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Investigating the Superpave Mixture Design Approach for Hot-Mix Asphalt in Kazakhstan

Abstract. *The purpose of this research was to assess the feasibility of constructing high-performance paving (Superpave) for Kazakhstan with only locally sourced ingredients. Similarly, a standard Marshall technique combination that meets the technical requirements of Kazakhstan was compared. One granite aggregate supplier, 2 aggregate grading, and 2 types of asphalt binder made up the test design. Consensus and source aggregate characteristics requirements met with the Superpave design mix method using locally manufactured granite aggregate. Also, the mixtures volumetric parameters indicated that the asphalt binder content of the superpave combination has shown lower than locally-traditionally Marshall mix. The combinations of Superpave fared better in rutting and moisture resistance tests than those made in the conventional manner. After the ITS values from both samples were averaged, the decrease in significance for the superpave mixtures was 9.1%. It was below the 20% loss level required by the Superpave guidelines. Also by rutting resistance results were significantly differences for 85.5% PG70 with 9.5mm NMAS. All of these results point to the superiority of new method Superpave over the Marshall method.*

Key words: *Superpave, Marshall mix design, rutting, asphalt pavement, moisture resistance.*

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1. Introduction

Extreme rutting (permanent deformation) and moisture-induced problems in hot-mixture asphalt (HMA) pavements caused by repeated high loadings and sharp continental environment are a global issue of great concern in the transportation business. New build pavements may deteriorate prematurely as soon as 2 years after completion. Transportation agencies at the municipal level have noticed this, and the massive yearly budget for upkeep is indicative of this. Pavement design is being done using the classic designing approach (pressing) and the Marshall method in many industrialized nations, including Kazakhstan. In Kazakhstan, HMA mixes are being developed using the Marshall mixture design approach.

The Hubbard-Field approach was the first formal design method for asphalt mixes, as per Roberts et al. (2002); the Hveem method of asphalt mixture design was finalized in 1959, and the whole process was published in the Asphalt Institute Manual Series 2 and in ASTM 1557. Back in the years before 1943, Bruce Marshall tried to come up with a technique to measure the asphalt content of mixes in the lab by developing a process called the Marshall mixture design method.

Not only in the United States, but also in a broad variety of other nations, did the Marshall mixture design approach see extensive adoption. Unfortunately, several highways began experiencing issues, such as early rutting, throughout the pavement's service life in the 1980s. Many engineers speculated that the difficulties stemmed from the impact compaction process used to create the specimens [1-5]. Impact compaction does not replicate the densification that happens under traffic, and the Marshall mixture design approach lacks a rigorous theoretical basis (Roberts et al. 2002). A considerable budget was allocated in 1987 under the Strategic Highway Research Program to begin the changeover from the Marshall technique of mixture design to the Superpave approach. Superpave, an abbreviation for better performing asphalt pavements, is a novel performance-based mixture design process created in 1993 [5-7]. Most of the states in the United States now use Superpave. For this reason, now is the perfect opportunity for all nations to embark on a paradigm change to either improve their current HMA design system or switch to one that is more effective. Kazakhstan was chosen as a case study country so that its design performance could be compared to that of other nations' using Superpave HMA mixes [8-12].

2. Methods and Materials

There were two parts of this investigation. For the first part of this research, researchers employed the Superpave mixture design approach and the more traditional Marshall method to create HMA blends. Local aggregate qualities were also examined to ensure they met the rigorous consensus and source aggregate criteria used in the Superpave system before the mixture design process began. For the Marshall mixture design, we additionally double-checked that the aggregate conditions outlined in the local standards were met [13, 14].

A total of eight mixes were created for this purpose, four of which were created using the Marshall method and the other four using the Superpave method. For the purpose of this research, the provider of aggregates were local factories of the region used in road building. All aggregate gradations were chosen for their compatibility with the local specifications and Superpave gradation requirements, and they all fall within the top and lower limitations [15].

Although the weather in Kazakhstan varies from region to region, the supply of performance-graded (PG) asphalt binder is based on the higher temperature that is typical its part of the area. The effect of the decreased temperature is disregarded. Asphalt binders PG 64 (B1) and PG 70 (B2) were employed in this study. Each of these bindings is equal to a Penetration Grade (PEN) of 70/100 or 60/70.

In the second stage, the HMA mixes were tested to determine their properties and how well they performed. HMA's long-term deformation was measured using the moisture susceptibility and rutting tests, and mixes were characterized using the resilient modulus and dynamic creep tests [16-19].

3. Results and Discussion

3.1 HMA's testing volumetric qualities

As can be shown in Table 1, the aggregate qualities satisfy the acceptance requirements set forth by both Superpave and local technical specifications for HMA mixtures use. The features that are generally agreed upon are the angularity of the coarse aggregate, the angularity of the fine aggregate, elongation and flakiness, and clay content.

Table 1. The aggregate properties

Test names	Results	Specification limits
Coarse agg. angularity	77%	55-100 %
Fine agg. angularity	54%	>45
Flat and elongated sand	6.21%	<10
Equivalent	47.2%	>45
Soundness	6.5%	>10-20%
Toughness	12%	<45%
Deleteriousness	2.1%	0.2-10%
Local specification requirements for aggregates:		
Impact value	23%	<30%
Abrasion	23%	<30%
10% Fines	270 kN	>100 kN
Water absorption	0.8%	<2%

Useful characteristics in the evaluation included toughness, soundness and the presence of harmful substances.

Medium-to-high flow of traffic was selected for mixed design project. Design density for PWD mixture was achieved by compacting specimens with 75 blows per face, which is equal to 60–30 million ESALs for the Superpave mix design procedure [20-24]. To achieve this loading by Superpave, we need the gyration number 100. The aggregates design lines (Figures 1 and 2) that were created to fulfill Superpave and Marshall requirements for nominal maximum size of aggregate (NMAS) of 12.5 and 9.5 mm, respectively, are shown.

Aggregate was mixed with asphalt binder at 4% to 6.5% by weight in all of the batches. The parameters of optimal binder content, bulk density, voids filled with asphalt (VFA), and flow were calculated for a traditional mix with a 4% design air void content.

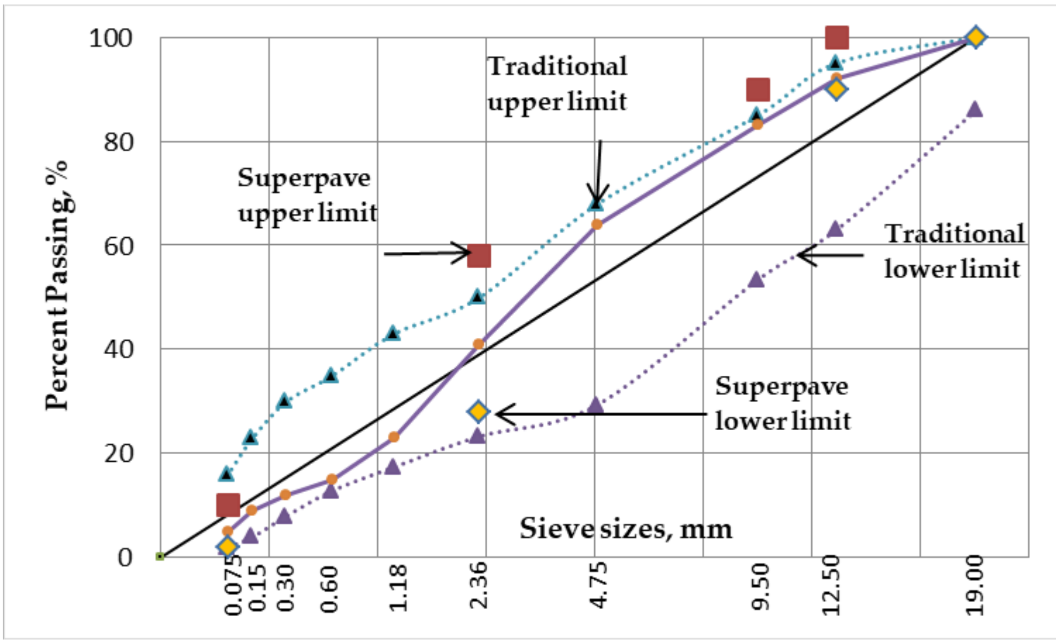

Figure 1. Aggregate design lines with size 12.5 mm

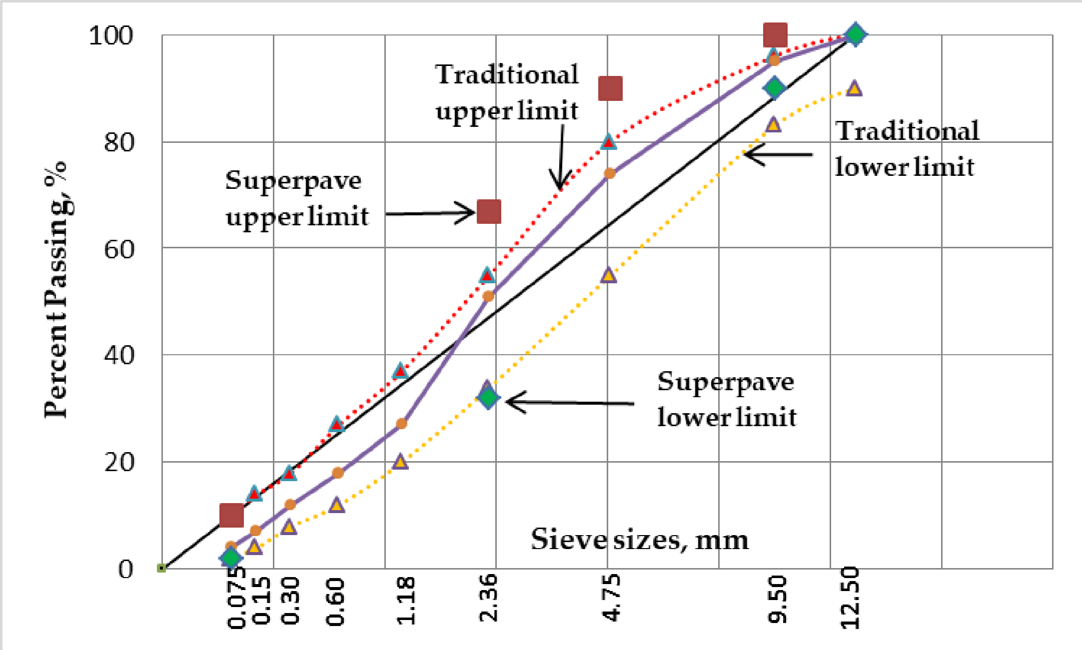

Figure 2. Aggregate design lines with size 9.5 mm

Mixed at optimum binder, the specimens of Superpave should exhibit volumetric qualities that are satisfactory in light of the predetermined Superpave standards. A SGC Compactor was used to compress the Superpave samples. The parameters of pressing for 6,000,000 ESALs were used with starting (N_{ini} 8 gyrations), design compaction (N_{des} 100 gyrations), and maximum effort (N_{max} 160 gyrations). Each specimen measured at designed gyration 150 mm in diameter and between 110 and 120 mm in height, depending on the relative density of the mixes. After estimated bulk specific gravity (G_{mb}) and theoretical maximum specific gravity (G_{mm}) of the mixture. The Superpave mix's optimum binder was then determined in order to provide desirable volumetric characteristics with air percentage 4%. For the volumetric characteristics usually take the VMA, VFA, Va (air voids) and DP (dust percentage). In Table 2, we can see the volumetric features of the design mixes that are associated with optimum binder content for all mixture [25, 26].

Superpave mixes with the same NMAS had lower optimum binder than conventional way of designing HMA. Most of the researchers came to the same conclusion between 2000-2007. Whereas both of the method mixtures faced with the standard limits and the combination show almost 0.5% greater than that of the Superpave mix. As a result, the Superpave mixes use less asphalt binder than conventional ones do for the same designed aggregate. It's possible that varying compaction techniques are to blame for these phenomena.

Table 2. The mixtures volumetric qualities

Test names	12.5-1	12.5-2	9.5-1	9.5-2	Standard limits
Traditionally mixes					
Optimum binder	5.7	5.9	6.0	6.3	-
Stability, kN	10.1	10.2	10.3	10.9	>8 kN
Flow, mm	3.6	3.6	3.2	3.4	2-4 mm
VFA, %	74	75	76	76	70-80%
SuperPave mixes					
Optimum binder	5.0	5.2	5.3	5.5	-
Va, % (air voids)	3.89	4.1	3.96	4.2	4%
VMA, %	14.1	14.6	14.2	14.5	>14
VFA, %	73.0	73.5	73.1	73.6	65-76%
DP	0.7	0.7	0.8	0.8	0.6-1.2

Note: 12.5-1 refers to PG 64 and 12.5-2 refers to PG70

The optimum binder of mixes with gradation size 9.5 mm is greater compared to mixes with 12.5 mm because the finer aggregates surface area requires a greater quantity of bitumen to cover the particles. The need for the minimum VMA is an essential signal that the mixture should have at least the minimal amount of binder that is authorized. This will guarantee that the combination will be durable.

3.2 HMA's pavement performance qualities

The sensitivity and durability of the Asphalt mix to deformations may be determined by evaluating the performance of the pavement. This is a very crucial step. As part of this investigation, tests for rutting and moisture susceptibility were carried out to ascertain the level of resistance to permanent deformation and, separately, damage caused by moisture.

The moisture sensitivity test uses AASHTO T283 method without taking into account the soundness test treatment [27]. It was shown that 2 subgroups of the compressed specimens, both had 4% air voids on average. Due to the climate condition in Kazakhstan the vacuum taking levels between 70-80 % were used for the test. The conditioned samples being stored in water bath at 60^{0}C for 24 hours. Then the specimens moved to the 25^{0}C degrees water bath for 2 hours before the testing. Table 3 displays all the results calculation that clear both conditioned and unconditioned samples tensile strength ratio (TSR) based on ITS measurements. Superpave mixes ITS loss meaning were 9.1% after averaging both samples ITS. This met the 20% losses threshold stipulated by Superpave standards (Asphalt Institute standard 2001). Figure 3 shows the apparatus representation used in moisture susceptibility test.

Table 3. Moisture susceptibility test results

Design types	Indirect Tension Test (kPa)		TSR (%)	Indirect Tension Test (kPa)		TSR (%)
	Unconditioned	Conditioned		Unconditioned	Conditioned	
	Superpave mix			Traditional mix		
12.5-1	626.4	513.9	82.0	460.8	459.6	99.7
12.5-2	671.5	634.7	94.5	464.1	451.7	97.3
9.5-1	703.7	615.8	87.5	544.6	536.1	98.4
9.5-2	640.2	632.4	98.8	515.8	497.9	96.5

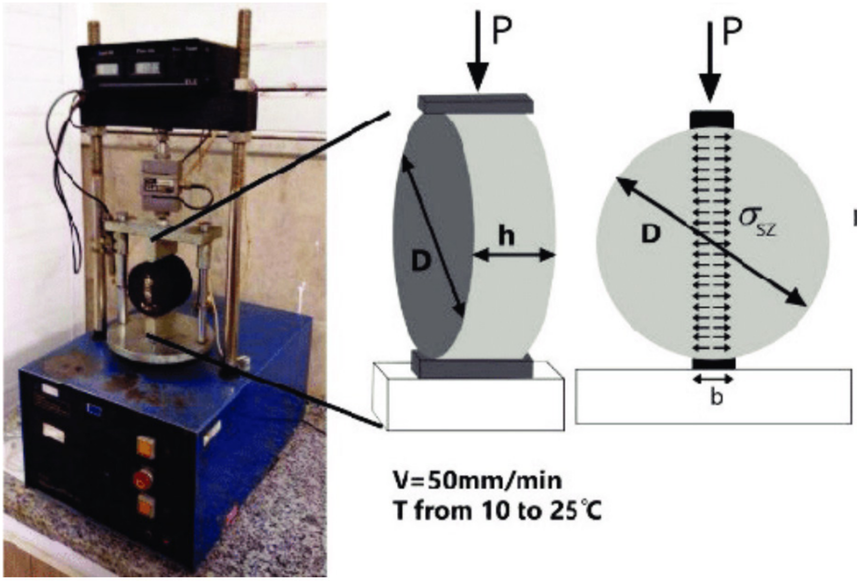

Figure 3. Moisture susceptibility test setup

The rutting depth test conducted by 20-4000 Wheel track testing machine which is designed to test asphalt concrete for rutting resistance in air and in water. The unit is compatible with asphalt samples obtained on a sector press or in the form of samples. Simultaneously two samples can be tested and there are several mould configurations have been developed for testing: 320x260 mm; 340x280 mm; 300x300 mm; 410x260 mm; 400x300 mm, but for tests the samples diameter must be - 150 mm in 2 pieces. Overall testing procedure program were set according to EN 12697-22. First, the samples were prepared on a 300x300 mm mold in special sector compactor, which is designed for the preparation of compacted asphalt samples 320 x 260 mm (410 x 260 mm optional) with a height of 40-120 mm in accordance with EN12697/33, Part 5.2. Thereby the samples were prepared approximately in 10 min, with 300x300 mm and 50 mm height by traditional method of designing, also samples compacted by SGC in circled form to save on material. After compactor, samples cooled in room temperature not less than for 24 hours, subsequently, tested for 20000 passages by 2 samples in parallel in 9 hours. The received results are assumed as high temperature and intensive movement rutting resistance indicator, which meet the standard.

As the result, Superpave mixes was much greater resistant for rutting than conventional method. A reduction of frictional resistance within aggregates is thought to be the consequence of too much bitumen in combination, leading to decreasing load capacity. Superpave design were shown to be less prone to rutting than the conventional way of designing. As can be seen in figure 4, the Superpave designs that make use of the PG 70 bitumen type are most resistant. The study's comparison results of various mixes show that HMA mixture is really affected by bitumen binder type and the design methodology.

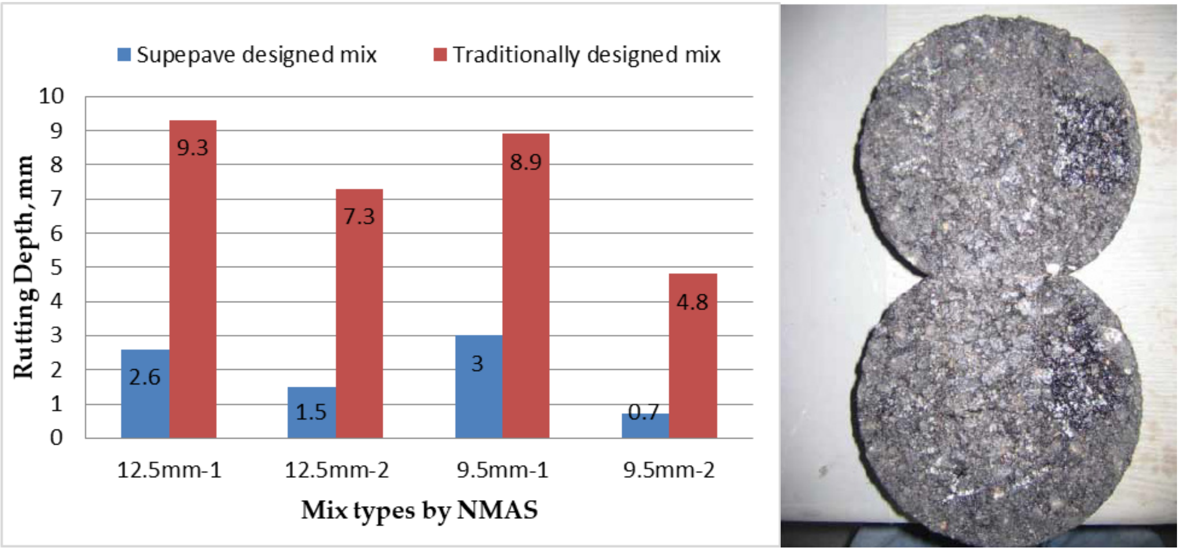

Figure 4. Rutting results diagram and SGC compacted samples after test

4. Conclusions

The purpose of this study was to assess the feasibility of implementing the Superpave mixture design in Kazakhstan using locally sourced materials. A standard mixture developed using the Marshall approach and meeting regional technical requirements served as a point of comparison. According to the data collected during the experiments, it was concluded that granite aggregates are suitable for use in the Superpave mixture design method. As shown by their volumetric characteristics, Superpave-designed combinations need far less binder than conventional mixtures. This is associated with the increased mixture density produced by the compactive effort using SGC, which generates a better aggregate orientation. All of the mixes tested demonstrated good resistance to moisture-induced damage, however the ITS was found to be greater for the Superpave-designed combinations than the control groups. ITS result values from both samples were averaged, the decrease in significance for the superpave mixtures was 9.1% that is below the 20% loss level required by the Superpave guidelines. When put through dynamic creep testing, Superpave combinations do better than regular mixtures when it comes to resisting ruts. Specifically, rutting outcomes were much better by PG grades, and then by NMAS sizes 12.5 mm and 9.5 mm, providing 79% and 85.5% better rutting resistance for PG70, respectively.

In the United States, the Superpave system is being widely used. The findings reported should be verified via a trial project so that the Transportation Ministries in Kazakhstan may have a deeper understanding of the Superpave system and how well these pavements performed in comparison to the standard approach presently utilized. Long-term field project monitoring should be included into future studies that aim to compare the two HMA mixture design approaches.

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Қазақстанда ыстық аралас асфальтқа (НМА) арналған Superpave қоспасын жобалау тәсілін зерттеу

Аңдатпа. Бұл зерттеудің мақсаты Қазақстан үшін тек жергілікті ингредиенттерден жоғары тиімді жол жабынын (Superpave) жасау мүмкіндігін бағалау болды. Сол сияқты Қазақстанның техникалық талаптарына сәйкес келетін Маршалл техникасының стандартты комбинациясын салыстыру жүргізілді. Гранитті агрегаттың бір жеткізушісі, агрегаттың 2 түрі және асфальтбетонды байланыстырғыштың 2 түрі сынақ жобасын жасады. Бастапқы толтырғыштың өнімділігіне сәйкес талаптар жергілікті гранитті толтырғышты қолдана отырып, Superpave design mix әдісін қолдана отырып орындалады. Сонымен қатар, қоспалардың көлемдік параметрлері superpave комбинациясындағы асфальтбетон тұтқыр құрамының дәстүрлі Маршалл қоспасына қарағанда төмен екенін көрсетті. Superpave комбинациялары әдеттегі әдіспен жасалғандарға қарағанда икемділік пен ылғалға төзімділік сынақтарында жақсы нәтиже көрсетті. Қоспаның сипаттамаларын талдағаннан кейін, біз супер-беттік қоспалар осы салада қолданылатын әдеттегі араластыру әдісіне қарағанда қаттырақ екенін анықтадық. Екі үлгінің де ITS мәндері орташа алынғаннан кейін супер төселген қоспалар үшін маңыздылықтың төмендеуі 9,1% құрады. Бұл Superpave нұсқаулары талап ететін 20% жоғалту деңгейінен төмен болды. Сондай-ақ, 9,5 мм NMAS бар 85,5% PG70 үшін соққыға төзімділік нәтижелері айтарлықтай айырмашылықтар болды. Осы нәтижелердің барлығы Жаңа Superpave әдісінің Маршалл әдісінен артықшылығын көрсетеді.

Түйін сөздер: Суперпэйв әдісі, Маршалл әдісі, асфальтбетон, ылғалға төзімділік, дөңгелек ізіне төзімділік тесті.

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Исследование подхода к расчету состава смеси по Superpave для горячего асфальтобетонного покрытия в Казахстане

Аннотация. Целью данного исследования была оценка возможности создания высокоэффективного дорожного покрытия (Superpave) для Казахстана исключительно из местных ингридиентов. Таким же образом было проведено сравнение стандартной комбинации оборудования Marshall, отвечающей техническим требованиям Казахстана. Один поставщик гранитного заполнителя, 2-х видов заполнителя и 2-х видов асфальтобетонного вяжущего разработал тестовый проект. В зависимости от характеристик основного заполнителя требования выполняются с использованием метода Superpave design mix с использованием местного гранитного заполнителя. Кроме того, объемные параметры смесей показали, что содержание вязкости асфальтобетона в комбинации superpave ниже, чем в традиционной смеси Marshall. Комбинации Superpave показали лучшие результаты в тестах на гибкость и влагостойкость, чем те, которые были изготовлены обычным способом. Проанализировав характеристики смеси, мы обнаружили, что суперповерхностные добавки более твердые, чем обычный метод смешивания, используемый в этой отрасли. После усреднения значений ITS для обоих образцов снижение значимости для смесей с супермощением составило 9,1%. Это было ниже уровня потерь 20%, требуемого руководящими принципами Superpave. Также по результатам устойчивости к колееобразованию были обнаружены значительные различия для 85,5% PG70 с 9,5 мм NMAS. Все эти результаты показывают превосходство нового сверхволнового метода над методом Маршалла.

Ключевые слова: Суперпэйв, Маршалл, подбор состава, асфальтобетон, колеяобразование.

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