STOP OF REFLECTIVE CRACK PROPAGATION WITH THE USE OF PET GEOGRID AS ASPHALT OVERLAY REINFORCEMENT

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Abstract
Asphalt concrete overlays placed over cracked pavements suffer large stresses at the interface under the passage of traffic loads, leading to the reflection-cracking phenomenon. This paper presents a laboratory study for evaluation of the effect of a polyester geogrid as an interlayer reinforcement between a cracked asphalt concrete layer and a non cracked one. The quantitative and qualitative evaluation of the effects of reinforcement system in relation to the traditional rehabilitation technique of asphalt concrete overlay was performed using dynamic fatigue tests were conducted on prismatic beams resting on an elastic foundation that were conceived to simulate a cracked pavement after rehabilitation, with the load applied at the two critical positions: on bending and on shearing. The beams with dimensions of 460 x 150 x 75 mm, had a pre-crack with an opening of 3, 6 and 9 mm. The geogrid was placed on the crack tip. Increases on the fatigue life were observed. The cracking mechanism was changed from a process controlled by a single dominating crack to another one where several micro cracks were formed. These micro cracks were of lower severity, leading to a better performance for the asphalt concrete overlay. The presence of the polyester geogrid had the effect of drastically reducing the opening of the reflective crack and reducing of the plastic deformation on the fatigue life. Simulation using Finite Element Model (FEM) explains the mechanism observed in laboratory.

1. Introduction
The acceptance of the rehabilitation system with geogrids has been increasing in the last years, and it shall continue to increase in the future. The use of geogrid in the asphalt concrete has brought structural benefits in pavement jobs. In order to understand the mechanisms through which the geogrid interlayer increases the fatigue-life, concerning reflection of cracks in asphalt overlays, fatigue tests in asphalt concrete beams with and without geogrid were performed. The geogrid was positioned exactly over the extremity of a pre-existing crack, and its termination criterion was considered when the first visible crack appeared on the surface. The peculiarities of the tests will be described in the following items.

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2. Fatigue Test

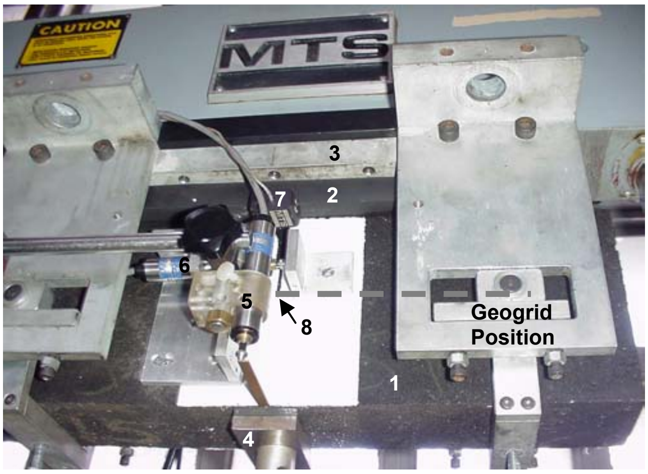
In order to make a qualitative and quantitative analysis, fatigue tests in asphalt concrete beams with and without reinforcement have been carried out with an elastic base as a support. A total number of 16 beams of asphalt concrete with dimensions of 75mm x 150mm x 460mm, was molded in laboratory were pre-cracked with varied openings (3mm, 6mm and 9mm). The geogrid was positioned exactly over the extremity of a pre-crack. The geogrid used in this test was HaTelit C 40/17 with the following properties:

- High tenacity polyester grid incorporating an ultra-light nonwoven, with bituminous coating, mesh size of 40 x 40 mm and nominal tensile strength of 50 kN/m @ 12% strain.

The type of loading was sinusoidal with application frequency of 20Hz, changing the load position in relation to the crack (bend/shear). The sinusoidal load was applied by hydraulic equipment through a steel plate (MTS), with dimensions of 40mm x 75mm, generating pressures of 549kN/m^2 (higher pressure), 424.5kN/m^2 (average pressure) and 326.5kN/m^2 (lower pressure). Between the steel plate and the asphalt concrete beam, a rubber was installed in order to minimize the concentration of stresses related to the stiffness of the steel plate. The termination criterion of the test was considered when the first visible crack appeared on the surface.

2.1 Instrumentation

The displacement meter CAM (Crack Activity Meter) was installed in laboratory in order to measure the horizontal movements of the reflection crack opening and the plastic deformation during the load application cycles. CAM was fixed by screws embedded within the asphalt concrete. A clip gage was used to record the precrack opening during the test. The central part of the beam was white painted in order to make easier the visual observation of the crack propagation. A scheme of the system instrumentation is shown on Figure 1.



(1) Asphalt concrete beam;
(2) Rubber base;
(3) Steel base;
(4) Cyclic load;
(5) LVDT-1 Plastic deformation meter;
(6) LVDT-2 Opening crack meter;
(7) Clip Gage-Opening pre-crack meter;
(8) Pré-crack with 3mm.

Fig. 1 – Instrumentation of fatigue test.

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2.2 Results

During each test, a large number of pictures with a digital camera were taken, showing the appearance and the propagation of the cracks linked to the number of cycles.

2.2.1 Visual Observation

In beams without geogrid, after a few load application cycles, the reflective crack comes out. Its growth, in bend mode and shear mode, was fast and practically vertical, following the face of aggregates found on the way (Figure 2). When the reflection crack reached the length of 7.5cm (AC thickness over the crack), the beam ruptured, and it was the end of the test. For the case of beams reinforced with geogrid, this vertical growth occurred up to 2cm and 3cm, respectively for the less severe case (pre-crack opening 3mm) and more severe case (pre-crack opening 9 mm). Thus, the geogrid reinforcement stops the propagation of the reflective crack. After load cycles, micro cracks come out becoming more and more visible, and interconnecting to each other, leading to the formation of new cracks of less severity spread over a greater volume of asphalt concrete (Figures 3). This fact was observed for the bend load position as well as the shear load position. In beams with reinforcement, the test was concluded when only one crack of less severity reached the surface. In such a condition, the beam can still resist to more load cycles, however, this criterion was chosen due to the long duration of each test, between 8 to 12 hours of uninterrupted follow-up.

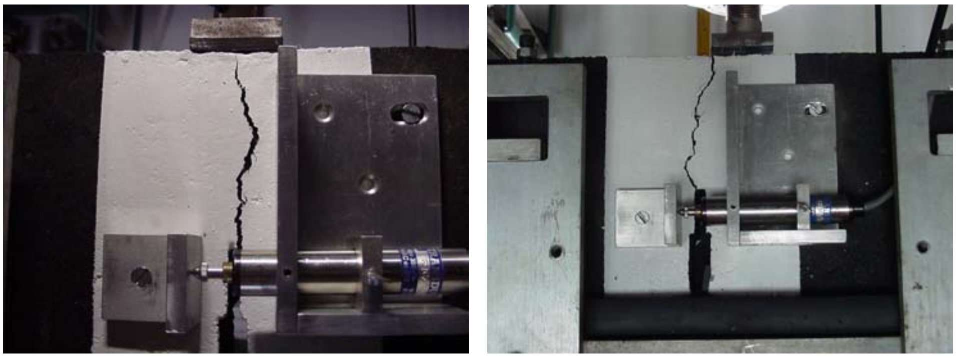

Fig.2 – Beam without geogrid: cracking pattern in the end of test (bending and shear mode)

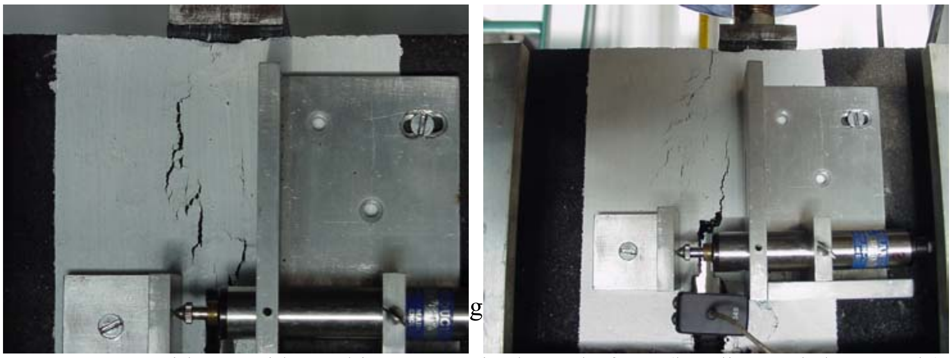

Fig.3 - Beam with geogrid: cracking pattern in the end of test (bending and shear mode)

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2.2.2 Numerical Results

The Factor of Effectiveness of Geogrid ($FEG = N_{f(with\ geogrid)} / N_{f(without\ geogrid)}$) which represents the beneficial effect of the geogrid was calculated as:

$$N_f = \frac{1}{c_f} \quad , \quad c_f \text{ is the fatigue consumption given for:} \quad c_{f_1} = \frac{1}{N_{f(B)}} + \frac{2}{N_{f(S)}}$$

as $N_{f(B)}$ represents the fatigue life of the beam with the load in the bend mode and $N_{f(S)}$ the fatigue life in the shear mode. In table 1 the calculated values were presented.

Table 1 – Geogrid Effectiveness Factor (*FEG*).

Precrack opening	Beam	$N_{f(F)}$ (Cycles)	$N_{f(C)}$ (Cycles)	C_{f1} (Cycles^{-1})	N_f (Cycles)	*FEG*
3 mm	Without geogrid	79.884	93.290	3.40×10^{-5}	2.95×10^{4}	6.14
	With geogrid	490.491	573.560	5.53×10^{-6}	1.81×10^{5}	
6 mm	Without geogrid	68.690	77.710	4.03×10^{-5}	2.48×10^{4}	4.60
	With geogrid	329.393	346.400	8.81×10^{-6}	1.14×10^{5}	
9 mm	Without geogrid	63.020	72.920	4.33×10^{-5}	2.31×10^{4}	5.11
	With geogrid	340.702	364.530	8.42×10^{-6}	1.18×10^{5}	

The plastic deformation in geogrid reinforced beams was reduced between 30 and 36%, with smaller movements of the pre-crack and the reflection crack opening in comparison to beams without reinforcement. The parts of the test results were illustrated in Figures 4 and 5. The complete results can find in reference [3].

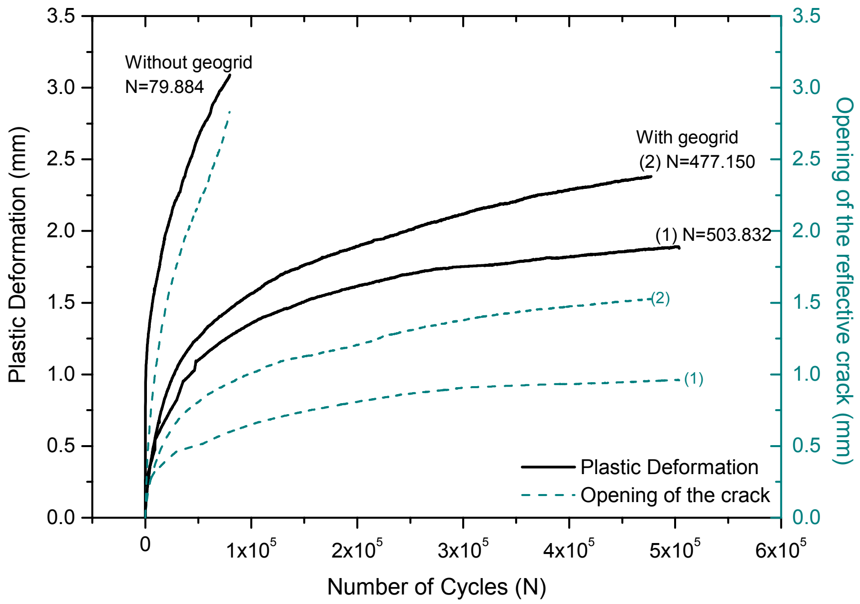

Fig. 4 - Fatigue test result – Pre-crack opening 3mm (Bend).

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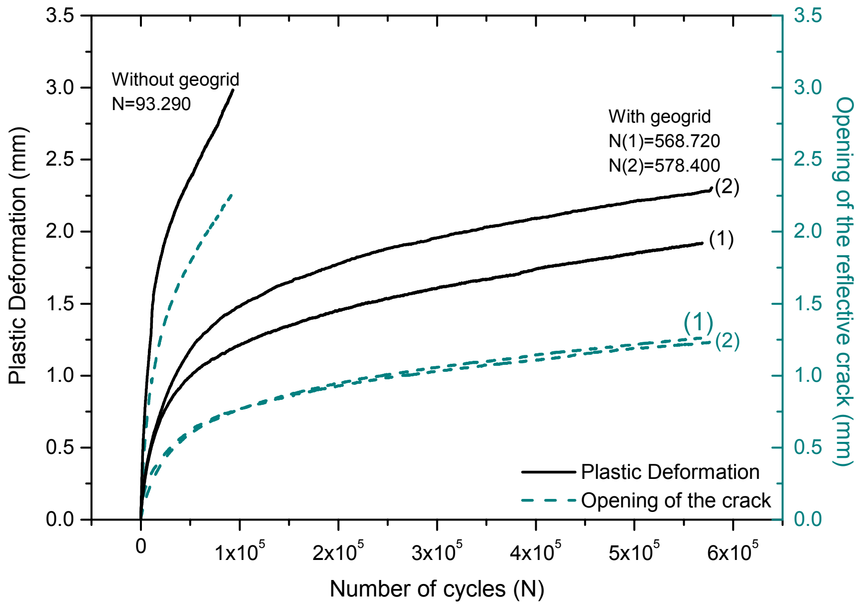

Fig.5 – Fatigue test result – Pre-crack opening 3mm (Shear).

3. Reflective crack simulation by the finite element method (FEM) by node release technique

Nowadays, there are many techniques and algorithm implemented in order to simulate crack propagation through FEM. Generally, laboratory specimen are molded or built with symmetry. During the analysis, this symmetry can be exploited to reduce the mesh size by half or more. Figure 6 is a schematic showing how lines of symmetry reduce the model size of a middle crack tension specimen to ¼ of the full specimen size. Symmetry boundary conditions along the vertical centerline of the specimen model the side to side symmetry. Since there is no cracking along the vertical centerline, these boundary conditions will not change during the analysis. Symmetry boundary conditions also exist along the crack face. The part of crack face that is fully closed is held by fixing conditions that can be efficiently released as crack propagation becomes necessary. This form of crack propagation is commonly called the nodal release algorithm [1]. This technique was going used here.

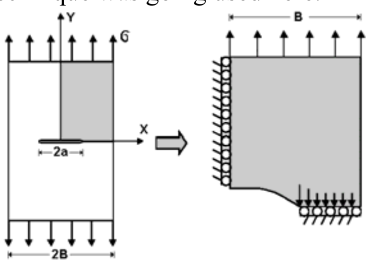

Fig.6 – Schematic Showing lines of symmetry for a middle crack tension specimen.

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3.1 Relationship between stress intensity factor and energy release rate

With two parameter is possible describe the behavior of cracks: the energy release rate (G) and the stress intensity factor (K). The energy release rate describes global behavior, while K is a local parameter. For linear elastic materials, K and G are uniquely related.
For a trough crack in an plate subject to a uniform tensile stress (Figure 6) G and K are given by [2]:

$$G = \frac{\pi \sigma^2 a}{E} \tag{1}$$

$$K = \sigma \sqrt{\pi a} \tag{2}$$

Combining these two equations leads to the following relationship between G and K for plane stress:

$$G = \frac{K^2}{E} \tag{3}$$

$$\frac{\partial U}{\partial a} = \frac{K^2}{E} \qquad \Rightarrow \qquad K = \sqrt{\frac{\partial U}{\partial a} E} \tag{4}$$

3.2 Simulation of the Fatigue Test by FEM

The simulation of the fatigue tests by FEM aims at understanding the mechanisms observed in laboratory. A bar element was used to represent the geogrid, and the plate element “Quad4" was used to represent the asphaltic concrete and the base. The theoretical moduli used were: $\boldsymbol{E}_{AC}$= 4000 MPa, $\boldsymbol{E}_{Elastic\ base}$= 50 MPa ($\nu$ = 0.3), and, for the geogrid: $\boldsymbol{E}_{Geogrid}$= 45454 MPa. In this qualitative analysis, it was considered a perfect bond between the plate and the bar elements.
The result of the static analysis is shown graphically on Figures 7 and numerically on Fig. 8. On Figure 7, the tensile stresses in the beam are presented in colors for different crack propagation lengths: the darker areas near the crack indicates the higher tensile stresses (traction). The FE simulation has shown a drastic reduction of the stress concentration in the crack tip due to the inclusion of the geogrid:

- At the first stage of simulation (Fig. 7a and 7b), the reduction of tensile stresses in the tip of the crack, due to the inclusion of geogrid, was about 56%. This explains the reason why, in laboratory, the beginning of reflective cracking was delayed due to the use of the geogrid as reinforcement.
- In the beam without geogrid, the tip of the crack is always the zone of higer tensile stresses (Fig. 7c, 7e and 7g). That is why the crack propagates straight towards the surface.
- In the beam with geogrid, as long as the nodes are released, simulating the crack propagation, the tensile stresses increase in the reinforcement element (geogrid) and decrease in the crack tip to such small values that they can be absorbed by the asphalt concrete element (Fig. 7d, 7f, 7h and 8). It explains, thus, the reason why, in laboratory, the propagation of the reflective crack in beams with geogrid is interrupted. The stress level acting in the crack tip is small in such a way that it cannot rupture the cohesion of the asphalt.

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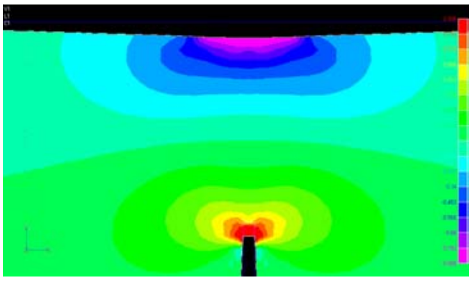
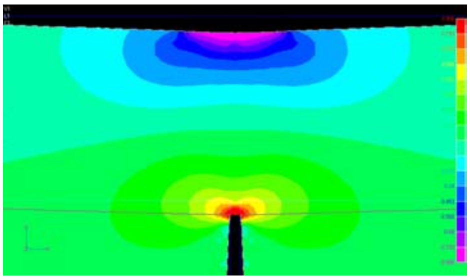
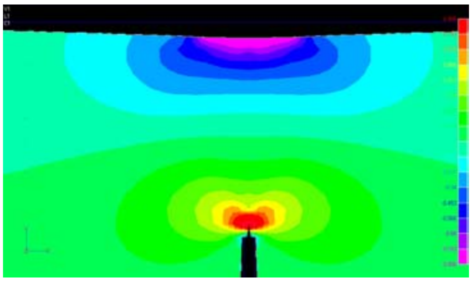


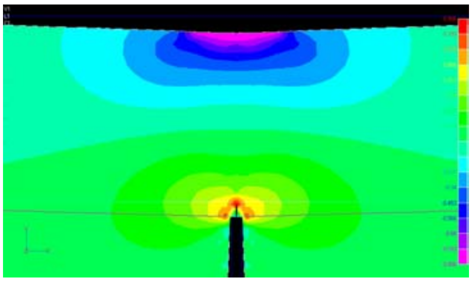
(a) Without geogrid, crack length = 0.0cm



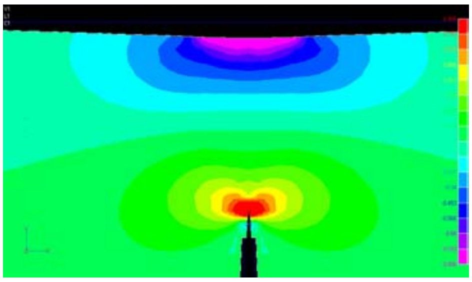
(b) – With geogrid, crack length = 0.0 cm



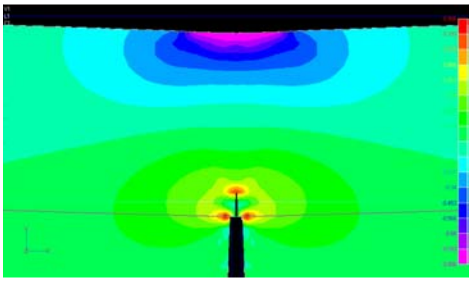
(c) Without geogrid, crack length = 0.5cm



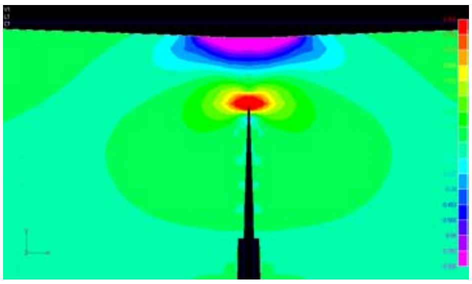
(d) With geogrid, crack length = 0.5cm



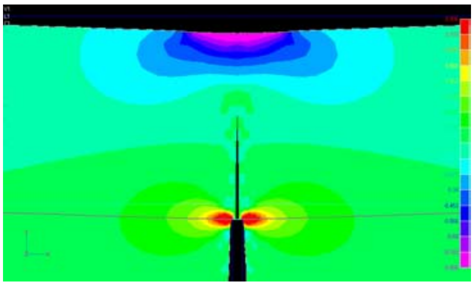
(e) Without geogrid, crack length =1.0cm



(f) With geogrid, crack length =1.0cm



(g) Without geogrid, crack length =5.0cm



(h) With geogrid, crack length =5.0cm

Fig. 7- Process zone formed by growing crack (tensile stress in the beams)

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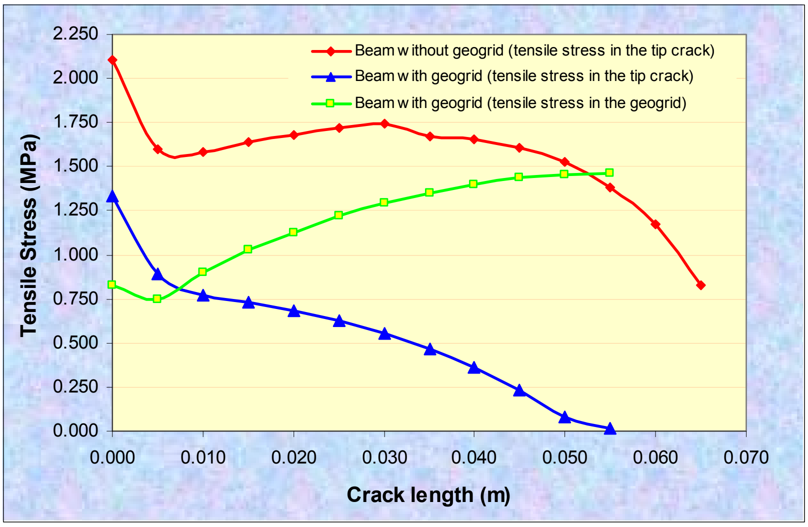

Fig. 8 – Tensile stress in the beams, with and without geogrid.

4 Conclusions

The laboratory investigation and FE simulation lead to the following conclusions:

- It was observed in laboratory that the inclusion of a polyester geogrid in an asphalt overlay modifies the pattern of reflective cracking propagation. At first, the beginning of crack propagation is delayed. The reflective cracking propagates to a certain length, then it stops. Additional microcrackings arise because of the asphaltic mass fatigue. Such microcrackings are spread over a greater volume within the layer, with a random propagation pattern and a very slow increment. The level of the stress transference along the walls of each microcracking is high, which helps on the reduction of the growth speed for mitigating the stress concentration in its extremity. The random direction of the microcrackings also acts in this way, leading to the occurrence of microcrackings with a geometric shape capable of blocking its subsequent growing.
- For the tested beams, Factors of Effectivness of Geogrid ranging from 4.45 up to 6.14 were obatined.
- In FE simulation, the observations done in laboratory were justified. It was seen that as the crack propagates, the tensile stresses in the tip of the crack decreases up to such a small value that the propagation stops. On the other hand, the tensile stresses in the geogrid increases as the cracks propagates.

References

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