Development and Field Application of Slurried-Cement Foamed Asphalt (SCFA) Stabilization

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ABSTRACT: On-site recycling of asphalt pavement can produce highly durable pavement that is as rigid as cement stabilized base and is suitably flexible because it contains foamed asphalt. However, the method produces dusts while spreading and mixing cement, which may adversely affect roadside environments. Dust-preventive cement is used as a solution and is effective up to a certain degree but cannot control dusts completely. Thus, the authors developed a technology that involves spreading cement after processing into slurry.

When cement is processed into slurry, hydration starts immediately after mixing, and the slurry undergoes time-historical changes in properties, such as workability and strength. The authors investigated the working time of slurry in laboratory and developed a machine (slurry machine) for spreading slurried cement fast and accurately on site. Accelerated loading test was conducted to check the durability of slurried-cement foamed asphalt (SCFA) stabilized base, which was shown to be sufficiently durable and have equivalent or better properties than ordinary bituminous cement stabilized base.

A field application of the method, which was executed by measuring the amount of dust at each working stage, such as while spreading slurried cement, showed that the values at every stages were similar to the amount before execution and that the method did not produce dusts. The resultant stabilized base also improved the bearing capacity of the pavement, showing that SCFA stabilization is also an effective method for reducing vibration.

KEY WORDS: Slurried cement, foamed asphalt, dust prevention, accelerated loading test.

1 INTRODUCTION

Recycling of pavement wastes has attracted attention these years from the viewpoint of protecting the global environment and actualizing recyclable social infrastructures. Cement foamed asphalt (CFA) stabilization is an on-site method for recycling pavement. The method produces stabilized base that is highly durable over a long period of time, as rigid as cement stabilized base, and suitable flexible because it contains foamed asphalt. On the other hand, the method produces dusts while spreading and mixing cement, which may adversely affect the roadside environments. Dusts are commonly controlled by using dust-preventive cement, which is somehow effective but cannot control dusts completely. The authors have investigated a technology that involves processing cement into slurry and spreading the slurried cement (Onikura et al. 2007, Ebisawa et al. 2008).

Recently, a road in Saitama City, Japan, which passed through agricultural fields, was found to require repairing and restoration of bearing capacity because the asphalt pavement on weak subgrade had deteriorated. Because the subgrade was difficult to improve, it was likely rational to strengthen the existing base. CFA stabilization was decided to be used as it can produce rigid and suitably flexible base and restore the traffic service quickly. In order to control adverse effects of cement dusts on roadside agricultural fields, the aforementioned slurried cement technology was used.

This paper overviews the series of works conducted for developing the technology, including the investigations on the working time of slurried cement, development of a spreading machine, and test applications for checking the durability of resultant pavement. The results of the field application are also described, which showed dust control effects by processing cement into slurry, restoration of the bearing capacity of the base by CFA stabilization, and reductions in vibration of the resultant pavement, which was an issue of the weak ground.

2 DEVELOPMENT OF SLURRIED-CEMENT FOAMED ASPHALT (SCFA) STABILIZATION

To develop the slurried-cement foamed asphalt (SCFA) stabilization method, the working time needed to be investigated for both slurried cement alone and mixed in CFA stabilized mixtures because hydration starts immediately after mixing cement with water for producing slurry. Development of a machine for spreading slurried cement was also decided necessary because it is difficult to spread the required amount of slurried cement fast on site by manpower. CFA stabilized bases that use powder cement have been proven to have the required durability (Katahira et al. 1999), but the durability of bases stabilized using slurried cement has not been investigated. Therefore, accelerated loading tests were conducted to assess the durability. The course of the development is described below.

2.1 Investigating the Working Time of Slurried Cement

Changes in strength of slurried cement alone were investigated by conducting bending and compression strength tests (strength after 7 days of curing, in conformity with JIS R5201) on 3 specimens (ratio of water to cement (W/C) = 60%) prepared 0, 3, and 5 hours after mixing respectively. As shown in Figure 1, the bending strength satisfied the target value of 2.0 MPa at all hours, but the compression strength dropped by leaving the slurry long after mixing and fell below the target value at 5 hours after mixing.

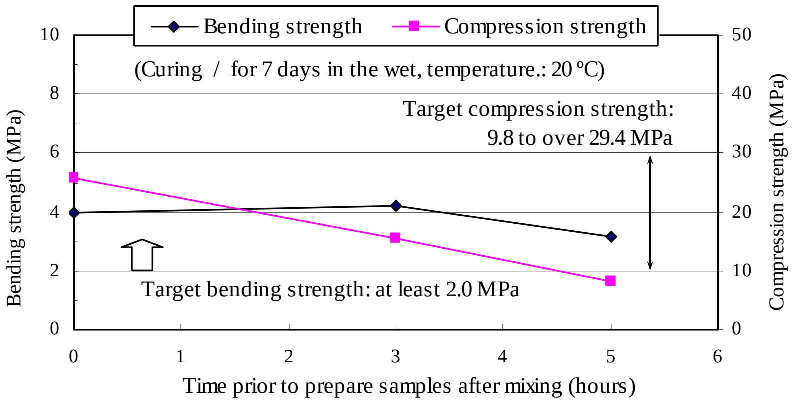


Figure 1: Changes in strength for slurried cement prepared at different time after mixing.

Thus, the working time of slurried cement was estimated to be about 4 hours from the viewpoint of strength although the time may vary by the conditions of the site. The flow value (P funnel) at 4 hours was about 12 seconds, showing satisfactory flowability. Then the mix proportion of SCFA stabilized base mixture was designed using materials of common grain sizes and following the Pavement Recycling Handbook (JRA 2004). Changes in unconfined compression strength and air void of SCFA mixture specimens that were left (until compaction) for different times after mixing are shown in Figure 2. The strength decreased and air void increased as the mixture was left longer, but the specimen left for about 5 hours was found to satisfy the target value.

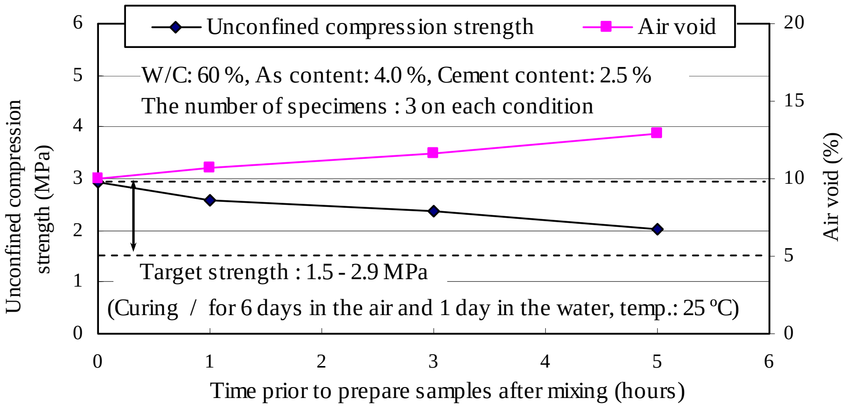


Figure 2: Changes in strength and air void for SCFA prepared at different time after mixing.

2.2 Developing a Machine for Spreading Slurried Cement

A machine (slurry machine) was developed for spreading slurried cement fast and accurately on site. An external appearance of the machine is shown in Figure 3. The machine has the following characteristics:

1) The tank of the machine is equipped with a mixing device to prevent slurried cement from separating.
2) There are 4 sets of nozzles and spreading plates to uniformly spread slurried cement.
3) The amount of slurried cement to be spread is controlled automatically interlocked with the traveling speed of the machine.
4) The machine is equipped with a scarifier to cut ditches for preventing the spread slurried cement from flowing out from the base course surface.

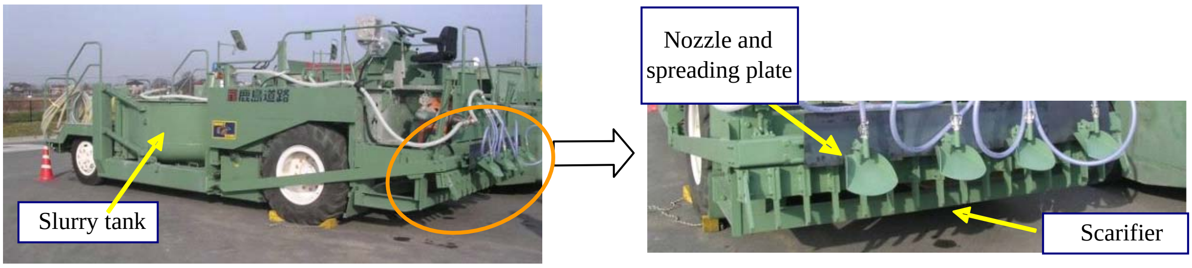
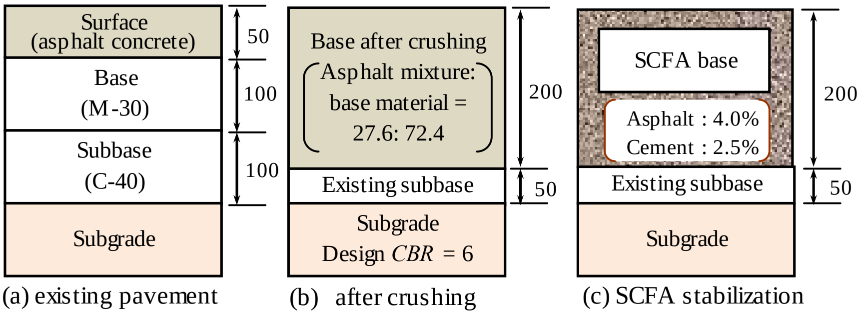


Figure 3: External view of the slurry machine.

The work consists of two lines : 1) production and transportation of slurried cement, and 2) on-site works. Slurried cement is prepared at a concrete plant, transported on an agitator truck, and loaded on the slurry machine at the site.

2.3 Durability Assessment by Accelerated Loading Test

In order to assess the durability of SCFA stabilized base, accelerated loading test was conducted in February 2006 at Kurihashi Techno Center of Kajima Road Co., Ltd. The cross section of the pavement tested in Figure 4 had a design traffic volume equivalent to N_3, and a wheel that was adjusted to 49 kN was passed for the fatigue failure number of 30,000 (Ebisawa et al. 2008). Length and width of the test section was 16 m and 2 m respectively.



(a) existing pavement (b) after crushing (c) SCFA stabilization

Figure 4: Cross section of the pavement at the accelerated loading test yard (unit: mm).

2.3.1 Configuration of Road Surface

After wheel passes of 30,000, the rut depth and cracking ratio were determined. Cracking ratio was defined as the ratio of sum of gridded surface areas (0.5 m x 0.5 m) having cracks to investigation area of the test section (8 m x 2 m = 16 m^2). The rut depth was about 8 mm, and the cracking ratio was about 16%. Both were sufficiently smaller than the target values (rut depth: 30 to 40 mm, cracking ratio: 30% to 40%) (JRA 1978) of ordinary roads of large traffic volumes, with which the need of repairing is judged, showing that the configuration of the road surface was satisfactory. The cracks reached a depth of 5 cm from the pavement surface, forming damage similar to top down cracking.

2.3.2 Bearing Capacity of Pavement

The deflection curves at each step determined at the center of the yard with a falling weight deflectometer (FWD) are shown in Figure 5. The deflection values at each sensor position are the means of the values at two measurement points after correcting into values for the standard load (49 kN).

The figure shows that stabilization of the granular base decreased deflections within a range of 30 cm from the centre of the loading plate, showing improved rigidity of the base course. Deflection after 30,000 wheel passes was similar to that soon after construction, showing that the bearing capacity did not drop.

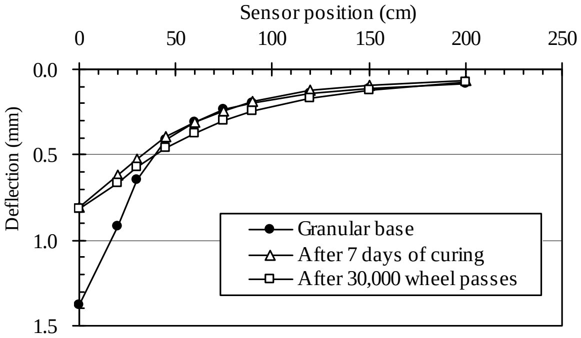


Figure 5: Deflection curves after crushing, 7 days of curing and 30,000 wheel passes.

The modulus of elasticity of each layer was determined by conducting back-calculation (BALM 99) of a two-layer model (25 cm base course and subgrade). Using Equation (1), which is a modification of the equation (AASHTO 1986) for calculating the layer equivalency factor a_i of AASHTO so as to agree with the actual conditions in Japan, a_i was estimated for the base courses. The results are shown in Table 1.

$$a_i = 0.623\log(E) - 1.095 \tag{1}$$

where, E is the modulus of elasticity of the base (MPa).

Table 1 Results of back-calculation and estimated layer equivalency factor of base course.

Time tested	Modulus of elasticity (MPa)		Estimated ai of the base course
	Base course	Subgrade	
Granular base course	231.6	73.2	0.38
SCFA after 7 days of curing	675.5	78.7	0.67
After 30,000 wheel passes	831.9	63.9	0.72

As shown in Table 1, the a_i of the granular base course was 0.38 but was as large as 0.67 in the SCFA stabilized base after 7 days of curing, which is almost equivalent to the a_i (0.65) of bituminous cement stabilized base shown in Attached Table 4.1 in the Guideline for Design and Construction of Pavement (JRA 2006). After 30,000 wheel passes, a_i did not decrease but increased to 0.72, showing that the structural bearing capacity did not drop.

3 FIELD APPLICATION OF SCFA STABILIZATION

3.1 Overview of the Project

The overview of the project is shown in Table 2. As described in Introduction, the said road passes through agricultural fields, and the asphalt concrete pavement on weak subgrade with a design CBR smaller than 3 was to be repaired.

Table 2: Overview of the project.

Item	Contents
Title of the project	Repairing City Road L867-1
Owner	Road Maintenance Section, South Construction office, Construction Department, Saitama City Government
Site	Miura, Minato-ku, Saitama City
Dates	March 11 and 12, 2008
Scale of the project	Length: 385 m, width: 4.2 m, execution area: 1,620 m^2
Design CBR	1 (weak subgrade)
Design traffic volume of the pavement	N_3 (less than 100 vehicles/day per direction) (Fatigue failure wheel passes: 30,000 passes/10 years)

3.2 Preliminary Surveys (Configuration of the Road Surface and the Bearing Capacity of Pavement)

As shown in Figure 6, alligator cracks had developed throughout the entire section, where many patches were also observed. The smoothness (σ_{3m}: standard deviation of unevenness at

1.5 m intervals) was about 4 mm and required repairing.

The bearing capacity of the pavement structure was measured using FWD. Deflection D_0 at the center of the loading plate was about 2.4 mm at all points measured, far exceeding the standard value of 1.2 mm (Abe et al. 1993) of the road, showing that the bearing capacity was insufficient.

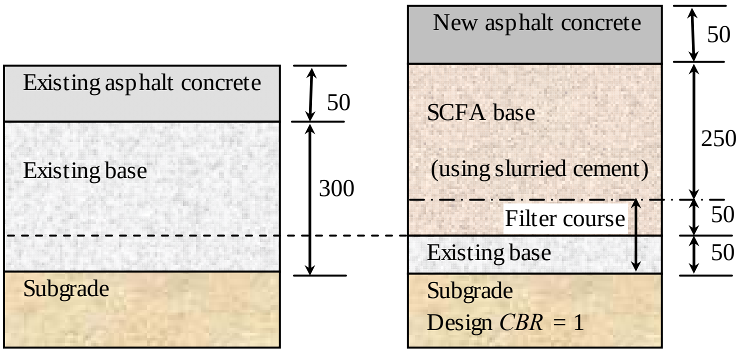
(a) panorama (b) close-up

Figure 6: Typical surface condition ((a) panorama, (b) close-up).

3.3 Investigating Pavement Section

As described above, the subgrade of the road was weak, and both the road surface configurations and bearing capacity had been seriously deteriorated. Removing existing pavement and improving the subgrade should have been executed, but were not economically advantageous and required to regulate traffic over a long period of time. Instead, the bearing capacity of the entire pavement was decided to be enhanced by stabilizing the existing base. Cement stabilization was also applicable if it was to simply strengthen the base. However, flexibility was also required to control cracks because the subgrade was weak.

It was decided to stabilize the 30 cm section of the existing asphalt concrete pavement and base course with SCFA and overlay 5 cm of new asphalt concrete pavement as shown in Figure 7. Assuming mixing of the subgrade soil, the 5 cm of the existing base plus the lower 5 cm of the SCFA stabilized base were treated as a filter course to prevent the intrusion of the subgrade soil into the base and was not included in evaluating the bearing capacity of the designed pavement.



(a) before repairing (b) after repairing

Figure 7: Cross section of pavement (unit: mm) ((a) before repairing, (b) after repairing).

3.4 Contents and Results of the Field Surveys

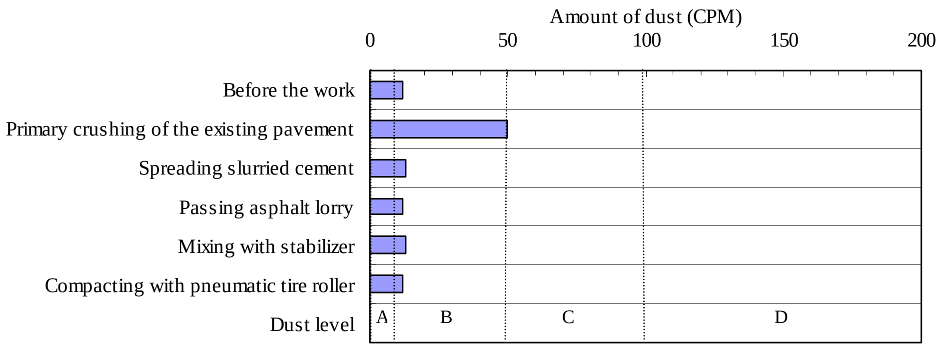
The surveys listed in Table 3 were conducted before, during and after execution to check the effects of slurried cement on reducing dusts during execution, the improvement of the bearing capacity and reduction of vibration by traffic load.

Table 3: Contents of surveys.

	Item	Content
During execution	Dust	Measuring with dust meter and anemometer
Before and after execution	Bearing capacity of pavement	Measuring deflection with FWD
	Vibration reduction	Measuring vibration caused by FWD

3.4.1 Dust Measurement during Construction

The amounts of dusts were measured using a dust meter (Shibata, P-5L2) at every execution stages including before execution. The results are shown in Figure 8. The levels and states of dusts are also shown in the figure (JRA 2007). Dusts were measured at 1.6 m from the dust source (the working machine). A view of the measurement is shown in Figure 9. Wind velocity and air temperature were also measured to understand the effects of the surrounding environment. As Figure 8 shows, almost no dust was produced while spreading slurried cement and mixing cement using stabilizer. Processing cement into slurry was quantitatively shown to be effective in controlling dusts.



Level	CPM range	Dust suspension state
A	1 - 10	In a relatively clean room
B	20 - 50	On pedestrian pass along a highway of a heavy traffic volume
	10 - 30	In relatively crowded train
C	50 - 100	Within an asphalt concrete plant
	about 50	Almost no dust is felt during field work
D	100 - 200	Within an asphalt concrete plant while a dump truck passes
	about 200	Dust is felt but only slightly

*The amount of dust is expressed in CPM (count per minute)

Figure 8: Amount of dusts during SCFA stabilization work.

Figure 9: View of dust measurement.

3.4.2 Evaluation of the Bearing Capacity of Pavement

On the 15th day from the SCFA stabilization, the bearing capacity of the pavement was measured with FWD. The bearing capacity of the entire pavement, including the subgrade, was evaluated from deflection D_0. From Figure 10, as mentioned previously, the pavement before the work was far insufficient in bearing capacity with a deflection value far exceeding the standard value (1.2 mm), on the other hand, after the SCFA stabilization, the value was below the standard value, showing that the bearing capacity was restored to the required level.

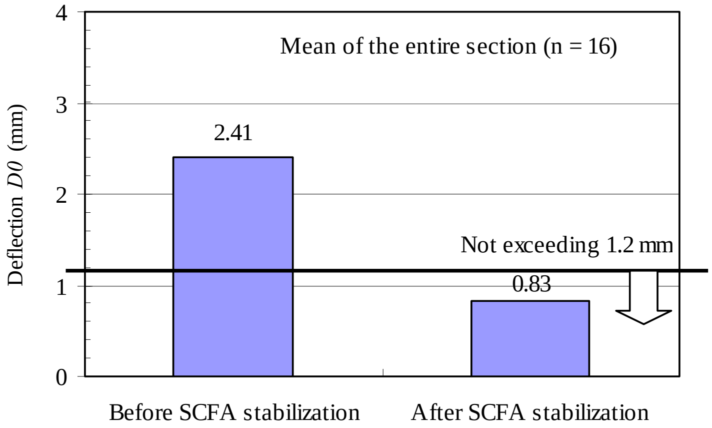


Figure 10: Profile of deflection D_0.

The *CBR* of the subgrade was estimated by substituting deflection D_{150} (mm) at the position 150 cm distant from the center of the loading plate into Equation (2) (Abe et al. 1993) and is shown in Figure 11 for before and after the work.

$$CBR = \frac{1}{D_{150}} \tag{2}$$

CBR was smaller than 3 as a whole before and after the work, showing that the subgrade falls within the category of weak subgrade. However, *CBR* was slightly larger after the work likely because the SCFA stabilization improved the bearing capacity of the entire pavement and increased the load distribution performance, and reduced the load to the subgrade.

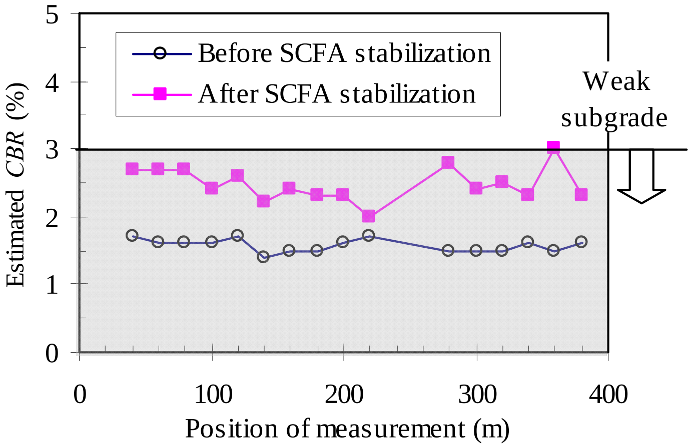


Figure 11: *CBR* before and after SCFA stabilization.

3.4.3 Evaluating the Reduction in Vibration by the Improvement of the Bearing Capacity of the Pavement

To understand how much vibration is reduced by the improvement of the bearing capacity of the pavement, vibration was measured on the pavement by using FWD as a vibration source in Figure 12.

The load and vibration acceleration (peak value) were measured before and after SCFA stabilization while applying load with FWD, and the values before and after the stabilization were compared by converting the values into vibration acceleration values for the standard load of 49 kN. The results are shown in Figure 13.

As shown in the figure, the vibration acceleration levels were 5 to 8 dB smaller after the SCFA stabilization than before the stabilization regardless of distances between the vibration source and vibration detector. This showed that the improvement of the bearing capacity of pavement was effective for reducing vibration. Traffic vibration is the vibration of the ground caused by vehicles traveling on roads and is known to be affected by level differences and smoothness of the road surface (Iwasaki et al. 1977). Total evaluation will be needed by also taking these effects into account.

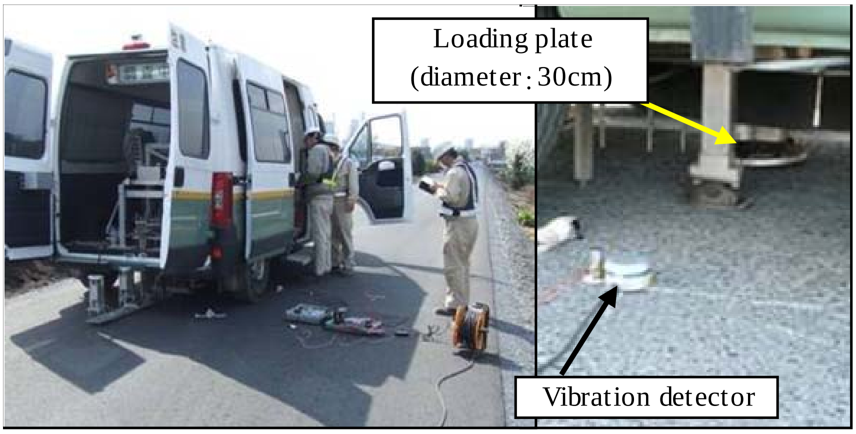


Figure 12: Vibration survey using FWD.

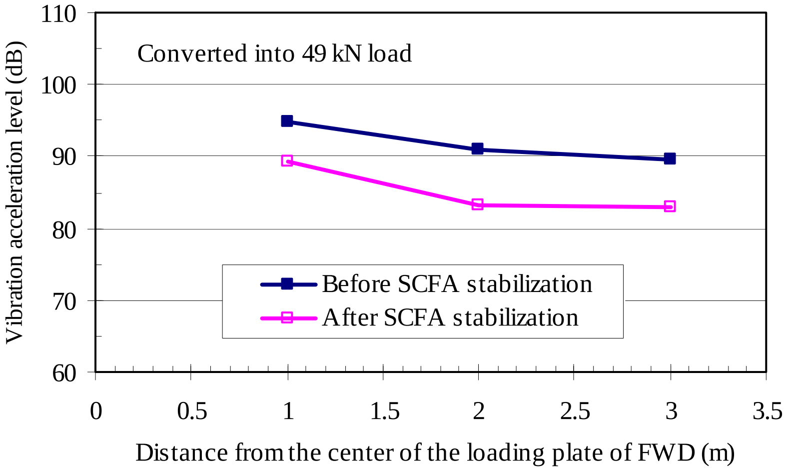


Figure 13: Vibration acceleration level in FWD (49 kN loading).

4 SUMMARY

The results of the investigations on SCFA stabilization are summarized below:

1) Processing cement into slurry was devised, and a spreading machine was developed to control dusts while spreading and mixing cement.
2) Accelerated loading test was performed to check the long-term durability, and the layer equivalency factor was estimated using FWD. The factor was found to be equivalent or larger than 0.65, which is the factor of bituminous cement stabilization.
3) Dusts were measured at all stages of an on-site application of the SCFA stabilization, including while spreading slurried cement. The amount of dusts was similar to the value before the work, and no dust production was observed.
4) The CFA stabilization method can improve the bearing capacity of pavement and is likely effective also for reducing vibration.

5 CONCLUSION

To execute CFA stabilization, cement was processed into slurry to control dusts. Because various investigations showed good results, the method was used for repairing an actual road, and the application showed that the method could effectively produce required results, such as controlling dusts and improving bearing capacity.

Because the road on which the method was used had a weak subgrade of a design *CBR* smaller than 3, a follow-up survey will be executed to carefully monitor the changes in serviceability.

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