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Laboratory Study on Bituminous Concrete Pavement Using Low Density Polyethylene

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ABSTRACT- In today's constructive world, traffic is increasing day by day. It ultimately influenced our road constructions. The objective of this research is to investigate the impact of incorporating low-density polyethylene (LDPE) into bituminous concrete pavements. The construction process of a flexible pavement road involves several stages, including the base course, placement of premix, rolling and check for quality control parameters etc. The robustness of bituminous pavements in resisting moisture damage is significantly impacted by environmental conditions.. Aging & oxidation of bituminous binder lead to the deterioration of the bituminous surfacing due to traffic movement after its construction. Moreover plastic pollution also causes damage to our environment. The process of mixing bituminous materials at elevated temperatures within Hot Mix Plants (HMA) results in the production of dangerous gases. This has a negative effect on the environment by contributing to climate change and reducing the potential transportation distance for flexible pavements. In this article a research investigation was carried out to probe into the influence of substituting Low Density Polyethylene (LDPE) waste in varying proportions within bituminous mixes at five distinct levels of bitumen contents 4.6%, 4.9%, 5.2%, 5.5 and 5.8%. This study investigated how different types of mixes affect Marshall Properties, which are important indicators of the quality and durability of bituminous mixes. The results showed that including plastic in the mixes improved their stability, with the greatest stability achieved when using 6.0% LDPE plastic. Therefore using low density polyethylene is a viable option for creating high quality bituminous mixes.

KEYWORDS- Bituminous, Concrete Pavement, Concrete Pavement, Density Polyethylene

I. INTRODUCTION

In India, the significance of transport is more because of its vastness as well as varied nature of geographical conditions. The Indian transport system is one of the most diversified, complex & extensive in the world. Transportation helps in economic, social, urban & cultural development. Essentially, there are three primary modes of transportation: Land (Road), Water (Sea), and Air transport. All types of paved surfaces can be classified into two main categories: Rigid and Flexible pavements. The objective of bituminous mix design is to determine the optimal proportions of bitumen, filler, fine aggregates, and coarse aggregates to create a mix that is manageable, sturdy, long-lasting, and cost-effective. Factors such as water infiltration, load stress from heavy vehicles, temperature-induced variations, and exposure to sunlight are among the various variables that can contribute to pavement failure. Heavy precipitations occurrences that can result in extensive flooding may subsequently undermine the structural integrity and accelerate the degradation of the pavement.. Floods can place a burden on transportation systems, both in the immediate aftermath and in the long term, by causing disruptions in transportation, damaging infrastructure, and requiring time-consuming recovery efforts. These impacts have the potential to adversely affect economies. The separation between the aggregate and bitumen is one of the most severe repercussions of flooding, resulting in loss of adhesion. It results in deterioration and consequently reduces the durability of pavements. Hence, proper provisions should be taken for the drainage of surface water. The utilization of plastic materials in our everyday existence is steadily escalating. The proper disposal of plastic waste has emerged as a significant issue. The plastic pollution has risen as a result of increasing population, switching lifestyles and technical revolutions. The proper recycling of these plastic wastes is essential to safe our environment. Plastic pollution is indeed a global problem. According to a report by IISc 3.4 million tons of plastic waste is produced in India out of which only 30 percent is recycled. While the remainder is disposed of in landfills or dumped. The ecological, societal, financial, and health hazards associated with plastic must be evaluated in conjunction with other environmental pressures such as climate change, ecosystem deterioration, and resource consumption.

As it's difficult to put complete ban on plastic, the government of India has initiated "Swatch Bharat Abhiyan" to implement 3R's policy (Reduce, Reuse, and Recycle). The durability of pavements and fatigue life were found to be increased if plastic waste management is done efficiently.

In this study, the discarded low density polyethylene (LDPE) material is utilized and gathered for experimentation. Its widespread application can be observed in the manufacturing of laminates, bottles, garbage bags, and food packaging, owing to its favorable attributes of high flexibility and cost-effectiveness. Incorporating LDPE waste into road construction not only improves the quality of road infrastructure but also provides an eco-friendly solution for plastic waste management [[18]][[20]][[22]]. LDPE is added to the bituminous mixes at varying proportions of 2.0%, 4.0%, 6.0%, and 8.0% by weight of bitumen, after determining the Optimum Bitumen Content of the control mix. The Marshall Test properties were evaluated to determine the OBC, which was determined to be 5.2%, and the optimal content of LDPE plastic was found to be 6.0%. The utilization of plastic waste in road construction promotes sustainable practices and contributes to the development of environmentally friendly roads.

II. LITERATURE REVIEW

In a study by PK Gautam [[8]], the exploration was carried out to examine the viability of utilizing previously employed materials in various layers of flexible asphalt. The results confirmed that the reuse of recycled materials not only offers an effective waste management solution, but also decreases the need for new materials and reduces overall construction expenses.

JJ Jafar [[9]] published a paper on “Utilisation of waste plastic in bituminous mix for improved performance of roads”. This research focuses on enhancing the mechanical properties of bituminous mixtures through the incorporation of plastic waste and chemical additives. The plastic waste was recycled and treated with a potent oxidizing mixture of dichromate and sulphuric acid, while the bitumen was treated with a cross-linking agent, polyethylene mine. Over a series of ten measurement cycles, the stiffness of the chemically modified mixtures exhibited a 10% increase.

Thakur Shivani and Duggal A. K.[[10]], “Review on Reutilization of Plastic Waste in Paving Mixes” In summary, the findings indicate that addition of waste plastic into flexible pavement can significantly enhance its quality and performance. By utilizing plastic waste in pavement construction, we can address unsound environment problem and contribute to sustainable waste management practices while improving the performance of flexible pavements.

Singh et al. [[11]], emphasized the importance of plastics in achieving cost savings, longevity when subjected to heat and increased strength as well as the potential of using plastic-coated aggregates to minimize porosity and enhance stability.

Yuetan Ma [[12]] published a paper on “The utilization of waste plastics in asphalt pavements”. This paper provides a comprehensive review of incorporating various types of waste plastics like HDPE, LDPE, PP, PS, PET, EVA, and PVC into asphalt pavements using wet and dry processes. HMA is a perfect application for reusing plastic waste in highway construction due to its high usage. The incorporation of waste plastics into asphalt mixtures has shown betterment in fatigue resistance, rutting resistance and moisture resistance indicating improved performance in these areas. Different approaches, such as polymer additives, chemical additives, and nano materials, have been adopted to mitigate these limitations.

Brian P. Grady [[14]] concluded in their study that the addition of plastic, regardless of whether it undergoes melting or not, can enhance stiffness-related properties. For Mel-table plastics, it is often possible to reduce the amount of asphalt, increase the solids content at the temperature of use. Although there is frequently an ideal amount of plastic to include, typically around 10% of the binder content or 1% of the total mixture, tensile strengths also show an upward trend. The ideal quantity may be affected by inadequate bonding between the plastic and the binder at the interface. This same concern can occasionally lead to diminished performance in fatigue tests, as these tests are highly responsive to the quality of interfacial bonding.

Greg White [[16]] in their study found that interest in recycling waste plastic for asphalt production has grown, but laboratory evaluations of its effects on binder and asphalt properties are lacking. Two recycled plastic products, one plastomeric and the other elastomeric, were evaluated in the lab. Compared to unmodified bitumen, the reprocessed plastic items heightened softening temperature, elastic recovery and binder viscosity. When mixed into asphalt, these recycled plastic products enhanced resistance to deformation and stiffness, although they also increased susceptibility to moisture damage and had no significant impact on fatigue life.

According to Khalid Ghuzlan's [[19]] research in 2015, incorporating PE (polyethylene) into the asphalt binder substantially enhanced its elasticity. However, higher PE content led to an increase in the rotational viscosity of the bitumen, rendering the PE-modified asphalt binders unworkable at these levels due to their high viscosity.

III. MATERIALS AND METHODOLOGY

A. Materials

1) Bitumen

This study makes use of VG-30 bitumen. This grade of bitumen is commonly used in asphalt mixtures for roads and highways, providing good resistance to rutting and fatigue, as well as adequate adhesion with aggregates. It is typically used in regions with moderate to high temperatures, where the pavement experiences significant thermal stresses. The properties of this grade conform to the viscosity graded pavement bitumen standards outlined in IS 73:2013 [2]. Physical properties of VG 30 grade bitumen are presented in Table 1.

Table 1 Characteristics of Bitumen

SR NO.	Characteristics	Test Method	Results	Requirement as per IS 73:2013, VG30
1.	Penetration Value at 25 °C	IS 1203	48.67 mm	45 Min.
2.	Softening Point	IS 1205	51.45 °C	47 Min.
3.	Specific gravity	IS 1202	1.008	----
4.	Absolute Viscosity at 60 °C	IS 1206	3244.34 Poise	2400-3600 Poise
5.	Ductility value at 25 °C	IS 1208	70 cm	40 Min.

2) Aggregates

Aggregates form the major portion of the pavement structure. It includes sand, gravels, crushed stone, and recycled concrete and so on. The aggregate adds strength to the overall composite material in the building of flexible pavements. There are two types of aggregates coarse and fine aggregates. In this study both are used for preparing the specimens. Mixing of aggregates is shown in Figure 2. Bituminous concrete layer is used as a wearing course. Nominal aggregate size of 19 mm for grade 1 with layer thickness 50 mm is chosen for this research. The physical proportion of aggregate is shown in Table 2 and blending, combined gradation of lab dry mixes is shown in Figure 1.

Table 2: Physical characteristics of Aggregate

Properties	Results	Test Method	Requirement as per MOR&TH 5th Revision 2013
Impact value (%)	17.77	IS 2386 Part-4	Maximum 24 %
Los Angeles Abrasion Value (%)	18.36	IS 2386 Part-4	Maximum 30 %
Combined Flakiness and Elongation (%)	26.82	IS 2386 Part-1	Maximum 35 %
Specific Gravity	2.861	IS 2386 Part-3	2.1 to 3.2
Water Absorption (%)	0.627	IS 2386 Part-3	Maximum 2 %

3) Low density polyethylene (LDPE)

Low density polyethylene is a flexible and translucent thermoplastic commonly used for packaging, agricultural films, and coating. It has a low melting point, water resistant, high chemical resistance, and good electrical insulation properties. LDPE is produced by free-radical polymerization of ethylene gas. Its low density and high ductility make it easy to process and mould into various shapes. it is used in road construction as a binder modifier in bituminous mixtures [[17]]. Its addition enhances the mechanical properties of asphalt, increases its resistance to cracking [[21]], and improves its durability [[15]]. LDPE asphalt mixtures have been shown to reduce pavement distress and extend the service life of roads. It is possible to mix LDPE with bitumen mix even though LDPE has a lower melting point compared to the heating temperature used for the bitumen mix. The reason for this is that LDPE has property known as thermo plasticity, which allows it to soften and become malleable when heated. The process of mixing LDPE with bitumen involves adding small pieces of LDPE into the bitumen mix while it is being heated and stirred. As the temperature of bitumen mix reaches around 150-165 degree Celsius, the LDPE particles start to soften and dispersed in the bitumen mix.

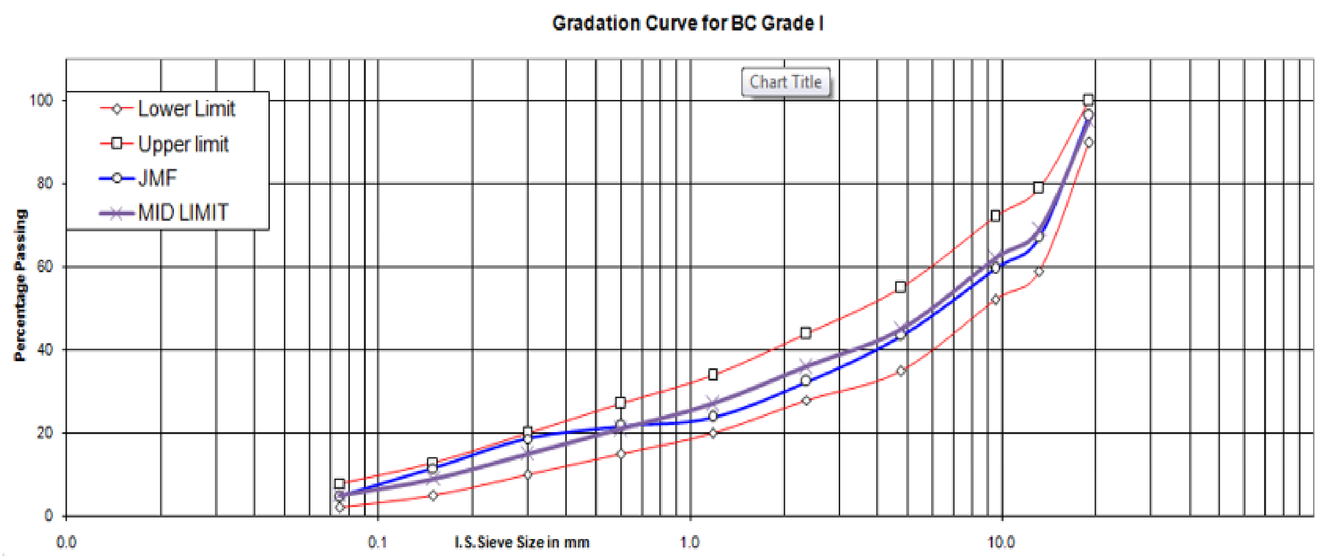

Figure 1: Blending, Combined Gradation of Lab Dry Mixes

Figure 2: Mixing of Aggregates

B. Methodology

The process comprises of a systematic approach for examining the quality of various materials, as well as the preparation and evaluation of both control mix and LDPE varying proportion samples in control mix sample, using the Marshall Mix design technique to assess the Marshall properties of the bituminous mixes. Figure 3 shows the LDPE waste selected for the research. Initially, tests pertaining to bitumen, aggregates, and filling materials were conducted in accordance with the guidelines prescribed by the IS Codes [[2]][[3]][[6]], IRC [[1]][[5]] and MOR&TH [[4]]. Traditionally, plastic is integrated into the mixture using two distinct approaches: the moist procedure and the dry blend procedure [[13]]. In this research, the dry blend process was employed.

Figure 3: LDPE

1) Marshall Stability test

The Marshall method [[7]] is a widely used technique for designing asphalt mixes. It involves preparing samples of asphalt mixture and subjecting them to a series of tests to determine their resistance to deformation when subjected to lateral loading. Marshall Testing Equipment is shown in Figure 4. The process begins by conducting tests on the bitumen, aggregates, and filling materials in accordance with the recommended IS Codes [[2]][[3]][[6]]. Then, a gradation of the aggregate is selected, and the Optimum Binder Content (OBC) is determined by preparing three specimens at five varying percentages of bitumen content as 4.6%, 4.9%, 5.2%, 5.5% and 5.8%. The Optimum Binder Content is determined to be 5.2% based on the weight of bitumen, which aligns with the desired OBC for Bituminous Concrete (BC) layer. The Optimum Bitumen Content corresponding to 4% air voids is then selected for the respective research. A mix is then prepared using a mould of 101.6 mm diameter and compacted with a 4.53 kg sliding weight hammer and 75 blows on each side of the specimens. The specimens are then allowed to cool and acclimate at room temperature for a specified period of time, typically 24 hours, after which their various properties, such as density, VMA, VFB, stability, flow, and air voids, are measured and analyzed to determine the optimum mix design.

Figure 4: Marshall Testing Equipment

The Marshal Strength and deformation examinations are carried out on each individual specimen. Each specimen is immersed in a water bath heated to 60 degrees Celsius for duration of 30 to 40 minutes prior to conducting the tests. Afterward, a load is uniformly applied on the lateral surface of the sample at a steady rate of 50.8 mm per minute until the highest load resistance is attained. The corresponding flow value is recorded for each of the three samples, and the results are averaged and reported. In summary, the procedure involves measuring the stability and flow properties of the samples under controlled conditions [[22]

Table 3: Marshall Properties of Control mix

Bitumen Content	Density (gm/cc)	Air Voids (%)	VMA (%)	VFB (%)	Stability (KN)	Flow (mm)
4.6	2.5190	5.51	15.17	63.68	12.10	3.00
4.9	2.5300	4.64	15.07	69.21	13.82	3.30
5.2	2.5340	3.98	15.21	73.83	14.30	3.60
5.5	2.5320	3.58	15.54	76.96	13.56	3.90
5.8	2.5260	3.29	16.01	79.45	11.20	4.42

Table 4: Marshall Properties of assorted mixes

Bitumen Content	Density (gm/cc)	Air Voids (%)	VMA (%)	VFB (%)	Stability (KN)	Flow (mm)
LDPE 2% + Control Mix	2.5312	4.08	15.30	73.33	14.20	3.68
LDPE 4% + Control Mix	2.5348	3.95	15.18	73.98	14.10	3.72
LDPE 6% + Control Mix	2.5366	3.88	15.12	74.34	14.35	3.76
LDPE 8% + Control Mix	2.5287	4.18	15.38	72.82	11.88	4.25

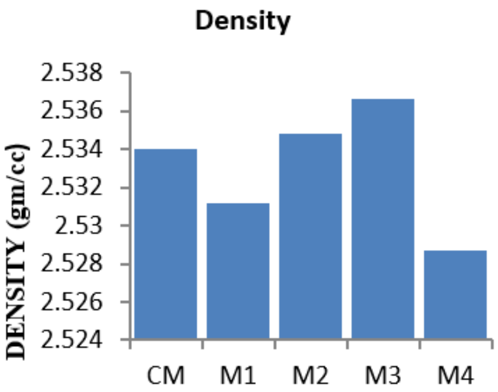

Figure 5: Density

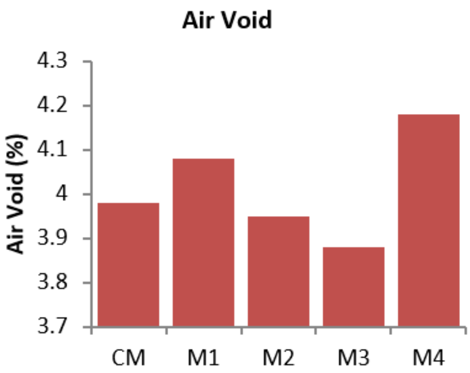

Figure 6: Air VoidFigure 5: Density

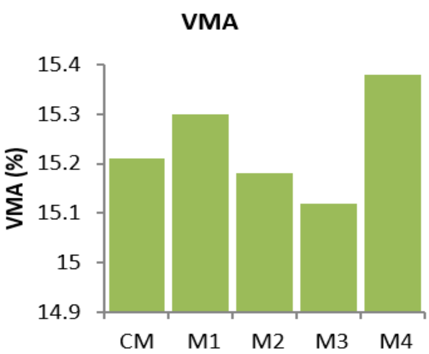

Figure 7: Void filled with mineral aggregates VMAFigure

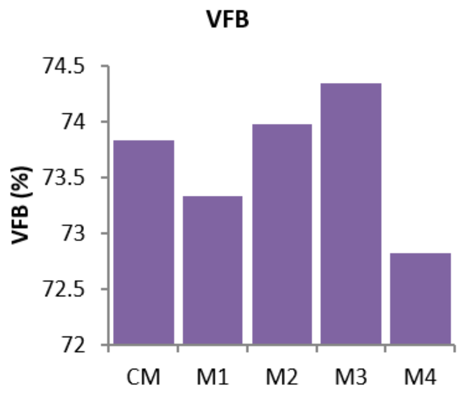

Figure 8: Void filled with Bitumen VFB

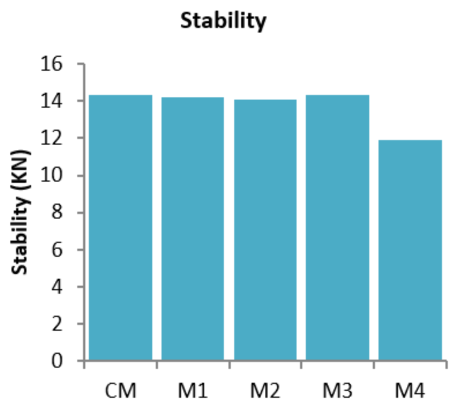

Figure 9: Stability

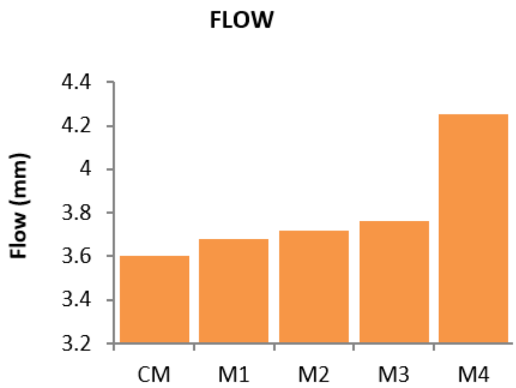

Figure 10: Flow

IV. RESULT AND DISCUSSION

The Marshall properties and the effects of incorporating LDPE into Bituminous concrete mixtures were investigated. The Bituminous concrete mixtures were prepared using VG 30 bitumen as the control mix, and LDPE waste was added to create modified mixtures. Table 3 presents the key characteristics of the control mix, and the optimum binder content was determined to be 5.20% by weight of the mixture, corresponding to a target air void of 4%. The minimum binder content required to achieve the optimum binder content (OBC) for bituminous concrete mix grade 1 was found to be 5.2% by weight of the mixture. The Marshall properties of the different mixtures are detailed in Table 3 and Table 4, respectively.

A. LDPE effect on the strength characteristics of Bituminous concrete mixes

The findings indicate that the LDPE plastic mix exhibits slight improvement in performance compared to the control mix. The inclusion of LDPE in the mix enhances its strength characteristics. The highest stability was achieved with a mixture containing 6% LDPE. Adding 2 & 4 % LDPE Plastic waste to Bituminous Concrete mix has slightly decrease the stability of the mix as compared to control mix. Adding 8% LDPE Plastic waste to bituminous significantly decrease the stability of the mix. The stability results for the various mixtures are depicted in **Error! Reference source not found.**.

B. LDPE effect on the bulk density and air voids of Bituminous concrete mixes

The findings indicate that the incorporation of 2% LDPE plastic results in a negligible decrease in bulk density. The 4% LDPE plastic results in a slight increase in bulk density. The highest density was achieved with a mixture containing 6% LDPE. Adding 8% LDPE Plastic waste to bituminous mix significantly decrease the density of the mix. **Error! Reference source not found.** illustrates the density of the BC mixtures.

The increase in bulk density indicates a decrease in air voids, which was observed when plastic waste was incorporated into the mixture. The air voids results for the various mixtures are depicted in **Error! Reference source not found.**.

C. LDPE effect on the VMA and VFB of Bituminous concrete mixes

Error! Reference source not found. depicts the changes in VMA (voids in mineral aggregate) as a result of incorporating LDPE plastic waste. The findings reveal adding 2% LDPE Slight increase in VMA and adding 4%, 6% decrease in VMA. **Error! Reference source not found.** depicts the changes in VFB (Voids filled with bitumen) as a result of incorporating LDPE plastic waste. Adding 2% LDPE slight decrease in VFB and adding 4 to 6% moderate increase in VFB in the mix. Further significantly decreases VFB at 8 % addition of LDPE plastic waste in the mix.

D. LDPE effect on the Flow value of Bituminous concrete mixes

Error! Reference source not found. depicts the addition LDPE plastic waste in bituminous mix increases the flow value of the mix from 2% to 8% LDPE waste in the mix.

V. CONCLUSION

The primary objective of this study is to investigate effective strategies for utilizing LDPE plastic waste, in bituminous mixtures. The findings indicate that LDPE has the potential to be successfully incorporated into bituminous mixtures, as evidenced by the following key results:

- The addition of plastic enhances the stability of the mixtures.
- The density of the mixtures with LDPE is initially decreased from control mix but this effect starts to increase till 6% LDPE waste in the mix. As we increase the percentage of plastic waste in mix, the density decreases significantly.
- The air voids are reduced after adding LDPE waste in the mix.
- An increase in flow value was also observed in the mixtures containing LDPE plastic waste.
- It also contributes into eco-friendly environment.
- It is important to carefully evaluate the performance of the mix under different condition and adjust the amount of plastic waste added according to achieve the desired results.
- The effect of LDPE plastic waste on the bituminous mix will depend upon the amount added and specific characteristics of the mix. The study determined that an optimal percentage of 6% LDPE plastic waste is identified.
- Therefore, based on the analysis of Marshall Properties test results, it can be concluded that the utilization of LDPE in bituminous mixtures is feasible.

Disclosure of Potential Conflicts of Interest

The researchers assert that they have no identifiable financial stakes or personal affiliations that may have impacted the results presented in this manuscript.

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