MECHANICAL COMPARISON BETWEEN A BASE LAYER OF CRUSHED ROCK AND A GRAVE EMULSION

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ABSTRACT: The aim of this work is to share the study of the use of Gravel Emulsion replacing crushed rock in pavement road base through numerical modeling applying the nonlinear elastic program (Fepave2) in comparison with a crushed rock base that was modeled from a pavement structure from an existing road.

Gravel Emulsion is a well graded crushed rock, asphalt emulsion and water. As a cold asphalt mixture in its early age the cohesion is low but as time goes by it builds up strength.

After 10 years of experience with Gravel Emulsion in urban paving with a single base layer and a thin wearing course. Cores were extracted on the field to evaluate the resilient Brazilian modulus (stress applied onto a cylindrical specimen).

As we found very good results, we decided to evaluate this material in simulating in a multilayer system in a state of stress of a design of an existing road, replacing the crushed rock base by Gravel Emulsion base. In this evaluation the repeated triaxial load test was used and the results were modeled using the Fepave2 (nonlinear elastic program) to check out the performance of both material and its fatigue life parameters.

KEY WORDS: GRAVEL EMULSION, PAVEMENT, MODELING

1 INTRODUCTION

In Brazil, some roads with little service time suffer restoration interventions, especially in problems caused by premature fatigue cracking and permanent deformation in the wheel tracks, even though they have been well built, following construction standards and rules established by specification control .

Most of these roads have exhibited early deterioration by using a crushed rock base in the structure. According to Cavalcante (2005), Motta and Guimarães(2008), And other scholars, the high level of resilience of the graded crushed rock base layer combined with a high load trafficking above 10^7, results in the inappropriate behavior of the structure due to its high ratio value of stiffness between the surface layer and the base layer causing the reduction of its life expectance, says Cavalcante (2005) "it promotes an incompatible stiffness between the base and the surface layer, regarding the load passes in which the structure submits, one of the major factors that culminate in premature cracking of the surface layer."

This study proposes to use a material that could match its stiffness with the surface layer, meeting the design criteria to achieve the life expectance of the road.

The main goal of this project is to evaluate the behavior of the pavement structure with replacement of a graded crushed rock base to an adapted Gravel Emulsion base. This Gravel Emulsion”, which is being used as a base layer on urban streets in the city of Recife, Brazil.

In evaluation carried out by Carvalho filho et. Al. (2006) and others, this material has been analyzed by destructive and nondestructive tests, which showed excellent performance.

In order to evaluate the behavior of the Plowing with emulsion, the triaxial repeated loads were designated to obtain mechanical parameters by using the FEPAVE2 program to analyze the mechanical parameters of the mixture as a base layer in a pavement structure. This enables a comparison between the Plowing with emulsion base and a graded crushed rock base layer in the analytical approach, based on studies by Cavalcante (2005).

2 PLOWING WITH EMULSION

Consists of making an asphalt mixture on the road bed by means of a simultaneous operation scarification-spread, local materials such as sand, graded gravel, milled material, and a slow setting asphalt emulsion. The methodology is simple, it does not need expensive and sophisticated equipment, being able to mix the materials "in situ". From a previous study of the particle size to frame such materials in a relatively wide range, we obtain mechanical strength and flexibility, so that the material does not deform and crack due to the passage of heavy vehicles, resisting in an exceptional way the fatigue factor.

2.1 The Historical Background

The experience being implemented in the urban network of Recife is performed in situ, with materials from quarry, applied directly on the leveled subgrade , being an adaptation of the French standard for Grave emulsion type 3, according to the French standard NFP-98-21 with asphalt content = 3.2% and 0/19 mm graded

2.2 Characteristics of Materials - Asphalt Emulsion

Within the art of asphalt mixtures, there is an engagement between the asphalt emulsion and the aggregate to achieve a desirable compaction, resulting from the agglutination of granular material and the bind. Within this expectation, we use an asphalt emulsion with a binder of penetration grade 50/70, which seems adequate to the northeast climate in Brazil. A slightly fluidized binder with solvent may only be used in exceptional cases.

With the intention that the emulsion can penetrate to a depth satisfactory, it is necessary to use a cationic emulsion breaking acid slowly with pH = 2. The maximum content of asphalt content of preferably 62%.

2.3 Aggregate Characteristics

This kind of technique is more tolerant when it comes to the particle size distribution seeing that we are using material with a maximum particle size of 30 mm due to the low binder content it creates a high friction angle that provides an excellent material to fight the fatigue and permanent deformation factors. The fact that the material is mixed on the road bed avoids problems with segregation and cohesive setting of the emulsion during compaction.

From the standpoint of particle size, all coarse aggregate diameter varying from 30 to 2 mm, and sand or filler from 2 mm to 50 microns. The aggregates must have an IP = 0, one should therefore avoid clay materials, especially with sand presence of colloidal clay.

The materials may be acidic or basic in nature, even those with a high amount of silica.

3. STRUCTURAL BEHAVIOR

One peculiarity of working with internal dry friction material is the high shear strength the loads exerted on this type of base are distributed in a bigger area influence, causing the "stress board area distribution" effect.

The particle size distribution adopted containing very coarse aggregate and the evolved emulsion develops a cohesion during compaction and the loads are transmitted to the subgrade in compression.

This results in:

- High friction angle
- Flexibility (due its support accommodation)
- Resistance to permanent deformation
- Modulus increasing over time

3.1 Modeling Analysis

For the modeling and obtaining of the parameters, different state of stresses were applied the strains in the repeated triaxial load machine were obtained, according to the heavy loads exerting on a pavement structure.

The software FEPAVE2 (Finite Element Analysis of Pavement Structures) allows the evaluation of pavement structures with multiple layers, according to the numerical approach arising from the theory of elasticity, directed to pavement structure as a semi-infinite and stratified up to 12 layers. Modeling using non-linear-elastic (modulus of resilience variable) and the calculation procedure is the finite element method (continuous medium divided into fictitious elements of finite dimensions, connected by nodal points which associate the frictionless joints) using 8 subroutines shown in Table 1, for determining the behavior of materials.

Table 1: Subroutines FEPAVE2 the behavior of the material.

TYPE	MATERIAL MODEL	BEHAVIOR
0	$Mr = f\left(T\,^{o}C\right)$	Temperature dependent
1	$Mr = k_1 \sigma_3^{k2}$	Confining pressure model
2	$Mr = k_2 + k_3(k_1 - \sigma_d)$, para $\sigma_d < k_1$ $Mr = k_2 + k_4(\sigma_d - k_1)$, para $\sigma_d > k_1$	Fine grained bi-Linear
3	$Mr =$ Constant	Linear-elastic
4	$Mr = k_2 + k_3(k_1 - \sigma_d).\sigma_3^{k5}$, para $\sigma_d < k_1$ $Mr = k_2 + k_4(\sigma_d - k_1).\sigma_3^{k5}$, para $\sigma_d > k_1$	Bi-linear combined
5	$Mr = k_1 \theta^{k2}$	Granular $f(\theta)$
6	$Mr = k_1 \sigma_d^{k2}$	K-model $f(\sigma_d)$
7	$Mr = k_1 \sigma_3^{k2} \sigma_d^{k3}$	Macêdo model $f(\sigma_3,\sigma_d)$

3.2 Dynamic Triaxial Test

The repeated triaxial equipment load utilized in this study was developed by COPPE in order to simulate the effect of moving loads on a pavement and measure the deformation of the material in a certain state of stress, which varies with the frequency, trying to approach the field conditions.

The results of this test allow obtaining the parameters determined by the Macêdo model behavior, where the specimens are submitted to different stresses levels. The Macêdo model defined by the expression below was introduced in Brazil (1996), represented by a generic term that applies to various types of soil that shows both behavior granular or clayey, nonlinear regression analyses of the laboratory data was used to obtain the experimental constants values of k2 and k3, respectively.

$$e_r = K_1.\sigma_3^{K_2}.\sigma_d^{K_3} \text{ as thus } MR = {}^{\sigma_d}/_{e_r}$$

$$MR = k_1.\sigma_3^{k_2}.\sigma_d^{k_3}$$

Where:

M_R - Resilient modulus (Kpa ou kgf/cm²);

σ_d - Repeated axial tension deviation (kPa ou kgf/cm²);

$\sigma_d = \sigma_1 - \sigma_3$;

σ_1 - Major principal stress;

σ_3 - Lower primary stress;

e_r - Specific deformation axial elastic or resilient corresponding to the number of applications σ_d.

4. COMPARISON BETWEEN G.E. VERSUS CRUSHED ROCK

4.1 Structure of BR-230/PB.

The federal highway BR230 in a state of Paraíba, Brazil, utilized in this study, belongs to the National Plan for Roads, cuts the state of Paraíba in the EW direction, and is the main axis of the link between the coast and the hinterland of the state.

In October 2001, the old road from (km 117.3 - km 147.9) was expanded. The duplication services were held concurrently with the restoration of the existing highway. The project design for the new highway pavement structure built alongside the old highway was in flexible pavement. The traffic design was 4.7 x10^7 (USACE), for a fatigue life of 15 years.

4.2 Structure analysed

Figure 1 schematically shows the structure studied consisted of a sub-base of a stabilized soil , crushed rock base and HMA surface layer and HMA binder layer.

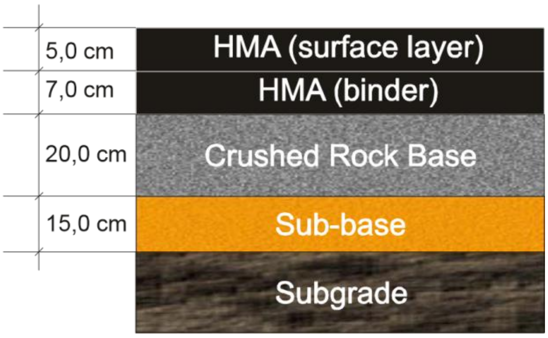

Figure 1: Structure of the pavement BR-232/PE (Cavalcante, 2005)

Sample # 4, analysed by Cavalcante (2005), collected from the road studied was sent to the laboratory of COPPE / FEDERAL UNIVERSITY OF RIO DE JANEIRO, where the specimen were tested in the triaxial repeated load with the support of professor Laura Maria Goretti da Motta. Table 2 shows the results of the resilient modulus (Macêdo model).

Table 2: Results of resilient module based on the Macêdo model of the specimens molded under field conditions.

STATISTICAL ANALYSIS BY REGRESSION BASED ON MACÊDO MODEL											
$MR = k1\sigma_3^{k2}\,\sigma_d^{k3}$											
STRUCTURE	SAMPLES	R^2	K_1	K_2	K_3	STRUCTURE	SAMPLES	R^2	K_1	K_2	K_3
Base	2º	0,97	6911	0,53	-0,16	Sub-base	2º	0,98	3849	0,52	-0,09
	3º	0,94	3846	0,44	0,13		3º	0,99	3382	0,45	-0,07
	4º	0,91	4127	0,19	0,11		4º	0,99	3893	0,54	-0,11
	5º	0,97	4655	0,45	0,04		5º	0,98	2165	0,06	0,48
Overlying subgrade	2º	0,99	3448	0,49	0,04	Subgrade	2º	0,99	3030	0,52	-0,06
	3º	0,95	5076	0,63	-0,25		3º	0,99	3571	0,45	-0,07
	4º	0,99	2564	0,5	0,00		4º	0,99	2475	0,47	0,03

Cavalcante (2005) also extracted cores of specimens along the highway studied and performed test modulus for HMA layers (surface layer) and HMA (binder), resulting in values present in Table 3.

Table 3

Brasilian Modulus for Hot Mix Asfalt			
HMA SURFACE LAYER	MR (Mpa)	HMA BINDER LAYER	MR (Mpa)
Average	3.567	Average	3.801
Standard deviation	294	Standard deviation	350
Variation Coef. (%)	8,25	Variation Coef. (%)	9,21

Cavalcante (2005), molded in laboratory specimens in grade B (binder layer), and grade C (surface layer) to obtain both resilient modulus by diametrical compression and fatigue test, whose results are summarized in Table 4.

Table 4: Results of Fatigue Te sts for HMA layers of BR-230/PB.

	(MPa) Average	FATIGUE EQUATION	
HMA surface Layer	3567	$N=2003{,}9 \times \Delta\sigma^{-2{,}6752}$	$N=6\mathrm{x}10^{-12} \times \varepsilon_t^{-3{,}4965}$
HMA binder layer	3807	$N=1584{,}1 \times \Delta\sigma^{-2{,}6752}$	$N=1\mathrm{x}10^{-8} \times \varepsilon_t^{-2{,}6752}$

Table 5: Stresses and Strains determined using the FEPAVE (Cavalcante, 2005).

		Speciments			
		2º Point	3º Point	4º Point	5º Point
HMA (Surf. Layer)	Horizontal Strain (cm/cm)	2,08E-05	2,17E-05	2,08E-05	2,14E-05
	Stress Diference (Mpa)	0,11	0,1	0,12	0,1
HMA (Binder)	Horizontal Strain (cm/cm)	1,79E-04	1,94E-04	1,54E-04	1,89E-04
	Stress Diference (Mpa)	0,62	0,66	0,56	0,65
Vertical Stress - Subgrade (Mpa)		0,01	0,01	0,01	0,01
Crushed Rock Base Avewrage Stiffness Modulus (Mpa)		74	43	151	55

Cavalcante (2005), in possession of these values and using the FEPAVE2 performed the modeling of stress and strain occurring in the pavement, through mechanistic analysis, reaching levels of effort whose floor is subjected shown in Table 5. Table 6 shows the efforts admissible for the life of the project.

Table 6: Permissible parameters for $N = 4.5 \times 10^7$ (Calcantante (2005).

HMA (Surf. Layer)		HMA (Binder)		Subgrade
Horizontal Strain	Stress Diference	Horizontal Strain	Stress Diference	Vertical Stress
(cm/cm)	(MPa)	(cm/cm)	(MPa)	(MPa)
$1{,}7.10^{-4}$	0,79	$1{,}4.10^{-4}$	0,68	0, 047

This concludes Cavalcante (2005). The difference in strength of the base layer related to the binder layer is the main factor in the structural behavior of the pavement, that is, one of the important factors for the appearance of early cracks in the pavement surface due to the incompatibility of stiffness between layers of the binder layer and the base layer.

Plowing with emulsion as base layer

Once having the assumption of the problems related of the difference in stiffness between the base layers of gravel and the binder HMA simple, as illustrated by Cavalcante (2001), various forms of Plowing with Emulsion were studied for verification through numerical modeling, through FEPAVE2 program, in replacement of the crushed rock base.

4.3 Samples Preparation

Samples were prepared in molds of size 10 cm diameter and 20 cm height and apparatus compacting in a modified proctor by impact. Two types of granites were applied in the region. Samples were prepared for three levels of asphalt content: 4.5%, 3.8% and 3.2%. In order to obtain maximum densification of the material, water was added to the mixture content obtained after a compaction curve, resulting in 7.2% water. Then, for each sample, depending on the amount of emulsion, enough water was added to achieve the optimum content of 7.2%. Thus 7,2% - (% EA) =% added water, which we call "water wetting" which in turn facilitates the dispersion of the emulsion in the mineral skeleton.

In this study we used two types of aggregates (quarry Guarany and Paradise) and two types of asphalt emulsion (Brasquímica and Greca), both slow setting. The emulsion from the Brasquímica showed a slower breaking compared to asphalt emulsion produced by Greca. The type of emulsifier used by these companies was attributed. The modeling performed is shown in table 7 and 8.

Table 7: Composition of samples 1, 2, 3 and 4 GE to perform the triaxial test.

Specimens	Asphalt Content	Aggregate	Emulsion	Emulsion Suplier	Curing
1	3,2	granite	SS	Braquímica	14 days
2	3,8	granite	SS	Braquímica	14 days
3	4,2	granite	SS	Braquímica	14 days
4	3,2	alkaline granite	SS	Greca	14 days

Table 8: Composition of samples 5, 6, 7 and 8 GE to perform the triaxial dynamic.

Specimens	Asphalt Content	Aggregate	Emulsion	Emulsion Suplier	Curing
5	3,8	alkaline granite	SS	Greca	14 days
6	4,2	alkaline granite	SS	Greca	14 days
7	3,2		SS	Brasquímica	28 days
8	3,2	alkaline granite	SS	Brasquímica	29 days

The particle size range used is shown in Table 9. It was prepared according to the mix of graded crushed rock produced in the region, which falls in the range of B graded crushed rock specificationl DNIT (DNIT 031/2006 - ES).

TABLE 9- *Grading curve for 0/30 Grave emulsion*

Nominal Sieve	2"	1"	3/8	4	10	40	200
0/30	100	75-80	49-75	30-60	20-40	15-30	3-8

Curve grading adapted (grade B DNIT)

The results of the triaxial tests performed are shown in Table 10;

Table 10: Results of dynamic triaxial performed.

Model Compound - $MR = k_1.(\sigma_3)^{k2}.(\sigma_d)^{k3}$									
Specimens	K_1	K_2	K_3	R^2	Specimens	K_1	K_2	K_3	R^2
1	8924	0,28	-0,36	0,96	5	6260	0,27	-0,23	0,97
2	5903	0,43	-0,21	0,98	6	6801	0,4	-0,33	0,98
3	5894	0,37	-0,2	0,98	7	9249	0,33	-0,13	0,98
4	5627	0,41	-0,1	0,97	8	8769	0,4	-0,11	0,99

4.4 Modeling the Behavior of Plowing with emulsion

Once done with the modeling program FEPAVE2, we obtain the values presented in Tables 11 and 12 for the stresses and strains that occur in the constituent layers of the pavement, replacing the structure, the base material (grade crushed rock).

Table 11: Results of samples 1, 2, 3 and 4 simulating as the base layer BR-230/PB

		Specimens			
		1	2	3	4
HMA (Surf. Layer)	Horizontal Strain (cm/cm)	2,18E-05	2,08E-05	2,09E-05	2,08E-05
	Stress Diference (Mpa)	0,13	0,11	0,12	0,11
HMA (Binder)	Horizontal Strain (cm/cm)	1,09E-04	1,66E-04	1,56E-04	1,69E-04
	Stress Diference (Mpa)	0,44	0,59	0,56	0,6
Vertical Stress – Subgrade (Mpa)		0,01	0,01	0,01	0,01
GE Average Stiffness Modulus (Mpa)		371	111	142	103

Table 12: Results of samples 5, 6, 7 and 8 simulating as base layer in BR-230/PB

		Specimens			
		5	6	7	8
HMA (Surf. Layer)	Horizontal Strain (cm/cm)	2,13E-05	2,10E-05	2,12E-05	2,09E-05
	Stress Diference (Mpa)	0,12	0,12	0,12	0,12
HMA (Binder)	Horizontal Strain (cm/cm)	1,32E-04	1,48E-04	1,33E-04	1,51E-04
	0,5	0,5	0,54	0,5	0,55
Vertical Stress – Subgrade 0,01(Mpa)		0,01	0,01	0,01	0,01

GE Average Stiffness Modulus (Mpa)	241	169	238	162

4.5 Life Expectance

In order to compare the life expectance behavior of a crushed rock graded aggregate with the adapted Gravel Emulsion, data was used with the fatigue equation proposed by Pinto (1991).

$$N_f = 9{,}07x10^{-9} \cdot \left(\frac{1}{\varepsilon_t}\right)^{2{,}65} \cdot \left(\frac{1}{M_R}\right)^{0{,}0633}$$

ε_t = Horizontal strain in the bottom of the HMA binder;
M_R = Modulus of the HMA binder layer.

Through the mechanical parameters obtained by Fepave 2 program, it was verified the life expectancy with both structure materials presented in this work.
For this reason we chose the specimens that better performed through the essays in which #4 was the sample of crushed rock and #1 the sample of GE. And so we applied the results of fatigue life in the traffic prediction study of the highway BR- 230 PB.

Table 13: Results of fatigue life applying Pintos´s model,

Specimens	thickness (cm)	ε(t)	Life Expectance
4º Sample of CR	10,0	1,67E-04	1,3E+07
	20,0	1,54E-04	1,6E+07
1º Sample of GE	10,0	1,37E-04	2,2E+07
	20,0	1,09E-04	4,0E+07

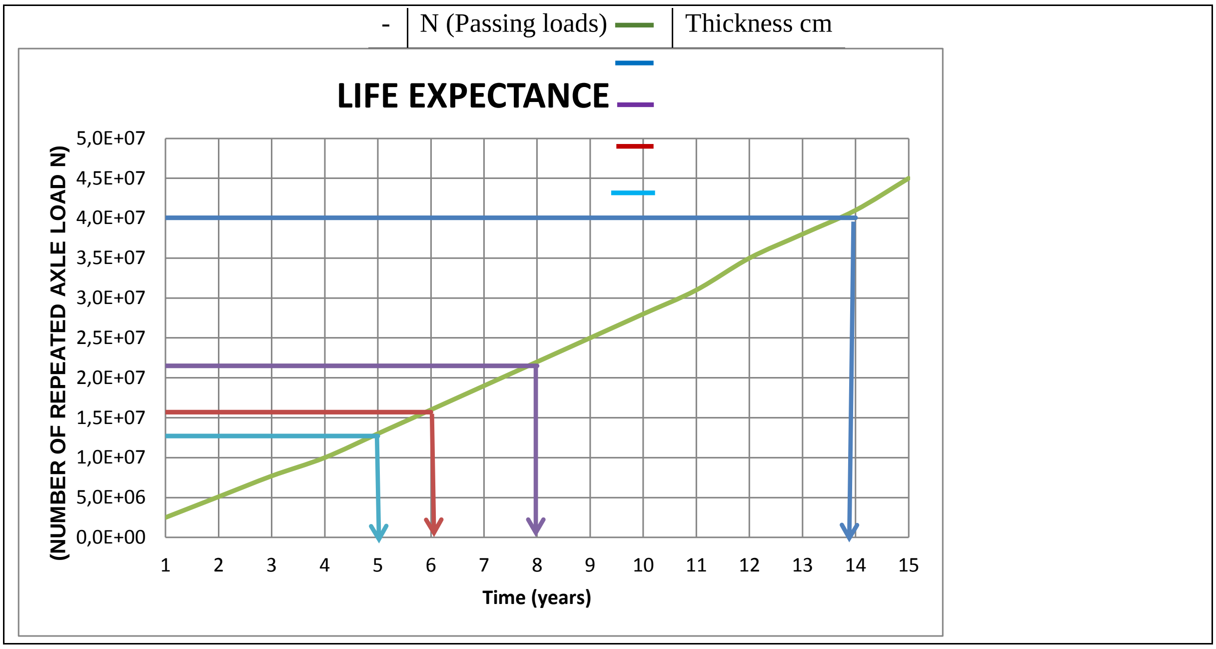

Figure: 2 Study of prediction traffic of Highway BR- 230/PB

The data can also be presented in the alternative manner shown in Figure 2 which shows that the ratio of thickness of crushed rock to Gravel Emulsion that is required to provide a better pavement life. For instance with a design thickness of 10 cm of Grave Emulsion, it would give a better life expectance than with 20 cm of crushed rock.

5. CONCLUSIONS

In the comparative study, we can appreciate the advantages of using GE adapted as (Plowing with emulsion), as a base layer in road pavement. Cavalcante (2005) illustrated in his work that using graded crushed rock base layer for road with traffic above (N usace> 10^7) lacks proper behavior due to a high stiffness ratio between the crushed rock base and HMA surface layer. In this study it was possible to perform numerical modeling of the behavior of GE, adopting the proposed Macêdo model (1996), and comparing it to graded crushed rock in the base layer, using the FEPAVE2, taking parameters of the characterization performed in the BR-230/PB highway as input.

We concluded that the parameters studied showed that samples of the adapted Gravel Emulsion showing lower asphalt content (3,2%) showed the best performance results, applying the fatigue factor for the binder layer in the structure of BR- 230 studied by Cavalcante (2005).

The analytical analysis of the G.E (Plowing with emulsion) molded in laboratory even in its early age showed higher modulus than graded crushed rock, reinforcing the understanding of its behavior for the case study.

One of the best material property is its evolutionary strength due to cold mix behavior, that builds up over time with the cohesion and the coalescence of the binder around the mineral surface increasing its modulus, thus improving its performance.

The data can also be presented in table 13 figure, which shows that with 10 cm thickness of Gravel Emulsion we can achieve a better life expectancy than with 20 cm thickness of crushed rock graded base.

As observed on cores, GE (Plowing with emulsion) in the city of Recife, with life service above 8 years, as GE changes over time, because in its early age it is impossible to extract cores, tests were performed with Brazilian modulus reaching the average of 3.500 MPa. Thus in modeling with this value using the FEPAVE2, adopting 10% of its value of 350MPa, the structure presented levels of stress and strain that would fulfill all the parameters of fatigue life.

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