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# Effect of limestone powder on self-compacting concrete

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## ABSTRACT

Self-compacting concrete (SCC) is an innovative construction material in the construction industry. It is a highly fluid and stable concrete that flows under its own weight and fills completely the formwork. The SCC requires high powder content (mainly of cement) up to 600kg/$m^3$ to achieve its properties. This will be problematic because increasing the cement content is not feasible, and may cause high cost and some other technical problems such as higher heat of hydration and higher drying shrinkage. This paper investigates the effect of limestone powder (LSP) on fresh and hardened properties of SCC due to the use of LSP as a partial cement replacement. For comparison, a control sample of concrete was prepared without LSP to compare it with the various samples containing different percentages of LSP as a partial replacement of cement. Four mixes with a constant amount of (superplasticizer, sand, coarse aggregate, and water) at various replacement levels of 0%, 10%, 20% and 30% from cement weight were prepared. The experimental results show that the LSP can be effectively used as a partial cement replacement on SCC to reduced cost and enhanced the performance of SCC in fresh and hardened stages.

**Keywords**: *Self-compacting concrete (SCC), Limestone powder (LSP), Mix design, Workability*

**مُستَخلَص:**

الخرسانة ذاتية الدمك (SCC) هي مادة بناء مبتكرة في صناعة البناء. وهي عبارة عن خرسانة عالية السيولة ومستقرة تتدفق تحت تاثير وزنها الذاتي وتملأ القوالب بالكامل. تتطلب SCC نسبة عالية من المسحوق (بشكل رئيسي من الأسمنت) حتى 600 كجم /م3 لتحقيق خصائصها. ستكون هذه مشكلة لأن زيادة محتوى الأسمنت غير ملائم ، وقد يتسبب في ارتفاع التكلفة وبعض المشاكل التقنية الأخرى مثل ارتفاع درجة حرارة الاماهة والانكماش العالي. تبحث هذه الورقة في تأثير مسحوق الحجر الجيري (LSP) على الخصائص الطازجة والمتصلدة لـ SCC بسبب استخدام LSP كبديل جزئي للأسمنت. للمقارنة ، تم تحضير عينة تحكم من الخرسانة بدون LSP لمقارنتها مع العينات المختلفة التي تحتوي على نسب مختلفة من LSP كبديل جزئي للأسمنت. تم تحضير أربعة خلطات مع كمية ثابتة من (الملدن الفائق والرمل والركام الخشن والماء) بمستويات استبدال مختلفة من 0٪ و 10٪ و 20٪ و 30٪ من وزن الأسمنت. أظهرت النتائج التجريبية أنه يمكن استخدام LSP بشكل فعال كبديل جزئي للأسمنت على SCC لخفض التكلفة وتعزيز أداء SCC في المراحل الطازجة والمتصلدة.

## 1 INTRODUCTION

Self-compacting concrete (SCC) is recognized as one of the largest discoveries in the development of concrete technology. It was discovered in the late 1980s by a Japanese professor, H. Okamura, who aimed to improve the quality of conventional concrete [1]. According to BS EN 206-9:2010 [2] SCC is defined as "Concrete that is able to flow and compact under its own weight, fill the formwork with its reinforcement, ducts, box outs, etc., whilst maintaining homogeneity", thereby conserving the energy and labor which would have otherwise been utilized for vibration. The composition of SCC is the same as normal concrete that is; cement, fine and coarse aggregates, water, mineral and chemical admixtures [1]. The difference in concrete mix design between SCC and conventionally vibrated concrete is; lower coarse aggregate content, increased paste content, low water/powder ratio, increased superplasticizer [3]. These help in maintaining the workability and cohesion of concrete. Due to high powder content (mainly of cement) it makes the SCC costlier in spite of lower labor cost and also leads to increased shrinkage and thermal expansion of concrete. To address these problems mineral additives such as pulverized fuel ash (PFA), ground granulated blast slag (GGBS) or limestone powder (LSP), and rice husk ash (RHA) have been used as partial replacement of cement [4]. When these mineral additives replace a part of the Portland cement, the cost of SCC will be reduced especially if the mineral admixtures are waste or industrial by-product. These mineral admixtures materials do not only decrease the cost of SCC, but also improve flowability and durability [5], reduce the heat of hydration in massive structures [6], increase early strength and control bleeding [7].

In limestone quarries, significant amounts of limestone powder (LSP) are produced as by-products of stone crushers. Large volumes of these powders are accumulated and it is a big problem to propose the utilization of these by-products from the aspects of disposal, environmental pollution and health hazards [8]. LSP has been used to produce cement in some countries, and in the recent EN197-1 specification [9], it is mentioned that up to 35% of LSP can be added to produce Portland limestone cement and Portland composite cement. The main component of LSP is calcium carbonate. It does not possess pozzolanic activity, but its use in SCC improves the deformability and viscosity, as well as reduction porosity [10].

In Sudan, two types of LSP are available. One type is finely ground Limestone powder, and the other is limestone dust, which is produced in quarrying operations. While the price of the first type of LSP is approximately twelve times less than the price of cement, the second type of LSP is actually a waste material. Thus, the successful utilization of limestone powder in SCC mixes would not only lower the cost of SCC but could also provide a solution regarding the disposal and environmental problems connected with this filler. The aim of the work reported in this paper was to investigate the influence of finely ground limestone powder on the fresh properties and strength characteristics of SCC mixtures.

## 2 STATE OF THE ART

### 2.1 General overview

BS EN 206-9:2010 [2] defines the properties of fresh SCC as follow:

***Flowability****:* the ease of flow of fresh SCC when unconfined by formwork and/or reinforcement.

***Passing ability****:* the ability of fresh SCC to flow through tight openings such as spaces between steel reinforcing bars without segregation or blocking.

***Viscosity***: the resistance to flow of fresh SCC once flow has started.

***Segregation resistance***: the ability of fresh SCC to remain homogeneous in composition while in its fresh state.

### 2.2 Basic mix design

The European guideline [11] states that There is no standard method for SCC mix design and many academic institutions, admixture, ready-mixed, precast and contracting companies have developed their own mix proportioning methods. The European guideline [11] states some of these mix design methods developed at academic and other institutions, but These Guidelines are not intended to provide specific advice on mix design so The European guideline gives an indication of the typical range of constituents in SCC by weight and by volume. These proportions are in no way restrictive and many SCC mixes will fall outside this range for one or more constituents.

Nan Su and et al. [13], [14] is one of these methods. They proposed a simple mix design procedure for SCC and their main focus was to fill voids of loosely filled aggregate with binder paste. They introduced a factor called Packing Factor (PF) for aggregate. It is the mass ratio of aggregate at a tightly packed state to that at a loosely packed state. This method is simple and uses a smaller amount of binders. The method is used to derive the mix design for the required target strength [14].

### 2.3 Limestone powder on SCC

A filler (powder) material is a ground material which passed 0.15 mm grounded similar to Portland cement fineness; it can be natural materials or processed mineral materials. It has uniform properties and fineness [15]. According to BS EN 197-1:1992 [9], filler or additive has been limited to 5% of cement content by weight. However, it allows the use of LSP up to 35% of cement content.

Nehdiet al. [16] stated that using LSP improves the consistency and stability of fresh SCC. Also, it reduces costs by lowering cement content. Menendez et al. [17] studied the effect of LSP in concrete and reported that utilizing the LSP with Portland cement increases the rate of hydration at early age and producing high early strength. The physical effect of LSP caused by small size of particles, which improves the packing density of powder and reduces the interstitial voids, thus decreasing entrapped water in the system [19]. LSP based SCC has a lower risk for bleeding, but mechanical strength is decreasing with increasing temperature [20]. In the presence of the limestone filler, the stability of the mixture is affected and the segregation is not observed [7]. Reference [21] stated that the mixing procedure has a great effect on the properties of SCC. However, the mixing time also affects the SCC fresh properties as well as its hardened properties such as compressive strength, splitting tensile strength, amount of water added and permeability of concrete [22]

## 3 MATERIAL AND METHODS

### 3.1 Materials

*Coarse aggregate (CA)*: The coarse aggregates used in SCC mixtures were single size crushed basalt obtained from TORYIA Mountain in Khartoum State, with a maximum size of 12.5 mm. The grading of coarse aggregates is conforming to BS 882:1992 [23]. The tests carried out on coarse aggregates for concrete mixes by using procedures conforming to the corresponding parts of BS EN 1097 [24], BS EN 933-1 [25] and BS 812-2 [26]. Table (1) shows the physical properties of Coarse Aggregates.

*Fine aggregate (FA)*: Natural sand conforming to BS 5075-1 [27] was used in the present research. The grading of fine aggregates is conforming to BS 882:1992 [23]. The tests carried out on fine aggregates for concrete mixes by using procedures conforming to the corresponding parts of BS EN 1097 [24], BS EN 933-1 [25] and BS 812-2 [26]. Table (1) shows the physical properties of Fine Aggregates.

*Water (W):* Potable tap water was used for the preparation of specimens and for the curing of specimens.

*Cement (C):* Ordinary Portland Cement (42.5 N) conforming to BS EN 197-1 [9] was used. The Chemical properties results are listed in Table (4). The physical properties results are listed in Table (1) and (3). whereas the phase composition of the clinker was given in Table (2).

*Superplasticizer(SP):* (Seraplast SP901) complies with BS 5075-3 and ASTM C494 Type F as high range water reducing admixture, having a relative density of 1.22 at 25ºC was used in this study. The recommended dosage range is 0.2 – 2.5 % of mass cement.

*Limestone powder (LSP):* Locally available limestone obtained from Atbara quarries (River Nile State in north-eastern Sudan) was used as partial cement replacement materials in the present work. Table (4) and (1) shows the chemical composition and physical properties of the LSP.

**Table 1: Physical property of materials**

| *Material* | *Specific gravity (SG)* | *Water absorption (%)* | *Fines modulus* | *Bulk Density (Kg/m³)* |
|---|---|---|---|---|
| *C* | 3.15 | - | - | - |
| *LSP* | 2.65 | - | - | - |
| *FA* | 2.62 | 0.508 | 2.21 | 1660 |
| *CA* | 2.82 | 0.722 | 6.14 | 1547 |
| *SP* | 1.19 | - | - | - |

**Table 2: The potential phase Composition of the clinker**

| *Element* | $C_3S$ | $C_2S$ | $C_3A$ | $C_4AF$ |
|---|---|---|---|---|
| *(%)* | 66.98 | 1.93 | 9.12 | 4.80 |

**Table 3: Physical property cement:**

| *Physical property* | | *Result obtained* |
|---|---|---|
| *Setting time* | *Initial setting time of cement (min)* | *135* |
| | *Final setting time of cement (min)* | *290* |
| *Compressive strength* | *2 Days* | *17.1 MPa* |
| | *28 Days* | *45.3 MPa* |

**Table 4: Chemical composition of OPC and LSP**

| Oxides in clinker (%) | OPC | EN 197-1 Limits | LSP |
|---|---|---|---|
| CaO | 60.31 | | 52.63 |
| $Al_2O_3$ | 4.45 | | 0.46 |
| $SiO_2$ | 18.27 | | 0.299 |
| $Fe_2O_3$ | 1.58 | | 1.46 |
| $K_2O$ | - | | < 0.1 |
| $Na_2O$ | - | | 1.5 |
| SO3 | 2.62 | Max 3.5% | 0.25 |
| Cl | - | | 0.51 |
| MgO | 1.85 | Max 6.0% | 1.62 |
| L.O.I | 3.52 | | 39.77 |

### 3.2 Mixture proportions

Nan Su method described in Ref [13] is used to determine the initial mix proportions and uses data and limits values stated in BS EN 206-9 [2].

After several trial mixtures, a mixture consistent with the BS EN 206-9 [2] was obtained as a reference mixture. The main content of this mixture (coarse aggregate, fine aggregate, cement, water, and superplasticizer) was fixed so that the influence of partial replacement of cement with limestone powder at varying percentages in the properties of fresh and hardened concrete was investigated. limestone powder replaces the cement by 10%, 20%, and 30%, of the total cement weight. Table (5) Lists mix proportions of SCC.

### 3.3 Mixing procedure

The mixing procedure and time are very important; thus the mixing process was kept constant for all concrete mixtures. All the ingredients were first mixed under dry conditions in the concrete mixer for one minute. Then 70% of the calculating amount of water was added to the dry mix and mixed thoroughly for five minutes. The remaining 30% of water was mixed with the SP and was poured into the mixer and mixed for three minutes. Thus, the total mixing time was 9 minutes. In this experimental work commercial mixer tilted drum mixer with 33 revolutions per minute (rpm) was used.

### 3.4 Tests methods.

#### 3.4.1 Tests on fresh concrete

In this study, the fresh properties of SCC with varying percentages of limestone powder are analyzed. The properties of SCC mixtures with various percentage of replacement of cement with limestone powder (0, 10, 20 and 30) are determined by conducting tests, identified in the BS EN 206-9:2010 [2] such as slump flow test [28] to measure flowability, T500 and V-funnel [29] test to measure speed of flow or viscosity, J-ring [30], and L-box test [31] is used to assess the passing ability and sieve segregation resistance [32] for the four samples considered for this research.

(a) Slump flow (b) J-ring

**Fig 1: Testing Fresh Properties of SCC**

#### 3.4.2 Tests on hardened concrete

##### 3.4.2.1 Compressive strength

Concrete specimens were batched, moulded and cured according to BS EN 12390-2 [33] standard. Cube specimens (150*150*150 $mm^3$) of 7, 14 and 28 days were tested for its compressive strength for all mixes. Three replicates of each mix were tested and the average strength was calculated. The split tensile strength was measured according to BS EN 12390-3 [34].

##### 3.4.2.2 Tensile strength

Concrete specimens (cylinders 150*300 $mm^3$) of 28 days were tested for its tensile strength for all mixes. Three replicates of each mix were tested and the average strength of these three cylinders are taken as the final results. The split tensile strength was measured according to BS EN 12390-6 [35].

##### 3.4.2.3 Flexural strength

Concrete specimens (Beams 500*100*100 $mm^3$) of 28 days were tested for its flexural strength for all mixes. Two samples of each replacement were tested and the average strength of these two beams was taken as the final results. The flexural strength was measured according to BS EN 12390-5 [36].

## 4 Results and Discussions

The main aim of this experimental research is to find out the effects of limestone powder as a partial cement replacement on the fresh and hardened properties of SCC.

### 4.1 Fresh Concrete Test Results.

Table 6 presents the results of fresh SCC parameters obtained from different tests carried out in this study. It also classifies the different prepared mixes, according to BS EN 206-9:2010 [2]. It was observed that all mixes were admissible and met the SCC acceptance criteria.
Regarding the effect of LSP dosage, Table 6 shows that increasing the LSP did not affect the viscosity, Passing ability, and Segregation resistance classification.

#### 4.1.1 Flowability of SCC

The test results show the possibility of using LSP as a partial cement replacement to increase the flowability of SCC (table 6). It is because that limestone powder with fine particle and smooth dense surface, which scattered between the cement particles, plays the role of deflocculant in the hydration of cement, which makes the fluidity of SCC improved [37], but with the increase of the limestone powder, the concrete becomes sticky, which makes the slump flow decrease.
the results obtained in the slump flow test shown in Table (6) varied from 720-590 mm which is an acceptable limit and complying with the requirements of BS EN 206-9 [2].
The slump flow varied in response to the percentage of the limestone powder. Sample with 20% limestone replacement had the highest slump flow. It was observed that the cement may be replaced with limestone up to 20 % to increase the flowability. The replacement of Portland cement with 30% limestone led to a reduction in flowability because with the increase in limestone powder the mix becomes denser and hence less self-compactable.

**Table 5: Mix Proportion of SCC. (kg/$m^3$)**

| Mix type | % of replacement | C kg/$m^3$ | LSP kg/$m^3$ | F.A kg/$m^3$ | CA kg/$m^3$ | SP kg/$m^3$ | W kg/$m^3$ | W/P | W/C |
|---|---|---|---|---|---|---|---|---|---|
| SCC-0 | 0 % | 407.8 | - | 1022.6 | 779.668 | 8.156 | 201.6 | 0.48 | 0.48 |
| SCC-1 | 10 % | 367.02 | 38.073 | 1022.6 | 8.156 | 8.156 | 201.6 | 0.48 | 0.53 |
| SCC-2 | 20 % | 326.24 | 75.904 | 1022.6 | 8.156 | 8.156 | 201.6 | 0.48 | 0.6 |
| SCC-3 | 30 % | 285.46 | 113.615 | 1022.6 | 8.156 | 8.156 | 201.6 | 0.48 | 0.68 |

**Table 6: Fresh properties of SCC and Classification of mixtures according to BS EN 206:9 [2]**

| *Mix / Property* | *SCC-0(Ref Mix)* | *SCC-1 (10%)* | *SCC-2 (20%)* | *SCC-3 (30%)* |
|---|---|---|---|---|
| *Slump Flow Diameter (mm)* | 674 | 701 | 720 | 590 |
| *Class* | $SF_2$ | $SF_2$ | $SF_2$ | $SF_1$ |
| *T50cm (sec)* | 2.51 | 2.98 | 3.38 | 4.53 |
| *Class* | $VS_2$ | $VS_2$ | $VS_2$ | $VS_2$ |
| *V-funnel (sec)* | 4.24 | 4.65 | 5.04 | 5.23 |
| *Class* | $VF_1$ | $VF_1$ | $VF_1$ | $VF_1$ |
| *L-Box H2/H1* | 0.811 | 0.814 | 0.842 | 0.779 |
| *Class* | $PL_2$ | $PL_2$ | $PL_2$ | - |
| *j-Ring(mm)* | 6 | 6 | 4 | 9 |
| *Class* | $PJ_2$ | $PJ_2$ | $PJ_2$ | $PJ_2$ |
| *Sieve Analysis%* | 12.45 | 12.27 | 10.49 | 8.67 |
| *Class* | $SR_2$ | $SR_2$ | $SR_2$ | $SR_2$ |

The increases were 3.85 % and 6.38 % for 10 % and 20 % compared to the reference mix (SCC-0) respectively. The flow diameter was found to be decreasing for 30% replacement by 14.23 % compared to the reference mix (SCC-0)

### *4.1.2 Viscosity of SCC*

The V-funnel test and T500 time assess the flow rate of SCC in the absence of obstructions. All SCC mixtures presented satisfactory the flow rate ranges according to BS EN 206:9 [2], which measured by V-funnel and T500 (table 6). The flow rate is in the field of 2.51-4.53s and 4.24-4.53s respectively, which is a good index of Viscosity.

Comparing the T500 times, it can be seen that concrete mixtures made with LSP reached slower the 50 cm diameter than concrete mixtures made without limestone, which means that their plastic viscosity is higher

### *4.1.3 Passing-ability of SCC*

Comparison of Passing ability test results of different combinations of mixes with the reference mix shows that Passing ability increase with an increase in the percentage of limestone powder up to 20% in the mixes. The sample with a 20% limestone replacement had the highest Passingability rate.

From table (6), the Passing-ability tests of the SCC samples are in the ranges according to BS EN 206-9 [2], which is an indication of a good passing ability between congested reinforcement.

### *4.1.4 Segregation resistance of SCC*

Table (6) shows that increasing in limestone powder ratio has improved the SCC stability (i.e. segregation resistance). It can be seen that the values of segregation resistance were between 8-13% for all mixes. The lower segregation resistance ratio means more segregation resistance. This gives an indication of the segregation resistance of the SCC mixes, which comply with the requirements of BS EN 206-9 [2].

## ***4.2 Hardened properties of SCC***

The hardened concrete test results are presented in Table (7) which included the 7, 14 and 28 days for compressive strength, 28 days for flexural and splitting strength. It shows that the compressive strength, splitting tensile strength and flexural strength of concrete is raised by replacing cement with LSP up to 30%.

### *4.2.1 Compressive Strength*

The test results on the cube compressive strength of SCC is given in Table (7) and plotted in Fig. 2.

It can be seen from Fig.2, the concrete strength increases with the increases of limestone powder, especially the early strength can increase more than 20%. This may be due to the fact that the inclusion of fine limestone powder may accelerate the hydration of $C_3S$ and hence early strength development [18].

Table (7) and Fig. 2 shows the increase in the compressive strength with time. It is clear from the

**Table 7: Fresh properties of SCC using limestone powder**

| *Mix type* | *% of LSP* | *Compressive Strength ($N/mm^2$)* | | | *Split Tensile strength ($N/mm^2$)* | *Flexural strength ($N/mm^2$)* |
|---|---|---|---|---|---|---|
| | | ***7 days*** | ***14 days*** | ***28 days*** | ***28 days*** | ***28 days*** |
| *SCC-0* | ***0*** | *15.9* | *18.2* | *22.7* | *3.15* | *4.0* |
| *SCC-1* | ***10*** | *16.8* | *19.2* | *23.4* | *3.17* | *4.12* |
| *SCC-2* | ***20*** | *16.9* | *21.2* | *24.9* | *3.22* | *4.35* |
| *SCC-3* | ***30*** | *19.7* | *23.2* | *25.4* | *3.37* | *4.63* |

figure that the mixtures containing LSP are indicating higher compressive strength. At (7) days age the increase in compressive strength around (5-20%) of without LSP mix SCC, at (14) days age the increase in compressive strength between (5-20%), and at (28) days age the increase in compressive strength between (3-11%) only.

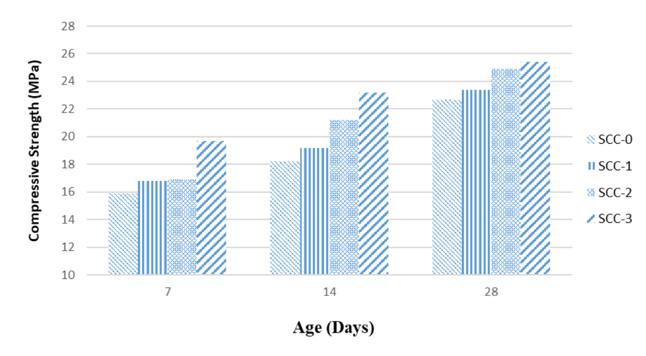


**Fig. 2. Effect of time in compressive strength of SCC**

All mixes of concrete formed by replacement of cement by LSP exhibit higher compressive strengths when compared to the reference mix i.e., 0% replacement.

In 10% replacement the compressive strength increases by 5.3% at 7days, 5.2% at 14days, 3% at 28days. In 20% replacement, the compressive strength increases by 5.9% at 7days, 14.15% at 14days, 8.84% at 28days. The maximum increase of 10.6 percent in compressive strength at 28 days has been observed at 30 percent replacement of cement by limestone powder compared with reference concrete. At 14days compressive strength increases by 21.55%. At 7days compressive strength increases by 19.28%.

### *4.2.2 Split tensile strength*

The test results on the split tensile strength of SCC is given in Table (7). It can be seen that tensile strength increases with the increases of limestone powder.

All mixtures formed by replacement of cement by LSP when compared to the reference mix i.e., 0% replacement, reveal higher tensile strengths at 28days. For 10% and 20% The use of LF as a partial cement replacement recorded increases in tensile strength, the increases were 0.63% and 2.17% respectively, compared with reference mixture (SCC-0). At 30% replacement of cement by limestone powder show a maximum increase of 6.9% compared with the reference mix.

### *4.2.3 Flexural strength*

The test results on the flexural strength of SCC is given in Table (7). It has been observed that the 28-days flexural strength increases up to 30% replacement of cement by limestone powder. All mixtures formed by replacement of cement by LSP when compared to the reference mix i.e., 0% replacement, reveal higher flexural strengths at 28 days. For 10% and 20% The use of LSP as a partial cement replacement recorded increases in flexural strength, the increases were 2.9 % and 8 % respectively compared with reference mixture (SCC-0). The maximum increase of 13.6 percent in flexural strength at 28 days has been observed at 30 percent replacement of cement by limestone powder compared with reference mixture.

## 5 Conclusions

The following conclusions can be drawn from the results of this study

1. The test results show that using limestone powder (LSP) as a partial cement replacement on SCC.
2. The addition of LSP up to 30 % by cement weight reduced cost and enhanced the performance of SCC in fresh and hardened stages.
3. The test results showed increases on workability of the concrete. The flowability and filling ability increased, and the segregation was reduced.
4. SCC mixtures that containing LSP Takes more time to flow compared to reference mixture, i.e. they have higher viscosity.
5. Up to 20% of cement can be replaced by limestone powder to improves self-compatibility and it did not affect on the SCC classifications.
6. Limestone powder can increase the early strength of SCC but does not much affect the late strength of the concrete.
7. The optimum content of limestone powder is 20% based on the comprehensive consideration of the influence of the LSP on the workability and the mechanical property.

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