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Trends of Marshall Mix Design Practices in Nepal: A Perspective on Compliance with Standard Specification of Road and Bridge Work 2016 Section 1309 and Fuller's Maximum Density Gradation

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Abstract

This comprehensive study delves into the minute details of Marshall Mix Design practices in Nepal, specifically examining their compliance with Section 1309 of the Standard Specification for Road and Bridge Works 2016 (SSRBW 2016). The research utilized robust secondary data collection from diverse sources, including laboratories, projects, and construction sites, enhancing the dataset's utility and uniqueness. Compliance checks against SSRBW 2016 standards indicated satisfactory performance in stability and flow but highlighted concerns in the Marshall and Filler-Binder Ratio. For the Marshall Quotient, only 82% and 76% and for the Filler-binder ratio, only 61% and 38% of mix designs of gradation type I and type II respectively, followed the standard specified in SSRBW 2016, indicating tender mix design practice in Nepal. Furthermore, the study employs statistical analyses to scrutinize critical parameters, including Root Mean Square Error (RMSE), shedding light on significant disparities in mid-point gradation and sample mean of the dataset. It also investigates the compliance of mix designs with Fuller's ideal gradation for maximum density, emphasizing the significance of aggregate gradation in pavement performance. The evaluation of gradation at 0.45, 0.5, and 0.55 exponents extends to the interplay of volumetric properties, emphasizing the need for refined gradation specifications to enhance the durability and overall performance of asphalt mixtures in the Nepalese context. In this study, RMSE results offer a quantitative measure of the percentage discrepancies between observed gradation and anticipated values of Fuller's gradation, resulting in RMSE values computed at 3.37%, 4.77%, and 6.74% for percentage passing in the mid-point grade of type I, and 8.23%, 10.89%, and 13.30% for mid-point grades of type II. This analysis provides a clear understanding of the deviation from Fuller's maximum density gradation. The study concludes with actionable recommendations for practitioners and policymakers, aiming to optimize mix designs gradation of Section 1309 of SSRBW 2016 for asphalt pavements in Nepal.

Keywords: Marshall Mix Design, Fuller's Maximum Density Gradation, SSRBW 2016, Hot Mix Asphalt, Marshall Quotient, RMSE, Filler-Binder Ratio

1. Background

Asphalt concrete is one of the most common types of pavement surface material used in the world (Su, 2020). Asphalt concrete is a porous material mainly composed of mineral aggregate, asphalt binder and additive made at a very high temperature of about 180-degree Celsius (Su, 2020; Zhang, 2020). The longevity of a bituminous road can be extended through effective pavement design, construction, and maintenance. When meticulously designed with the right blend of components, it will yield a resilient surface capable of withstanding substantial traffic loads, ensuring exceptional durability (Maharjan & Tamrakar 2018).

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For the design of Asphalt concrete, the Marshall Mix design method is one of the widely accepted method. The Marshall Mix Design method was initially developed by Bruce Marshall of the Mississippi Highway Department in 1939. This Design Method is a technique used to identify an optimal bitumen content that maximizes the strength of the mix while minimizing its cost. The Marshall test methods are set as standards by both the American Society for Testing and Materials (ASTM) and the American Association of State Highway and Transportation Officials (AASHTO) (Ministry of Physical Infrastructure and Transport, 2018).

Initially, the original Marshall method applies only to hot mix asphalt paving mixtures containing aggregates with maximum sizes of 25 mm or less (Jitsangiam et al., 2023). Subsequently, the US Corps of Engineers, through extensive research and correlation studies, improved and added certain features to Marshall's test procedure and, ultimately developed asphalt concrete mix design criteria (Singh, 2016).

In Nepal, the mix is generally designed using the Marshall Mix Design Method (Karna, 2016), as per the Standard Specification for Road and Bridge Works 2016 (SSRBW 2016) published by the Department of Roads. Initially, introduced in the Nepali road construction industry as SSRBW 2001 this guideline underwent revision and replacement by SSRBW due to loading conditions and traffic composition (Department of Roads, 2016).

Since Marshall mix design is largely empirical and has been practiced for many years through laboratory test procedures (Ministry of Physical Infrastructure and Transport, 2018; Singh, 2016), there is a need to establish a system for monitoring overall compliance in order trace the Marshall mix design practice and eliminate overall the tender mix design practice.

Objectives:
The main objectives of this study are to evaluate the Marshall mix design practice in Nepal. Some of the secondary objectives are given below:

1. Examine the gradation and Marshall mix properties according to section 1309 of SSRBW 2016 standards and discuss the theoretical impact of noncompliance on road pavement performance.
2. Test the significance level using t-statistics between the ideal gradation midpoint and sample mean.
3. To develop Fuller's Maximum Gradation at exponents 0.45, 0.50, and 0.55 to type I and type II gradation compromising restriction zone suggested by Superpave method.
4. To examine the deviation of the ideal mid-point gradation suggested by section 1309 of SSRBW 2016 to Fuller's maximum gradation using Root mean Square Error (RMSE)

2. Literature Review:

Asphaltic mix (AC) is a dense, continuously graded mix that relies for its strength on both the interlock between aggregate particles and properties of the bitumen and filler (Karna A., 2016). Mechanical and volumetric properties of asphalt concrete mix are dependents upon large number of physical properties of aggregate and binder. Also, the performance of the material is significantly impacted by the particle size distribution or gradation of aggregates of the pavement material. Aggregate gradation influences almost every important HMA property including stiffness, stability, durability, permeability, workability, fatigue resistance, skid resistance and resistance to moisture damage (Maharjan & Tamrakar, 2018; Abedali, 2015; Roberts et al., 1996). So, selecting the optimal aggregate gradation is necessary. The ideal aggregate gradation is the one that achieves the maximum density. maximum density condition occurs when fine particles are well-packed between coarser particles, minimizing the void spaces between them (Ministry of Physical Infrastructure and Transport, 2018; Singh & Yadav, 2016; Balitsaris, 2012; Transportation Research Circular, 2002).

Mineral aggregate constitutes a predominant 90-96% of the Asphalt mix by weight, or roughly 75-85% by volume, exerting substantial influence in resisting external loads and environmental conditions (Maharjan &

Tamrakar, 2018; Ministry of Physical Infrastructure and Transport, 2018; Pourkhorshidi et al., 2020). Given the empirical and site-specific nature of Marshall mix design, acknowledged for its labor-intensive character (Ministry of Physical Infrastructure and Transport, 2018; Othman & Abdelwahab, 2021) the resulting mix tolerances are notably narrow. The properties of Marshall mix, intricately linked to key performance parameters including resistance to permanent deformation, fatigue resistance, moisture resistance, and workability, as delineated in the Asphalt Institute Manual Series No. 2 (MS-2) (Abedali, 2015), mandate a rigorous monitoring process to ensure strict adherence to the specified values outlined in section 1309 of SSRBW 2016 (Department of Road, 2016).

Section 1309 of SSRBW 2016 guides the collection of essential information required before undertaking the preparation and execution of the Marshall Test for Hot Mix Asphalt (HMA). Additionally, Table 13.33 of SSRBW 2016 outlines the recommended optimal range of aggregate gradation and bitumen content for HMA, categorized by the Nominal Size of Aggregate. The specification specified the properties of the aggregate, the percentage passing through specific sieves and designates a minimum optimum content of 5.2% by weight, as illustrated in Table 1 and specified by Table 13.33 of SSRBW 2016.

Table 1. Composition Quantity of Bituminous Concrete Pavement Layers

Gradation	**I**		**II**	
Nominal Size of Aggregate	**19mm**		**13.2mm**	
Sieve Size (mm)	**Lower Limit**	**Upper Limit**	**Lower Limit**	**Upper Limit**
26.5	100	100		
19	90	100	100	100
13.2	59	79	90	100
9.5	52	72	70	88
4.75	35	55	53	71
2.36	28	44	42	58
1.18	20	34	34	48
0.6	15	27	26	38
0.3	10	20	18	28
1.18	5	13	12	20
0.075	2	8	4	10

Table 2. Requirements for Dense Graded Bituminous Macadam

Properties	**Viscosity Grade Paving Bitumen**	**Test Method**
Number of Blow	75 on each face of the specimen	
Minimum Stability (KN at 60 D Centigrade)	9	AASTHO T245
Marshall Flow (mm	2-4	AASTHO T245
Marshall Quotient	2-5	MS-2
% air voids	3-5	
% voids filled with bitumen	65-75	
minimum % Voids in Mineral Aggregate	12	ASTM D5581
Coating of aggregate Particle	95% minimum	IS 6241
Tensile Strength Ratio	80% minimum	AASTHO T 283

Section 1308(3) of SSRBW 2016 recommends a fine-to-bitumen content ratio for Asphalt mix within the range of 0.6 to 1.2. In contrast, IRC 135 from 2022 specifies a fine-to-bitumen content ratio between 0.8 to 1 (Indian Road Congress, 2022). Beyond adherence to gradation and quality specifications, the asphalt mixture must also comply with the requirements outlined in Section 1308(3) of SSRBW 2016, as delineated in Table 13.29 of SSRBW 2016 and mentioned in Table 2.

The Manual for Dense Graded Bituminous Mixes published by the Department of Roads (DOR) recommends testing five different bitumen contents for a single selected aggregate gradation. This extensive testing is crucial for evaluating various volumetric and strength criteria to determine the optimal binder content. To ensure sufficient data, a minimum of three test specimens is prepared for each bitumen content selected comprising, a Marshall mix design that involves testing five different bitumen contents typically require a minimum of 15 test specimens (Ministry of Physical Infrastructure and Transport, 2018).

To assess the proximity of the mid-point grade to the sample mean, a test statistic serves as a tool to measure the accuracy of the data distribution in connection with the null hypothesis during the analysis of data samples. The t-value, a specific type of test statistic, is employed in this evaluation, necessitating the examination of a null hypothesis asserting equality between the means of both test samples (Bevans, 2023). If the means are found to be significantly unequal, the null hypothesis is rejected in favor of the alternative hypothesis. The t-test statistics (Chai, 2014) is provided in Equation 3.

$$t = \frac{\bar{x} - \mu}{\frac{s}{\sqrt{n}}} \qquad \textit{Equation 1}$$

where $\bar{x}$ is the sample mean, μ represents the population mean, s is the standard deviation of the sample and n stands for the size of the sample.

Although, gradation considered in Marshall mix design can be monitored as per specifications, but we can't ignore the principal objective of selecting aggregate gradation. The grading employed in asphaltic concretes follows a philosophy centered on maximizing the density of the mineral aggregate (Maharjan & Tamrakar, 2018). This approach is rooted in a gradation proposed by Fuller and Thomson in 1907 (Fuller, 1907), expressed in Equation 3.

$$P = (\frac{d}{D})^n * 100 \qquad \textit{Equation 2}$$

where,

P = percent finer than an aggregate size
d = aggregate size being considered
D = Maximum Aggregate Size (MAS)
n = Exponent parameter which adjusts curve for fineness or coarseness (for maximum particle density n ≈ 0.5 according to Fuller and Thompson, FHWA uses 0.45 power graph for Superpave

The maximum aggregate size (MAS) is the smallest sieve through which 100% of the sample must pass. The nominal maximum aggregate size (NMAS) is the smallest sieve size through which the majority of the sample passes (up to 10% can be retained) (Abedali, 2015). Wang et al., (2010) use Fuller's gradation equation at exponent 0.35 for coarse aggregate and 0.25 for fine aggregate to evaluate the asphalt mix properties for 16mm down aggregate, and mix properties were found satisfactory for road pavement construction (Wang et al., 2010). Kutiya et al., (2019) also emphasized the importance of aggregate gradation on creep deformation of asphalt mix and conducted laboratory testing and come up with the idea that fine aggregate gradation affects the creep behavior of the asphalt mix (Mathew et al., 2020). Apeagyei, A.K (2022) concluded that dynamic modulus and gradation could be considered as potential rutting specification parameters for QC/QA purposes in the field (Apeagyei, 2011), suggesting proper investigation over gradation limit before the general application of specifications. For quality assurance of asphalt mix, examination of the present gradation limit of Section 1309 of SSRBW 2016 is essential.

Furthermore, the restricted zone given in Table 3 was firstly introduced by AASHTO M 323 then by the Superpave system. Also incorporated in Fuller's gradation to assure gradation not pass, upon passing through the restricted zone between the 4.75mm and 0.3mm sieves, this indicated a potential issue with the mix, suggesting an excess of natural sand that could lead to potential mix tenderness. Restriction Zone as specified by Asphalt Institute 7th edition Table 3.3 (Abedali, 2015) is given in Table 3.

Table 3. Restricted Zone for Different NMAS

Sieve Size, mm	Restricted Zone for Nominal Maximum Aggregate Size (Lower limit and Upper Limit)					
	25		19		12.5	
0.3	11.4	11.4	13.7	13.7	15.5	15.5
0.6	13.6	17.6	16.7	20.7	19.1	23.1
1.18	18.1	24.1	22.3	28.3	25.6	31.6
2.36	26.8	30.8	34.6	34.6	39.1	39.1
4.75	39.5	39.5	–	–	–	–

Analyzing aggregate gradation of different sources and different sizes and achieving the desired gradation by combining aggregates is one of critical steps in the design of hot mix asphalt mixes (Abedali, 2015; Tinga et al., 2016; Ramadhansyah et al., 2016; Hainin et al., 2015) and combined aggregate gradation shall be close enough to maximum density gradation yielding a mix design that meets the criteria of the mix design method as specifications (Ministry of Physical Infrastructure and Transport, 2018; Abedali, 2015; Fuller, 1907).

In order to quantify theoretical deviation of mid-point grade of section 1309 of SSRBW 2016 to fullers' maximum density gradation, the root mean square error (RMSE) has been used as a standard statistical metric to measure model performance assuming the error sample set is unbiased (Chai, 2014). The RMSE is calculated for the data set using Equation 3.

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=i}^{\mathbb{N}}(\,O_i - t_i)^2} \qquad \textit{Equation 3}$$

Therefore, this study focuses on evaluating compliance with Section 1309 of SSRBW 2016, analyzing the development of Fuller's gradation compromising the restricted zone, and assessing the theoretical deviation of mid-point grading (expected mean grade) from Fuller's maximum density gradation. Hypothesis testing of mid-point grading against the sample mean using t-statistics was also conducted.

3. Methodology

3.1 Data collection

This study is based on secondary data, 75 sample data were collected through rigorous visits to different laboratories such as Quality Research and Design Center (QRDC), a wing of the Department of Road (DOR) Nepal, Visow Lab Kathmandu, Everest Lab Kathmandu, Meh Geo Lab Lalitpur and thorough study of the thesis related to the Marshall Mix design in University Level of Nepal. Secondary data related to Marshall mix design were also collected from the different project offices and different road construction sites. Collected data of gradation for type I and type II gradation as per section 1309 of SSRBW 2016 were shown in Figure 1 and Figure 2.

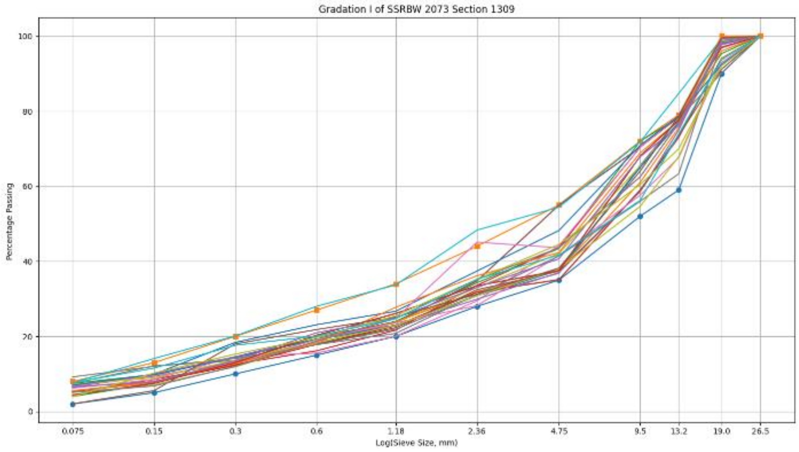

Figure 1. SSRBW 2016 Section 1309 Gradation I Data set

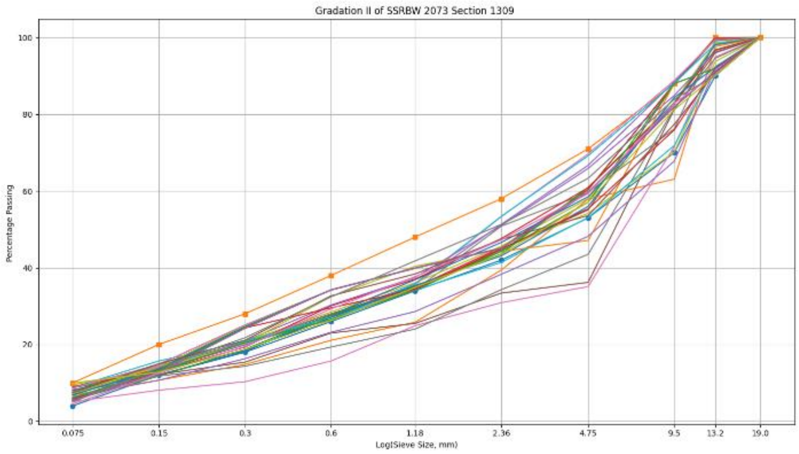

Figure 2. SSRBW 2016 Section 1309 Gradation II Data set

Data related to batching proportion, combined gradation, specific gravity of material used, mechanical properties, and volumetric properties at optimum bitumen content were collected. Also, mechanical and volumetric Properties at five different bitumen content was also collected in proper format. Uniqueness of Each of the Marshall mix designs were verified with project name and contract Id of the project.

3.2 Data analysis

Table 4. Statistical Information of Data Set Related to SSRBW 2016 Section 1309 Gradation I

Sieve Size, mm	***26.5***	***19***	***13.2***	***9.5***	***4.75***	***2.36***	***1.18***	***0.6***	***0.3***	***0.15***	***0.075***
Mean	100	96.39	75.69	64.28	41.81	33.73	24.17	19.39	14.08	8.93	5.77
Standard Error	0	0.55	0.81	1.03	1.06	0.81	0.48	0.43	0.39	0.36	0.32
Median	100	97.35	76.95	65.00	41.45	33.02	23.66	19.10	13.37	8.53	5.52
Mode	100	99.50	78.69	70.38	37.60	34.79	23.00	19.10	13.00	7.68	5.44
Standard Deviation	0	2.92	4.29	5.43	5.60	4.27	2.55	2.29	2.08	1.89	1.70
Sample Variance	0	8.50	18.43	29.52	31.40	18.22	6.51	5.25	4.33	3.59	2.90
Kurtosis		-0.81	2.07	-1.30	1.06	5.54	6.45	6.88	1.96	0.85	1.55
Skewness		-0.67	-1.11	-0.18	1.23	2.15	1.90	1.98	1.57	0.85	-0.83
Range	0	9.82	21.39	17.39	19.86	20.10	13.65	12.46	8.20	8.56	8.20
Minimum	100	90.11	63.31	54.61	35.10	28.20	20.05	15.54	11.90	5.54	1.00
Maximum	100	99.93	84.70	72.00	54.96	48.30	33.70	28.00	20.10	14.10	9.20

Table 5. Statistical Information of Data Set Related to SSRBW 2016 Section 1309 Gradation II

Sieve Size, mm	19.00	13.20	9.50	4.75	2.36	1.18	0.60	0.30	0.15	0.08
Mean	100.00	94.14	81.38	57.28	44.79	35.73	28.95	20.63	13.20	7.14
Standard Error	-	0.57	0.99	1.22	0.80	0.76	0.76	0.56	0.23	0.22
Median	100.00	92.20	81.97	59.68	45.11	35.90	28.01	20.50	13.30	7.29
Mode	100.00	91.10	81.97	59.68	45.11	39.89	34.21	20.50	13.30	7.50
Standard Deviation	-	3.49	6.04	7.40	4.87	4.63	4.61	3.43	1.41	1.34
Sample Variance	-	12.17	36.53	54.82	23.75	21.48	21.28	11.77	1.98	1.79
Kurtosis	-	(1.47)	1.60	2.77	1.76	1.05	0.65	1.03	3.78	(0.57)
Skewness	-	0.48	(1.27)	(1.39)	(0.88)	(1.24)	(0.77)	(0.82)	(1.37)	0.03
Range	-	9.75	25.73	34.60	22.50	17.77	18.56	14.77	7.60	5.50
Minimum	100.00	90.06	63.10	35.10	30.90	24.03	15.70	10.30	8.10	4.47
Maximum	100.00	99.81	88.83	69.70	53.40	41.79	34.26	25.07	15.70	9.97

Table 4 and Table 5 show a statistical range of collected data, grouped as per section 1309 of SSRBW 2016, type I and type II gradation, respectively, in order to make the presentation of the data more comprehensible. Table 4 and Table 5 show the data center (mean and median), most frequent values (mode), dispersion (standard deviation, sample variance and coefficient of variance), data extremes (minimum and maximum), and shapes of the distribution (kurtosis and skewness), making data interpretation relatively straightforward.

Table 6. Fuller's Gradation for NMAS 19mm at different exponents 0.45,0.50,0.55 along with Restricted Zone

Fuller Exponents	**0.45**	**0.5**	**0.550**	**Fuller Gradation Considering Restriction Zone**					
				0.450		**0.5**		**0.55**	
Sieve Size	Percentage Passing			Lower Limit	Upper Limit	Lower Limit	Upper Limit	Lower Limit	Upper Limit
26.5	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
19	86.10	84.67	83.28	86.10	86.10	84.67	84.67	83.28	83.28
13.2	73.08	70.58	68.16	73.08	73.08	70.58	70.58	68.16	68.16
9.5	63.03	59.87	56.88	63.03	63.03	59.87	59.87	56.88	56.88
4.75	46.14	42.34	38.85	46.14	46.14	42.34	42.34	38.85	38.85
2.36	33.68	29.84	26.44	34.6	34.6	34.6	34.6	34.6	34.6
1.18	24.65	21.10	18.06	22.3	28.3	22.3	28.3	22.3	28.3
0.6	18.18	15.05	12.45	16.7	20.7	16.7	20.7	16.7	20.7
0.3	13.31	10.64	8.50	13.7	13.7	13.7	13.7	13.7	13.7
0.15	9.74	7.52	5.81	9.74	9.74	7.52	7.52	5.81	5.81
0.075	7.13	5.32	3.97	7.13	7.13	5.32	5.32	3.97	3.97

The statistical analysis of the datasets reveals that the collected data are considered as a wide range of data, enhancing their utility and uniqueness. Data collected through different sources were analyzed, and their compliance with SSRBW 2016 Section 1309 was checked, and presented in Table 8

Compliance of gradations were also carried out after the development of the Fuller's gradation using equation (I) for NMAS 19mm and NMAS 13.2 mm shown in Table 6 and Table 7 respectively. Also, gradation comprising restricted zones was formulated. Their graphical plot for NMAS 19 mm and NMAS 13.2mm at different exponents were presented in Figure 3, Figure 4, Figure 5, Figure 6, Figure 7, and Figure 8, respectively.

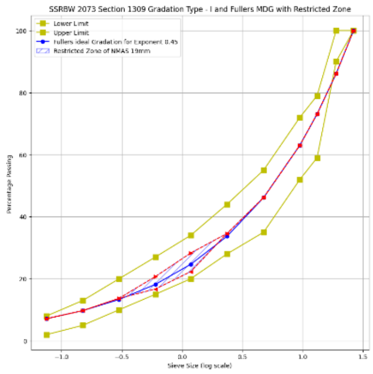

Figure 3. Fuller's MDG at n = 0.45 along with Restricted Zone for NMAS 19mm

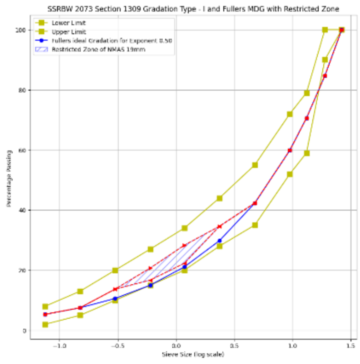

Figure 4. Fuller's MDG at n = 0.50 along with Restricted Zone for NMAS 19mm

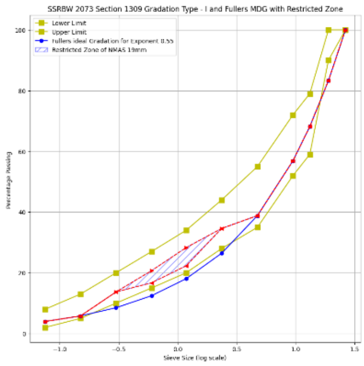

Figure 5. Fuller's MDG at n = 0.55 along with Restricted Zone for NMAS 19mm

Table 7. Fuller's Gradation for NMAS 13.2 mm at different exponents 0.45,0.50,0.55 along with Restricted Zone

Fuller Exponents	**0.45**	**0.5**	**0.550**	**Fuller Gradation after Considering Restriction Zone**					
				0.450		**0.5**		**0.55**	
Sieve Size	Percentage Passing			Lower Limit	Upper Limit	Lower Limit	Upper Limit	Lower Limit	Upper Limit
19.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
13.20	84.88	83.35	81.85	84.88	84.88	83.35	83.35	81.85	81.85
9.5	73.20	70.71	68.30	73.20	73.20	70.71	70.71	68.30	68.30
4.75	53.59	50.00	46.65	53.59	53.59	50.00	50.00	46.65	46.65
2.36	39.12	35.24	31.75	39.1	39.1	39.1	39.1	39.1	39.1
1.18	28.64	24.92	21.69	25.6	31.6	25.6	31.6	25.6	31.6
0.6	21.12	17.77	14.95	19.1	23.1	19.1	23.1	19.1	23.1
0.3	15.46	12.57	10.21	15.5	15.5	15.5	15.5	15.5	15.5
0.15	11.32	8.89	6.97	11.32	11.32	8.89	8.89	6.97	6.97
0.075	8.29	6.28	4.76	8.29	8.29	6.28	6.28	4.76	4.76

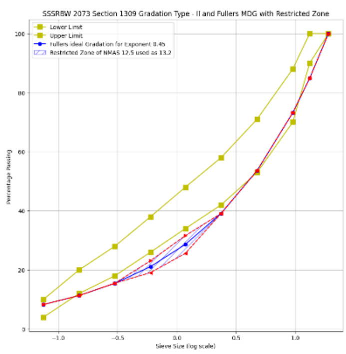

Figure 6. Fuller's MDG at n = 0.45 along with Restricted Zone for NMAS 13.2mm(approx.)

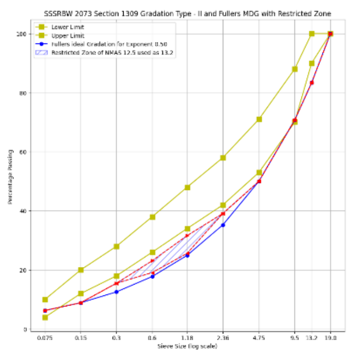

Figure 7. Fuller's MDG at n = 0.50 along with Restricted Zone for NMAS 13.2mm(approx.)

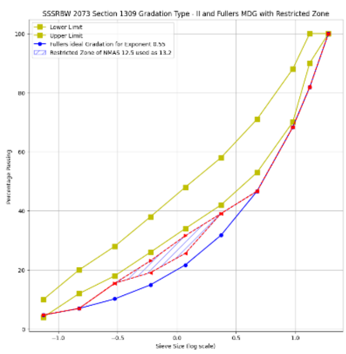

Figure 8. Fuller's MDG at n = 0.55 along with Restricted Zone for NMAS 13.2mm(approx.)

3.3 Statistical Analysis

Statistical analysis was carried out for two conditions. Firstly, Hypothesis testing was carried out based on the sample mean and expected mean (mid-point grades) of the aggregate gradation as specified in section 1309 of SSBRW 2016 using t-statistics at significance level of 5% for each percentage passing through sieve. In this hypothesis testing Null Hypothesis (NH) is considered as difference between sample mean and mid-point gradation is not significant and Alternative hypothesis was considered as significant difference between sample mean and mid- point gradation. Hypothesis testing results were presented in Table 9 and Table 10.

Also, Root means square error between maximum density gradation and mid-point grade was analyzed to identify to what extent our specification SSRBW 2016 section 1309 is deviated with respect to Fuller's maximum density gradation The analysis was carried out using the powerful Excel tool and using Python 10.8.

4. Results and Discussion:

4.1 Compliance for SSRBW 2016

Marshall mix design that are designed according to section 1309 of SSRBW 2016, in Nepal were examined based on parameter specified in Table 8. The Table 8 provides a summary of the Marshall Mix Design properties for two different gradations (I and II) against the standard values specified in the SSRBW 2016 standard for Viscosity Grade Paving Bitumen. Compliance percentages indicate how well each gradation meets the specified criteria.

Table 8. Summary of Compliance Evaluation of Mix Properties as per SSRBW 2016 Section 1309

Marshall Mix Design Properties	**Properties values for Viscosity Grade Paving Bitumen**	**Status As per SSRBW 2016**	
		Gradation I	Gradation II
Number of Samples			
Minimum Stability (KN at 60 D Centigrade)	9	100%	100%
Marshall Flow (mm	2-4	97%	97%
Marshall Quotient	2-5	82%	76%
% Air Voids	3-5	97%	86%
% VFA	65-75	75%	26%
minimum % VMA	12	100%	100%
Coating of aggregate Particle	95% Minimum	NA	NA
Tensile Strength Ration	80% Minimum	NA	NA
Filler -Binder Ratio, SSRBW 2016	0.6 - 1.2	61%	38%
Filler -Binder Ratio, IRC 135, 2022	0.8-1	29%	14%

As per the standards outlined in SSRBW 2016, the Asphalt Concrete pavements must meet a minimum stability requirement of 9 KN at 60°C. It is crucial to highlight that all the samples included in the analysis have demonstrated exceptional stability, exceeding the stipulated minimum value.

Additionally, the flow values, indicating the horizontal deformation of the asphalt mix at the maximum load, fall within the desired range of 2-4 mm for 97% of the samples, suggesting that the majority of the samples possess optimal deformation characteristics.

However, when examining the Marshall Quotient (MQ), a parameter reflecting the stiffness of the mix or resistance to share, it becomes evident that only 82% and 76% of the samples meet the specified requirements. The MQ is calculated by dividing the stability (KN) by the flow (mm), and it serves as an indicator of the mixture's ability to withstand load (Putri et al., 2023). Higher MQ values suggest a stiffer or more brittle mix, while lower values indicate a mix that may fail to withstand the load, potentially leading to the development of ruts (Tong et al., 2022). In this context, the 82% and 76% compliance rates highlight that a significant number of the samples demonstrate satisfactory stiffness. However, there is room for improvement in meeting the specified standards for this particular parameter.

Modifying any factor or mix design procedure may lead to a decline in performance or service life. Research has shown that mixtures consolidating to less than 2 percent air voids are prone to rutting and shoving in heavy traffic locations (Hafeez & Kamal, 2009). Problems may arise if, over time, the final air void content exceeds 5 percent or if the initial construction involves over 8 percent air voids, leading to issues like brittleness, premature cracking, raveling, and stripping (Ministry of Physical Infrastructure and Transport, 2018; Abedali, 2015). In this context, 97% and 86% of the samples meeting specified requirements suggest areas for improvement in adhering to the specified standards.

Voids in Mineral Aggregate (VMA) denote the total volume of voids in compacted aggregate, critical for asphalt mix durability. An inadequate VMA may compromise durability, while excessive VMA poses stability challenges and results in uneconomical binder consumption, leading to rapid binder oxidation if voids are inadequately filled (Chadbourn et al., 2000; Pouranian & Haddock, 2018; Kandhal & Chakraborty, 1992). The objective is to provide ample space for asphalt, ensuring adhesion to aggregate without bleeding during temperature fluctuations. Design bitumen contents within a specific range may exhibit bleeding or plastic flow, and extra compaction from traffic can cause rutting in high-traffic areas (Park, 2007). Optimal design bitumen content should be slightly left of the low point on the VMA curve. If the mix is on the left-hand side, it would be scorched, susceptible to segregation, and likely to have elevated air voids (Balitsaris, 2012). In our study, both gradations meet the requirement by 100%.

The interrelation of VFA, VMA, and Percentage Air Voids in asphalt mix design requires attention. While any two values can solve for the third, incorporating VFA criteria is vital to avoid mixes with marginally acceptable VMA. VFA primarily limits maximum VMA levels and bitumen content, restricting allowable air void content (Department of Roads, 2016; Balitsaris, 2012). Mixes designed for lower traffic volumes struggle to meet VFA criteria. In contrast, those for heavy traffic with low air voids fail, indicating increased susceptibility to top-down rutting (Zhang et al., 2019), with only 75% and 26% of job mix meeting standards.

The filler-binder ratio is a pivotal determinant of Hot Mix Asphalt (HMA) workability, notably affecting resistance to plastic deformations (Vale et al., 2016). Higher filler content imparts stiffness to the mix, on the other hand asphalt become more fragile and consequently more susceptible to crack under fatigue and low temperatures. Due to these antagonistic effects on performance, selecting the right amount of mineral filler to compound asphalt is a task of great importance (Vale et al., 2016). IRC 135, 2022 prescribes a ratio of 0.8 to 1 (Indian Road Congress, 2022), and SSRBW 2016 recommends 0.6 to 1.2 (Department of Roads, 2016). This property significantly influences the workability of asphalt mixtures, as a low Filler-Binder ratio can render a mix challenging to compact. However, compliance issues arise, with only 61% and 38% of mixes meeting this requirement, posing potential quality concerns in the field. Additionally, considerations for aggregate composition must address potential inadequacies in voids for optimal bitumen coverage within Gradations in Marshall Design.

4.2 Statical Evaluation

The Table 9 and Table 10 presents results from a statistical analysis of SSRBW 2016 section 1309 Grade I and Grade II respectively. Each row corresponds to a different sieve size, with corresponding mid-point grades, sample means, standard errors, sample sizes, standard deviations, t-values, degrees of freedom, and critical values for one-tailed and two-tailed tests. The analysis involves comparing the sample means to a null hypothesis (NH) that indicates no significant difference between mid-point grade and sample mean.

In summary, the Table 9 and Table 10 provides a detailed statistical assessment of each sieve size for SSRBW 2016 section 1309 type I and type II gradation respectively, determining whether the observed sample means warrant rejecting the null hypothesis. Rejections suggest a significant difference from the mid-point grade, while failed to reject indicate consistency with the null hypothesis.

Table 9. Summary of Hypothesis Testing using T- Statistics for SSRBW 2016 section 1309 Gradation I

Sieve Size	Mid-point grade	Sample Mean	Standard Error	Sample Size	Standard Deviation	t-value	Degree of Freedom	Critical value (0ne-tail)	Critical value (two-tailed)	Verdict (one -tailed Test)	Verdict (two-tailed Test)
26.5	*100*	100	0	28	0		27	1.703	2.052		
19	*95*	96.39	0.55	28	2.92	2.53	27	1.703	2.052	Reject NH	Reject NH
13.2	*69*	75.69	0.81	28	4.29	8.25	27	1.703	2.052	Reject NH	Reject NH
9.5	*62*	64.28	1.03	28	5.43	2.22	27	1.703	2.052	Reject NH	Reject NH
4.75	*45*	41.81	1.06	28	5.60	3.01	27	1.703	2.052	Reject NH	Reject NH
2.36	*36*	33.73	0.81	28	4.27	2.82	27	1.703	2.052	Reject NH	Reject NH
1.18	*27*	24.17	0.48	28	2.55	5.87	27	1.703	2.052	Reject NH	Reject NH
0.6	*21*	19.39	0.43	28	2.29	3.73	27	1.703	2.052	Reject NH	Reject NH
0.3	*15*	14.08	0.39	28	2.08	2.35	27	1.703	2.052	Reject NH	Reject NH
0.15	*9*	8.93	0.36	28	1.89	0.20	27	1.703	2.052	Fail to Reject NH	Fail to Reject NH
0.075	*5*	5.77	0.32	28	1.70	2.39	27	1.703	2.052	Reject NH	Reject NH

An assessment of compliance with Fuller's maximum density curve, adhering to specified exponents and a restricted zone per The Asphalt Institute, was executed. The study concentrated on Nominal Maximum Aggregate Size (NMAS) of 19mm and 13.2mm, aligning with SSRBW-2016 Section 1309 type I and type II gradations. For type I aggregate, the analysis revealed that 79% of the mix conforms to the restricted zone, suggesting a potential tendency toward a tender mix. Remarkably, the restricted zone for NMAS 13.2mm was approximated using the 12.5mm zone, analogous to SSRBW 2016 type II gradation. The outcome unveiled a discrepancy, indicating that the specified gradation range in SSRBW 2016 fails to encompass the Fuller's maximum density curve along with restriction zone shown in Figure 10 and Figure 9 thus contravening the primary mix design principle directing towards achieving maximum density. As mix failed to creates more particle-to-particle contact, in HMA which would increase stability, reduce water infiltration and resistance to frost action.

In response to the observed deviation highlighted in Figure 9 and Figure 10, an extensive inquiry was conducted to precisely quantify the disparities inherent in mid-point grades for type I and type II gradations, as well as the Fuller Maximum Density Gradation. The assessment utilized the Root Mean Square Error (RMSE) as a robust metric. The resulting RMSE values, computed at 3.37%, 4.77%, and 6.74% for percentage passing in the mid-point grade of type I, and 8.23%, 10.89%, and 13.30% for mid–point grades of type II, distinctly delineate the magnitude of percentage discrepancies between observed and anticipated value indicates there is significant difference and needs rectification of gradation specified in section 1309 of SSRBW 2016 via laboratory research.

Table 10. Summary of Hypothesis Testing using T- Statistics for SSRBW 2016 section 1309 Gradation II

Sieve Size	Mid-Point grade	Sample Mean	Standard Error	Sample Size	Standard Deviation	t-value	Critical value (0ne-tail)	Critical value (two-tailed)	Verdict (one-tailed Test)	Verdict (two-tailed Test)
19	100	100	0	37	0	0				
13.2	95	94.14	0.57	37.00	3.49	1.51	1.703	2.052	Fail to Reject NH	Fail to Reject NH
9.5	79	81.38	0.99	37.00	6.04	2.39	1.703	2.052	Reject NH	Reject NH
4.75	62	57.28	1.22	37.00	7.40	3.88	1.703	2.052	Reject NH	Reject NH
2.36	50	44.79	0.80	37.00	4.87	6.5	1.703	2.052	Reject NH	Reject NH
1.18	41	35.73	0.76	37.00	4.63	6.92	1.703	2.052	Reject NH	Reject NH
0.6	32	28.95	0.76	37.00	4.61	4.02	1.703	2.052	Reject NH	Reject NH
0.3	23	20.63	0.56	37.00	3.43	4.2	1.703	2.052	Reject NH	Reject NH
0.15	16	13.20	0.23	37.00	1.41	12.09	1.703	2.052	Reject NH	Reject NH
0.075	7	7.14	0.22	37.00	1.34	0.63	1.703	2.052	Fail to Reject NH	Fail to Reject NH

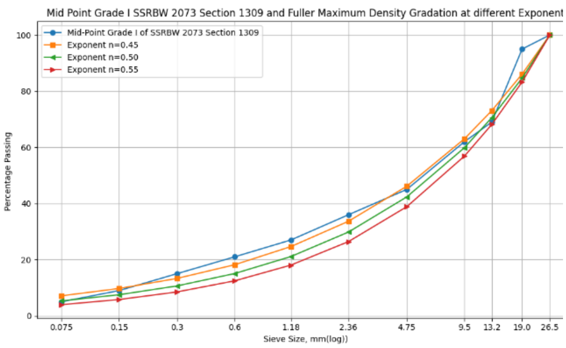

Figure 9. Mid-Point Grade I of SSRBW 2016 Section 1309 and Fuller's Maximum Density Gradation at different Exponents

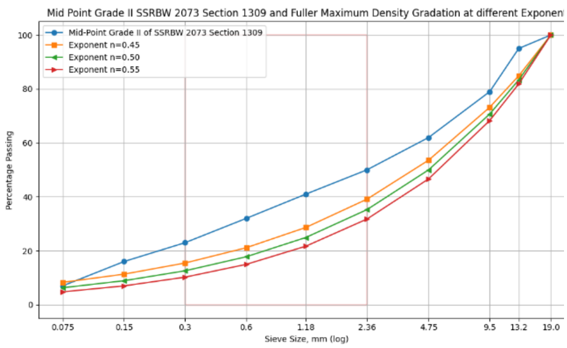

Figure 10. Mid-Point Grade II of SSRBW 2016 Section 1309 and Fuller's Maximum Density Gradation at different Exponents

5. Conclusion

In conclusion, this study conducted a thorough analysis of Marshall Mix designs practice in Nepal, focusing on section 1309 of SSRBW 2016 gradation types I and II. The research utilized a robust secondary data collection from diverse sources, including laboratories, projects, and construction sites, enhancing the dataset's utility and uniqueness. Statistical evaluation identified variability in sample means across different sieve sizes, revealing areas for improvement in parameters like Marshall Quotient and filler-binder Ratio in Marshall mix design. Compliance checks against SSRBW 2016 standards indicated satisfactory performance in stability and flow but highlighted concerns in Marshall and Filler-Binder Ratio. Such that for Marshall Quotient only 82% and 76% and for Filler-binder ratio only 61% and 38 % of mix designs of gradation type I and type II respectively, follows the standard specified in SSRBW 2016 indicating premature mix design practice in Nepal. Hypothesis testing revealed significant differences between mid-point gradation and sample mean of data set, emphasizing the need for nearer selection of gradation while designing. Investigating deviation from Fuller's maximum density gradation curve uncovered disparities quantified by Root Mean Square Error values. Recommendations include future examine mix produced as per gradation specified in section 1309 of SSRBW 2016 and mix as per Fuller's gradation to evaluate the mechanical and volumetric properties of asphalt mixtures. Overall, this study offers valuable insights for asphalt industry practitioners and policymakers, guiding future efforts to optimize mix designs for the long-term sustainability of asphalt pavements as volumetric parameters have a significant correlation with its pavement performance, especially against rutting and moisture (Wang et al., 2012).

6. Further Research

The information shared is based on how road pavements were designed before, following SSRBW 2016, Section 1309 guidelines. Using statistical evaluation gives us a theoretical understanding of these designs' deviations. For future studies, suggesting a direct comparison of Marshall mix properties based on Section 1309 of SSRBW 2016 and testing against Fuller's maximum density gradation in a laboratory could provide insights into their significance thus offering opportunities for enhancing the specified gradation in Table 13.33 of SSRBW 2016.

References

Abedali, A. H., 2015. *MS-2 Asphalt Mix Design*. Asphalt Institute.

Apeagyei, A. K., 2011. Rutting as a function of dynamic modulus and gradation. *Journal of Materials in Civil Engineering*, 23(9), pp. 1302-1310.

Balitsaris, M., 2012. Deviations in Standard Aggregate Gradation and its Effects on the Properties of Portland Cement Concrete. *All Theses*, 1502.

Bailey Method for Gradation Selection in Hot-Mix Asphalt Mixture Design, 2002. *Transportation Research Circular*, E-C044.

Bevans, R., 2023. An Introduction to t Tests | Definitions, Formula and Examples. *Scribbr*, [online] Available at: https://www.scribbr.com/statistics/t-test/ [Accessed 2 February 2024].

Chadbourn, B. A., Skok, Jr., E. L., Crow, B. L., and Spindler, S., 2000. *The Effect of Voids in Mineral Aggregate (VMA) on Hot-Mix Asphalt Pavements*. Minneapolis: University of Minnesota, Department of Civil Engineering.

Chai, T., and Draxler, R. R., 2014. Root mean square error (RMSE) or mean absolute error (MAE)? – Arguments against avoiding RMSE in the literature. *Geoscientific Model Development*, 7(3), pp. 1247–1250.

Department of Road, 2016. *Standard Specification for Road and Bridge Work*. Government of Nepal.

Fuller, W. B., and Thompson, S. E., 1907. THE LAWS OF PROPORTIONING CONCRETE. *Transactions of the American Society of Civil Engineers*, 59, pp. 67-143.

Government of Nepal Ministry of Physical Infrastructure and Transport Department of Roads Maintenance Branch, 2018. *Manual for Dense Graded Bituminous Mixes (DBM/BC)*.

Hafeez, I., and Kamal, M. A., 2009. Impact of Hot Mix Asphalt Properties on its Permanent Deformation Behavior. *prr.hec.gov.pk*.

Hainin, M. R., Aziz, M. M. A., Ali, Z., Jaya, R. P., El-Sergany, M. M., and Yaacob, H., 2015. Steel slag as a road construction material. *Jurnal Teknologi*, 73(4), pp. 33-38.

IRC: SP:135, 2022. *Manual for the Design of Hot Bituminous Mixes*. Indian Road Congress.

Jitsangiam, P., Nusit, K., Teeratitayangkul, P., Ping Ong, G., and Thienchai, C., 2023. Development of a modified Marshall mix design for Hot-mix asphalt concrete mixed with recycled plastic based on dry mixing processes. *Construction and Building Materials*, 404, 133127.

Kandhal, P., and Chakraborty, S., 1992. EVALUATION OF VOIDS IN THE MINERAL AGGREGATE FOR HMA PAVING MIXTURES. *National Center for Asphalt Technology*, Auburn University.

Karna, A., 2016. Appropriate Asphalt Mix Design for Nepal. Nepal: Pulchowk Campus, Institute of Engineering.

Kuity, A., and Das, A., 2020. Effect of Gradation of Fine Aggregates on Creep Deformation of Fine Aggregate Mix (FAM) and Asphalt Mix. In: Mathew, T., Joshi, G., Velaga, N., and Arkatkar, S. (eds) *Transportation Research*. Lecture Notes in Civil Engineering, vol 45. Singapore: Springer.

Maharjan, R., and Tamrakar, G.B., 2018. Effect of Aggregate Gradation Variation on the Marshall Mix Properties of Asphalt Concrete.

Mathew, T. V., Joshi, G. J., Velaga, N. R., and Arkatkar, S., eds., 2020. *Transportation Research*. Lecture Notes in Civil Engineering. Singapore: Springer.

Othman, K. M. M., and Abdelwahab, H., 2021. Prediction of the optimum bitumen content using artificial neural networks. *Metallurgical and Materials Engineering*. https://doi.org/10.30544/579.

Park, T., 2007. Causes of bleeding in a hot-in-place asphalt pavement. *Construction and Building Materials*, 21(12), pp. 2023–2030.

Pouranian, M. R., and Haddock, J. E., 2018. Determination of voids in the mineral aggregate and aggregate skeleton characteristics of asphalt mixtures using a linear-mixture packing model. *Construction and Building Materials*, 188, pp. 292–304.

Pourkhorshidi, S., Sangiorgi, C., Torreggiani, D., and Tassinari, P., 2020. Using Recycled Aggregates from Construction and Demolition Waste in Unbound Layers of Pavements. *Sustainability*, 12(22), 9386.

Putri, E. E., Kasyafi, F. M. R., and Ahmad, F., 2023. Performance of rubber asphalt in split mastic asphalt mixture. *E3S Web of Conferences*, 464, 11009.

Ramadhansyah, P. J., Aqeela, M. N., Amiera, J. S. N., Norhafizah, M., Norhidayah, A. H., and Dewi, S. J., 2016. Use of coconut shell from agriculture waste as fine aggregate in asphaltic concrete. *ARPN Journal of Engineering and Applied Sciences*, 11(12), pp. 7457-7462.

Roberts, F.L., Kandhal, P.S., Brown, E.R., Lee, D.Y., and Kennedy, T.W., 1996. *Hot Mix Asphalt Materials, Mixture Design, and Construction*. National Asphalt Pavement Association Education Foundation. Lanham, MD.

Singh Lodhi, D. K., and Yadav, R. K., 2016. Effect of Gradation of Aggregates on Marshall Properties of SDBC Mix Design. *International Journal of Research in Engineering and Technology*, 05(02).

Student, 1908. The probable error of a mean. *Biometrika*, 6, pp. 1–25.

Su, J.-F., 2020. Self-healing pavements using microcapsules containing rejuvenator: from idea to real application. In: *Eco-Efficient Pavement Construction Materials*. Elsevier, pp. 249–314. https://doi.org/10.1016/B978-0-12-818981-8.00011-4.

Tinga, T. L., Jayaa, R. P., Hassana, N. A., Yaacoba, H., Jayantib, D. S., and Ariffinc, M. A. M., 2016. A review of chemical and physical properties of coconut shell in asphalt mixture. *Carbon*, 7, p. 15.

Tong, J., Ma, T., Shen, K., Zhang, H., and Wu, S., 2022. A criterion of asphalt pavement rutting based on the thermal-visco-elastic-plastic model. *International Journal of Pavement Engineering*, 23(4), pp. 1134–1144.

Vale, A. C. do, Faxina, A. L., and Grecco, F. L. G., 2016. Effects of filler/bitumen ratio and bitumen grade on rutting and fatigue characteristics of bituminous mastics. *Proceedings of 6th Eurasphalt & Eurobitume Congress*. https://doi.org/10.14311/EE.2016.298.

Wang, D. Q., Tan, Y. Q., and Xu, H. N., 2012. The Representative Volumetric Parameter for Dense-Graded Asphalt Mixture. In: *Advanced Materials Research* (Vols. 446–449, pp. 3334–3340). Trans Tech Publications, Ltd. https://doi.org/10.4028/www.scientific.net/amr.446-449.3334.

Wang, L. J., Liu, H., and Zhao, S. Y., 2010. Aggregate gradation design of asphalt mixture with stone-to-stone contact based on Fuller's model. *Journal of Shanghai University (English Edition)*, 14(5), pp. 387-390.

Zhang, H., Chen, Z., Zhu, C., and Wei, C., 2020. An innovative and smart road construction material: thermochromic asphalt binder. In: *New Materials in Civil Engineering*. Elsevier, pp. 691–716. https://doi.org/10.1016/B978-0-12-818961-0.00022-3.

Zhang, W., Shen, S., Wu, S., Chen, X., Xue, J., and Mohammad, L. N., 2019. Effects of In-Place Volumetric Properties on Field Rutting and Cracking Performance of Asphalt Pavement. *Journal of Materials in Civil Engineering*, 31(8). https://doi.org/10.1061/(ASCE)MT.1943-5533.0002767.