SEISMIC RETROFIT OF ASPHALT PAVEMENTS USING CONFINED- REINFORCED EARTH

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ABSTRACT

Reducing the risk of earthquake-induced damage to road is needed to promote safety and disaster mitigation and recovery. Especially, it is strongly needed for pavement performance to keep the emergency traffic remain in service despite severe earthquake. This paper presents a seismic retrofit technique of asphalt pavements using Confined-Reinforced Earth (CRE) consisted of 1) compacted soil, 2) geosynthetics and 3) post-tensioning anchors. Geosynthetics are placed at upper, middle, and lower surface of compacted base course or subgrade layer. Rigid steel anchors are vertically penetrated from the top to the bottom layer and locked by anchored to the lower geosynthetics. Confining by the anchors is the application of both compressive and confined force to the compacted soil layers, and gives a pre-tensile force to geosynthetics. The high flexural rigidity of CRE is for overcoming weakness of base course or subgrade in tension and flex/bending. In this paper, the seismic retrofit technique of asphalt pavements using CRE included 1) structure, 2) construction method, and 3) the results of full scale in-situ tests are presented.

1. INTRODUCTION

One of the responsibilities of road administrators and companies is to maintain or rapidly resume its essential road and business operations in the event of severe earthquakes. Many road administrators and companies in Japan have established a so-called Business Continuity Plan (BCP) to ensure that they can maintain key operations in the event of a major disaster and minimize negative effects on customers and suppliers.

Road pavements which are adjacent to highway structures such as bridges and culverts are often damaged due to the settlement of highway embankments around abutments and wing walls by severe earthquakes. In addition, liquefaction causes severe failure of wing walls and approaches. Traffic is easily intercepted by the earthquake damage to road pavements. At least, to keep the emergency traffic remain in service despite severe earthquake is the most important subject of a Business Continuity Management (BCM) to promote safety, disaster mitigation and recovery.

The major countermeasures for seismic retrofit of ground in Japan are soil improvements, such as deep soil stabilization, sand compaction pile and grouting. The past experiences in Japan prove that these methods are very effective for use in seismic retrofit of ground; however, there are some difficulties for use in road “in service”.

This paper presents a newly developed seismic retrofit technique of asphalt pavements using Confined-Reinforced Earth (CRE). CRE is a reinforced base course or subgrade layer which is consisted of compacted soil, geosynthetics and post-tensioning anchors. In this paper, the seismic retrofit technique of asphalt pavements using CRE included structure, construction method, the results of full scale in-situ tests are presented.

2. CONFINED-REINFORCED EARTH

2.1. Structure

Figure 1 shows the structure of CRE applied to road subgrade. The basic concept of CRE is developed referring to the geosynthetics-reinforced soil technique which has been examined by many Japanese research workers [1] [2] [3] [4] [5]. CRE is a composite structure consisted of compacted soil, geosynthetics and post-tensioning anchors. The high flexural rigidity of CRE is for overcoming weakness of base course or subgrade in tension and flex/bending. Because of the high flexural rigidity of CRE, the performance of the seismic retrofit of asphalt pavements which are adjacent to highway structures shown in Figures 2 is set to be able to keep the emergency traffic remain in service despite severe earthquake in this study.

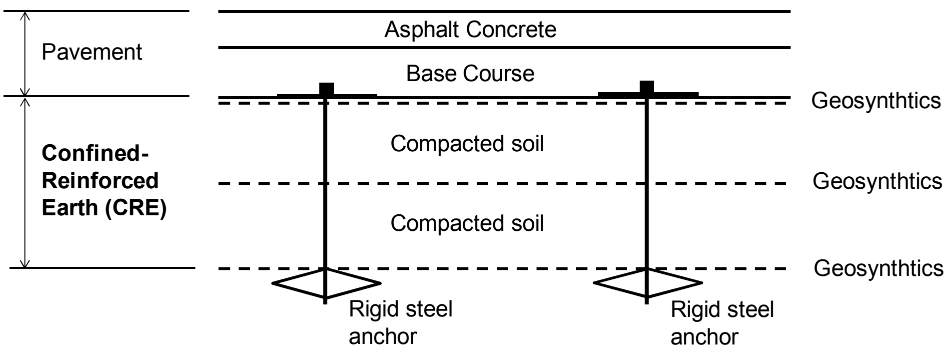
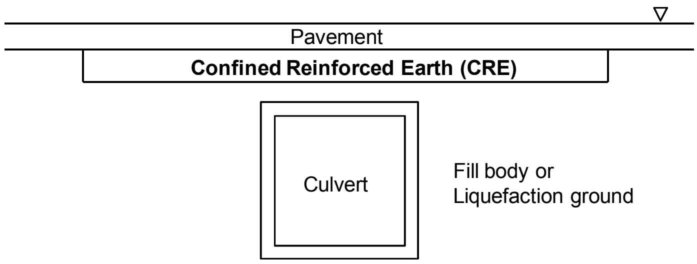
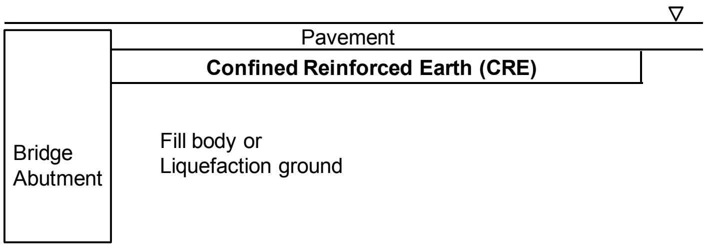


Figure 1 - Composite structure of CRE



a) Box culvert approach



b) Bridge approach

Figures 2 - Examples of CRE application

2.2. Materials

Compacted soil is a main engineering material for use in CRE. Selection of soil material is very important to keep the reinforced effect of CRE. Crushed stone for mechanical stabilization is the best material due to the high compression and shear strength. High degree of compaction is also effective to the reinforced effect of CRE.

Geosynthetics are placed at upper, middle, and lower surface of compacted soil for overcoming weakness of base course or subgrade in tension. Photographs 1 show the newly developed high strengthens geosynthetics for CRE which are high tensile strength of 200kN/m and low strain of 4.5%. The width of a sheet of geosynthetics is maintain as same as road width.

Rigid steel anchors are vertically penetrated from the top to the bottom layer and locked by anchored to the lower geosynthetics for overcoming weakness of flex/bending. Photograph 2 shows the newly developed post-tensioning anchor for CRE which improved a slope reinforcement anchor. Confining by the anchors is the application of both compressive and confined force to the compacted soil layers, and gives a pre-tensile force to geosynthetics.

Photographs 1 - High strengthen geosynthetics for CRE

Photograph 2 - Rigid steel anchors for CRE

2.3. Construction

After preparing the lower subgrade, geosynthetics is placed at the part of reinforced area (see photograph 3). Then crushed stones are carefully laid by bulldozer or motor grader (see Photograph 4) so that the geosynthetics may not be fractured and crushed stone is fully compacted by rollers (see Photograph 5).

After constructing the two compacted soil layers and placement of the three sheet of geosynthetics, then rigid steel anchors are vertically penetrated from the top to the bottom layer by small pile driving machine (see Photograph 6) and locked by anchored to the lower geosynthetics by hydraulic jack (see Photograph 7). It should be noted that the construction time of setting anchors is about 40 to 50 anchors per hour by a pair of machines.

Finally, a top steel plate is set through a rod and a rod is fixed with a nut by torque wrench (see Photograph 8). Confined load of 10-20kN can be exactly maintained by setting torque. CRE layer after construction is shown in Photograph 9 and 10. By use of this construction method, rapid construction of CRE is fully possible so it is realistic enough to apply this CRE for road in service.

Photograph 3 - Geosynthetics placement

Photograph 4 - Laying

Photograph 5 - Compaction

Photograph 6 - Anchor driving

Photograph 7 - Anchor locking

Photograph 8 - Confining

Photograph 9 - CRE layer
(Cables are for sensors to correct data of in-situ test)

Photograph 10 - Top of the anchor

3. FULL SCALE IN-SITU TEST OF CONFINED-REINFRCED EARTH

3.1. Cantilever model test

To verify the flexural rigidity of CRE, full scale cantilever model tests were carried out in Fukui, Japan as a joint research project by Chuo University, NIPPO Corporation Research Institute and Maeda Kosen co., Ltd. in November 2009.

Three cantilever models constructed were 10.0m length, 3.0m width and 0.5m, 0.75m and 1.0m thickness respectively. Three sheets of geosynthetics (tensile strength of 200kN/m, maximum strain of 4.5%) were placed in each cantilever models. After every placement of geosynthetics, the crushed stone for mechanical stabilization (maximum particle size of 30mm) was spread over up to 0.15m thickness and fully compacted by the vibration roller. The degree of compaction was about 90%. Rigid steel anchors were set by the pitch of 0.5m in square. Confined load by the anchors was 15kN. Markers were installed at every 0.5m interval on the side of the cantilever models to observe horizontal and vertical displacement.

Cantilever models of CRE used in this test are shown in Figure 3. The experiment began by removing each firing styrene of 0.5m length by injection of orange oil, which were supporting cantilever. Photograph 11 shows one of the test results of 1.5m cantilever span.

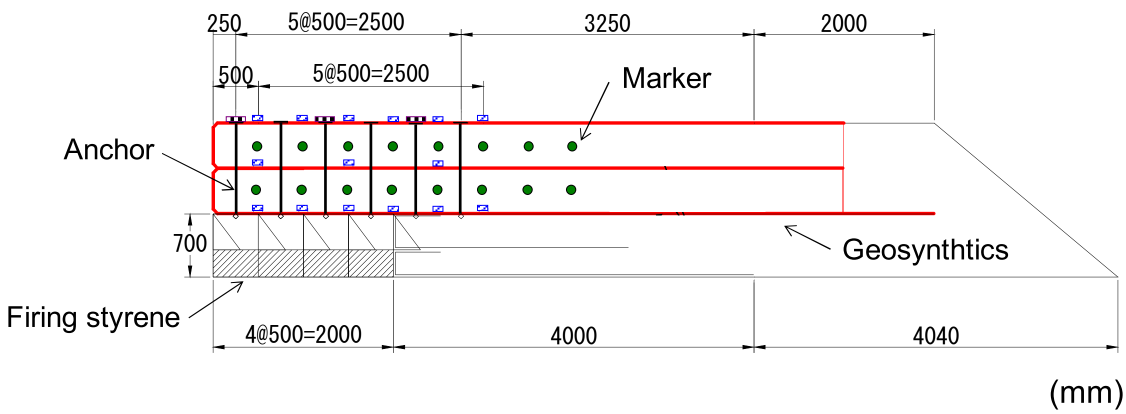


Figure 3 - Cantilever models reinforced by CRE

Photograph 11 - Cantilever model test (0.5m thickness, 1.5m span)

Table 1 - Measured maximum vertical displacement of cantilever models (mm)

Cantilever span (m)	Cantilever thickness 0.5m	Cantilever thickness 0.75m	Cantilever thickness 1.0m
0.5	0	0	0
1.0	11	15	10
1.5	77	98	93

Table 2 - Estimated young modulus of cantilever models (kN/m^2)

Cantilever span (m)	Cantilever thickness 0.5m	Cantilever thickness 0.75m	Cantilever thickness 1.0m
1.0	2707	846	707
1.5	3938	1319	775

The measured maximum vertical displacement at each step is summarized in Table 1. The estimated young modulus which the cantilevers are assumed as a linearly elastic model is summarized in Table 2.

Table 2 shows the interesting characteristics of CRE that;

・The more deformation is bigger, the more young modulus of CRE becomes stiffer.
・The magnitude of flexural rigidity (stiffness) of CRE is not depend on cantilever thickness (secondary cross-section moment) but the spacing of geosynthetics in this experimental condition.

3.2. Full scale in-situ test

To verify the seismic performance of CRE which the asphalt pavement adjacent to highway structures is able to keep the emergency traffic remain in service after severe earthquake, a full scale in-situ test were carried out in the yard of Hitachi Construction Machinery Camino Co., Ltd., Saitama, Japan as a joint research project by Chuo University, NIPPO Corporation Research Institute and Maeda Kosen Co., Ltd. in 2010.

The trial embankment constructed were 25m length, 3.6m width and 2.5m height at the top of embankment shown in Photograph 12. Asphalt pavement on CRE was consisted of asphalt concrete of 50mm thickness, base course of 300mm thickness and CRE of 600mm. Three sheets of geosynthetics (tensile strength of 200kN/m, maximum strain of 4.5%) were placed at every 300mm height of CRE. After every placement of geosynthetics, the crushed stone (maximum particle size of 40mm) was spread over up to 0.15m thickness by bulldozer and fully compacted by the vibration roller and tyre roller. The degree of compaction was about 95%. Rigid steel anchors were set by the pitch of 0.6 in square. Confined load by the anchors was 20kN. Markers were placed at every 0.6m interval on the asphalt pavement to observe vertical displacement.

Photograph 12 - Trial embankment

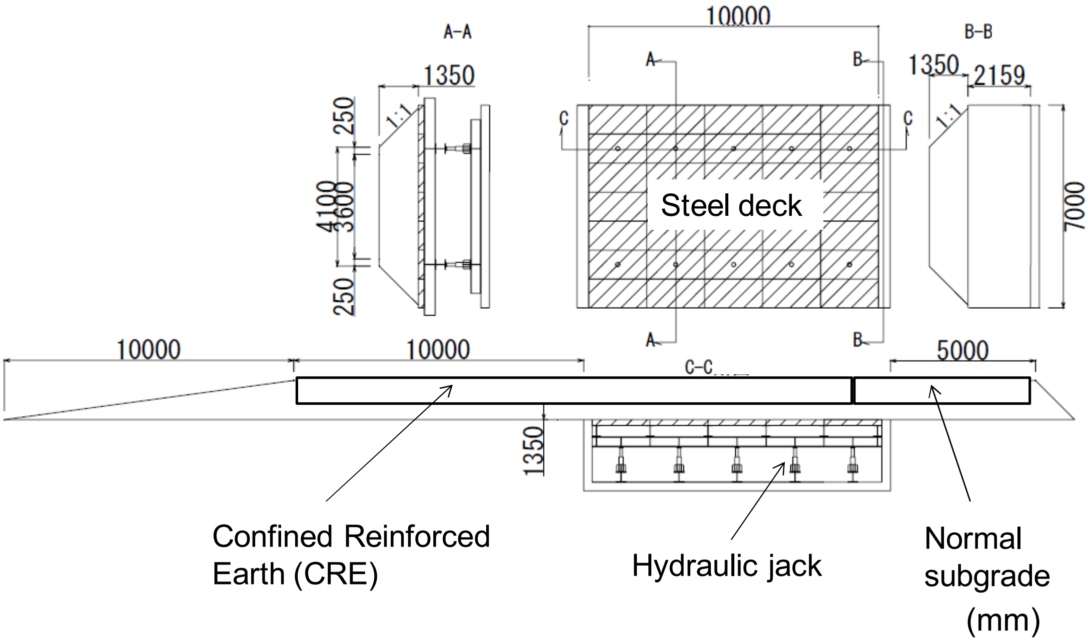


Figure 4 - Structure of trial embankment

Trial pavement on normal subgrade was asphalt concrete of 50mm thickness, base course of 300mm thickness and subgrade of 600mm crushed stone layer for comparing with the performance of asphalt pavement on CRE. Trial embankment used in this test is shown in Figure 4. The experiments to simulate the severe earthquake-induced damage began by statically juck down the steel deck of 10m length using ten multi-controlled hydraulic jucks, which were supporting steel deck.

The measured surface profile of asphalt pavement at each step is summarized in Figure 5. Photograph 13 and 14 show the surface deformation of asphalt pavement on CRE and normal subgrade after 300mm forced settlement respectively. Photographs 15 and Photograph 16 show the trafficability tests on asphalt pavement on CRE and normal subgrade after 300mm forced settlement respectively.

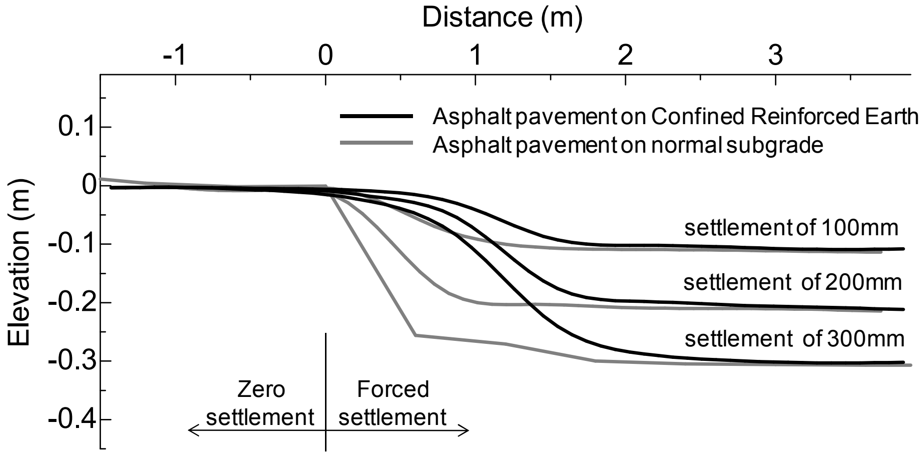


Figure 5 - Measured surface profile of asphalt pavement on CRE and normal subgrade

Photograph 13 - Deformation of asphalt pavement on CRE after 300mm forced settlement

Photograph 14 - Deformation of asphalt pavement on normal pavement after 300mm forced settlement

Photographs 15 - Trafficability test on asphalt pavement on CRE after 300mm forced settlement

Photograph 16 - Trafficability tests on asphalt pavement on normal subgrade after 300mm forced settlement

Photograph 17 - Durability test

CRE gave the smooth surface propile of asphalt pavement and good trafficability, but the heavy cracks and faulting was occurred on asphalt pavement on normal subgrade so that the trafficability could not be kept at all. Photograph 17 shows the durability test by total load of 200kN after 300mm forced settlement. CRE gave the good traficability and durability of asphalt pavement during test.

4. CONCLUSION

In this paper, the seismic retrofit technique of asphalt pavements using Confined-Reinforced Earth (CRE) included its structure, construction method, and the results of full scale in-situ tests are described. CRE as a seismic retrofit of asphalt pavement can be rapidly constructed, so it is realistic enough to apply CRE for road in service. Full scale in-situ tests show the good trafficability and durability of asphalt pavement on CRE after the forced settlement to simulate the severe earthquake-induced damage. It can be concluded that CRE is fully expected as a tool for use in Business Continuity Plan (BCP) and Business Continuity Management (BCM) of road administrators and companies to promote safety and disaster mitigation and recovery of road in near future.

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