Mixing Ratio and Properties of Vegetation Concrete for the Ecological Slope Protection

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Abstract: One of the most efficient and environmentally friendly methods for preventing a slope is to vegetate it. Vegetation concrete, an important environmental protection material, has a promising potential for developing ecological slope protection. In this study, the method of preparation, physical mechanical properties and suitable plant species under the target porosity of 30% were developed and explored, based on the mix proportion design and planting test of vegetation concrete. The results indicate that the aggregate particle size, water-cement ratio, cement content and grade are key factors affecting strength, under the target porosity. Investigations find a design method which is suitable for vegetation concrete, can be obtained for the porosity of 30%, water-cement ratio of 0.3, cement content of 250kg/m^3, aggregate particle size of 10~15mm. In planting test, Sasa argenteostriata has the best tendency of growth, the roots are strong and can be perfectly combined with vegetation concrete, to form an organic whole of root-concrete-soil.

1. Introduction

Current slope protection technology problems mainly include non-ecological afforestation effect, poor connection with the natural environment, short of soil and water conservation ability, low strength and insufficient anti-erosion ability. Many approaches to negate these problems have been developed as a form of slope protection. Some methods that are used for surface protection include vegetation, geotextiles, wire mesh, soil stabilising agent as well as inorganic methods of slope protection which primarily involve using concrete including shotcrete, precast, concrete canvas and masonry. Although differing in function, durability and cost, they are all similar in the sense that they don’t provide substantial resisting forces to the slope as retaining structures and anchoring systems do[1]. Therefore, it is imperative to study ecological slope protection materials.

Vegetation concrete studied in this paper refers to a kind of concrete or concrete products, take porous concrete with a certain pore size and porosity as skeleton, fill with materials required by plant growth, so that plant roots grow in the pores or through concrete extend into the subsoil[2]. This kind of concrete has good water permeability because of its continuous pore structure. Macroporosity can provide the spatial basis for plants to grow, so that the concrete can be organically combined with the plant growth matrix and has excellent water storage and drainage capacity, which is suitable for the current construction of "sponge city" in China[3]. Vegetation concrete takes both ecological environment and engineering requirements into account. It is an important new environmental protection material for the development of green ecological slope protection.

The concept of ecological materials is first put forward in Japan, and then the vegetation concrete river revetment method is formulated[4]. Many abroad scholars have studied on vegetation concrete. Lian and Zhuge[5] found that water-cement ratio has a significant influence on the performance of vegetation concrete and there is an optimal water-cement ratio range through experimental research. Tang et al.[6] in response to the requirement of immediate slope protection and revegetation, analyses growing various native Australian grass species on vegetation concrete. Many domestic scholars also have done a lot of research and achieved a lot of results. Li et al.[7] introduces the development process of slope greening and discuss the research progress of vegetation concrete from many aspects. Shi et al.[8] proposed ecological concrete slope protection method and experimental study on its planting method. Jiang et al.[9] clearly introduced the relevant research on planting and purification performance of vegetation concrete. The application of vegetation concrete in China started at the beginning of the twentieth century. Moreover now, it has been applied in many practical projects. For example, the flood control project of Gandong scenic belt in Nanchang, China[10], and the ecological management project of a section of drainage channel in Xinning county, Hunan province of China in recent years[11]. However, in general, the research and application of vegetation concrete in China is still in its infancy[12], moreover a standardized and unified mix proportion design method is not available.

Main studies of this paper are investigating on vegetation concrete usage in ecological slope protection, to test the preparation method and physical mechanical properties, to optimize the mix proportion, to use the self-prepared specimen for conducting the plant growth adaptability test, and to discuss whether the plant species is suitable for planting.

2. Mix Proportion Design and Test Preparation

2.1. Mix Proportion Design

The mix proportion was designed by the technical conditions of Japanese vegetation concrete preparation. Depend on the Japan Shimizu, the porosity of vegetation concrete is 20%, the compressive strength is about 20Mpa and when the porosity is 30%, the compressive strength is about 10MPa[13].At present, there is no unified regulation on the strength of this kind of concrete in China. According to the design index of Japan, if it is mainly used for ecological slope protection, the requirement is over 10Mpa[14].

In fact, vegetation concrete is a kind of microporous concrete without sand. There is only coarse aggregate, no fine aggregate, which is the widely difference between it and ordinary concrete. The aggregate is wrapped with thin cement slurry to bond the aggregate particles to each other, forming a porous material with a continuous pore structure[15]. Therefore, the strength of the vegetation concrete depends on the bonding ability between the aggregates. In addition to the mix proportion design method with design porosity, water-cement ratio, aggregate particle size and gradation as parameters[16], in order to ensure good adhesion between aggregates, the grade and cement content should be considered.

According to the relevant data, the porosity of vegetation concrete should be controlled in 18%～35%, and the water-cement ratio should be controlled in 0.2～0.55. This test was designed with a porosity of 30%, meanwhile P・O32.5 and P・O42.5 grade ordinary Portland cement were used, crushed stone was used as aggregate while 10~15mm and 15~20mm were used as aggregate gradation[17]. Among, the particle sizes of 10~15mm and 15~20mm were represented as series A and series B, and the grouping numbers were 1~9, representing 9 working conditions. In the later stage of the experiment found that it is necessary to reduce alkalinity[18], in order to increase the strength of vegetation concrete. SR-5Z concrete reinforcing agent is used in the working conditions of groups A9 and B9 groups. The specific mix proportion was shown in Table 1.

2.2. Specimen Production

The production of vegetation concrete is different from the ordinary concrete. There is no formal test regulation for vegetation concrete in China. The production is carried out with reference to specification for mix proportion design of ordinary concrete[19] and standard for test methods of performance on ordinary fresh concrete[20]. As shown in Table 1, 150mm×150mm×150mm cube specimens was made in 9 working conditions, among which 9 cube specimens were made in 1st~8th working conditions, and 3 cube specimens were made in the 9th working conditions, a total of 150 cube specimens.

Preparation process: this problem of the mixing process of vegetation concrete is particularly frequent in studies, many scholars come up with a lot of methods, such as “shell made law”, one-mixing, multiple-mixing and coarse aggregate enveloped with cement paste[21], have their both advantages and disadvantages. During the mixing process, the project team adopts the combination of mechanical stirring and hand mixing, summarize a step-by-step mixing method. Firstly, the coarse aggregate is soaked with some water, and a certain amount of cement is added for mixing. Secondly, the remaining cement and water are added after evenly mixing. Finally, mix for 2-3 minutes until the cement slurry wrap around the coarse aggregate particles and it shows a luminous state. In the process of specimen production, the cement slurry formed by vibrating compaction of vegetation concrete is more easily deposition than spading compaction. Therefore, during the process of specimen production, spading compaction should be used. Each specimen should be charged in three times, further, for every 1/3 volume charge, spade evenly with vibrator, and finally plaster level off with a spatula.

Concrete curing: because the porosity of vegetation concrete is high and water loss is fast, ordinary natural curing methods are not suitable. Specimens should be placed indoors, together with the mold and curing of sealing film. After 3 days, demould and then soak in the water tank, curing for 28 days.

Table 1: Mix proportion and physical mechanical properties of vegetation concrete.

Number	Particle Size (mm)	Coarse Aggregate (kg/m^3)	Cement Mark	Water-cement Ratio	Cement (kg/m^3)	Additive (kg)	Strength of 28d (Mpa)	Mean Strength of 28d (Mpa)	Connected Porosity (%)	Strength of 90d (Mpa)	Mean Strength of 90d (Mpa)
A1	10~15	1575	P·O 32.5	0.3	150	—	1.63~3.78	2.69	30	1.88~3.82	2.80
A2	10~15	1575	P·O 42.5	0.35	150	—	3.26~5.61	4.65	32	3.80~7.62	5.90
A3	10~15	1575	P·O 42.5	0.4	150	—	2.38~4.12	2.99	30	3.00~3.94	3.55
A4	10~15	1575	P·O 42.5	0.45	150	—	4.03~5.20	4.75	31	5.21~6.30	6.24
A5	10~15	1575	P·O 42.5	0.5	150	—	3.33~6.49	5.77	31	4.33~7.68	6.77
A6	10~15	1575	P·O 42.5	0.3	200	—	5.28~7.07	6.03	28	8.51~11.49	10.12
A7	10~15	1575	P·O 42.5	0.35	200	—	5.27~7.50	6.51	29	6.87~8.50	7.79
A8	10~15	1575	P·O 42.5	0.4	200	—	5.51~7.33	6.25	33	6.25~8.24	7.16
A9	10~15	1575	P·O 42.5	0.3	250	15	10.68~13.8	12.75	31	—	—
B1	15~20	1555	P·O 32.5	0.3	150	—	3.19~4.29	3.83	33	3.60~7.60	5.60
B2	15~20	1555	P·O 42.5	0.35	150	—	2.85~5.17	3.71	31	4.17~6.08	4.84
B3	15~20	1555	P·O 42.5	0.4	150	—	3.41~4.16	3.73	32	6.02~6.83	6.43
B4	15~20	1555	P·O 42.5	0.45	150	—	4.33~5.70	4.48	33	5.44~6.35	6.08
B5	15~20	1555	P·O 42.5	0.5	150	—	4.13~5.19	4.75	35	5.08~5.27	5.14
B6	15~20	1555	P·O 42.5	0.3	200	—	5.34~6.14	5.58	32	6.30~8.64	7.47
B7	15~20	1555	P·O 42.5	0.35	200	—	4.70~6.50	5.5	34	4.28~7.10	6.22
B8	15~20	1555	P·O 42.5	0.4	200	—	2.43~6.51	5.61	33	3.40~9.97	5.92
B9	15~20	1555	P·O 42.5	0.3	250	15	8.98~10.27	9.8	30	—	—

2.3. Test of Physical Mechanical Properties

2.3.1. Test Scenario

The compressive strength test was conducted in accordance with a standard for test methods for mechanical properties of ordinary concrete[22]. The electrohydraulic pressure testing machine equipment was used for the compressive strength. Six specimens from 1st~8th of groups A and B were taken for strength measurement after 28 days, and other three specimens were taken for strength measurement after 90 days. Since only three specimens were made in group 9, no concrete age study was conducted and their strength was measured after 28 days. The interconnected porosity was measured by volume drainage method. Test results are shown in Table 1.

2.3.2. Failure Phenomena and Analysis

The During the compression test, cracks gradually expand from the top to the bottom, connected pores passed through the specimen, leading to adhesive failure, as shown in Figure 1 (a). The corners of some specimens show split of angular aggregate, while the aggregate itself is not crushed when failure, as shown in Figure 1 (b). Some of the specimens are crushed and scattered but aggregates still intact, as shown in Figure 1(c). Main failure mode of specimen is shear failure. What can be seen is that the strength failure of vegetation concrete mainly results from the strength of connection between aggregates.

(a) (b) (c)

Figure 1: Performance of compression test.

2.3.3. Mechanical Property Analysis

Data from Table 1, the strength of A1 and B1 using P·O 32.5 grade cement is respectively up to 3.78Mpa and 4.29Mpa, which is 2~4Mpa lower than that of P·O 42.5 grade cement under the same condition. The results of aforementioned investigations indicate that the cement grade has obvious influence on strength. The higher the cement grade is, the stronger the vegetation concrete will be. In Figure 2(a), strength values of particle size A are generally higher than that of particle size B, which indicate that the smaller the aggregate particle size is, the higher the strength of the vegetation concrete will be. However, the mean strength of A1 and A3 groups is significantly lower than that of B1 and B3 groups, which is not conform to the general trend. After further research and analysis, find that the rough surface of specimen suffers in uneven force. During the test, the partial corners in the surface of specimen is crushed while the whole specimen does not damaged, the mechanical press deems as structure failure, gives rise to test stop, which explains the reason the low strength of specimens.

As shown in Figure 2(b), the influence of water-cement ratio on vegetation concrete is analyzed by comparing with 2nd~5th working conditions. With the increase of water-cement ratio, the strength of vegetation concrete changes little. Therefore, the effect of increasing water-cement ratio for strength is not significant, under the premise of the target porosity of 30%.

Trend in Figure 2(c) shows the vegetation concrete strength increase follows the amount of cement increase. In group 9, not only cement content, but also additives were added, and the strength reached 10Mpa, exactly as the vegetation concrete of ecological slope protection requires. Under the premise of the target porosity of 30%, the increase of cement content has a significant impact on improving vegetation concrete strength, and the appropriate addition of additives can better meet strength requirements of the vegetation concrete of ecological slope protection. It reveals that mix proportion used in 9th working conditions is the best choice for production of vegetation concrete under the premise of the target porosity of 30%.

Age of concrete also has some influence on the strength of vegetation concrete. Taking A particle size as an example, establish the relation diagram, as shown in Figure 2(d). With the increase of age, except the strength of group A1 (P·O 32.5) remains almost unchanged, the strength of vegetation concrete in other groups increase 1Mpa~6Mpa with different degrees. The strength of group A6 (water-cement ratio 0.3) is 6.03Mpa after 28 days, and reaches 11.49Mpa after 90 days, almost increase double. Now, water-cement ratio 0.3 can better meet the strength requirements of ecological slope protection of vegetation concrete.

The experiment results show that, under the target porosity of 30%, aggregate particle size, age and cement content are key factors that affect the strength of vegetation concrete, while the water-cement ratio has relatively little influence. The smaller the aggregate particle size is, the larger the cement content is, and the smaller the water-cement ratio is, the higher strength of the vegetation concrete is.

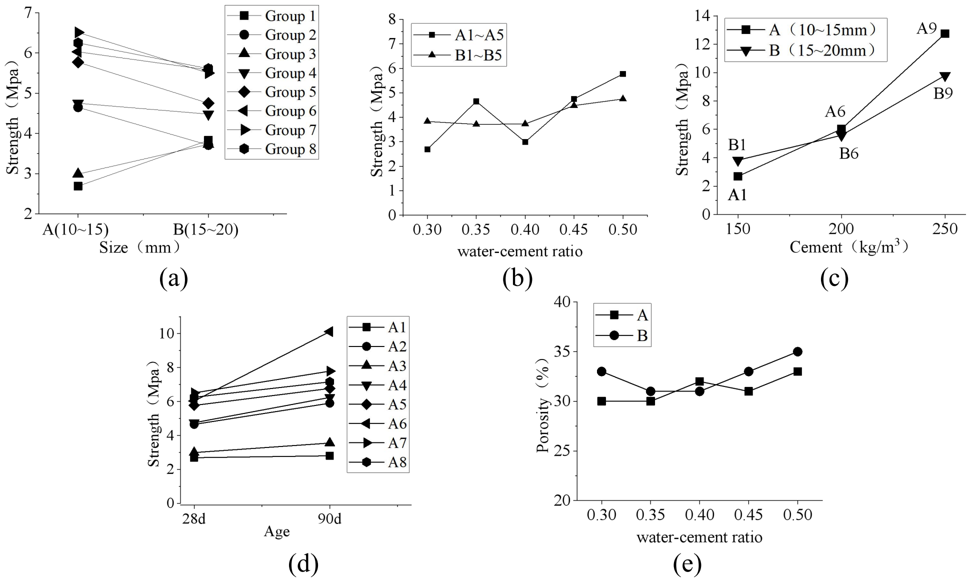

Figure 2: (a)The relationship between compressive strength and aggregate particle size; (b) The relationship between compressive strength and water-cement ratio; (c) The relationship between compressive strength and cement content; (d) The relationship between compressive strength and age; (e) The relationship between porosity and water-cement ratio.

2.3.4. Porosity Analysis

The test target porosity is 30%. However, vegetation concrete specimens formed by mechanical stirring and hand mixing, make a difference between actual measured porosities and the target porosity. As Table 2 showed, the actual measured porosity is close to the target porosity. In the case of certain target porosity, the actual measured porosity is related to the water-cement ratio, and it is affected by the water-cement ratio. As shown in Figure 2(e), the actual measured porosity tends follow the increase of water-cement ratio.

3. Planting Experiment

3.1. Test Preparation

Comparing and analyzing the physical mechanical properties test results of vegetation concrete, it found that the mix proportion corresponding of working condition 9th meet the practical requirements of ecological slope protection engineering, in terms of strength and porosity. Hence, vegetation concrete of working condition 9th was used as ecological slope protection material to conduct the planting experiment.

For planting experiment, A (10~15mm) and B (15~20mm) particle sizes were adopted, and 9 vegetation concrete base layers specimens about 0.4m×0.4m×0.1m were made respectively, a total of 18. There is only small space for plants to grow in. As it requires that adapt to special growth environment of vegetation concrete in addition to ensure its rapid and normal growth, perennial herbs were adopted[2]. According to the real situation of Sichuan Basin in China, choose three plant species

Cynodon dactylon(L.)pers, Agrostis stolonifera and Sasa argenteostriata to carry out the experiment. The thickness of soil substrate covering vegetation concrete has an important impact on plant growth and engineering construction. 5~15cm is generally selected. Combining with the research of several scholars[23] and the characteristics of these three plant species, the thickness of soil substrate covering vegetation concrete was determined to be 8cm.

3.2. The Preparation Process of Planting

Three plants in each group were planted with three test base layers. It covered with a layer of soil substrate of thickness of 8cm on the surface (0.016m^2) in vegetation concrete. And then the grass seed of Cynodon dactylon(L.)pers and Agrostis stolonifera were planted with 5g in each, and Sasa argenteostriata transplanted by 1:1 ratio. Three pots of plants were planted in natural soil as the control group, represented by the letters CG. As shown in Figure 3(a), A9 groups of vegetation concrete test specimens located in the dotted line frame, B9 groups located in the solid line frame. Both A9 and B8 groups have three rows, from the top to the bottom in the picture are Cynodon dactylon(L.)pers, Agrostis stolonifera and Sasa argenteostriata, respectively represented by the letters C, A and S. By the way, the pictures in Figure 3 are taken from the same direction with the position unchanged.

The experiment of planting begins in mid-march. In order to ensure that the growing environment of plant species conforms to the actual natural state, the experiment conducted by natural environment, water is poured once in the morning and evening in the first week. After that, there is no water pouring except for the case of temperature is over 30℃. Its natural state is retained in other cases, and no fertilization measures are taken.

3.3. The Condition of Plant Growth

Comparing After 21 days of planting, the plants in the two groups grow well, as strong as those in the control group. In terms of growth situation, the adaptability of Sasa argenteostriata is the best. Its root system can expand and grow rapidly. The adaptability of Agrostis stolonifera is the second, which can completely cover the test specimen and Cynodon dactylon(L.)pers is the worst, grows slowly, as shown in Figure 3(b). On the 40th day, all three plants show a good growth trend. And the most obvious growth and the fastest increase in height among three plants is Agrostis stolonifera, as shown in Figure 3(c). After 90 days, as the temperature rises, Agrostis stolonifera withers and yellows while the other two groups are still in good state, as shown in Figure 3(d).

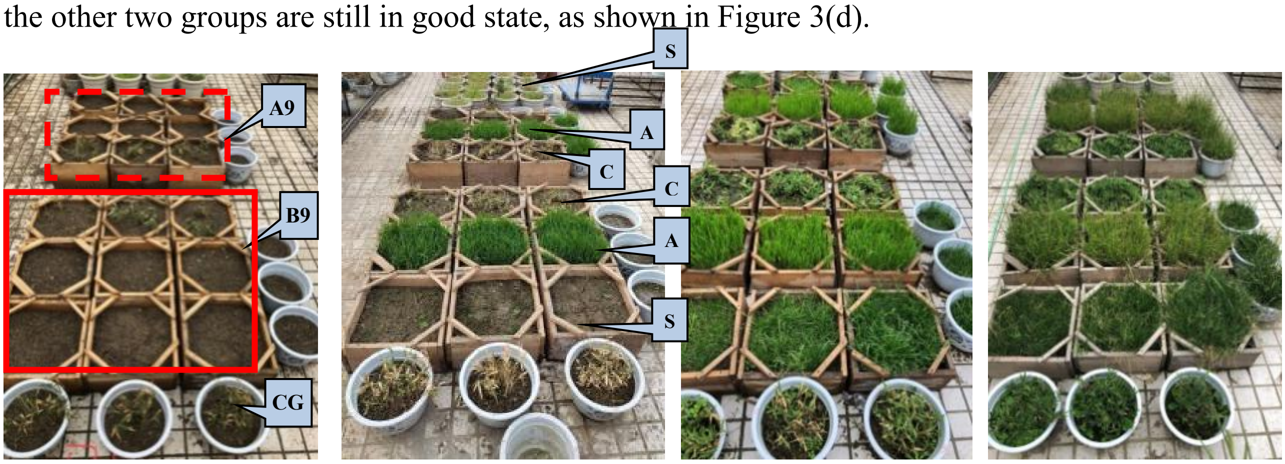

Figure 3: Plant growth record: (a) 1st Day; (b) 21th Day; (c) 40th Day; (d) 91th Day.

(a) (b) (c)

Figure 4: Growth of Agrostis stolonifera: (a) growth height; (b) root elongation; (c) depth of root development.

Among three plants, Agrostis stolonifera is the highest. On the 35th day, the height of Agrostis stolonifera exceeds 20cm, which still rises after cutting treatment, as shown in Figure 4(a). Comparing with the other two plants, its root system is the weakest. Pull out a small amount of Agrostis stolonifera, the growth of its roots is observed, as shown in Figure 4(b), the length of roots over 15cm. As shown in Figure 4(c), the development of root system can be viewed from the section. It is obvious that plant roots can penetrate through the soil substrate into the pores of the test specimen and form a good composite structure with vegetation concrete.

During the treatment of watering, some water seeps from the bottom of the vegetation concrete test specimen, testify to the vegetation concrete has a certain capacity of water storage and seepage. The height of soil substrate changes from 8cm to about 5cm after 6 months, indicate that as time goes by, the height of the soil substrate gradually decreased, merged with the vegetation concrete test specimen and form a composite structure. After test detection, the pH of the soil substrate in the two groups are in the neutral range, and the substance contents in the soil components all accord with the plant growth demand, as shown in Table 2.

Table 2: Soil composition of vegetation concrete test specimen.

Name	Total P	Available P	Total K	Available P	Organic Matter	Total N	Available nitrogen	pH
Unit	g/kg	mg/kg	g/kg	mg/kg	g/kg	g/kg	mg/kg	—
C-CG	0.20	35.60	14.37	159.00	32.90	0.26	20.49	7.80
C-A9	0.20	41.10	13.30	225.00	41.70	0.65	61.18	7.63
C-B9	0.19	37.28	14.40	189.00	38.77	0.81	72.01	7.63
S-CG	0.19	39.61	17.57	184.00	38.35	0.74	64.79	7.57
S-A9	0.19	40.93	18.37	240.67	41.28	0.73	76.97	7.47
S-B9	0.21	38.00	16.30	279.00	42.12	0.81	73.84	7.53
A-CG	0.20	37.97	18.17	109.33	41.91	0.84	64.78	7.73
A-A9	0.21	35.59	17.30	134.67	37.30	0.66	56.04	7.80
A-B9	0.20	35.98	18.13	125.67	32.90	0.67	61.53	7.77

4. Conclusion

(1) The key factors affect the compressive strength of vegetation concrete are aggregate particle size, water-cement ratio, cement content and grade. The smaller the aggregate particle size is, the smaller the water-cement ratio will be and the higher the cement content is, the stronger the compressive strength of concrete will be. Vegetation concrete has a character of low strength in early stage. Its compressive strength has been improved to a certain extent as the age of vegetation concrete increases. Under the target porosity of 30%, mixture proportion method of water-cement ratio 0.3, cement content 250 kg/m^3, aggregate particle size 10~15mm and quantitative additive are adopted. It not only meets the strength requirements of vegetation concrete in ecological slope protection, but suits for the natural growth of plants.

(2) At the target porosity of 30%, plant roots can get into the internal pores of the vegetation concrete specimens through soil substrate. By the action of soil substrate and the plant growth metabolism, the root system gradually passes through the vegetation concrete, extend to the soil layer below, and organically combine with the concrete, form a complex combination eventually.

(3) There is not really much difference in plant growth between the two groups of vegetation concrete test specimens. Both the vegetation concrete test specimens of the two sizes have capacity of water storage and seepage and are suit for these three plant species. However, the ecological slope protection requirement of strength is above 10Mpa, the aggregate particle size of 10~15mm is preferred. As soon as the selection of plant species, the growth characteristics of three plants in vegetation concrete test specimens are different. In a short, Sasa argenteostriata have the best performance that its root system is strong and extents rapidly. Cynodon dactylon(L.)pers germinates shows retarded growth in the early stage but rapid growth in the later stage, moreover it also has good coverage, it's also a good choice for vegetation concrete. Although Agrostis stolonifera grows the fastest and has a good coverage, considering it poor root system and weak drought resistance, it's not recommended.

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