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Evaluating the Performance of Bitumen Emulsion Stabilized Bases in Low Volume Sealed Roads: *A Case Study from Kiambu County (E443 Road)*

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Abstract

This paper presents a study on the performance evaluation of Bitumen Emulsion Stabilized Gravel Base on E443 road in Kiambu County. Kenyan manuals and guidelines do not provide criteria for performance evaluation of bitumen emulsion stabilized materials (BESM). This research characterizes the road construction materials and investigates their influence on the BESM base, evaluates both the quality compliance of the as-built constructed BESM base and the performance levels of the BESM base road against road construction standards. This study concludes that there was noncompliance to subgrade and subbase specifications resulting to inadequate BESM base support, and nonconformity of as-built BESM base to mix design specifications affected the base elastic modulus. E443 Road performance was rated poor due to poor drainage, poor road surface and low layers' elastic modulus. Comprehensive studies on construction materials characterization at 10-years design life, BESM mix design on gravel used and performance levels' correlation are recommended.

Keywords: Bitumen emulsion, evaluation, performance, specifications, stabilized

INTRODUCTION

The uptake of bitumen emulsion stabilization technology in Kenya was around the year 2012 to 2017. Egis et al. (2021) gives some of the government of Kenya (GoK) funded projects under Roads 2000 Phase II Batch 1, 2 & 3 low volume seal roads constructed in different regions. About 144 km were constructed to low volume standards at a total cost of KShs. 3.6 billion, using the specifications outlined in Pavement Design Guideline (PDG1) for Low Volume Sealed Roads, 2017. E443 Road was completed about December, 2019 to bitumen emulsion stabilized gravel base standards. The Trials targeted a mix of residual binder content of 2.5 to 3.25% and Indirect Tensile strength (ITS) comprising of ITS dry of 175 to 225 kPa, ITS soaked of 75 to 100 kPa and Tensile Strength Ratio (TSR) greater or equal to 50.

The design pavement structure is as presented in **Figure 1**. The 100 mm BESM base was com-posed of 2% cement stabilized gravel for the lower layer 67 mm resulting from the compaction of 110 mm loose material, and top 33 mm BESM layer resulting from the compaction of 50 mm loose gravel material with 2% cement, 2% lime and 2% emulsion mix proportions.

There are no records on conclusive performance monitoring and evaluation of the above road projects constructed using BESM technology in our country. The construction industry is heavily information centric and requires effective management of the information for the efficient timely delivery of projects, (Melody et al., 2024). Further, Godfrey et al. (2024) highlights the four steps in the strategic management process involving environmental scanning, strategy formulation, strategy implementation and evaluation, a criterion which should be followed in case of adoption of a new construction technology.

THEORY

Massoud et al. (2016) defined soil stabilization as the process of blending and mixing materials with a soil to improve the soil strength and durability.

Unlike lime and cement stabilization, bituminous

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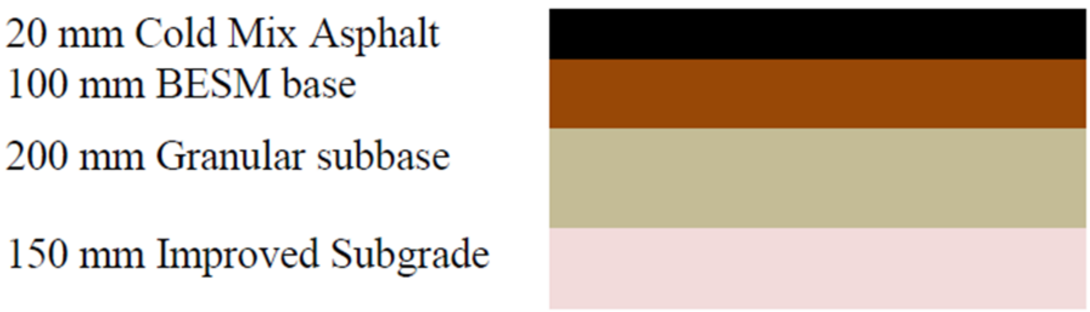

FIGURE 1
E443 Road Pavement Structure
Source: Egis et al. 2021

stabilization is used in both plastic and non-plastic road construction materials. With granular materials that are non-plastic, the bitumen is used to improve cohesive strength, while with plastic materials the bitumen insulates the fine plastic soil particles thus minimizing moisture damage and loss of strength due to moisture. The mechanisms involved are filling of voids in the mix with bitumen and film forming around the soil particles enabling clumping together of particles. This prevents water ingress into the soil mass. Bitumen is usually mixed into the pulverized soil as emulsions, cutbacks, or foams to im-prove penetration and adhesion in the soil, (SABITA, 2020).

Simarpreet et al. (2016) explained emulsions as dispersion of small droplets of one liquid in an-other liquid and adds that bitumen emulsion is a two-phase system consisting of bitumen and water. His laboratory trials on emulsion stabilized soil gave a maximum shear strength at 6% bitumen emulsion content. SABITA (2020) and BSI (1984) classify bitumen emulsions as either anionic or cationic and their general use. The type of emulsifier used determines the type of charge on the bitumen particles, that is, either positive or negative charge. Bitumen particles with negative charge are termed as anionic bitumen emulsion with pH more than 7 while and positively charged particles are the cationic bitumen emulsion with pH less than 7. The usabil-ity of either anionic or cationic bitumen emulsions in road construction has been established by British Standards Institute (BSI). BSI (2006) guides on the use of cationic bitumen emulsions while BSI (2016) gives the specifications for anionic bitumen emulsions for roads and other paved areas.

Salomon (2006) in Transportation Research Circular E-C102 for Asphalt Emulsion Technology indicated that bitumen emulsion sets or breaks the moment it is in contact with either the soil sample, road surface or aggregate as illustrated in **Figure 2**.

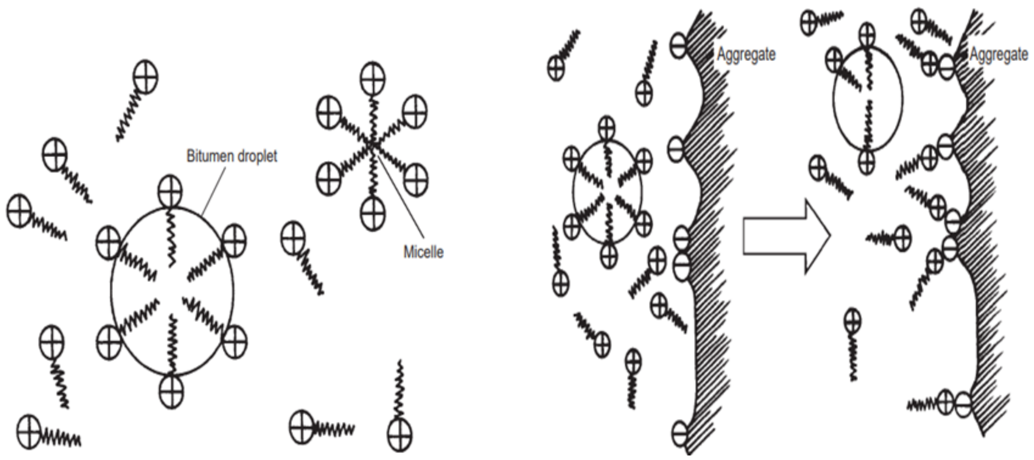

FIGURE 2
Emulsifier Micelles in a Stable Solution and Breaking
Source: Salomon, 2006

Evaporation, absorption of water by the aggregate and chemical reactions between the aggre-gate and the emulsion result to emulsion setting. All the water must be lost before curing takes place. Salomon (2006) illustrated as in **Figure 3** how the emulsified asphalt transforms to a con-tinuous asphalt film in order to act as binding agent in road construction materials.

Soil stabilization using bitumen emulsion is not a common practice in Kenya. Kenyan manuals; Ministry of Transport and Communications., (1987) and Ministry of Transport and Public works., (1986) mainly present material specifications for hot mixed asphalts but not bitumen emulsions stabilized materials. However, Kenya has recently borrowed this technology from the south African practice (SABITA, 2020) and incorporated some of the specifications in its guide-line for design of BESM base roads (PDG1, 2017). The guideline provides a 2- stage mix design procedure consisting of the preliminary tests of aggregate material, followed by mix design for Bitumen Stabilized Material (BSM) 3 for base. Design of BSM 3 base material follows a proce-dure described as Marshall Method for Emulsified Asphalt and Aggregate Cold Mixture Design suitable for low-trafficked roads in which the base layer is constructed using BSM with maxi-mum particle sizes of 25 mm and prepared at ambient temperatures (Asphalt Institute,1997).

The common practice for road pavement construction requires that minimum thickness and ma-terial quality requirements for subgrade and sub-base layers need to be achieved for adequate support of the base layer (Ministry of Transport and Communications., (1987). It states that all underlying layers should have structural strength not less than 10% of the subsequent layers. Consequently, the E443 road pavement structure shown in **Figure 1** should have treated gravel base of 1000 MPa minimum elastic modulus supported by neat gravel base of 200 MPa elastic modulus.

A critical design parameter in the design of BSM 3 base material is the residual binder content, that is, the remaining binding agent after curing is complete. SABITA (2020) provided a range of 2.8% to 4.2% gross emulsion as the emulsion content required for mixing and processing of BESM mixes which results to residual binder of 1.7% to 2.5% after curing. PDG1, 2017 speci-fies the use of A4-60% bitumen emulsion as per BSI (2016), containing 60% water and 40% of bitumen content of emulsion and retaining 2.0 % residual bitumen content after curing. Jessica et al. (2023) had concerns on the air pollution due to carbon dioxide concentrations but this is addressed since no heating is required in the use of bitumen emulsion.

In Kenya, BSM 3 materials are specified for base construction for LVS roads of traffic loading of 100,000 equivalent standard axles to one million equivalent standard axles (PDG1, 2017). **Table 1** gives some of the material properties or target specifications for BSM 3 as base materi-al for low volume road.

COTO (2020) specifies suitable materials of G4 to G6 quality gravel for use as BSM in which the gravel material has to meet the plasticity index criterion of less than 7% before stabilization. Further, additional fines of at least 2% content are needed for improved workability and break-ing time of gravel-emulsion mix. The preferred additional fines for bitumen stabilization, also

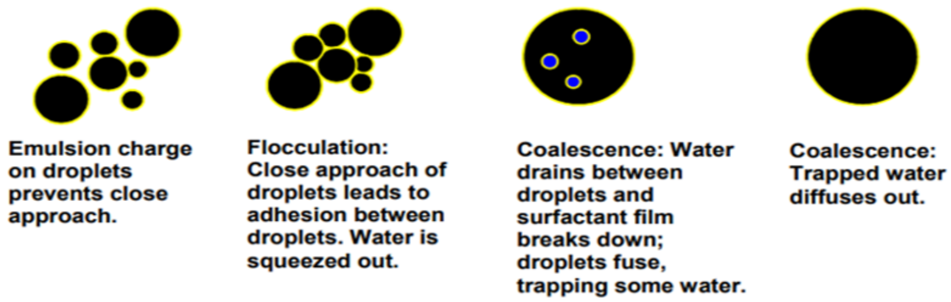

FIGURE 3
Stages in the Breakdown of Emulsions
Source: Salomon, 2006

TABLE 1
Bitumen Emulsion Stabilized Materials, BSM 3

Material Before Treatment			Bitumen Stabilizer and Active Filler	
Material Class		Min G30	Bitumen Binder: Slow setting A3 and A4 anionic and K3 cationic emulsions	
Grading Envelope	Sieve size	% Passing		
	50	100	**Lime for Pre-treatment and Active Filler:**	
	37.5	90 -100	Hydrated Calcium lime (see standard specifications).	
	28	80 -100		
	20	60 -100	**Cement for Active Filler:**	
	10	35 - 90	Portland cement (CEM 1 – 42.5Mpa) complying to KSEAS 18-1 or HRB complying with BS EN 13282	
	5	20 - 75		
	2	12 - 50	Amounts required: Max 1%	
	1	10 - 40		
	0.425	7 - 33		
	0.075	4 - 20	**Recommended Residual Binder Content:**	
CBR after 4-day soak		Min 30%	**Material**	**Residual Bitumen (%)**
Plasticity Index		7 -12%	Reclaimed asphalt pave-ment	1.75 – 2.50
Organic Matter		Max 1%	Graded Crushed Rock	2.25 – 3.00
Grading Modulus		1.2 – 2.7	Gravels of CBR ≥ 30%	2.5 – 3.25
			Gravels/sands of CBR ≥ 20%	2.5 – 4.0
Treated Material:				
The Mix shall comply with the following specifications				
Property	**Specimen curing regime &moisture conditions**			**Specification**
ITS dry (kPa)	100mm diameter Marshall specimen cured for 72 hours at 400C			125 - 225
ITS wet (kPa)	100mm diameter Marshall specimen cured for 72 hours at 400C and soaked for 24 hours			50 - 100
TSR	Tensile strength Ratio: (ITS wet/ITS dry) x100%			Min 50%

Source: PDG1, 2017

termed as active fillers are hydrated lime, cement, and fly ash. Water is another material crucial for mixing of the bitumen stabilization materials.

No records on performance monitoring and evaluation of the road projects constructed using BESM technology in our country. There is need therefore, to evaluate the BESM base roads to understand their performance and inform related investments (Godfrey et al., 2024). This study will characterize the subgrade and pavement layers of E443 Road and investigate their influ-ence on the BESM base, evaluate the compliance of the as-built constructed BESM base mate-rials to design specifications for BSM 3 base material provided in Pavement Design Guideline (PDG1) for Low Volume Sealed Roads, 2017 and evaluate the performance levels of the BESM base road in terms traffic loading class, layer elastic modulus, residual life, road surface and drainage condition against design standards and road construction practice.

RESEARCH METHODS

Field and laboratory investigations done on E443 road included surface condition surveys, traffic surveys, trenching and sampling of road pavement materials for laboratory testing, and deflection measurements using Falling Weight Deflectometer (FWD) equipment.

Surface Road Condition

Surface road condition was carried out through visual inspection on the entire road. Observations were made on the road carriageway and off the carriageway to establish the road surface condition and drainage condition. Defects observed on the carriageway were potholes, cracks, deformations, road edge failure and worn out surfacing. Off the carriageway distresses such as unshaped drains, over vegetated drains, blocked / broken culverts, presence or absence of drains were observed at different sections of the road. Road defects were captured through photographing and field notes. **Figures 4 a&b** presents the typical surface and drainage condition on E443 road.

a) Intact section with lined drains at km 2.3

b) Cracks, pot holes and no drains at km 3.5

FIGURE 4a&b
E443 Road Condition
Source: Nzai, 2025

Trenching and sampling of road construction materials

Trenching and sampling of base, subbase and subgrade materials were carried out in accordance to Ministry of Transport and Communications., (1987), Road Design Manual Part III Materials and Pavement Design for New Roads, Kenya. The surfacing material was extracted by milling off the asphalt concrete layer and sampled for testing as per AASHTO Designation T 168-96: Sampling of Bituminous Paving Mixtures, **Figures 5 a&b**.

A trench of 1m length by 1m width by 1.2 m depth was dug at the road edge at 1km interval to extract the pavement materials. The nature of each pavement layer was established and thicknesses measured. Excavated materials were sampled separately for BESM base, subbase and subgrade in polythene bags. **Figures 6 a&b** shows the sampling of materials and determination of the as-built pavement thicknesses.

Deflection Measurements

The road deflections were measured using the Primax 2500 model Falling Weight Deflectometer (FWD) equipment, **Figures 7 a&b**, that meets requirement of ASTM D4694 - 09, 1996 and ASTM D4695 - 03, 2008. The deflection measurements were conducted in an alternating manner on both lanes at intervals of approximately 100 m on the Outer Wheel Path (OWP) at an offset of about 0.7 m from the edge of the carriageway. At each drop point, raw deflection (rd) readings were taken for the nine (9) consecutive geophone points of 0, 20, 30, 60, 90, 120,150, 180, and 210 cm. This non-destructive testing of the pavement was done to establish the current performance levels in terms of layer elastic modulus, pavement residual life,

a) Milled cold AC surfacing **b)** Surfacing thickness measurement

FIGURE 5a&b
Extraction and Logging of AC Surfacing
Source: Nzai, 2025

a) Sampling of excavated pavement material **b)** Layer thickness measurement

FIGURE 6a&b
Sampling and Logging for BESM Base, base and subgrade
Source: Nzai, 2025

a) Van Integrated FWD Equipment **b)** Deflection Measurement

FIGURE 7a&b
Non Destructive Testing for Deflection measurements
Source: Nzai, 2025

overlay requirements and pavement critical layer.

Laboratory Testing

The field samples were subjected to laboratory testing and analysis. Subgrade, subbase and base materials were subjected to materials classification tests including grading to 0.075mm, Atterberg limits, compaction test using standard Compaction of 2.5 kg rammer for subgrade materials and heavy compaction of 4.5kg rammer for pavement materials, and California Bearing Ratio (CBR) and swell measured after 4-days' soak on samples moulded at 100% Maximum Dry Density (MDD) and Optimum Moisture Content (OMC). Further, BESM base material was subjected to Indirect Tensile Strength (ITS) testing (both dry and soaked ITS), grading modulus (GM) test and binder recovery (residual binder) test and emulsion content test to assess its performance under the current traffic loading and prevailing climatic conditions. ITS test was conducted in accordance to the procedures outlined in AASHTO Designation T 283-89: Resistance of Compacted Bituminous Mixtures to moisture induced Damage. Two sets of the collected BESM base material were thoroughly mixed with water, placed in 100mm diameter moulds and compacted at 75 blows using the Marshall compactor. One set of the moulded specimens was oven cured at 40 degrees for 72 hours, then crushed for ITS dry testing. The other set was soaked in water for 24hrs at 25 degrees Celsius for determination of soaked strength (soaked ITS). **Figures 8 a to f** shows photographic illustration of the laboratory procedures.

RESULTS AND DISCUSSION

Different data analysis methods were used depending on the nature of the data collected. Predictive analysis was used to determine traffic loading from historical data. Descriptive data analysis method was employed where measures of central tendency like mean or average and

a) Weighing of the BESM base material

b) Mixing with water

d) Marshall Compacting at 75 blows

c) Mixed material in 100mm diameter

e) Oven curing of compacted material f) ITS testing using Multi-Speed Tester

FIGURE 8a to f
Laboratory Procedures for Indirect Tensile Strength Test
Source: Nzai, 2025

dispersion measures such as range were used to describe datasets. Also quantitative analysis method was helpful in identifying patterns and quantifying relationships as depicted by either field or laboratory data results.

Traffic loading

The average daily traffic (ADT) and average vehicle equivalence factor (VEF) were obtained from Egis et al. (2021) survey report. For 10-year design period and 5% annual traffic growth, the forecasted traffic loading for E443 road is 74,274 cumulative standard axles, as indicated in **Table 2**.

From the findings, E443 traffic loading even when projected for 20 years is less than 1millon Cumulative Equivalence Standard Axles (CESA). The forecasted traffic aligns with the specifications of bitumen stabilised materials (BSM 3) for base layer (PDG1, 2017). Thus the performance level of E443 in terms of traffic loading is deemed satisfactory and deterioration of the roads cannot be attributed to traffic loading.

Sampled Pavement Layers and Subgrade Materials Testing

The test results presented in **Table 3** show that the surfacing didn't meet both the binder content of 5.5 to 7.0% and grading specifications for Cold Asphalt Concrete (AC) mix 0/14mm for the sizes 4mm to 0.15um sieves. The gradation of the mix is coarse, and disagree with PDG1 (2017) Cold AC mix specifications.

Summarized test results for the bitumen emulsion stabilized material (BESM) base are presented in **Table 4**.

The base layer material was composed of very clayey gravel of intermediate plasticity comprising

TABLE 2
Cumulative ESA on E443 road based on various growth rates

Design Period, Yr.	Annual Traffic Growth Rate, %				
	4.0%	4.5%	5.0%	5.5%	6.0%
5	31,984	32,305	32,629	32,957	33,288
7	46,640	47,354	48,079	48,817	49,567
10	70,897	72,563	74,274	76,030	77,834
15	118,242	122,732	127,424	132,326	137,447
20	175,843	185,252	195,258	205,901	217,223

Source: Nzai, 2025

TABLE 3
Surfacing Material Test Results

Test Location	Layer Thickness, mm	Residual Binder, %	Particle Size Distribution or Grading% Passing										
			20	14	10	6.3	4	2	1	0.425	0.3	0.15	0.075
0+050	20	5.4	100	100	88	64	45	34	21	10	8	5	3
1+000	20	5.3	100	99	92	67	47	36	23	12	9	6	3
2+000	20	3.9	100	99	96	64	46	31	18	9	7	4	3
3+075	30	5.5	100	100	87	67	49	35	23	13	11	7	4
4+000	30	5.3	100	96	83	61	46	32	20	11	9	5	3
5+000	20	5.5	100	97	83	61	45	31	19	10	8	5	3
5+700	20	5.3	100	99	93	65	44	31	18	10	8	6	3
Specs.	20	5.5-7.0	100	90-100	70-95	55-85	46-75	35-60	25-45	14-32	11-27	6-17	3-8

Source: Nzai, 2025

TABLE 4
Base Material Test Results

Chainage	Layer Thickness, mm	Grading Modulus, GM	Plastic index, PI %	CBR %	Dry ITS, kPa	Soaked	TSR, %	Residual BC, %
Km 0+050 LHS	100	2.21	14	35	ITS, kPa	Crumbled	-	0.9
Km 1+000 RHS	100	2.21	12	30	225	Crumbled	-	1.0
Km 2+000 LHS	100	2.18	12	40	273	Crumbled	-	1.1
Km 3+000 RHS	100	2.10	14	35	139	Crumbled	-	1.0
Km 4+000 LHS	100	2.14	14	60	242	Crumbled	-	0.9
Km 5+000 RHS	100	2.04	11	60	265	Crumbled	-	1.0
Km 5+700 LHS	150	2.20	12	35	255	Crumbled	-	0.8
Specifications	100	1.2-2.7	7	30	125- 225	50 - 100	Min 50%	2.5-3.25

Source: Nzai, 2025

gravel of 41 to 56%, sand of 22 to 38% and silt/clay of 20 to 24%, and the layer thickness, grading modulus and CBR specifications agree with the design provisions (PDG1, 2017).

The plasticity index (PI) values of the stabilized gravel varied from 11% to 14% and this opposes with COTO (2020) provisions for quality gravel suitable for use as BESM in which the plasticity index criterion of less than 7% should be met before bitumen emulsion stabilization. It is observed that the residual binder content ranged from 0.8% to 1.1% and contradicts the provisions by SABITA (2020) that specifies a gross emulsion content of 2.8% to 4.2% for mixing and processing of BESM mixes which results to residual binder of 1.7% to 2.5% after curing. In addition, the soaked ITS crumbled during testing and negates the concept of improved strength and durability of soil stabilization by Massoud et al. (2016). The soaked sample crumbled under soaked ITS testing since there was no sufficient binder to provide the required binding of the granular material. The results concur with Simarpreet et al. (2016) findings that there is need to consider high bitumen emulsion content for realization of maximum shear strength of the granular material. **Table 5** presents the test results that indicate noncompliance in subbase layer thickness of 200 mm, Plastic Index (PI) criterion of less than 15% and the plastic modulus (PM) criteria of max. 250.

The subgrade class ranged from S1 to S3 as shown in test results presented in **Table 6**. Therefore, in areas with S1 and S2 subgrades, the foundation strength was inadequate to support the constructed road pavement and contradicts with PDG1 (2017) on the minimum subgrade class specification of S3 subgrade for paved road. In addition, the subgrade optimum moisture values showed a substantial variance indicating ineffective road drains.

Characterization of the road construction materials indicate inadequate road foundation strength below S3 subgrade class and noncompliance with specifications for quality of surfacing, base and subbase materials, and sub-base layer thickness. Also evaluation of the as-built BESM material indicate noncompliance to design mix for BSM 3 base material. The study strongly agrees with

TABLE 5
Subbase Material Test Results

Chainage	Layer Thickness, mm	Plastic Index, PI%	Plastic Modulus, PM	OMC %	CBR % 4 -days soak
Km 0+050	200	13	741	13.5	29
Km 1+000	200	16	880	15.0	25
Km 2+000	200	12	648	15.6	27
Km 3+000	100	18	990	12.1	30
Km 4+000	200	14	784	11.9	29
Km 5+000	100	15	855	12.6	30
Km 5+700	150	13	676	14.3	27
Specifications	200	<15%	<250		Min 25

Source: Nzai, 2025

TABLE 6
Subgrade Material Test Results

Chainage	MDD Kg/m3	OMC %	CBR % 4 days soaked	Subgrade class
Km 0+050	1660	16.0	5	S1
Km 1+000	1523	18.2	6	S2
Km 2+000	1465	21.5	7	S2
Km 3+000	1600	16.2	10	S3
Km 4+000	1415	22.2	6	S2
Km 5+000	1580	17.0	11	S3
Km 5+700	1410	24.0	7	S2

Source: Nzai, 2025

Ministry of Transport and Communications., (1987) that compromise on layer thicknesses and layer material properties result to inadequate support of the subsequent layers and insufficient strength of the pavement layers.

Structural Condition Evaluation using Falling weight Deflectometer (FWD)

In accordance to ASTM D5858 - 96(2015), RoSy design software was used to back calculate pavement and subgrade layers' moduli and thereby the condition of pavement and subgrade material. **Table 7** gives the findings on back calculation analysis of the pavement performance.

The overall pavement structural integrity as indicated by the mean SNP was worst where the subgrade was poorest. The overall critical layer for the roads was subbase. All sections had subbase strength less than ten times the subgrade strength. This scenario opposes the design principle according to Ministry of Transport and Communications., (1987) that requires all underlying layers to have structural strength not less than 10% of the subsequent layers. The subbase has mean elastic modulus of below 200 MPa and will not provide the required support to the BESM base.

The residual life and strengthening thicknesses under the prevailing road condition were also determined for selected design periods and presented in **Table 8**. The road is substantially deteriorated requiring 80mm Dense Bitumen Macadam (DBM) overlay to serve for the next 10 years.

Note: Thicknesses greater than 60mm the overlay material is DBM and for thicknesses less than 60mm, the overlay is Asphalt Concrete.

Drainage and Road surface Condition

Figure 4 shows the road drainage and surface condition. Generally, the intact sections were

TABLE 7

Mean Elastic Modulus, Critical layer and Structural Number

Homogeneous Section	Mean Elastic Modulus (MPa)			Critical layer	Mean Pavement Structural Number (SNP)
	BESM Base	Sub-base	Sub-grade		
Km 0+000 - 0+ 905	281	136	44	Sub-grade	1.94
Km 0+905 - 4+703	488	93	104	Sub-base	2.68
Km 4+703 - 5+302	366	92	70	Sub-base	2.18
Km 5+302 - 5+703	437	95	154	Sub-base	2.76
Overall Mean	393	104	93	Sub-base	2.39

Source: Nzai, 2025

TABLE 8

Residual life and overlay requirement

Homogeneous Section	Mean Residual Life (yrs.)	Mean Overlay Requirement, mm				
		5 - yrs.	7 - yrs.	10 - yrs.	15 - yrs.	20 - yrs.
Km 0 - 0+ 905	5	50	55	65	80	105
Km 0+905 - 4+703	5	65	75	80	90	100
Km 4+703 - 5+302	5	65	70	80	90	100
Km 5+302 - 5+703	6	70	75	85	95	105
Overall Mean	5	65	70	80	90	105

Source: Nzai, 2025

noted to have working drains whereas potholes and interconnected cracks were observed in poorly drained sections. In most sections of the road, the drains were either non-existent or blocked, contrary to the provisions of Ministry of Transport and Public works (1986) that requires drains to be well shaped and free flowing. The optimum moisture contents (OMC) for sub-base and subgrade varied considerably and this could be attributed to the poor drainage condition. Further the cracked and pot holed road surface may have allowed ingress of water into the BESM base. This uncontrolled moisture ingress to the base from the road surface and the drains would definitely affect the BESM base performance. BSM 3 material is quite sensitive to moisture levels and this could explain the reason as per why the soaked ITS sample crumbled under testing.

More elaborate data for both field and laboratory investigations that supported this research can be accessed through the link provided in Appendix A.

CONCLUSION

It was concluded that characterization of the road subgrade and subbase indicated noncompliance to materials and layer thickness specifications, rendering them inadequate to support the BESM base for effective transfer of stresses and strains resulting from traffic loading. Secondly, nonconformity of the as-built BESM gravel base to the BSM 3 material mix design specifications affected the BESM base stiffness and thus its structural integrity. Lastly, a conclusion was made that E443 BESM base road had poor performance due to poor drainage and road surface conditions, and low layer elastic modulus that caused the premature failure of the pavement.

RECOMMENDATIONS

The following recommendations are made from findings and conclusions of this study:

i. Monitoring of E443 road to the end of 10-years design life to obtain comprehensive data on BESM performance;

ii. Conduct a mix design for clayey gravel of intermediate plasticity used on E443 road to inform on optimum emulsion content and residual binder content required to provide sufficient binding of the granular material for its optimum performance; and,

iii. Research on correlation between performance levels namely the road surface condition, drainage condition and layer elastic modulus to the performance of BESM base road.

Recommendations for further Study include:

i. Evaluation of the rest of the roads in the country constructed to BESM base standards to appreciate their performance levels;

ii. Construction of further trial sections using materials and designs in full compliance with design specifications for comprehensive study;

iii. Further research on emulsion stabilized gravel base using different gravel types in the country;

iv. Design and construction of trial sections using Bitumen emulsion stabilized graded crushed stone (GCS) materials; and,

v. Design and construction of trial sections using formed bitumen for both gravel and GCS construction materials.

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Appendix A

The data that support the findings of this research are openly available in this link: https://drive.google.com/drive/folders/14jCVomV9nh2g1Jm-2EpV0i9OWczbb9w-?usp=sharing