On-site Application of Pedestrian-friendly Pavements using Pressurized Fluidized Bed Combustion Ash and Bamboo Chips

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ABSTRACT: This study aims to develop pedestrian-friendly pavement materials by mixing decomposed granite soil with Pressurized Fluidized Bed Combustion (PFBC) ash and shredded bamboo material (hereinafter called bamboo chips). Eco-friendly materials have been receiving attention for use in paving pedestrian-friendly walkways, such as sidewalks and promenades in parks. The use of soil-based pavements could help resolve environmental problems, but much work still needs to be done to improve the strength of these materials before they can be put into widespread use. One goal of this study was to find ways to effectively utilize coal ash as a stabilizer because the disposal of coal ash has been getting more difficult. Furthermore, in order to make pavements less likely to crack, this study tried mixing bamboo chips crushed to fiber with the paving material. Therefore, this study performed tests to determine the best designs and materials for pedestrian-friendly pavements, evaluating the mechanical and leaching properties of the pavements as well as the toughness gained from on-site construction. The results indicated that in building pedestrian-friendly pavements, adding bamboo chips to the material gives softness to the pavement body that can reduce the strain on the legs of pedestrians, increase safety, and satisfies Japanese geo-environment standards.

KEY WORDS: Pedestrian-friendly pavement, On-site construction, Coal fly ash, Bamboo chips.

1 INTRODUCTION

In recent years, the idea of a pedestrian-friendly soil-based pavement has drawn a great deal of attention because of its advantages in terms of environmental protection, global warming, and the alleviation of the heat-island effect. There have also been growing needs in the landscaping area. Hence, much research and development has been devoted to various pedestrian-friendly pavements. However, there still remain problems with cracking and ablation after paving, so the durability of such a pavement is an unresolved issue (Sato et al., 2006). Consequently, this study was conducted to develop a new pavement material that mixes Pressurized Fluidized Bed Combustion (PFBC) ash and shredded bamboo. PFBC is a type of coal fly ash. Coal fly ash comes from coal-burning facilities such as coal-fired power stations, and about 11.15 million tons of it was produced in 2005, an increase of about 300,000 tons, compared with the previous year in Japan. Furthermore, the demand for coal power generation in the electric industry has been increasing because of the rising price of crude oil in recent years. Considering all this, the use of coal ash is expected to continue increasing. Effective use of coal ash accounts for about 96% of the total. However, the rest of ash has been put in a disposal site. In future, because it has become difficult to secure large-scale disposal sites, it will become increasingly important to expand the effective utilization of coal ash. One possible solution to the problem stems from the fact that coal ash becomes a solid material similar to cement by combustion technology of coal ash (Mori et al., 2006).

A different set of issues affects bamboo chips. The price of domestic bamboo shoots has been in slump, and the production of bamboo shoots has been decreasing as imports have increased and alternate materials have been developed. Therefore, there are more bamboo groves than needed. Still, bamboo must be felled to keep the bamboo groves healthy, and the disposal of this bamboo has become a problem, particularly since bamboo is fibrous and resists decomposition, so it is difficult to dispose of effectively.

In this study, we examine a new method for using both coal ash and bamboo to create pedestrian-friendly pavements. If the PFBC ash was used by itself, we would expect to run into problems such as brittle failure. After paving, it was likely that cracks would form as the material hardened or as the walking load stressed the material. Thus, it was necessary to think about adding materials with a great deal of toughness to resist brittle failure. This study looks not only at how to remedy brittle failure but also at expanding the effective use of bamboo by adding bamboo chips that have been crushed into the fiber state. In short, this study focuses on using PFBC ash as a pavement material, addressing the issue of brittle failure by adding bamboo, and expanding the use of bamboo.

This study performed compression tests for these pedestrian-friendly pavement materials in preparation for later on-site tests. From the testing results, testing condition of on-site test construction was decided. Subsequently, on-site test construction was conducted.

2 SAMPLES AND TESTING PROCEDURE

2.1 Samples

The soil used for the experiments was decomposed granite soil. The coal ash used as the solidification material was PFBC ash generated by a Pressurized Fluidized Bed Combustion system. And, the bamboo chips were used after having been shredded and moisturized. Figure 1 provides particle-size curves for the soil and PFBC ash, and Table 1 gives the physical properties of all three materials. The decomposed granite soil had a wide particle

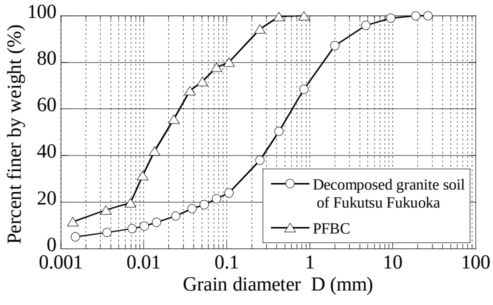


Figure1: Particle-size curves for samples (Decomposed granite soil and PFBC).

size distribution, and the PFBC ash contained a larger percentage of the finer grains than the decomposed granite soil.

Table1: Physical properties of samples.

	Density	Water content	Maximum grain size	Fine grained fractions	Uniformity coefficient	Coefficient of curvature	Plasticity index	Ignition loss
	ρ_s (g/cm^3)	w (%)	D_{max} (mm)	Fc (%)	U_c	U_c'	I_p	Ig-loss (%)
Decomposed granite soil	2.718	12.3	19	21.5	54.9	3.66	N.P.	3.6
PFBC	2.919	0.04	0.85	77.9	—	—	N.P.	—
Bamboo chips	1.514	21.7	—	—	—	—	—	—

2.2 Decision of mixing condition for on-site construction

We performed unconfined compression tests to determine the mixing proportions for the on-site construction test. We chose target strength of more than 0.3 MPa and less than 0.5 MPa. This particular range was picked so that the pathway would support the weight of a person walking on heels. In our experiment we performed compaction tests (JIS A 1210, A-b) to determine the density of each sample and to obtain the optimum water content and maximum dry density. The water content of each specimen was set at the optimum water content obtained from the compaction test. For the specimen density (D ($=\rho_d/\rho_{d\ max}$) = 95%) five layers in the mould were formed by tamping. The specimens were 5 cm in diameter and 10 cm in height. Each specimen was sealed in plastic and cured at 20°C for 7 days. Table 2 shows the mixing conditions and Table 3 shows the testing conditions of the laboratory experiment. The additive ratio shown in Table 2 refers to the ratio of the weight of the solidification material or the toughening material to the dry weight of the decomposed granite soil.

Figure 2 shows the unconfined compression test results for the different mixing formulae. There were five different mixing formulae that satisfied the strength requirement. On the basis of these results (Kawahara et al., 2008), we decided on five mixing formulae for use in the on-site construction; these are shown in Table 4. Case1 to Case4 was performed to observe how the solidification and toughness varied as the percentages of solidification and toughness materials changed. Case 5 was used to the cement solidification material by itself.

Table2: Mixing proportions of laboratory experiment.

Soil	Solidification material		Toughness material	
		Additive ratio (%)		Additive ratio (%)
Decomposed granite soil	PFBC	0 7 10 13	Bamboo chips	0 2 5 8

Table3: Testing condition of laboratory experiment.

Test method	Spec	Terms and conditions			
Compaction test	JIS A 1210	A-b			
Unconfined compression test	JIS A 1216	water content	Degree of compaction (%)	Curing day (day)	Require Strength (kN/m^2)
		Optimum moisture content	95	7	$300 \leqq q_u \leqq 500$

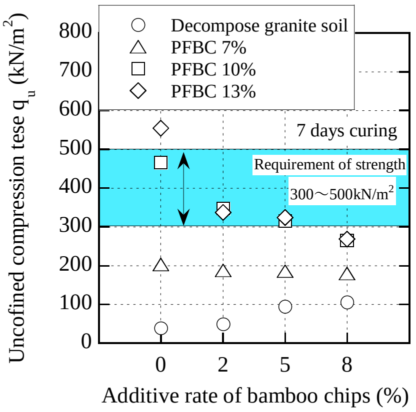


Figure2: Unconfined compression test results for the different mixing formulae.

Table4: Decision of mixing conditions for use in the on-site construction.

No.	Mixing condition
Case1	PFBC 10%
Case2	PFBC 10% + Bamboo chips 5%
Case3	PFBC 13% + Bamboo chips 2%
Case4	PFBC 13% + Bamboo chips 5%
Case5	Cement solidification material

3 OVERVIEW OF ON-SITE CONSTRUCTION

3.1 On-site construction

The on-site construction was performed at the Anzu-no-sato athletic park in Fukuoka. Figure 3 shows the diagrammatic illustration of on-site construction. Each segment of the road was 2 m wide and 10 m long, and the total length was 50 m. The pavement was 0.07 m thick.

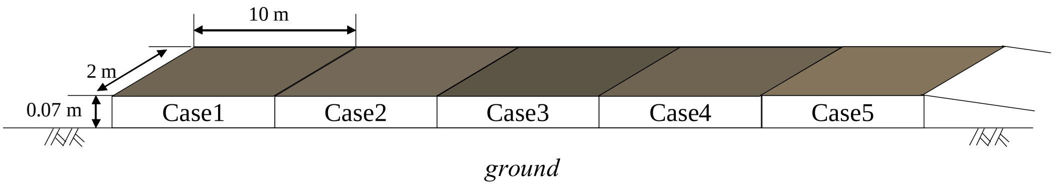


Figure3: Diagrammatic illustration of on-site construction.

3.2 Construction technique

A backhoe and track-mounted soil recycler was used to mix the materials. Track- mounted soil recyclers are composed of three parts: (a) an earth and sand hopper, (b) a solidification hopper, and (c) a discharge belt conveyer. The soil volume of the decomposed granite soil was measured by the backhoe, which had 0.45-m^3 buckets. Photo 1 shows the construction procedure. After a bulldozer produced a smooth, compact base, wood forms (as shown in (1)) were put in place to make it possible to perform a surface compaction of the materials. Then, the mixed material was paved by an asphalt finisher (as shown in (2)), and the rolling compaction was performed by a roller (as shown in (3)).

(1) Placing wood form (2) Laying operation (3) Surface compaction

Photo1: Construction procedure

3.3 Survey methods of on-site

A follow-up survey was performed to rate the course on the seven characteristics shown in Table 5, which also describes the examination methods used in the follow-up surveys. Figure 4 shows the points at which the measurements were taken for the survey.

Table5: Evaluation items and examination methods of surveys.

Evaluation item	Measurement method
Hardness	1) Simple bearing capacity test
Skid	2) Skid resistance test
Crack	3) Crack percentage (Sketch)
Surface character	4) Surfacing gravel fraction test and surfacing sand fraction test
Road surface temperature	5) Test for measurement of road surface temperature
Walking comfort (Elasticity)	6) Golf ball test (GB test) and Steel ball test (SB test)
Environment assessment	7) Japanese leaching test (JLT46)

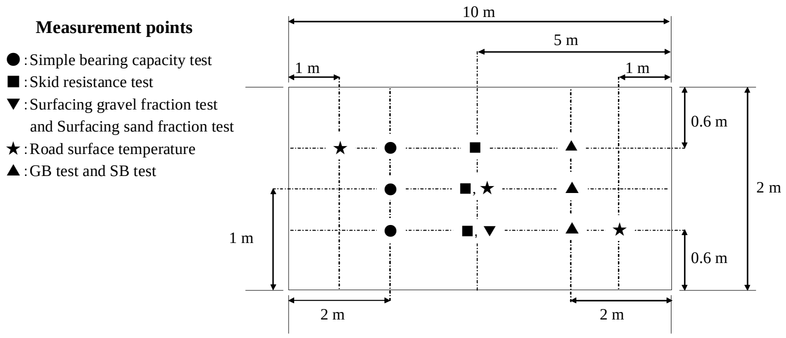


Figure4: Measurement points of surveys.

3.3.1 Ground bearing capacity test

The study evaluated pavement hardness using an impact value that was derived from the impact acceleration measured by a simple bearing-capacity test using Eq. (1).

$$Impact \quad value \quad (Ia) = \frac{Accelerated\ velocity\ (gal)}{2.78 \times 980 (gal)} \tag{1}$$

3.3.2 Skid resistance test

The skid resistance test measures the skid resistance of a pavement surface with a portable skid resistance tester. This test was conducted under wet conditions where the pedestrian-friendly pavement surface had been sprinkled with water. The study evaluated the safety of walking with a skid resistance value (BPN).

3.3.3 Crack percentage

Crack percentage refers to the amount of cracking that occurred on the pedestrian-friendly pavements surface. This crack percentage was determined using Eq. (2). The crack area was measured with a sketch method that measured crack length using a sketch divided into 0.5-m intervals.

$$Crack\ percentage(\%) = \frac{Crack\ area\quad (m^2)}{Compartment\quad area\quad (m^2)} \times 100 \qquad (2)$$

3.3.4 Measurement of road surface temperature

The road surface temperature was measured to determine how much the pedestrian-friendly pavement lowered the temperature of the pavement. The decrease in the road surface temperature was measured by comparing the road surface temperature of pedestrian-friendly pavements developed in this study to the temperature of asphalt pavement. The measurement of the road surface temperature was performed once every one hour between 8: 00 am and 6: 00 pm on 10 Oct, 2008.

3.3.5 Elasticity test

The elasticity test was performed to evaluate the walking comfort provided by the shock absorption and impact resilience of the pavement. The shock absorption and impact resilience are determined as the coefficient of rebound using a golf ball (GB) or steel Ball (SB), respectively. These can be calculated by the rebound height when the GB or SB is dropped freely from 1 m. For our experiment, the golf ball was a coated type, and the steel ball had a 1-inch diameter and was regulated as JIS B 1501. The coefficient of rebound was calculated using Eq. (3)

$$Coefficient\ of\ rebound\ (GB\ or\ SB)\ (\%) = \frac{H_0}{H} \times 100 \qquad (3)$$

where H_0 is the average rebound height (cm), and H is the height from which the ball was dropped (100 cm).

3.3.6 Japanese leaching test

In general, when solidification materials such as cement or PFBC are used in a pedestrian-friendly pavement, it is necessary to observe Japanese geo-environment standards. In this study, we performed the Japanese leaching test (JLT46) to investigate the geo-environmental compliance after 7 days of curing the pavement materials. JLT46 is the leaching test method specified by the environmental quality standards to assess soil in Japan.

4 RESULTS AND DISCUSSIONS

4.1 Evaluation of pedestrian-friendly pavement hardness by ground bearing capacity test

Figure 5 shows the relationship between Impact acceleration (Ia) and the number of elapsed days after paving. This figure indicates that the Ia of each pedestrian-friendly pavement materials is somewhere between 15 and 30. The strength of pavement increases with curing, because of the increase in the Ia with an increase in elapsed days. It is believed that the reason Ia-value decreased three months after construction is that the changing climate or length of days affected the moisture state of the pedestrian-friendly pavement. Furthermore, regardless of number of elapsed days after paving, these data indicate that the Ia of each pavement material developed in this study is lower than that of Case 5, the solid material. The lowest values were for Case 2 and 4, both of which included five percent of bamboo chips. Thus, we can conclude that the addition of bamboo chips gives softness to the pedestrian-friendly pavements.

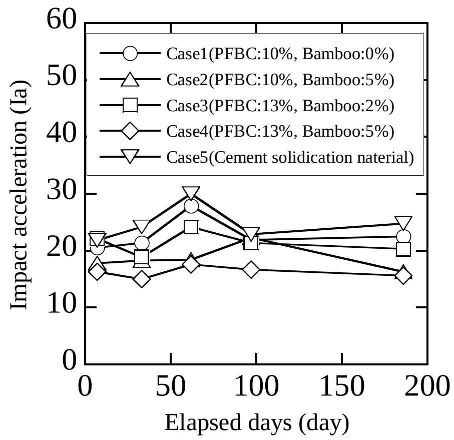


Figure5: Relationship between Ia and elapsed days.

4.2 Evaluation of skid resistance (BPN) of pedestrian-friendly pavement

Figure 6 shows the relationship between British Pendulum Tester Number (BPN) and elapsed days after construction. In the skid resistance test, the different mixing formulae have no effect on the measured value. Furthermore, the BPN for each of the mixing formulae has a value of approximately 60 regardless of the number of days elapsed since construction, and satisfied required skid resistance value for pedestrian-friendly pavements more than 45 values sufficiently. As the different formulae compare favorably with Case 5, the pedestrian-friendly pavement materials developed in this study are at little risk of pedestrian falls regardless of the number of elapsed days since construction.

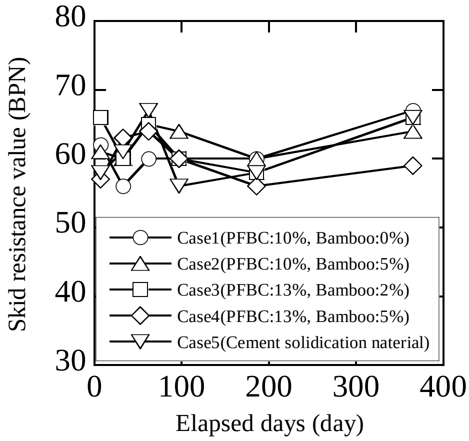


Figure6: Relationship between BPN and elapsed days.

4.3 Evaluation of cracks on pedestrian-friendly pavement

Figure 7 shows the results of the follow-up survey of crack percentage. These data indicate that there were no cracks in the pavement surface in Case 3, 4, and 5 in the first 3 months after paving. However, some amount of cracking in the pavement did appear in Case 1 and Case 2. It is believed that the reason for the cracking in Case 2 is that the addition of bamboo chips led to the pavement having low strength.

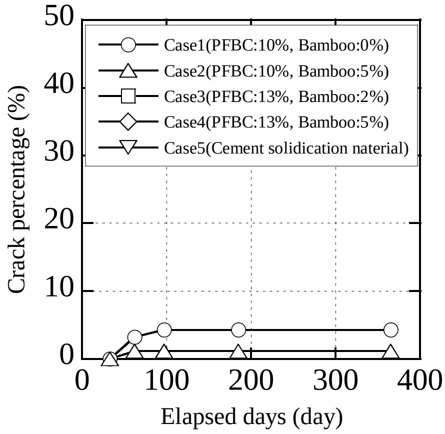


Figure7: Relationship between crack percentage and elapsed days.

4.4 Evaluation of road surface temperature of pedestrian-friendly pavements

Figure 8 shows the relationship between road surface temperature and time. This figure indicates that each type of pedestrian-friendly pavement had a low temperature compared with asphalt pavement. Moreover, each type of pedestrian-friendly pavement developed in this study had a low temperature compared with Case 5, the solid material. Thus, these pavements have the effect of decreasing the road surface temperature.

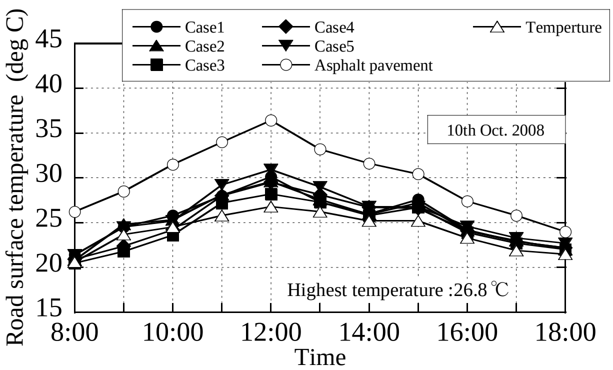
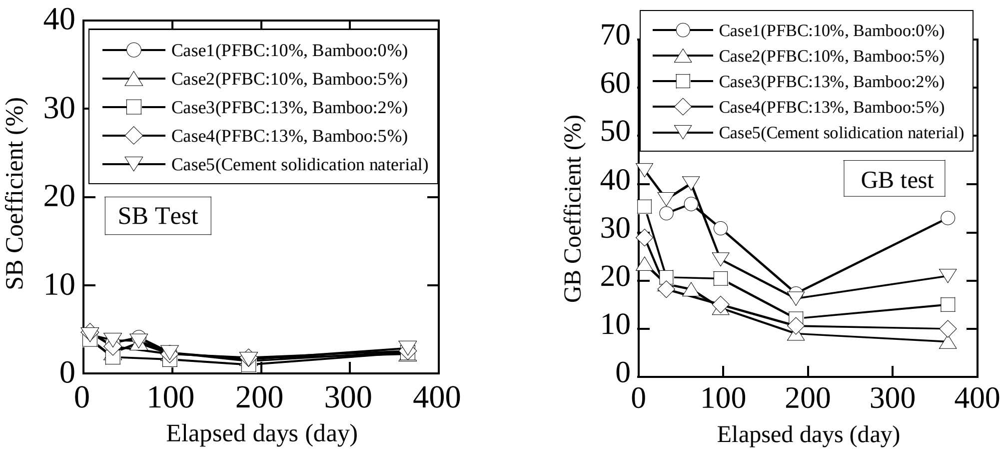


Figure8: Relationship between road surface temperature and time.

4.5 Evaluation of walking comfort of pedestrian-friendly pavement

Figure 9 shows the relationship between SB or GB coefficient and elapsed days. As the SB coefficient was under 5% for each case, no difference was observed between the different pavement types. On the other hand, there was a difference in the GB coefficient. There was an approximately 10% difference in GB between the material with added bamboo chips (Case 2, 3 and 4) and the material without added bamboo chips (Case 1 and Case 5). The bamboo chips give softness to pavement body and can reduce the strain on the legs of pedestrians. The SB and GB coefficients decreased with increasing elapsed time after construction. It is believed that this decrease is due to the effect of bamboo chips appearing on the road surface because of ablation or else the effect of moisture on the pavement as the weather changed.



(a) SB coefficient (b) GB coefficient

Figure9: Relationship between coefficient of rebound and elapsed days.

Figure 10 shows the range of SB and GB coefficient for different materials. Previous studies have determined these coefficients for artificial grass, polyurethane, clay and asphalt pavements (Japan Road Association, 2007). The figure indicates that the SB and GB coefficients for the pedestrian-friendly pavements developed in this study are smaller than that of artificial grass, polyurethane, and asphalt pavements and equivalent to clay pavement. Thus, it is believed that the pedestrian-friendly pavements developed in this study should reduce the strain on the legs of pedestrians.

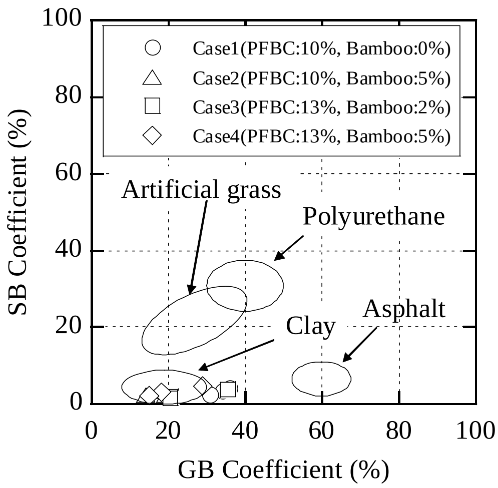


Figure10: Relationship between SB coefficient and GB coefficient.

4.6 Effect on geo-environment by pedestrian-friendly pavement

Table 6 shows the results of JLT 46. The concentrations of these heavy metals in each case were less than the maximum specified by Japanese geo-environment standard. Therefore, these pedestrian-friendly pavements, which developed in this study, are safe for the ground environment.

Table6: Results of Japanese leaching test (JLT 46).

	Case1	Case2	Case3	Case4	Japanese geo-environmental standard
Cd	N.D.	N.D.	N.D.	N.D.	0.01
Pb	N.D.	N.D.	N.D.	N.D.	0.01
Cr^{6+}	0.029	0.010	0.015	0.007	0.05
As	0.002	0.003	0.002	0.004	0.01
Se	0.005	0.005	0.003	0.005	0.01
F	0.6	0.6	0.6	0.6	0.8
B	0.43	0.42	0.44	0.40	1.0
T-CN	N.D.	N.D.	N.D.	N.D.	N.D.
T-Hg	N.D.	N.D.	N.D.	N.D.	0.0005

5 CONCLUSIONS

This study aimed to develop pedestrian-friendly pavement materials by mixing decomposed granite soil with PFBC and bamboo chips. A summary of this study is as follows.

(1) The pedestrian-friendly pavement is given softness by the addition of bamboo chips.
(2) The pedestrian-friendly pavement material developed in this study presents lesser risk of falling for pedestrians.
(3) The pedestrian-friendly pavements can be restrained cracks by the adding Bamboo chips.
(4) These pedestrian-friendly pavements decrease the road surface temperature compared with asphalt pavement.
(5) The pedestrian-friendly pavements with added bamboo chips give softness to pavement body and can reduce the strain on the legs of pedestrians.
(6) The pedestrian-friendly pavements developed in this study are safe as they satisfy the Japanese geo-environment standard.

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