

Original Research Article

Sustainable Study of Local Lateritic Soils Compressibility

ABSTRACT

The compressibility, ~~the settlement(s)~~ and the settlement duration of the lateritic soils of Yaoundé in Cameroon increase with water content (w). The increase in settlement with water content is more accentuated with a strong load than a weak load. The compaction also considerably decreases the compressibility of these soils, rendering the action of water almost null on the variation of settlement except when the compaction is not made with the Proctor optimum. These significant observations compel us to consider only, for a lateritic soil or another, the compressibility characteristics under immersion conditions. The findings of this work agree with the principle of the oedometric test described in the French Standard NF P 94 900.

Key words:

Keywords: lateritic, water content, compression index, compaction, consolidation.

1. INTRODUCTION

Lateritic soils are in abundance in the intertropical zones. They are soft soils with color varying from red to yellow, rich in alumina and iron oxides and which harden when they are exposed to free air [1 – 3]. These soils represent a significant source of materials for the works of engineering structures such as roads, bridges or dams [4]. ~~their strong thickness places them naturally as the principal support of civil engineering works. Receive loads that can change their initial structure by settlement, they are said to be compressible soils.~~ This settlement phenomenon of soils sometimes causes damages on buildings (cracking of walls, collapse of buildings, sometimes rutting of roadways). One of the various causes of this phenomenon is the variation of the water content in soils due to the variability of the country yearly water fall and to the change in velocities of water absorption of different sub-soils. Several studies on the behavior of lateritic soils only take into account the saturated state to tackle the variation in soil settlement [5 – 7].

~~Since local soils are seldom found in the absolute saturated/unsaturated state in their natural environment, the principal advantage of the present research work is to solve engineering problems related to the massive use of local available lateritic soils for the construction industry by suggesting alternatives dimensioning approach, trough experimental testing results and geotechnical indicators such as their compressibility and their settlement of disturbed and undisturbed saturated (sat) and unsaturated (u_{sat}) natural soil samples.~~

2. METHODOLOGY

~~Identification and~~ compactions tests were carried out in accordance with standards and regulations defined by AFNOR (Association Française de NORmalisation, French Standard Agency).

and the odometer compression test was the principal test of this study. This test, performed in the loading stage (24 hours), consisted of putting the sample in a rigid envelope, exerting a vertical pressure on its upper end using a piston, and measuring at the end of each loading stage after stabilization, the depression leading to the determination of various characteristics of compressibility pertaining to the analyzed soil sample [8 – 10]. These tests were carried out on intact samples (IS) taken from a lateritic profile of Yaoundé (Figures 1), and on compacted samples (CS) carried out in the laboratory using results of Proctor compaction tests. The analysis of these samples with the odometer was done at different water content. For the intact samples, two cases of water content were retained: the natural water content (i.e. without water addition in the odometric cell) and the saturated state. In the case of compacted samples, the samplings were made according to the optimal water content (w_{opt}) at 80%, 100% and 120%.

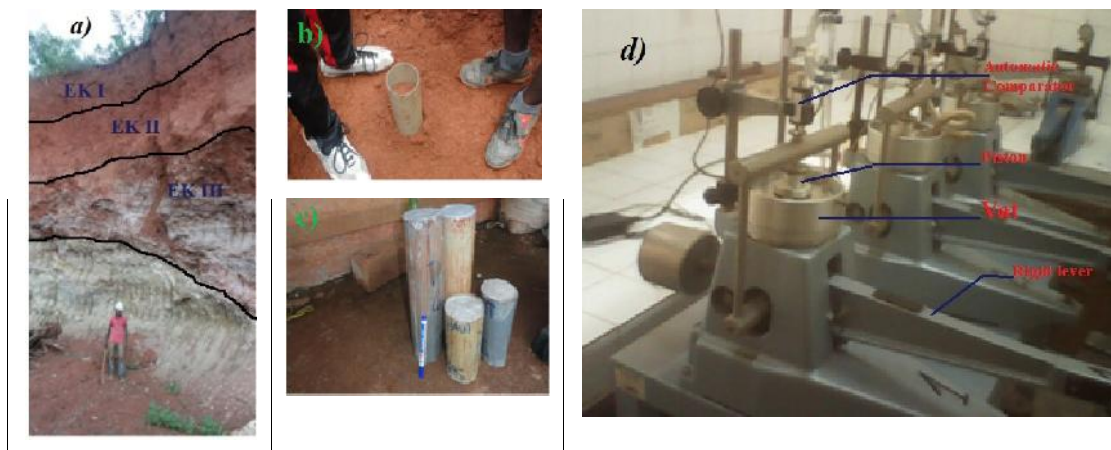


Figure 1 : Experimental setup: a) Sampling site; b) Intact samplings; c) Conservation of intact samples; d) Battery of odometers.

2.1 Experimental Setup.

The tests were carried out on two categories of samples (intact and compacted) by means of a battery of three loading sets by weight automatics odometers (Figure 1.d). Each apparatus comprises a cell made up with a laterally rigid ring with smooth interior walls. The ring is equipped with a cylindrical case that can receive a test-tube of 50 mm diameter and 20 mm thickness, placed between two porous stones. The whole system is placed inside a rigid vat at the bottom of which rests a lower porous stone. The vertical load is applied to the test-tube by means of a piston, on the base of which is fixed the upper porous stone. The piston slides on the ring with a weak play and a negligible friction and the load, applied by means of a weight, is transmitted to the test-tube by a rigid lever which takes support on the head of the piston.

2.2 Experimental Protocol

The execution of each test was made in accordance with the procedure recommended by Mieussens and al. [8], with the exception of some formulations made for the needs of the present study. These formulations are primarily the case of unsaturated samples and that of compacted samples. Thus the following protocol of these samples for the present analysis is made:

- 75 • The operation starts by cutting test tubes. It is carried out using the cylindrical case of the
76 odometric ring. The case is pressed on the cylinder of the sample taken on the site, while
77 using a knife, the material, opposed to the sinking of the ring, is progressively cut to ease
78 the process. This operation is continued until the material entirely crosses the ring. After
79 which, the upper and lower extremities of the test tube are leveled by means of a tight
80 wire pressed on the ring. Concerning the compacted samples, test tubes samples are not
81 taken, but are instead reconstituted from Proctor trials data. In this case, a point of the
82 Proctor curve is set and starting from the values of water content (w) and of dry density
83 (d_s) of this point, the corresponding wet density (d_n) is determined by the equation $d_n =$
84 $d_s(1+w)$. Knowing the volume (V) of the ring, the wet weight (W_n) of the material is
85 calculated using expression $d_n = W_n/V$. Then a weight of dry material greater than W_n is
86 taken and moisten with the quantity of water necessary to obtain the water content set on
87 the Proctor curve. The material is homogenized and the weight W_n of wet material is
88 taken. Using a laboratory sampler, the wet material obtained is filled in the ring, thus
89 reconstituting a compacted sample with a known water content;
- 90 • The test tube contained in the odometric ring is weighed to determine the initial physical
91 parameters of the material, and thereafter placed on the lower porous stone in the vat.
92 After centering the ring using a fitting device and, having tightened his three nuts, the
93 higher porous stone and the piston are placed. Then, the vat is filled with water, whose
94 level will be kept almost constant throughout the trial (the saturation case). Some test
95 tubes (intact and compacted) were analyzed without adding water in the vat throughout
96 the experiment (case of unsaturation).
- 97 • Loads are applied by successive steps of which the duration depends on 90% of the
98 consolidation time, with a rate of double increment. An initial load of 5 kPa is applied to
99 prevent any possible crack caused by the destruction restructuration of the material in
100 order to prevent its swelling after the mounting operation described above. The
101 compression of the test tube is hundredth of millimeter measured by means of an
102 automatic comparator assembled on the piston and connected to a computer through
103 which the data are recorded and treated to produce the compressibility curves. A cycle of
104 unloading loading is carried out as soon as one detects an elbow on the curve
105 representing the variation in thickness of the test tube according to the pressures applied.

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108 3. RESULTS AND INTERPRETATION

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110 3.1 Identification of samples

111 The Anglo-Saxon classification HRB (Highway Research Board), based on the Atterberg
112 limit values and the granulometry data [11], allowed us to classify the analyzed samples into
113 A-7-5 (17), A-7-5 (6) and A-7-5 (4) classes for sample sites EK I, EK II and EK III
114 respectively. Physical parameters obtained and the granulometric distribution of these
115 samples are presented in Figure 2 and table 1.

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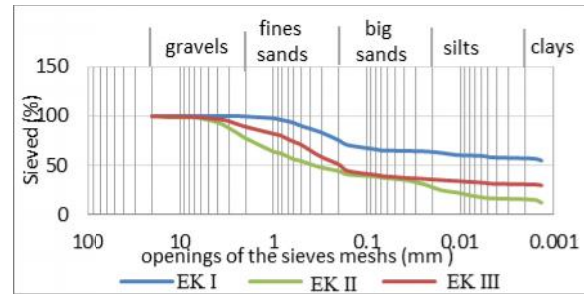


Figure 2 : Granulometric curves of analyzed samples

Table 1 : Parameters identification of analyzed samples

PHYSICAL PARAMETERS			
	EK I	EK II	EK III
W_L	73,61	67,76	62,4
I_p	40,27	34,47	18,33
d_a	1,32	1,48	1,29
d_r	2,71	2,84	2,67
w (%)	27,74	14,27	21,67
γ_h (kN/m ³)	16,8	16,9	15,7
γ_d (kN/m ³)	13,2	14,8	12,9
γ_s (kN/m ³)	27,1	28,4	26,7
γ_{sat} (kN/m ³)	18,3	19,6	18,1
e	1,06	0,92	1,07
n (%)	51	48	52
c (%)	49	52	48
w_{sat} (%)	39,02	32,27	39,95
S_r (%)	79,46	37,14	61,72

W_L = liquid limit ; I_p = plasticity index ; d_a = apparent density; d_r = real density; γ_h = wet voluminal weight; γ_d = dry voluminal weight; γ_s = voluminal weight of solid constituents; γ_{sat} = voluminal weight of saturated soil; e = vacuum index; n = porosity; c = compacity; w_{sat} = saturation water content; S_r = saturation degree.

3.2 Compaction

A compaction test is done to simulate the conditions under which the utilized material would be used for the construction of platforms or fills. According to BCEOM (Bureau Central d'étude pour les Equipements d'Outre-Mer, *Central Studies Office for Oversea Infrastructures*) and CEBTP (Centre Expérimental de recherche et d'étude des Bâtiments et Travaux Publics, *Experimental Research and Study Centre for Buildings and Public Works*), values of CBR (California Bearing Ratio), presented in Table 2, place the soils of Yaounde in classes S2 (EK I and EK III) and S4 (EK II). These research offices estimate that materials of class S2 ($5 < CBR < 10$) can be used for the construction of embankments, while those of class S4 ($15 < CBR < 30$) could be well used for the construction of the foundation and roadbed for light traffics [12, 13].

Table 2 : Values of compaction tests

Proctor	EK I		EK II		EK III	
	γ_{dmax} (kN/m ³)	W_{opm}	γ_{dmax} (kN/m ³)	W_{opm}	γ_{dmax} (kN/m ³)	W_{opm}
	17,15	20,5	19,2	15,9	18,6	14,8
CBR	8%		23%		9%	

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139 3.3 Compressibility

140 Tables 3 and 4 show that the water content increment in the studied lateritic soils causes
 141 an increase of compression (C_c) and swelling index (C_g) [14, 15] with a reduction in the
 142 vacuum index (e_0) under constant load. Moreover, this variation of water content seems not
 143 to affect the consolidation stress (σ'_p) in the case of intact soils, but not for compacted
 144 samples. This variation of the consolidation stress with water content for compacted samples
 145 could be the result of compaction errors. These errors are possibly due to human factors of
 146 the experimenter while performing the Proctor test.

Table 3 : characteristics of compressibility (case of intact samples)

Characteristics of compressibility	EK I		EK II		EK III	
	sat	Usat	sat	Usat	sat	Usat
C_c	0.376	0.348	0.376	0.199	0.294	0.282
C_g	0.014	0.009	0.009	0.003	0.019	0.010
σ'_p (bars)	0.55	0.55	1,00	1,00	1,40	1,40
e_0	0.970	1,140	0.898	0.960	0.855	1,010

Table 4: characteristics of compressibility (case of compacted samples)

Characteristics of compressibility	EK I				EK II				EK III			
	90% W_{opm} (usat)	110% W_{opm} (usat)	100% W_{opm} (usat)	100% W_{opm} (sat)	90% W_{opm} (usat)	110% W_{opm} (usat)	100% W_{opm} (usat)	100% W_{opm} (sat)	90% W_{opm} (usat)	110% W_{opm} (usat)	100% W_{opm} (usat)	100% W_{opm} (sat)
C_c	0.048	0.060	0.049	0.051	0.081	0.074	0.068	0.074	0.061	0.076	0.066	0.054
C_g	0.004	0.007	0.008	0.009	0.007	0.007	0.006	0.006	0.014	0.018	0.007	0.011
σ'_p (bars)	0.74	0.50	0.35	0.70	1,00	0.70	0.85	0.70	0.37	0.45	1,20	0.90
e_0	0.759	0.596	0.586	0.547	0.578	0.534	0.460	0.458	0.516	0.602	0.458	0.452

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a) Intact samples

b) Compacted samples

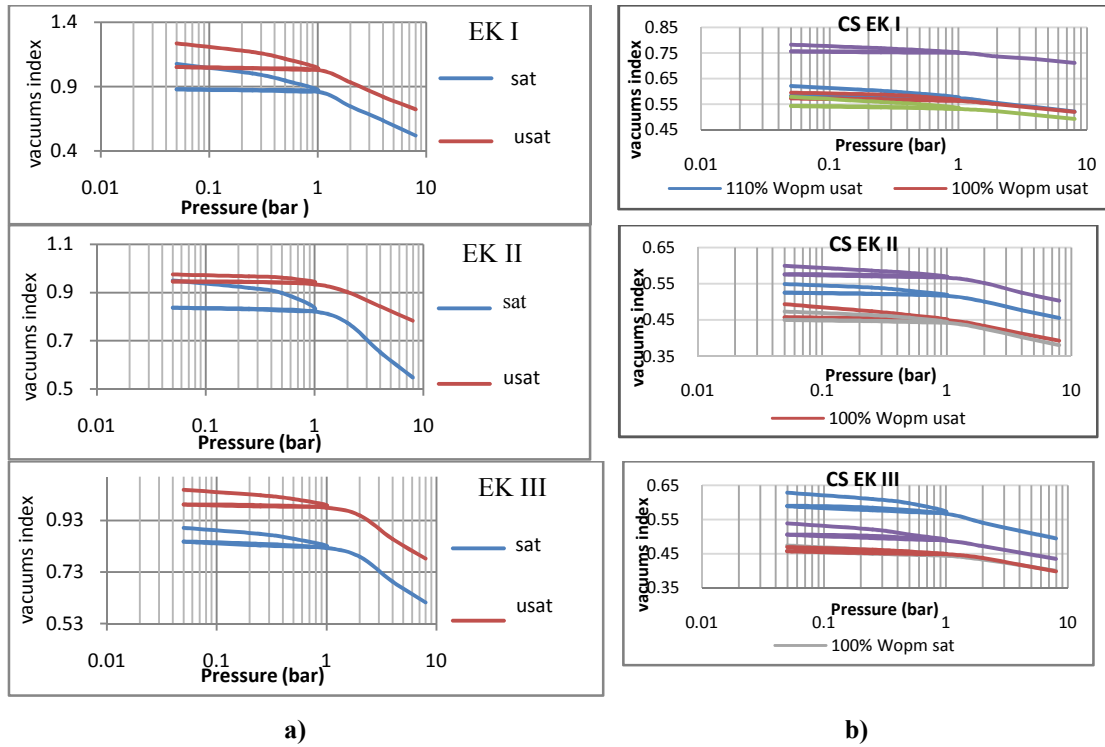


Figure 3 : curves of compressibility for (a) Intact sampling and (b) compacted Sampling

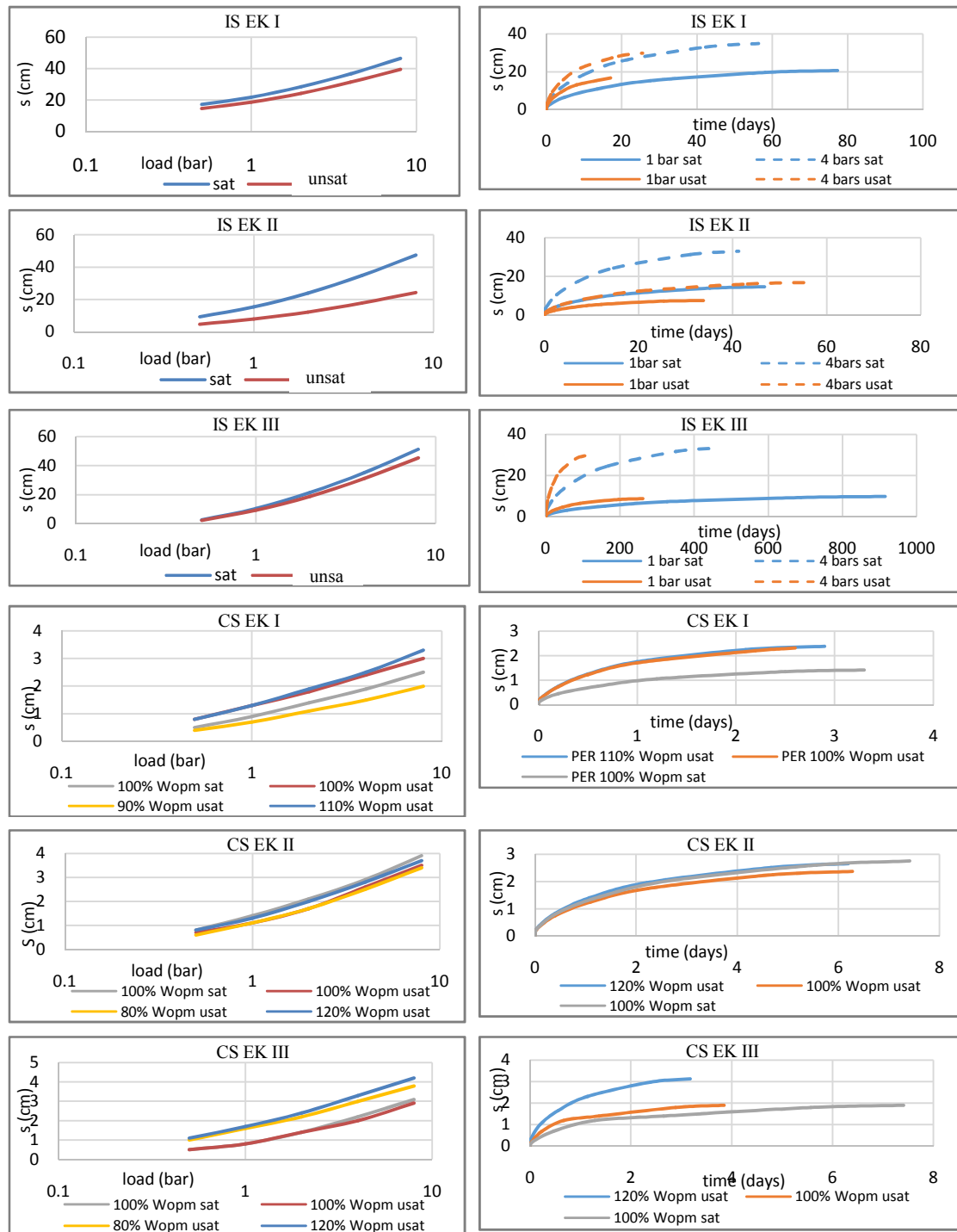
3.4 Settlement Analysis

Settlement calculations are done according to the Terzaghi law.

$$s = \frac{H_0}{1 + e_0} \left[C_g \times \log \left(\frac{\sigma' p}{\sigma' v_0} \right) + C_c \times \log \left(\frac{\sigma' v_0 + \Delta \sigma'}{\sigma' p} \right) \right]$$

where H_0 is the average thickness of the horizon and σ'_{v0} is the original constraint. Their values are respectively 0.168 bar and 200 cm for EK I, 0.76 bar and 250 cm for EK II, and 1.22 bar and 400 cm for EKIII.

The settlement variation curves, as function of the load, show that the settlement value increases with water content and especially that, this increase is as larger as the value of the load is large. This implies that the settlement induced by lower pressure (stresses) on the soil is less affected by the water content variation effect than that the settlement induced by high pressure on the soil. With regard to the compacted samples, the curves of Figure 4.a show that the ground with high CBR (EK II) is least affected by the variation of settlement when we change from one state of water content to another (sat or usat). The thickness of the compacted bed being taken to 70 cm according to Bufalo et al [16], the curves of figure 4.a (CS EK III) show that settlement is higher when the compaction is not made with the Proctor optimum [17]. The time of settlement here is given by the relation: $t = \frac{H_0^2 \times T_v}{4 \times C_v}$.



a) curves of settlement as function of to load

b) variations of settlement as function of time

Figure 4 : Settlement (s) diagrams as function of load (a), and of time (b).

Figure 4.b gives the evolution of settlement in these soils as function of time (T_v = time factor; C_v = consolidation ratio). Concerning the intact soils, one notes that the duration of settlement under weak loads (1bar) is higher than under high loads (4bars) when the soil is saturated. This progression of the settlement duration is related to the degree of lubrication of the grains of the soil. When the soil is saturated, friction between the grains is almost null, so under heavy loads, the grains will move faster during settlement. However in the contrary, the contact area between the grains being higher, the resistance of the soil to settlement might bring a fast stop of settlement under low pressure. In a general way, whatever the load, these curves show that the settlement duration increases with water content. For the compacted samples, one notes in a general way that the time of settlement is slightly higher for the compactations with 100% w_{opt} (more precisely for the saturated cases).

4. CONCLUSION

The present research work, based on experimental testing of in-situ local lateritic soils, is an engineering tool in the hand of designers and constructors in order to assess the massive use of these available low cost materials. Obtained results display important geotechnical properties widely influenced by environmental and loading conditions and human factors. Considered natural soil samples were saturated and unsaturated, disturbed and undisturbed, and they displayed different behaviors related to compaction and to settlement:

- the compression and swelling indexes increase with the increment of the water content with the reduction in the vacuum index under constant load;
- the settlement value increases with water content;
- the settlement induced by lower pressure on the soil is less affected by the water content variation effect than the one induced by high pressure;
- the duration of settlement under weak loads is higher than the one under high loads when the soil is saturated and undisturbed;
- compacted samples with high CBR are least affected by the variation of settlement when we change from one state of water content to another.

It appears very important and straight forward, for a lateritic soil foundation below an infrastructure, to decrease the pressure exerted on these soils by redesigning dimensions of load application surface, or applied loads intensity and settlement amplitudes when the soil is saturated in order to comply with existing safety requirements. For the design and construction of traffic loads above platforms, the materials with strong CBR would be adapted due to the fact that their settlement varies very little depending on whether they are compacted with the Proctor optimum or not.

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