Retrofit Technique for Asphalt Concrete Pavements after seismic damage

Technique de réhabilitation pour chaussée en béton d'asphalte après dommage sismique

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ABSTRACT: Reducing the risk of earthquake-induced damage to road is needed to promote safety and disaster mitigation and recovery. It is strongly needed for pavement performance to keep the emergency traffic remain in service despite severe earthquake. This paper presents a retrofit technique of asphalt pavements using Confined-Reinforced Earth (CRE) consisting of 1) compacted soil, 2) geosynthetics and 3) post-tensioning anchors. Confining by the anchors is the application of both compressive and confining 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, 1) structure of the retrofit technique of asphalt pavements using CRE, 2) construction method, 3) the results of full scale in-situ tests are presented.

RÉSUMÉ : La réduction du risque de dommage routier induit par un tremblement de terre est nécessaire pour la sécurité, l'atténuation de l'effet de la catastrophe et la remise en service. La performance du pavement pour permettre le trafic d'urgence qui doit rester en service est visée. L'article présente une technique de rehabilitation des chaussées d'asphalte à l'aide d'un sol renforcé confiné (CRE) par 1) un sol compacté, 2) géosynthétiques, et 3) post-pension d'ancrages. Les ancrages en acier rigide sont placés verticalement du haut vers la couche de base et verrouillé à la base des géosynthétiques. Le confinement des sols compactés s'effectue par l'application des deux forces (de compression axiale et latérale) qui applique une pré-tension aux géosynthétiques. La grande rigidité à la flexion de CRE contre balance la faiblesse de la couche de base ou de la couche de fondation en traction et flexion. L'article présente 1) la structure de chaussées, 2) la méthode de construction, et 3) les résultats des essais « in situ » pleine échelle.

KEYWORDS: pavement, earthquake, seismic retrofit, confined-reinforced earth, geosynthetics.

1 INTRODUCTION.

Reducing the risk of earthquake-induced damage to road is strongly recquired to promote safety, disaster mitigation and recovery. Road pavements which are adjacent to highway structures such as bridges and culvert boxes are often damaged due to the differential settlement of highway embankments around bridge abutments, edge of culvert boxes and wing walls during and after severe earthquakes. Traffic is easily intercepted by the earthquake damage to road pavements. In one of the precept of the Great East Japan earthquake (2011), to keep the emergency traffic remain in service after severe earthquake is the most important subject especially for emergency activity.

This paper presents a newly developed seismic retrofit technique of asphalt concrete pavements using Confined-Reinforced Earth (CRE). CRE is composed by compacted soil, geosynthetics and post-tensioning rigid anchors. Confining by the anchors is the application of both compressive and confining force to the compacted soil layers, and gives a pre-tensile force to geosynthetics.

The basic idea of implementing pre-stresses in reinforced earth was advanced technology even from a gloval perspective as follows (Uchimura et al. 1996, 2003, 2005). The high rigidity of CRE is apparently useful in preventing excessive differential settlement of the road pavement despite severe earthquake.

In this paper, 1) structure of the seismic retrofit technique of asphalt pavements using CRE, 2) construction method, 3) application of actual highway embankment, 4) the results of full scale in-situ tests are presented.

2 STRUCTURE

Figure 1 shows the structure of CRE applied to road subgrade of asphalt concrete pavement. CRE is a composite structure consisting of compacted crushed stone, geosynthetics and post-tensioning anchors. The high flexural rigidity of CRE is for overcoming weakness of base course or subgrade intension and bending.

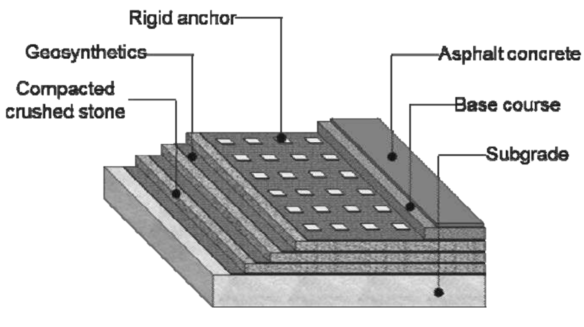
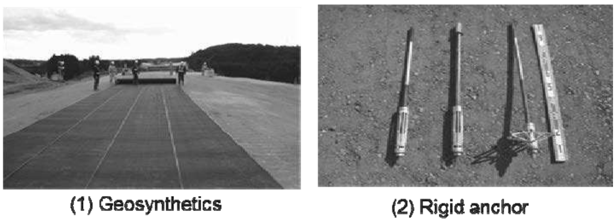


Figure 1. Structure of Confined-Reinforced Earth applied to asphalt concrete pavement.

Compacted soil is a key material for use in CRE. Selection of soil material is very important to keep the reinforced performance 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. The crusshed stone layers are sandwitched by four layers of geogrid and confined by confining rigid steel anchors.

Photograph 1 (1) shows geosyntheyics used in this method. The geosynthetics for use in CRE has high tensile strength of 200kN/m with low strain of 4.5%. The width of a sheet of geosynthetics is maintain as same as road lane width.

Photograph 1 (2) shows the newly developed post-tensioning rigid steel anchor used in CRE. This anchor was improved from a slope reinforcement anchor. The anchors is vertically penetrated from the top to the bottom layer and locked to the lower geosynthetics.



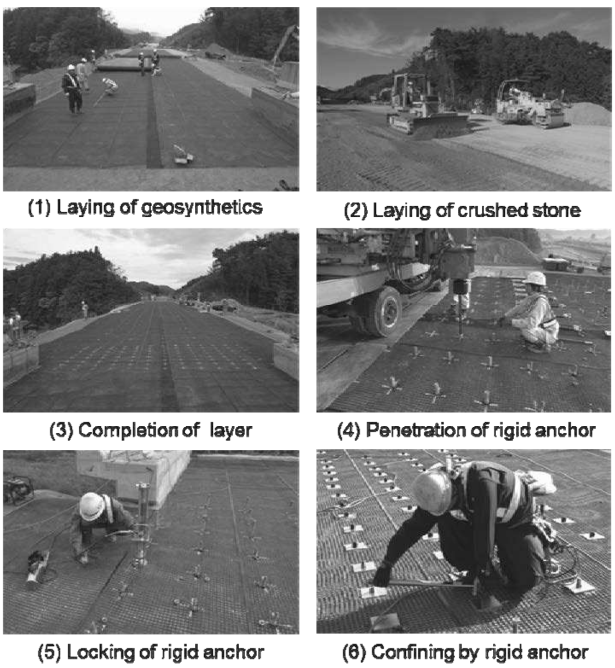
Photographs 1. Geosynthetics and confining rigid steel anchors using Confined-Reinforced Earth.

3 CONSTRUCTION METHOD

Photographs 2 show the construction sequence of CRE. After preparing the lower subgrade, the 1st layer of geosynthetics is laid on the area to be reinforced (Photograph 2 (1)).

Then crushed stones are carefully laid by a bulldozer or by a motor grader (Photograph 2 (2)) on the 1st layer of geosynthetics and the layer of crushed stone is fully compacted by vibrating rollers (Photograph 2 (2)). After placing three layers of compacted crushed stone and laying of 2nd ,3rd and 4th layers of geosynthetics (Photograph 5 (3)), rigid steel anchors are vertically penetrated from the top to the bottom layer by the small pile driving equipment (Photograph 2 (4)) and mechanically locked to the lower geosynthetics employing a small hydraulic jack (Photograph 2 (5)).

It should be noted that the construction time of setting anchors is very short (about 40 to 50 anchors per hour). Finally, a top steel plate is set through a rod and is fixed to the rod



Photographs 2. Construction method of Confined-Reinforced Earth. (Construction in Joban Highway in Fukushima, Japan, 2011)

with a nut using a torque wrench (Photograph 2 (6)). Confining load of 30kN can be exactly maintained by setting torque. By use of this construction method, rapid construction of CRE becomes possible making it practical enough to apply this CRE for road in service. Photograph 3 shows the application of CRE for seismic retrofit of asphalt pavement on the actual highway embankment in Joban Highway, Fukushima, Japan, constructed in 2011.

Photograph 3. Application of Confined-Reinforced Earth for actual highway embankment in Joban Highway, Fukushima, Japan, 2011.

4 FULL SCALE IN-SITU TEST

4.1 Trial embankment

A full-scale test of this high rigidity reinforced earth was carried out in the field in Ibaraki, Japan, from 9th to 16th March 2011 as shown in Photograph 4. The constructed trial embankment was of 25m length, 4m width and 2.5m height at the top of embankment. Full-scale asphalt pavements were placed on the trial embankment. The asphalt concrete pavement consisted of asphalt concrete of 50mm thickness and base course of 300mm thickness. Two types of asphalt pavement were constructed. The first type was conventional asphalt concrete pavement placed on the compacted soil subgrade, while the second was asphalt pavement placed on the high rigidity confined-reinforced earth consisting of the crushed stone sandwiched by four layers of geosynthetics and confined by confining rigid anchors.

We aimed at direct comparison of performance of the two pavement types by artificially generating the differential settlement of trial embankment such as often seen during severe earthquakes. The forced differential settlement of the embankment was realized by using 10 multi-controlled large hydraulic jacks supporting the steel deck (10m long) placed under the embankment body. The layout of the trial embankment is shown in Figure 2.

Photograph 4. Trial embankment after testing of 550mm differential settlement. (Confined –Reinforced Earth tested in Ibaraki, Japan, 2011)

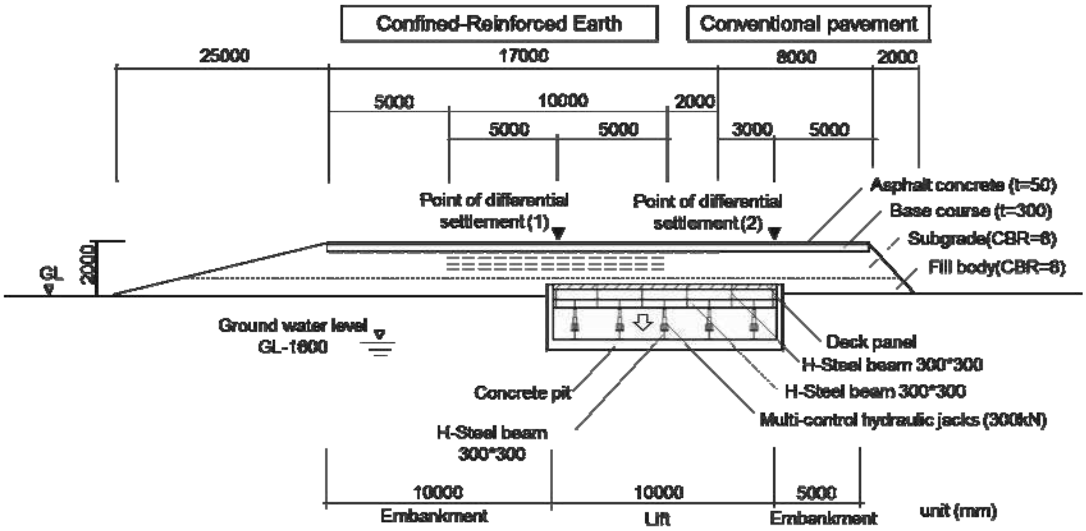
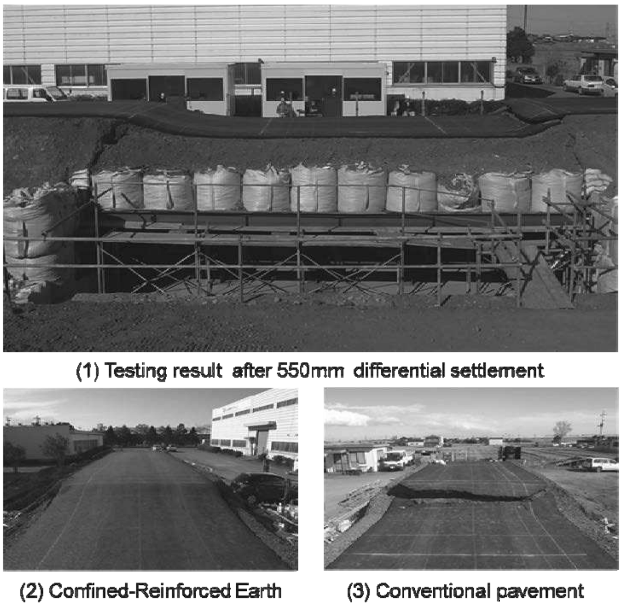


Figure 2. Layout of the trial embankment (Constructed and tested in Ibaraki, Japan, 2011)



Photographs 5. Deformation performance of Confined–Reinforced Earth (550mm differential settlement, tested in Ibaraki, Japan, 2011).

4.2 Deformation performance

Trial embankment after testing looks as shown in Photographs 5. It is clearly observed that the central part of road is artificially lowered by 550mm. Experimental results indicate that use of the newly developed high rigidity confined-reinforced earth (CRE) can maintain the minimum road usability for vehicles even when the amount of differential settlement reaches approximately 600 mm.

Although the asphalt pavement settles together with the embankment, there is no crack or sharp gap in the CRE pavement shown in Photograph 5 (2). Instead, the CRE asphalt pavement settled in a gentle curve as shown in Figure 3. Conversely, in the case of conventional asphalt pavement, the asphalt pavement splits resulting in a step-like gap that started to appear when the forced settlement reached approximately 200 mm. The gap at the stage of differential settlement of 550 mm is shown in Photograph 5 (3).

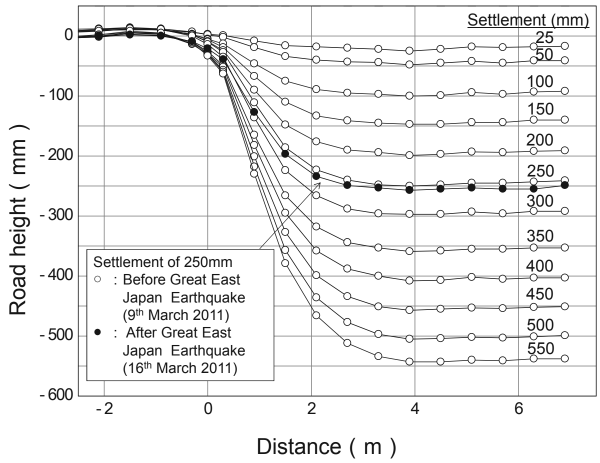


Figure 3. Surface deformation profile of asphalt concrete pavement reinforced by Confined-Reinforced Earth.

4.3 Seismic performance

On 11th March, 2011, the Great East Japan Earthquake of Magnitude 9 occurred during the test when the settlement was 250mm. About 200gal of seismic power acted on the trial embankment. Deformation of CRE being compared with conventional pavement before and after the earthquake is shown in Photographs 6. Figure 3 also shows that excessive deformation of CRE did not occur after the earthquake.

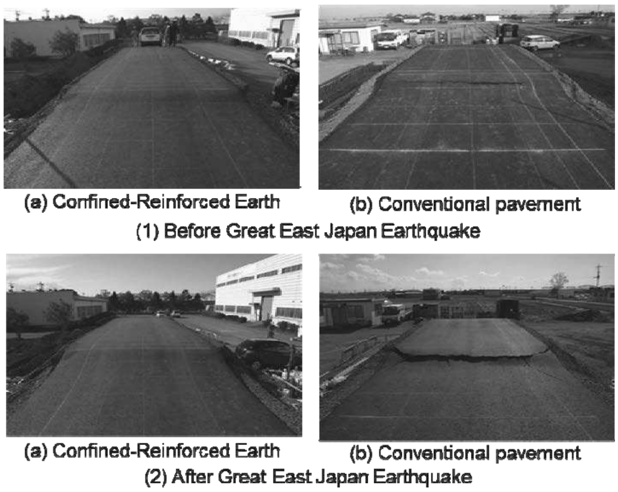
There was no additional crack or gap in the CRE pavement after the earthquake as seen in Photographs 6. Conversely, in the case of conventional asphalt pavement, the cracks of asphalt pavement further opened after the earthquake.

Photograph 7 shows the perfect soundness of CRE as seen in the structure of the asphalt pavement after the earthquake. Only small amount of additional deformation of the CRE structure was observed after the severe earthquake as shown in Figure 3.

4.4 Traficability

Photographs 8 show the trafficability tests of asphalt concrete pavement reinforced by CRE after 550mm differential settlement. The longitudinal curve of CRE is gentle enough for all types of vehicles to drive at low speed. Conversely, in the case of conventional asphalt pavement, it is obviously impossible for vehicles to drive in such conditions.

The authors consider that the high rigidity subgrade using the confined-reinforced earth can contribute to the construction of



Photographs 6. Seismic performance of Confined–Reinforced Earth (Tested in Ibaraki, Japan, 2011).

Photograph 7. Longitudinal cross section of Confined–Reinforced Earth and asphalt pavement after the Great East Japan Earthquake (550mm differential settlement).

Photographs 8. Traficability tests of Confined-Reinforced Earth

safer and more durable roads and can be used as an anti-earthquake measure to prepare roads for damage from major earthquakes as well as a measure against excessive differential settlement of road embankments placed in vicinity to box culverts and/or bridge abutments.

5 CONCLUSIONS

The structure of the seismic retrofit technique for asphalt concrete pavements using Confined-Reinforced Earth (CRE), construction method and the results of full scale in-situ tests were described. Full scale in-situ tests show the acceptable performance of CRE after the forced settlement to simulate the severe earthquake-induced damage.

After experiencing the acceptable performance of high rigidity confined-reinforced earth observed at trial embankment, we still had two major technical problems related to (1) relaxation of pre-stresses and (2) materials unfavourable to be used. Apparently the degree of time dependency of the relaxation of pre-stresses depends on the kind of compacted material and degree of compaction. Distinct definition and complete rejection of unfavourable materials are also unavoidable factors to guarantee successful performance. To avoid the difficulties arising from these two problems, the authors have decided to use only crushed stones (and crushed concrete) traditionally used as the base course materials. The authors have also decided not to make the design of confined-reinforced earth too much relying on the high level of pre-stresses being implemented, i.e., the authors intend to make design procedure that requires just confinement on the movement of crushed stone particles and requires moderate pre-stressing. In the course of developing reinforced earth technology, the authors have tried to find out practical methods of specifying the material parameters of compacted materials and compacted crushed stones used in the reinforced earth structures. Some of these methods are concisely summarized by Ohta et al. (2007) and by Ishigaki et al. (2008).

The seismic retrofit technique for asphalt concrete pavements using CRE gives minimum functionality of roads for vehicle access which is essential for initial emergency response such as lifesaving and firefighting activities, as well as for emergency restoration of plant functionality and other aspects of corporate Business Continuity Plans (BCP).

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