Development of Cement Foamed-Asphalt Stabilization Technology in Japan

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ABSTRACT: The cold stabilization method using foamed asphalt is applied to all parts of the world as the method which is excellent for saving energy and natural resources. However, there are a few differences in the mixture proportion or the construction method for foamed asphalt stabilization, depending on traffic conditions or weather conditions of the area (country) where it is introduced. In Japan, the in-place base course recycling in which both cement and asphalt are mixed with existing base course materials at the in-situ position is used widely as CFA method (Cement Foamed-Asphalt stabilization method), taking high temperature and humidity into consideration. With this construction method, the cumulative total area as many as 5 million square meters has been achieved since 1997. This paper describes CFA method in Japan.

KEY WORDS: Foamed asphalt ,CFA, CO_2, cost

1. INTRODUCTION

At the United Nations Framework Convention on Climate Change Conference of 3rd. held in Kyoto on December 1997, the protocol was adopted that the amount of greenhouse gases emission in Japan should be reduced by at least 6% from 2008 to 2012 on the average as compared with the level in 1990. Given the adoption of this framework, the whole society in Japan takes a very deep interest in saving natural resources and energy etc. The road industry has also been carrying various researches and developing technologies about pavement contributing to reduction in environmental burden.

Against the background of this situation, CFA Engineering Association organized by five pavement companies in Japan has started around 1997 the development of materials of a stabilized base used with foamed asphalt and cement, which contribute to saving resources and energy and reducing CO_2 emissions. Since then, the Association has been continuing research and public relations activities regarding CFA method.

This paper describes how we take both foamed asphalt and cement, and instances of construction.

2. FOAMED ASPHALT

2.1 Feature of Foamed Asphalt

Foamed asphalt is a bubbly material foamed by adding a very small quantity of water or vapor to the hot asphalt within a control device. The volume of foamed asphalt expands immediately ten to twenty times as large as that of the original liquid asphalt. Under this condition, the viscosity of asphalt decreases considerably, and mixing it with wet aggregate in wet condition becomes possible at normal temperature.

Relationship between the amount of water (water-asphalt ratio) and the properties of foamed asphalt is shown in figure 1. If water is added more, the expansion ratio is higher, on the other hand, the half-life time is shorter, which is the time from when the volume of foam is the largest to when it reduced by half. Therefore it is necessary that the water-asphalt ratio should be determined within the range where the expansion ratio is ten times or more (approximately from 10 to 20 times) and the half-life time is ten seconds or more (approximately from 10 to 20 seconds). The water-asphalt ratio is normally from 1.5 to 2.5 % (see Figure 1).

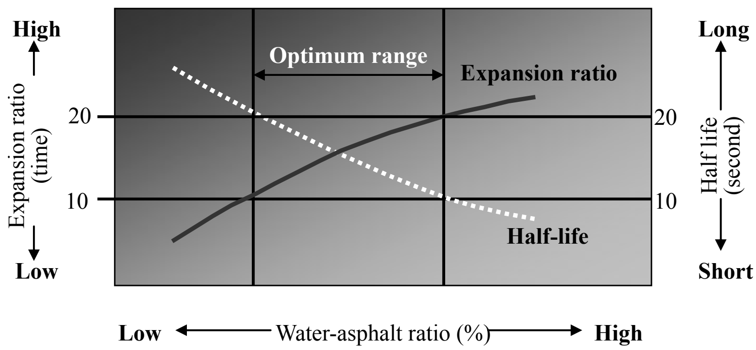


Figure 1: Relationship between water-asphalt ratio and foaming properties

2.2 Foam Equipment

There are two types of the foam equipment used in Japan such as the distribution type and the independent type (see Figure 2). The former distributes the asphalt that was foamed in the mixing chamber through the piping to spray nozzles. On the other hand, the latter makes foamed asphalt at the tip end of independent spray nozzles, because a spray nozzle has been integrated with a mix chamber.

2.3 Mechanism of Foamed Asphalt

Foamed asphalt dose not coat coarse aggregate but forms filler-bitumen with fine particles in the mixture of foamed asphalt and aggregate. This filler-bitumen is distributed uniformly as a small lump in the mixture, and bonds between coarse aggregate like spot welding when compacted by rolling equipment, thus strength in the mechanism rises.

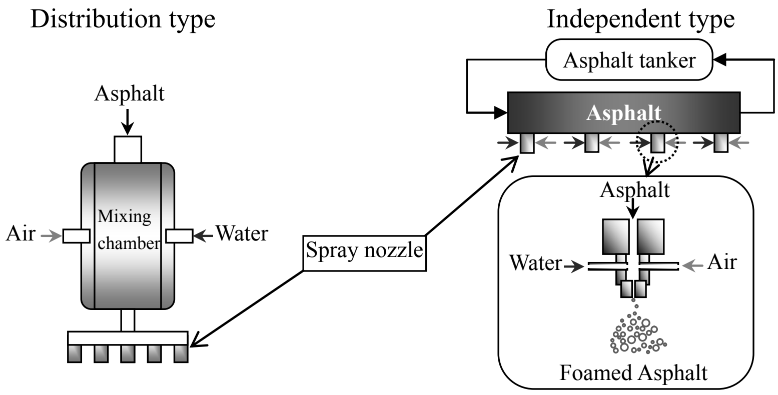


Figure 2: Foam equipment

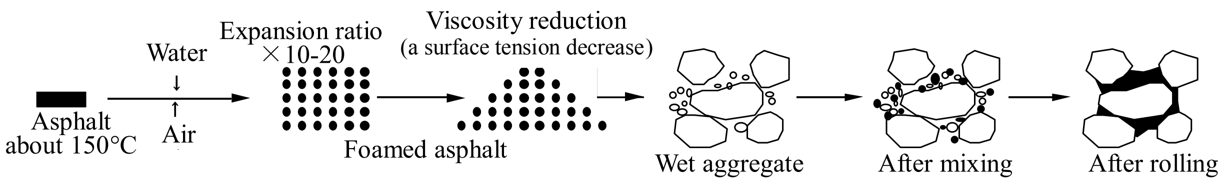


Figure 3: Mechanism of foamed asphalt

3. CFA Method

The stabilization method using foamed asphalt mainly is applied to recycling base course in-situ using cement together as the CFA Method in Japan now. Features, applications, materials, tests, and examples are described below.

3.1 Features of CFA Method

Features of the CFA method are as follows:

(1) This method can reduce carbon dioxide emissions: it is a cold mixing, therefore, energy for heating aggregate is unnecessary.

(2) This method achieves resource conservation and cost reduction: it constructs the recycled base in situ, and therefore, new materials are not required.

(3) This method reduces the burden on road users and residents in the neighborhood: its cost for the construction is lower and its progress of a project is faster than those of the reconstruction method, therefore it can shorten the construction period

(4) This method is excellent in durability: it has flexibility, therefore, it is unlikely to cause cracks on the surface.

(5) This method allows an early traffic opening to realize: the strength increases fast, and there is no need for curing after stabilization.

3.2 Application and Structural Design

When the CFA method is applied to recycling base course in-situ, it is desirable that base course materials of more than 10 cm is left, which work as subbase course, between the recycled base course and subgrade.

It is necessary to investigate whether the buried piping exists before the construction with the CFA method. General finished thickness of the CFA method is 10 to 30 cm. But, if the finished thickness is larger than 20cm, it is necessary to use a vibratory roller that offers highly effective compaction.

The coefficient of relative strength (compared to asphalt surface course) for the CFA method is 0.65 by T_A method in Japan, and a greater value is set compared with other in-place recycled base course methods using only cement. (see Table 1).

Table 1: Coefficient of relative strength of in-place recycling base course

Method	Standard	Coefficient of relative strength	Thickness (cm)
Recycled cement stabilization	Unconfined compressive strength (7 days) 2.45 MPa	0.50	15 to 30
Recycled cement stabilization(Only existing recycled granular materials.)	Unconfined compressive strength (7 days) 2.9 MPa	0.55	
Recycled cement foamed asphalt stabilization (CFA method)	Unconfined compressive strength: 1.5 to 2.9 MPa Displacement: 5 to 30 (1/100 cm) Residual intensity ratio: 65% or more	0.65	10 to 30

3.3 Materials

Materials used in the CFA method are cement, asphalt, and base course materials. Typically, we use Portland cement or slag cement, and we use the asphalt whose penetration grade is from 60 to 80 or from 80 to 100. Base course materials is recycled one that is obtained by crushing and mixing pavement in situ, added supplementary material such as crusher-run, and the quality of modified CBR, PI (Plasticity Index), and gradation confirmed in advance.(see Table2).

Table 2: Quality of aggregate using in-place recycling basecourse

Modified CBR	PI	Gradation envelope					
		Sieve size (mm)	53.0	37.5	19.0	2.36	0.075
20 or more	9 or less	Weight percentage of the fraction passing a sieve (%)	100	95～100	50～100	20～60	0～15

3.4 Mixing Test

In the CFA method mix design, firstly, foamed asphalt content is calculated from the gradation of base course materials, secondly, optimum moisture content is determined, and thirdly, the common range of cement contents where all properties, obtained from Marshall unconfined compression test, conform to standards is found, before the cement content is determined as the median of the common range. (see Figure 4)
Table 3 shows the testing condition of Marshall unconfined compression test.

Table 3: Marshall unconfined compression test

Item	Condition etc.,
Size of specimen	φ101.6mm×68.0mm
Condition of curing	6 days (air) 1 day(water)
Rate of loading	1 mm/min

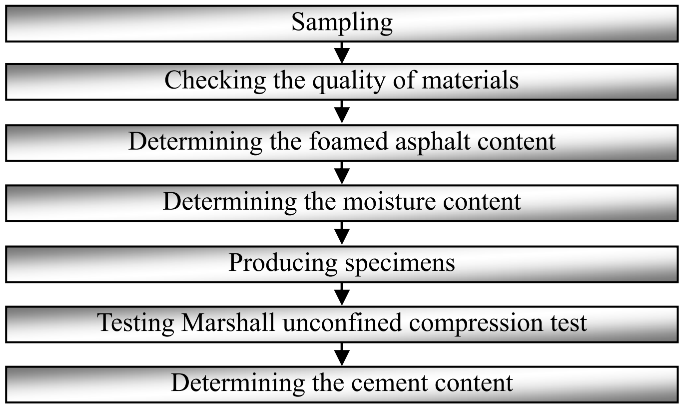


Figure 4: Flowchart of CFA mix design

(1) Foamed asphalt content

Foamed asphalt content that will be added is calculated from the gradation of base course materials. (see equation (1))

$$p = 0.03 \times a + 0.05 \times b + 0.2 \times c \qquad (1)$$

p : Mass percentage of foamed asphalt to recycled base course materials (%). The lower limit of the asphalt content is 3.5%, and the upper limit is 5.5%.

a : Mass percentage of recycled base course materials remaining on 2.36mm sieve (%)

b : Mass percentage of recycled base course materials passing through 2.36mm sieve, but remaining on 0.075mm sieve (%)

c : Mass percentage of recycled base course materials passing through 0.075 mm sieve (%)

The equation is established by approximating the actual asphalt content used for the CFA method so far in Japan. The correlation between the actual asphalt contents and the asphalt content obtained from equation (1) is shown in Figure 5.

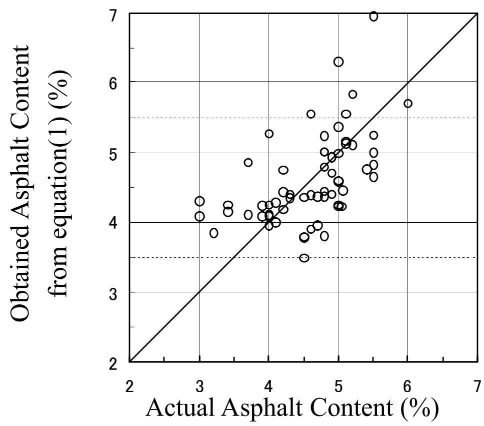


Figure 5: Relationship between actual asphalt content and obtained one from equation (1)

(2) Optimum moisture content

Usually, a mixture for mixing test will be mixed with 2.5 % cement content and with the foamed asphalt content calculated from the gradation of base course materials. The moisture content changes in five different contents with 1 % increments, using the expected optimum moisture content as the median content. The moisture content that provides the maximum dry density is determined from the relationship between the moisture content and dry density that is obtained from compaction test.

In addition, the materials are put into mixture in order of aggregate, cement, water (for adjustment), and foamed asphalt, before compaction using a Marshall rammer with fifty times on both sides so that specimens should be 68.0±1.3 mm thick.

(3) Making and curing of test pieces for Marshall unconfined compression test

Specimen for an unconfined compression test is fabricated as described above. The cement content is set with three values of 1.0%, 2.5%, and 4.0%. The specimen are cured in the air at 25℃ for 6 days before submerged in water at 25℃ for 1 day. The water absorption is calculated from the difference in the mass of the specimen before and after curing in water.

(4) Unconfined compression test (Marshal1 unconfined compression test)

After the above curing, the specimen are immersed in water at 30±1°C for 30 minutes. After immersion, immediately, they are tested by an unconfined compression test at a compression speed of 1 mm per minute. The compressive strength and displacement of the specimen are determined using the compressive strength-displacement curve created from the test results, and the residual intensity ratio is calculated from (2). The cement content to be added will be determined as a median of the common cement content range to meet the all CFA standards (see Figure 6, (2), and Table 4).

$$\text{Residual intensity ratio: } \sigma_r = \sigma_{2L_1} \div \sigma_m \times 100 \qquad (2)$$

σ_m : Unconfined compressive strength (N/mm^2)

σ_{2L_1} : Retained unconfined Compressive Strength (N/mm^2)

L_1 : Displacement (1/10mm)

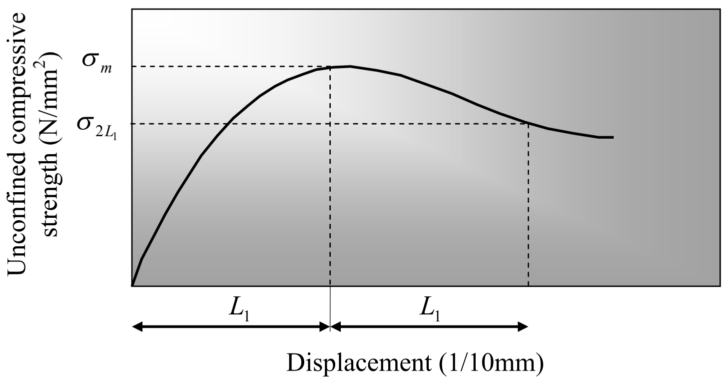


Figure 6: Relationship curve of displacement and unconfined compressive strength

Table 4: CFA standard values

Unconfined compressive strength	1.5 ～ 2.9 N/mm^2
Displacement	5 ～ 30 (1/10 mm)
Residual intensity ratio	65% or more

(5) Additive amount of stability material and property

The following relations are shown among properties measured in the unconfined compression test, asphalt content, and cement content. :

1) Unconfined compressive strength decreases as foamed asphalt content increases, and increases as cement content increases (see Figure 7).

2) The residual intensity ratio increases as asphalt content increases, and decreases as cement content increases (see Figure 7).

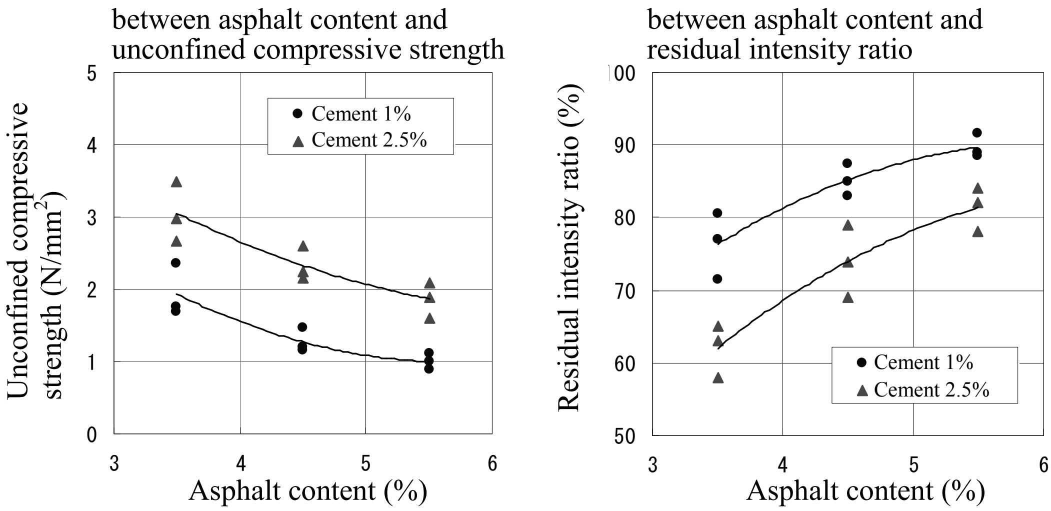


Figure 7: Relationship between asphalt content and properties

3.5 Construction Process

In-place recycled base course by the CFA method is a construction method of crushing existing asphalt concrete, and mixing it at the same time with stabilizer such as cement and foamed asphalt, and with existing base course materials, eventually grading and compacting to construct a stabilized base. If an existing asphalt concrete layer is 10 cm or more thick, only the existing base course may be stabilized after the layer is removed by a road planer.

In the CFA method, we are using construction equipment usually used in the base course construction excluding a stabilizer with foam equipment (see Figure 8).

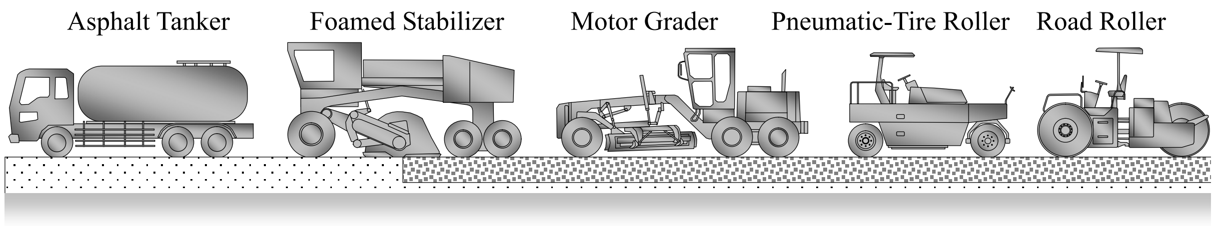


Figure 8: Execution system chart of the CFA method

4. AMOUNT OF CO_2 EMISSIONS AND CONSTRACTOIN COST

The trial calculation on the amount of CO_2 emissions and construction cost was done concerning the case of repairing by means of CFA method so that it could withstand the increase of design traffic volume, and we compared this case with the one of reconstruction method.

Besides, the test calculation of the amount of CO_2 emissions was done according to "Pavement Performance Evaluation Method" in a separate volume (the Japan Road Association). Table 5 and Figure 9 show the calculation condition of amount of CO_2 emissions and construction cost.

Table 5: Calculation condition of carbon-dioxide emissions & construction cost

Item		Producing condition
Design CBR		6
Design traffic volume (number of vehicle/day/direction)	Before repair	From 40 to less than 100 (T_A=16cm)
	After repair	From 100 to less than 250 (T_A=21cm)
Repaired area		700m^2

(T_A: Required thickness of a full depth hot mix asphalt)

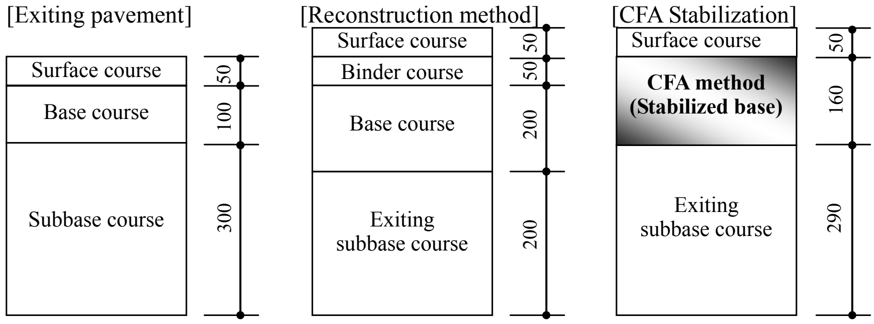


Figure 9: Structures

The Result of calculation is shown as in Figure 10. CFA method made it possible for us to reduce approximately 20% of amount of CO_2 emissions in comparison with reconstruction method. Seeing from each item, it is evident that CO_2 is much emitted in times of construction. This is because in the case of reconstruction method a lot of CO_2 is emitted from constriction vehicles used for both carrying out established materials and carrying in new ones. And it turns out that construction cost is also cheaper than reconstruction method 35%.

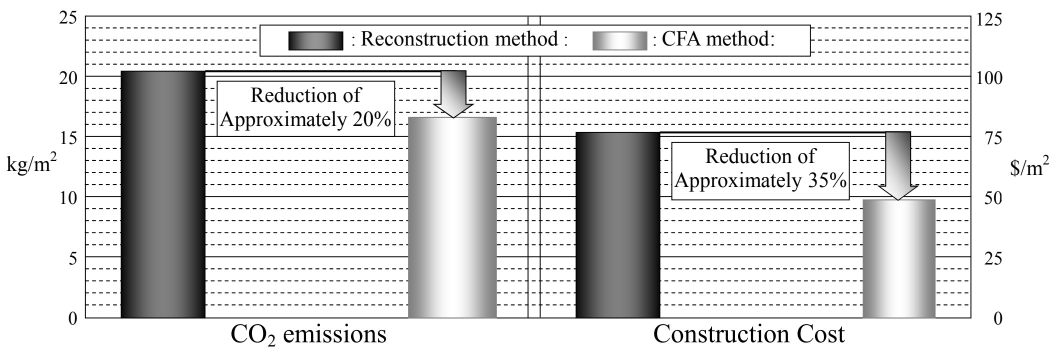


Figure 10: Comparison chart of carbon-dioxide emissions & construction cost

Thus the difference between CFA method and reconstruction method is much influenced by the amount of CO_2 emissions in time of construction.

From this result, we can say that CFA method is an environment-friendly one, meeting the needs of the times in terms of saving resources and reducing CO_2 emissions.

5. CONSTRUCTION EXAMPLE

The CFA method is generally applied to strengthening the structure of the damaged pavement. (in-place base course recycling). The table 6 shows other applications that makes the best use of the feature of CFA method. The application example is the following.

Table 6: Applications of the CFA method

Application example	Content
Re-recycled base	Strengthening of structure, Effective use of existing material
Expressway	Structural build-up when there is limitation in thickness of pavement
Temporary road	Strengthening of structure, Effective use of marginal aggregate
Farm road	Dust laying, Strengthening of structure(Unused in asphalt surface course)

5.1 Application Case

The construction example where the CFA method was applied to in-place recycled base course is described below. The example is an application to a badly damaged road. It was scheduled to be repaired by replacement method using new base course materials. However, CFA method was actually adopted because stabilization leads to effective use of by-product from construction sites (the existing base course material is available).

(1) Site Condition
The mix design used for stabilized base and the pavement structure is shown below. (see Table 7, Figure 11).

Table 7: Mixing ratio and property values

Term	Proportion (%)		Unconfined compressive strength(N/mm^2)	Displacement (1/10 mm)	Residual intensity ratio (%)
	Asphalt	Cement			
Laboratory	4.0	2.5	2.5	15	79.8
Job site			2.4	13	76.8
Standard			1.5 ～ 2.9	5 ～ 30	65 or more

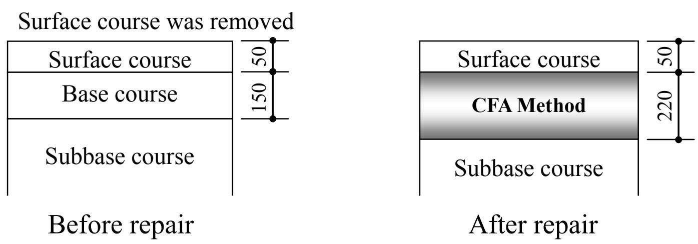
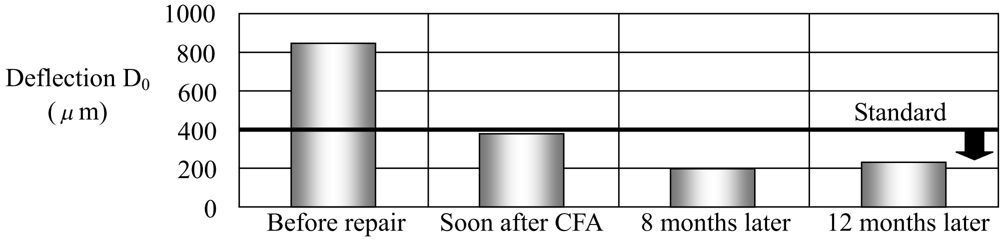


Figure 11: Construction structure

(2) Result

A change over 12 months in bering capacity (deflection) measurements with a falling weight deflectometer (FWD) are given as follows (see Figure 12).

The deflection D_0 was reduced from 900 μ m before repair to 300 μ m after stabilization by the CFA method. It was confirmed that sufficient bearing capacity was secured for the design traffic by having applied the CFA method. Both the deflection D_0 measured 8 months and 12 months later were small values compared with that measured soon after stabilization. It is thought that asphalt mixed in the mixture was extended with the passage of time, increasing the bond strength between aggregates further.



Figete12: Trend of deflection measurements

6. CONCLUSION

With CFA method , the cumulative total area as many as 5million square meters has been achieved since March 1997 in Japan (see Figure 13). We are continuing research and development to aim at spread as the alternative of the hot asphalt mixture, application to new fields.

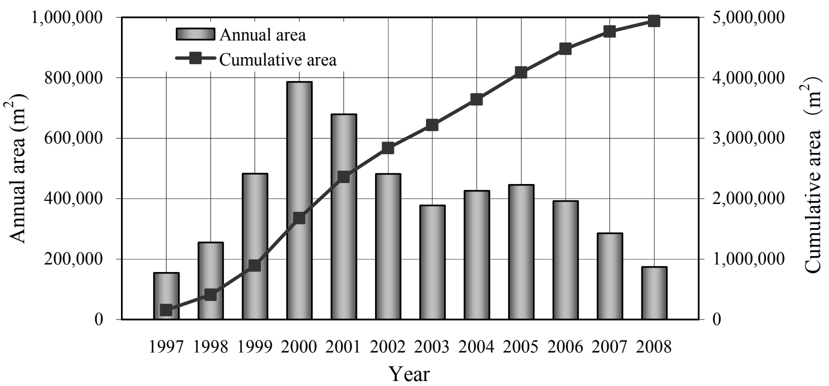


Figure 13: Annual and cumulative achievement area

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