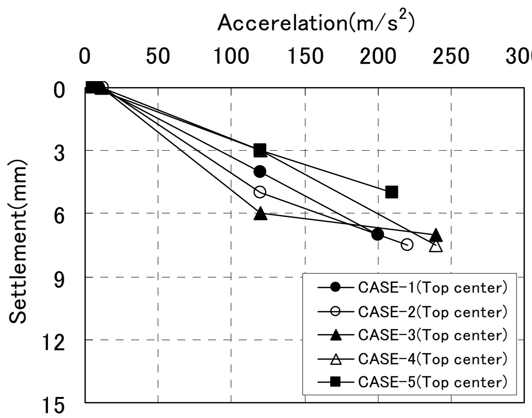


Figure 9 Vertical Displacement Comparison (top center)

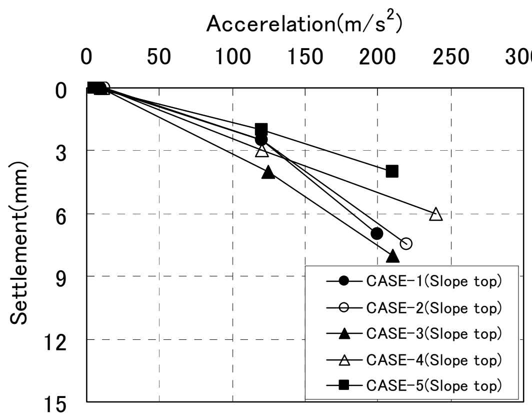


Figure 10 Vertical Displacement Comparison (Light side slope top)

4.2 Acceleration Response in Embankments

Figure 11 shows the set acceleration, and acceleration response in the basic foundation and embankments of Cases 1 to 5. The set acceleration (gal) is shown in the parentheses in the table.

It was confirmed that there was no increase of acceleration response in the foundations in all cases for the first vibration (set acceleration: 100 gal). In the embankment, there was a slight increase between the half-point in height and the embankment top. For the second vibration (set acceleration: 200 gal), as in the first vibration, there was no confirmed increase in the foundation. However, the acceleration response from the bottom of the embankment to the top greatly increased.

When the acceleration response of the embankment top reached 4 times that of the set acceleration, no great difference was observed in each case, whether with or

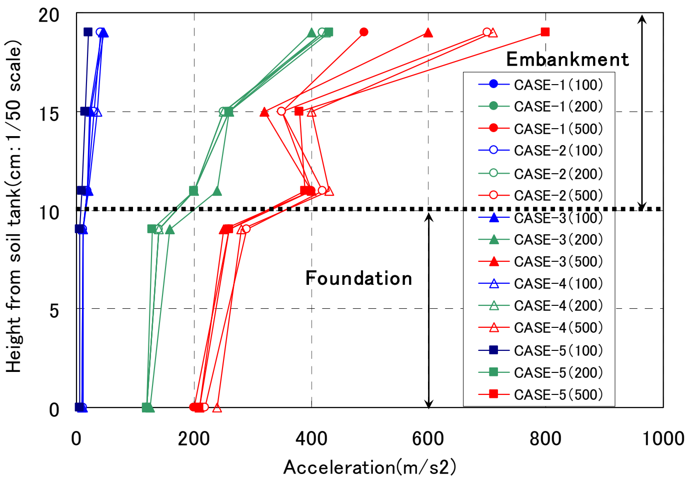


Figure 11 Acceleration Response of Basic Foundation and in Embankment

without the reinforcing strengthening, and with different reinforcing bar placement. This can be owned to some uniform rigidity of the embankment.
For the third vibration (set acceleration: 500 gal), the acceleration response from the foundation to the mid-point in height of the embankment were similar in all cases. However, the top of the embankment responses were different for each case.
The acceleration response of the embankment top in Case 1 was slightly bigger than that of the second vibration (set acceleration: 200 gal). The acceleration responses of Cases 2 to 5, with the reinforcing strengthening, increased greatly. It can be thought as a reason that the shear strength was insufficient in Case 1 (no strengthening) in the third vibration (set acceleration: 500 gal).
On the other hand, in Cases 2 to 5, in particular in Case 5, we placed bars and bearing pressure plates in the upper part of the embankment, and longer bars (in comparison to Cases 2 to 4) and bearing pressure plates in the lower part of the embankment. It can be conjectured that with this reinforcing strengthening, the entire embankment functioned as a strengthening embankment, and the acceleration response of the embankment top increased.
Due to the ground motion of the third vibration (set acceleration: 500 gal), the embankment itself tended to sink directly down. It can be thought as a reason that longer oblique bars and bearing pressure plates mitigated deformation of the entire embankment, and the bars under the roadbed and bearing pressure plates further mitigated the deformation due to sinking. We conjecture that the roadbed bars in Case 5 concaved more in comparison to Case 4 for this reason (Figures 6 and 8).

5. CONCLUSION

We found that we could achieve seismic strengthening (mitigation of deformation of embankment), even for Level II Earthquake Motion, by using reinforcing bars as seismic strengthening material in existing embankments. This type of measure can be effective for short or narrow embankments with relatively favorable foundations, considering the limit of reinforcing bar lengths and the execution. However, at this point the seismic strengthening evaluation is merely qualitative. In the future we plan to conduct quantitative studies of the seismic strengthening of reinforcing bars with Level II Earthquake Motion, by warp analysis, etc. Also, we plan to inspect the seismic strengthening effect of reinforcing bars for embankments with poor foundations.

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