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PERFORMANCE OF CONCRETE WITH SUBSTITUTION OF FLY ASH AND SILICA FUME AFFECTED BY SEAWATER

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ABSTRACT

Concrete is one of the primary construction materials, both for land and sea environments. Aggressive environmental factors, including abrasion by waves and ocean currents, often damage concrete in the marine environment. The research analyzed the effect of adding fly ash and silica fume without cement additives or other admixtures on concrete performance. The test object that is made is then immersed in freshwater and seawater. The specimens were tested in the laboratory to obtain concrete performance variables such as compressive strength and abrasion coefficient. Testing of abrasion on the samples resulted in adding fly ash and silica fume in the optimal amount to the concrete, which can reduce mass loss due to abrasion. From the test results of concrete soaked in seawater, the addition of fly ash had a good impact on the compressive strength and abrasion resistance of concrete, whereas in silica fume substitution concrete with substitution variations of 5%, 7%, and 10%, the compressive strength and abrasion values had the required achievement values. Substitution concrete with fly ash and silica fume as green concrete can increase the reliability of concrete against abrasion compared to ordinary concrete.

Keywords: Fly ash, Silica Fume, Concrete, Compressive Strength, Abrasion

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1. INTRODUCTION

Concrete is one of the main components of construction on land and sea. Standards that apply to concrete materials used in marine environments must have a higher compressive strength value than buildings on land. Research on seawater's effect on concrete's compressive strength shows that the compressive strength value decreases if the concrete is soaked continuously for 28 days. In this study, concrete submerged in seawater at seven days of age reached a compressive strength value of 20 MPa and then decreased to 14 MPa at 28 days of age.[1,2].

Buildings in a marine concrete environment must have more specific characteristics, including high concrete quality, low permeability, and abrasion resistance. Seawater contains chloride and sulfate compounds which are corrosive to concrete and reinforcement, so these buildings require building materials impermeable to seawater so that the penetration rate of chloride into the concrete becomes slower or longer.[3]

Actions of the marine environment, such as sea waves, contribute to the decline in the performance of coastal buildings such as piers, revetments, groins, and breakwaters. Sea waves are a cyclical force that will act on buildings on the sea coast and cause abrasion on the concrete construction. In addition to these environmental factors, vehicular traffic and loading and unloading activities at the pier also affect the condition of the wharf structure, especially the plates that experience surface erosion/abrasion due to vehicle wheels.

Innovations in concrete technology are always required to answer the challenges of concrete needs. The resulting concrete is expected to have good quality, strength, and durability in corrosive and aggressive environments without neglecting economic value. It is necessary to find alternatives to obtain quality concrete resistant to aggressive environments by providing cement replacement materials.[4, 5]. The use of concrete in construction is closely related to cement production as one of the elements in making concrete. Production of Portland cement during the manufacture of cement clinker will result in considerable CO2 emissions[6, 7].

Reducing the amount of cement by adding or replacing the whole cement is also expected to reduce production, which impacts reducing carbon dioxide exhaust emissions and global warming. Green Concrete enhances three factors of sustainability: environmental, economic, and social impact. The key factors to identify green concrete are the amount of Portland cement substitute, manufacturing process, method, performance, and sustainability impact.[8].

Substitute concrete with fly ash and silica fume is known as environmentally friendly concrete (green concrete) because this concrete uses waste left over from industrial production or power plants, which can cause environmental pollution. This waste material needs an extensive disposal area; besides that, fly ash and silica fume have the potential to pollute the air and affect public health. Research on the effect of using fly ash and silica fume on concrete has been carried out by researchers in this field.[9–14].

Several studies have been conducted in the form of research on compressive strength, flexural strength, and permeability. Tests for abrasion of concrete affected by seawater have not been carried out too much.

This research aims to determine the effect of fly ash and silica fume substitution on the performance of concrete, especially on the compressive strength and resistance due to concrete abrasion, which is affected by seawater.

2. REVIEW OF LITERATURE AND METHODOLOGY

The test object was made by adding several variations of fly ash and silica fume substitution to the concrete. The fly ash used is type F, a waste from PLTU Suralaya. The cement used is type II cement. The test object that has been made is then immersed in different water, namely freshwater and seawater, to know the effect of seawater on concrete. The results of the compressive strength and permeability tests on specimens immersed in freshwater and seawater were then compared. The seawater used comes from Rancabuaya Beach, Garut Regency, West Java, which has not been affected by pollutants.

2.1. Concrete

The use of cement replacement materials in concrete has a very long history. During the last 25 years, many studies have been carried out on this type of concrete. Due to the high impact of this additive on concrete structures and procedures, this study is still ongoing. Additive substitution can improve concrete's mechanical and chemical properties, including increasing compressive strength, flexural and tensile strength, and exemplary performance in increasing durability and reducing corrosion and permeability of concrete.

Concrete with the addition of fly ash and silica fume is currently considered an environmentally friendly concrete (green concrete) because it uses waste and reduces cement production, which causes a reduction in CO2 emissions. The advantages of using fly ash concrete and others are that it is durable, reduces industrial waste and energy consumption, and reduces carbon dioxide exhaust emissions.

2.2. Fly Ash

The fly ash used in this test is fly ash which is waste from the Suralaya steam power plant in Banten, Indonesia. The fly ash produced is type F which, according to ASTM C 618, is fly ash produced by burning bitumen or anthracite coal and contains less than 10% CaO. Low-calcium fly ash, commonly known as Class F fly ash, is only pozzolanic and does not have cementitious characteristics. Less than 20% lime is present in Class F fly ash also has cementitious qualities similar to Portland cement. Class F fly ash suits high sulfate, structural concrete, and High-Performance Concrete environments. It can also be used at high concentrations in concrete mixes.

2.3. Silica Fumes

Silica fume is also known as micro silica, which results from reduced quartz with coke in electric furnaces to produce silicon and ferrosilicon alloys. Before the mid-1970s, almost all silica fume was vented into the atmosphere. However, after environmental problems occurred and the results of research on silica fume can be used as a mixture in concrete, silica fume was finally applied to concrete with high performance (quality).[15]

Silica fume in the concrete mixture is intended to produce concrete with high compressive strength. Concrete with high strength, for example, for structural columns or shear walls, pre-cast or prestressed concrete, and several other purposes.

Using low amounts of silica fume (under 5% by weight of cement) does not result in a higher strength than concrete because the quantity of silica fume will not be sufficient to cover the surface of all the coarse aggregate particles. Still, the beneficial use of silica fume is also limited to no more than 10% of the weight of the cement used; this is due to the use of excess silica fume, which will not be able to cover the surface of the aggregate.[13]

2.4. Portland cement

The cement used to manufacture the test specimens is type II cement which, according to the classification of SNI 15-2049 2004 and ASTM C 150, is cement with moderate sulfate resistance.[7]

This type of cement in use produces moderate sulfate resistance and heat of hydration. Its composition: 46% (C3S), 29% (C2S), 6% (C3A), 11% (C4AF), 2.9% (MgO), 2.5% (SO3). Type II Portland cement is used for buildings in marine, dam, and irrigation environments or mass concrete requiring low heat of hydration and surface conditions with high sulfate exposure.

Figure 1. Fly Ash and Silica Fume

2.5. Concrete Compressive Strength

The compressive strength of concrete is the ability of concrete to accept a compressive force per unit area. Concrete compressive strength identifies the quality of a structure. The higher the desired level of structural strength, the higher the quality of the concrete produced.

The compressive strength value of concrete is obtained through standard testing procedures, using a testing machine by applying a multilevel compressive load to the concrete cylinder test object until it cracks/crumbles. Standards used SNI 1974-2011 and ASTM C39-99 for the compressive strength test.

The specimen in the form of a concrete cylinder with a diameter of 15 cm and a height of 30 cm is pressed by a load P until it collapses. Because there is a compressive load P, compressive stress occurs in the concrete (fc') equal to the load (P) divided by the cross-sectional area of the concrete (A). Or written with the following formula:

$$f_c' = \frac{P}{A} \qquad (1)$$

fc' is compressive strength (N/mm2 or MPa)

Compressive strength testing was carried out on specimens aged 28 days, 52 days, and 90 days. Tests were carried out on samples treated with freshwater and seawater.

2.6. Abrasion Coefficient

Wear tests are usually carried out using testing standards based on SNI 3419-2008 and the Manual for Concrete Abrasion Machine, 1985 Tanifuji & Co-Japan, concerning laboratory abrasion tests. In principle, this concrete abrasion testing machine imitates the flow of debris flowing through the building, which causes the abrasion force of the impact flow on the concrete surface of the building. In making the design of the building, it is necessary to determine the quality of the concrete through which the debris flows so that the structure resists the abrasion forces of the debris flow and the age of the building as planned.

The percentage of loss in weight of the test object indicates the durability, quality, and quantity of the binder. This procedure can also be modified to use for other mixtures. The test object is made in the form of a block with dimensions of width x length x height = 15 cm x 30 cm x 4 cm or 15 cm x 30 cm x 6 cm.

Testing the specimens was carried out in stages, namely 1 hour, 2 hours, and 3 hours. Each time step on the test object is measured by weight to calculate the mass loss due to abrasion testing.

Calculate the abrasion volume and concrete coefficient in each test period using the following formula.

Abrasion Volume $$V_n = \frac{W_0 - W_n}{V} \times 100\% \quad (2)$$

Where

W0= Total weight of mold and test piece before testing (kN)

Wn= Total weight of mold and test piece after testing (kN)

Vn = volume of abrasion (cm^3)

Abrasion Coefficient $$K = \frac{V}{A} \quad (3)$$

K = Abrasion coefficient (cm^3/cm2)

V = volume of the test object (cm3)

A = Surface area of the test object (cm2)

Average Abrasion Coefficient $$K_a = \frac{\sum K_i}{6} \quad (4)$$

Ka = Abrasion coefficient (cm^3/cm2)

Ki = Abrasion coefficient of each test object (6 pieces)

3. RESULTS AND DISCUSSION

3.1. Concrete Mix

Manufacturing concrete test specimens is based on the results of ordinary concrete mixtures where added materials are substituted by reducing Portland cement. Variations in substitute materials are based on previous studies conducted by other researchers. The following is the composition of the substitute material on the test object. The substitution value of fly ash in concrete is 10%, 20%, and 30% by weight of cement, while the substitution of silica fume is 5%, 7%, and 10% by weight of cement.

In this study, the use of fly ash in concrete did not use activating materials such as Sodium Hydroxide (NaOH) and Sodium Silica Dioxide (Na2SiO3) to see to what extent the effect of fly ash on compressive strength without an activator in concrete.

3.2. Compressive Strength Test Results

Compressive strength testing is the primary and most important thing in determining the quality of concrete and the strength achieved. Compressive strength of ordinary concrete using particular cement type II. Compressive strength testing is recommended until the age of the concrete reaches 90 days because it is predicted that it will only get the desired compressive strength at that time. The specimens were tested at the concrete age when 28, 56, and 90 days.

3.3. Concrete Compressive Strength Test Results with Fly Ash

Extending fly ash is expected to reduce the cement used in concrete while maintaining the planned compressive strength value. Adding variations of fly ash into the concrete of 10%, 20%, and 30% impacts the compressive strength of this concrete.

The following is the average compressive strength of concrete with variations in the fly ash mixture from the test results:

Table 3. Compressive Strength of Concrete with Fly Ash

No	Specimen Code	Average Compressive Strength (MPa)		
		days		
		28	56	90
1	COC 0%	38.05	50.05	55,22
2	COS 0%	34,42	49.97	54,76
3	CFCs 10%	43,37	48,77	49,34
4	CFS 10%	37.01	43,67	45.30
5	CFCs 20%	36.65	50.08	55.02
6	CFS 20%	37,73	45,69	50.88
7	CFCs 30%	34,28	46,56	49,24
8	CFS 30%	34,27	43,81	46,60

The specimen code indicates the variation of fly ash substitution and the specimen's treatment method. COC is ordinary concrete with freshwater treatment, while COS is ordinary concrete with seawater treatment. CFC denotes fly ash substituted concrete with freshwater treatment, and CFS is fly ash concrete with seawater treatment. The percentage shows the variation of fly ash substitution in concrete.

Seawater used for curing concrete is original seawater that has not been affected by pollutant waste and is taken from Rancabuaya Beach in the south of Java Island. The results of the salinity test showed a salinity level of 6.82%.

The design compressive strength of concrete is usually achieved at 28 days of concrete age, which is 38.05 MPa. This value has exceeded the planned compressive strength target of 30 MPa and the targeted average compressive strength (fcr') of 33.9 MPa; as time goes on, the average compressive strength value of ordinary concrete increases until it reaches 55.22 MPa at 90 days of concrete age.

In COS 0% ordinary concrete treated with seawater immersion, when the concrete is aged 28 days, the average compressive strength reaches 34.42 MPa. This matter slightly affects the decrease in compressive strength, although not too significant. The compressive strength still meets the design compressive strength and the required average (target) compressive strength. At 56 days and 90 days, the compressive strength of concrete increased linearly up to 54.76 MPa. This value has no significant difference with freshwater-treated concrete (COC0%).

The best compressive strength value achieved by fly ash substituted concrete with freshwater treatment was with a fly ash substitution variation of 20% (COC20%), gaining a compressive strength of 55.02 MPa at 90 days of concrete age. In concrete added with fly ash soaked in seawater, the compressive strength value of fly ash concrete reached the highest compressive strength value in 20% (COS 20%) fly ash mixed concrete, where the compressive strength achieved was 50.88 MPa.

This matter also shows that seawater reduces the compressive strength of this fly ash concrete. The optimal mixture variation in this study is the 20% fly ash concrete interpretation. Giving fly ash as much as 10% and 30% compressive strength results are still below the concrete with 20% fly ash.

3.4. Concrete Compressive Strength Test Results with Silica Fume

Silica fume substituted concrete has reached the design compressive strength at 28 days. At 28 days, all concrete with substitution variations of 5%, 7%, and 10% achieved the targeted average compressive strength value (fcr').

The average compressive strength value of silica fume concrete at the best 90 days of concrete is concrete soaked in freshwater with 7% silica fume substitution (CSC7%), which is equal to 51.6 MPa, while the highest compressive strength value of silica fume concrete immersed in seawater is concrete with 10% silica fume (CSS10%) with an average compressive strength value 48.31 MPa.

The strength test results on silica fume concrete specimens show a tendency to decrease compressive strength compared to ordinary concrete at 90 days. However, this value still has a compressive strength value above the targeted average compressive strength (*fcr'*).

Table 4. Compressive Strength of Concrete with Silica Fume

No	Specimen Code	Average Compressive Strength (MPa)		
		days		
		28	56	90
1	COC 0%	38.05	50.05	55,22
2	COS 0%	37,38	49.97	54,76
3	CSC 5%	46,70	46,77	49,40
4	CSS 5%	40,71	46,67	47,71
5	CSC 7%	42.93	48,26	51,60
6	CSS 7%	35,76	42.56	44.55
7	CSC 10%	39.59	44,11	47,89
8	CSS 10%	38,13	42.65	48,31

CSC denotes silica fume substitution concrete with freshwater treatment, and CSS is silica fume concrete with seawater treatment.

3.5. Abrasion Test Results

Results of Concrete Abrasion Test with Fly Ash Substitution

The abrasion test results for 3 hours on ordinary concrete showed that the weight loss in ordinary concrete soaked in freshwater was 107.18 grams, and in ordinary concrete soaked in seawater was 130.17 grams. There was an increase in weight loss in the two ordinary concretes with these different treatments. This shows that seawater has the effect of increasing the volume of eroded concrete particles.

In fly ash substituted concrete, the weight loss after testing for 3 hours was in the range of 95.61 grams to 115.44 grams, with the abrasion coefficient values being in the range of 0.22 cm^3/cm^2 to 0.25 cm^3/cm^2. Adding fly ash to concrete with freshwater treatment with 10% and 20% substitution slightly reduced the weight loss in the concrete samples after abrasion testing. There is a significant decrease in weight loss in fly ash concrete soaked in seawater compared to ordinary concrete soaked in seawater. The weight loss value in ordinary concrete soaked in seawater of 130.17 grams can be reduced to 106.25 grams with a 10% fly ash substitution. The abrasion coefficient on ordinary concrete is 0.29 cm^3/cm^2, which decreases to 0.24 cm^3/cm^2 on seawater-treated concrete.

Table 7. Average Mass Loss of Concrete with Fly Ash Substitution

Specimens	**Average Mass Loss (gr)**			**Average abrasion coefficient (cm^3/cm^2)**		
	1 hour	**2 hours**	**3 hours**	**1 hour**	**2 hours**	**3 hours**
COAs	45.05	75.02	107,18	0.08	0.16	0.24
SOA	50.88	64,26	130,17	0.11	0.21	0.29
CFAC 10%	34,56	66,81	95.61	0.08	0.15	0.22
CFAS 10%	38,23	72,87	106,25	0.09	0.16	0.24
CFAC 20%	37,74	68,20	102.81	0.08	0.16	0.24
CFAS 20%	39,14	74,14	106,82	0.09	0.17	0.24
CSAC 30%	41,72	73.95	102.85	0.09	0.17	0.23
CSAS 30%	36,47	76,57	115,44	0.08	0.17	0.25

Table 8.. Average Mass Loss of Concrete with Silica Fume Substitution**Specimens**	**Average Mass Loss (gr)**			**Average abrasion coefficient (cm^3/cm^2)**		
	1 hour	**2 hours**	**3 hours**	**1 hour**	**2 hours**	**3 hours**
COAs	45.05	75.02	107,18	0.08	0.16	0.24
SOA	50.88	64,26	130,17	0.11	0.21	0.29
CSAC 5%	37,52	81.99	120.15	0.08	0.18	0.26
CSAS 5%	44,28	88.58	126.03	0.10	0.19	0.27
CSAC 7%	39,47	75.35	113,14	0.09	0.17	0.25
CSAS 7%	36,47	76,57	115,44	0.08	0.17	0.25
CSAC 10%	30.03	74,44	111.97	0.07	0.16	0.25
CSAS 10%	46,20	93.80	133.78	0.10	0.21	0.28

Concrete Abrasion Test Results with Silica Fume Substitution

Abrasion testing on concrete with silica fume showed the test results, namely the addition of silica fume to ordinary concrete (COA) with freshwater immersion slightly increased the average weight loss after abrasion testing from 107.18 grams to ordinary concrete increased to 120.15 grams with silica fume substitution 5 % (CSAC5%) and 115.44 grams in concrete with 7% (CSAC7%) silica fume substitution. In 10% silica fume concrete (CSAC10%) the average weight loss value again increased to 133.78 grams.

The abrasion coefficient ranges from 0.25 cm^3/cm^2 to 0.28 cm^3/cm^2 for both types of concrete curing, namely with freshwater and seawater immersion. The abrasion coefficient for concrete immersed in seawater silica fume with 5% and 7% substitution has a better coefficient value than ordinary concrete. This matter shows that adding 5% and 7% silica fume provides better resistance to abrasion than ordinary concrete in a marine environment on 5% (CSAC5%) silica fume concrete. In 10% (CSAC10%) silica fume substitution concrete, it achieves an average weight loss due to abrasion of 111.97 grams.

In ordinary concrete (SOA) immersed in seawater, there is a decrease in the average weight loss due to abrasion from 130.17 grams to 126.03 grams.

Based on BS 882-1992 and IS383-1970, which state that the maximum weight loss allowed in the abrasion test is 30% of the initial weight, the weight loss in concrete with fly ash and silica fume still meets the requirements.

4. DISCUSSION

Relationship between Compressive Strength and Abrasion Coefficient

Abrasion testing of concrete added with fly ash and silica fume showed that immersion in seawater increased mass loss in ordinary concrete. The abrasion coefficient of up to 0.29 cm^3/cm^2 is higher than the coefficient of ordinary concrete immersing in freshwater of 0.24 cm^3/cm^2.

In fly ash substitution concrete with freshwater immersion with concrete age of 56 days, it has an abrasion coefficient of approximately 0.22 cm^3/cm^2 to 0.24 cm^3/cm^2, meaning that the addition of 10% fly ash can reduce the value of the abrasion coefficient to 0.02 cm^3/cm^2. In fly ash concrete with seawater immersion, the weight loss and abrasion coefficient value decreased to 0.24 cm^3/cm^2 compared to ordinary concrete with seawater immersion with an abrasion coefficient of 0.29 cm^3/cm^2. This matter shows that the effect of adding fly ash is sufficient to contribute to the resistance of concrete to abrasion in marine environments.

Figure 18. The relationship between *fc'* and *ka* FA Concrete

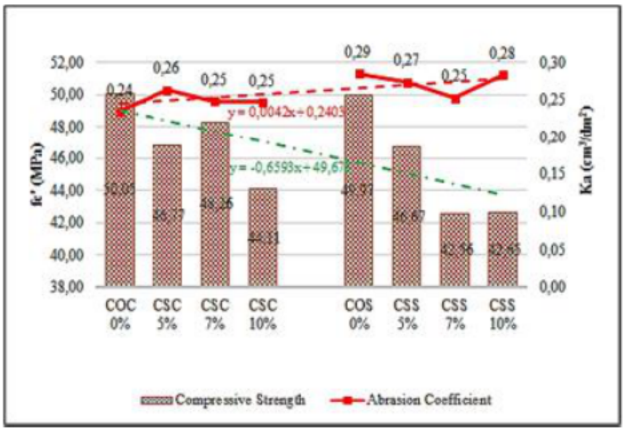

Figure 19. The relationship between *fc'* and *ka* SF Concrete

Figure 18. the trendline of decreasing compressive strength due to the addition of fly ash and seawater immersion has little effect on the trendline of the achieved abrasion coefficient. The value of the coefficient of abrasion (loss of mass) slightly increases with the addition of fly ash variations and a decrease in the compressive strength of the concrete.

Adding silica fume in concrete with silica fume has an abrasion coefficient of 0.25 cm3/cm2 to 0.28 cm^3/cm^2. For ordinary concrete with seawater treatment, the coefficient reached 0.29 cm^3/cm^2; when silica fume substitution was added to the concrete, the good results obtained were a decrease in the abrasion level of up to 0.25 cm3/cm2 at 7% silica fume variation. The addition of silica fume to concrete immersed in seawater has an impact on reducing the abrasion coefficient of concrete immersed in seawater.

As in concrete with fly ash substitution, concrete with silica fume shows the same trendline. Figure 19 shows that decreasing compressive strength due to adding silica fume and seawater immersion has little effect on the trendline of the achieved abrasion coefficient. The value of the abrasion coefficient slightly increases with the addition of silica fume variations and a decrease in the compressive strength of the concrete.

Similar research that has been done shows that the effect of adding fly ash or silica fume to concrete has a good effect, where silica fume substitution will reduce mass loss due to abrasion.[16,17]. The abrasion coefficient also represents the mass loss of concrete after testing. Based on the compressive strength and abrasion test data on concrete specimens, a relationship is obtained between mass loss or the abrasion coefficient on compressive strength. As the compressive strength increases, the abrasion coefficient decreases.

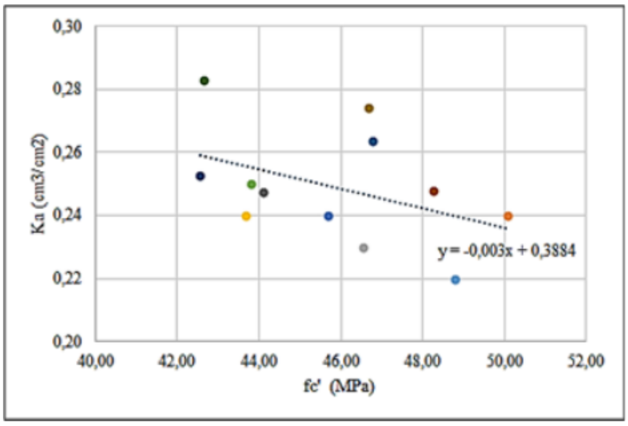

Figure 20. Correlation of Compressive Strength and Abrasion Coefficient

5. CONCLUSION

The influence of seawater has an impact on reducing the compressive strength of concrete. This matter can be seen in the compressive strength achieved by concrete immersed in seawater which is lower than concrete immersed in freshwater. Even though the compressive strength value achieved is lower than ordinary concrete, concrete with the addition of Fly Ash and Silica Fume as substitutes for green concrete used in marine environments can achieve and exceed the design quality of fc' 30 MPa. and the average target *fcr'* compressive strength is 33.9 MPa. Test results on concrete show that mass loss and abrasion coefficient on fly ash concrete have better values on concrete with seawater and freshwater immersion than concrete with silica fume substitution.

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