Journal Publication of International Research for Engineering and Management (JOIREM)
Volume: 02 Issue: 4 | Mar-2024
ISSN (O) 3107-6696

Premature Rutting in Urban Flexible Pavements

A Comparative Performance Evaluation of Marshall and Superpave Mix Design Frameworks Using a Failed Road Case Study

Engr. Emeka Chukwuka MSc

MSc Project Management, MSc Civil Engineering, United Kingdom

---***---

Abstract - Premature rutting in flexible pavements remains a persistent challenge in urban infrastructure, particularly under increasing axle loads and elevated service temperatures. This study presents a performance-based investigation of a failed dual carriageway that developed rut depths exceeding 15 mm within three years of construction. The original asphalt mixture was designed using the Marshall method. A forensic reassessment was undertaken through renewed Marshall volumetric analysis and a theoretical Superpave-based performance evaluation.

Laboratory reassessment identified an optimum binder content of approximately 5.6% under Marshall criteria, whereas field records indicated a constructed binder content closer to 6.0%. Although Marshall optimisation could have reduced deformation risk, the absence of climate-adjusted binder grading and mechanistic performance validation contributed to premature rutting. The findings suggest that empirical volumetric design remains adequate for moderate traffic conditions but is insufficient for high-temperature, high-traffic urban environments without supplementary performance-based evaluation.

Keywords: Premature rutting; Flexible pavements; Marshall mix design; Superpave; Performance Grade (PG) binder; Urban road infrastructure; Asphalt volumetrics; Permanent deformation; Pavement performance evaluation; Life-cycle cost analysis

1. Introduction

Urban flexible pavements are increasingly exposed to early-life structural distress, with rutting representing one of the most prevalent failure modes. Rutting is defined as permanent deformation within wheel paths resulting from cumulative shear strain and densification under repeated loading.

The causes of rutting are multifactorial and typically include excessive binder content, inadequate aggregate interlock, insufficient high-temperature binder stiffness, poor modelling of field compaction, and traffic loading exceeding original design assumptions.

The case examined in this study involves a dual carriageway resurfaced using a Marshall-designed asphalt mix. Within three years, rut depths progressed from approximately 5 mm to more than 15 mm, accompanied by bleeding and flushing during high-temperature periods. This paper evaluates whether limitations inherent in Marshall mix design contributed to failure, whether a Superpave-based framework could have mitigated the risk, and whether empirical methods remain viable under contemporary urban loading conditions.

2. Literature Review

2.1 Marshall Mix Design Philosophy

The Marshall method, developed during World War II for rapid airfield construction, is fundamentally empirical. It evaluates stability at 60°C, flow at peak load, and volumetric parameters such as VMA, VFB, and air voids. The method relies on static loading and volumetric balance rather than mechanistic performance modelling.

Its principal advantages include simplicity, relatively low equipment requirements, and widespread global adoption. However, limitations arise from its reliance on static loading, absence of climate-based binder grading, and limited ability to predict rutting under repeated traffic loading.

2.2 Superpave Framework

Superpave, developed under the Strategic Highway Research Program (SHRP), introduced a performance-oriented methodology. It incorporates Performance Grade (PG) binder classification, gyratory compaction to simulate field densification, rheological testing using the Dynamic Shear Rheometer, and evaluation of the rutting parameter $G^*/\sin\delta$.

Unlike Marshall, Superpave integrates traffic level, climatic temperature, and mechanistic material response. The framework is predictive rather than empirical, aiming to simulate in-service pavement behaviour prior to construction.

Journal Publication of International Research for Engineering and Management (JOIREM)
Volume: 02 Issue: 4 | Mar-2024
ISSN (O) 3107-6696

3. Case Study Description

The investigated pavement structure consisted of a Marshall-designed asphalt wearing course placed over a base course and granular sub-base. The road was designed for medium traffic classification; however, post-construction observations revealed significantly higher heavy axle loading than anticipated.

Distress manifested as longitudinal rutting, binder migration leading to surface bleeding, and progressive loss of surface texture. Core samples confirmed binder-rich zones and low in-place air voids, indicating over-lubrication of the aggregate skeleton.

Core Samples

4. Research Methodology

The study followed three analytical stages.

First, a Marshall re-evaluation was undertaken using trial binder contents ranging from 4.5% to 6.0%. Stability, flow, and volumetric properties were re-analysed to determine revised optimum binder content. Second, volumetric performance assessment was conducted through bulk density calculations using:

Gbcm = Wa / (Wa − Ww)

Air void trends and density peaks were analysed graphically to determine balanced volumetric behaviour.

Third, a theoretical Superpave evaluation was performed using assumed climatic data reflecting high pavement surface temperatures of approximately 60°C and moderate winter lows. A binder grade of PG 64-22 or PG 70-22 was considered appropriate. Rutting susceptibility was assessed qualitatively using the G*/sinδ framework.

5. Results

5.1 Marshall Re-Analysis

Maximum stability and peak density occurred at approximately 5.5% binder content. Four percent air voids were achieved near 5.8%, resulting in a Marshall average optimum binder content of approximately 5.6%.

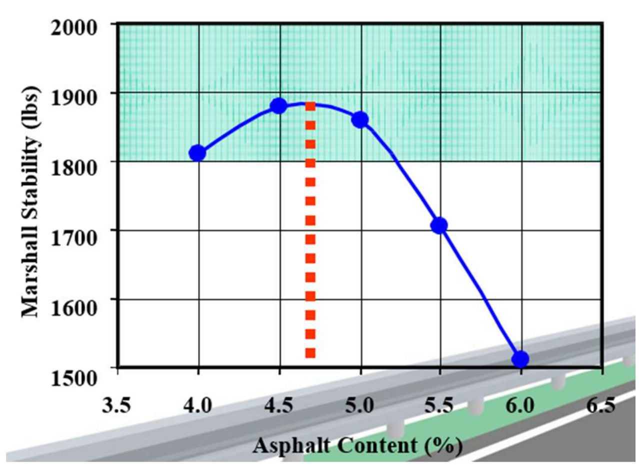
Field records, however, indicated construction binder content closer to 6.0%. Although a 0.4% increase appears marginal, this deviation significantly affects rut resistance by altering internal friction and aggregate interlock.

5.2 Rutting Mechanism

At 6.0% binder content, increased lubrication between aggregate particles reduced internal friction and shear strength under repeated loading. While Marshall stability remained acceptable under static conditions, the absence of repeated load simulation meant susceptibility to permanent deformation was not captured during design.

5.3 Superpave Comparative Evaluation

Under a Superpave framework, binder selection would have been climate-adjusted using PG classification. Gyratory compaction would have simulated field densification, and the rutting parameter G*/sinδ would have been evaluated. Such an approach likely would have resulted in lower effective binder content, selection of a stiffer binder grade, and improved rut resistance.



6. Discussion

Marshall design is fundamentally based on volumetric balance, whereas Superpave is grounded in performance prediction. In this case, failure did not arise from miscalculation within the Marshall framework but from its inability to adequately model

Journal Publication of International Research for Engineering and Management (JOIREM)
Volume: 02 Issue: 4 | Mar-2024
ISSN (O) 3107-6696

traffic densification, climatic softening, and repeated shear loading.

For moderate traffic conditions, Marshall remains efficient and economical. However, for heavily trafficked urban corridors exposed to elevated temperatures, empirical design alone may not provide sufficient protection against permanent deformation.

7. Life-Cycle Cost Implications

Premature rutting necessitates early resurfacing, disrupts traffic flow, and increases whole-life maintenance costs. Although Superpave implementation entails higher initial testing and equipment costs, lifecycle savings may justify its adoption in high-demand environments. Mix design selection should therefore be guided by a cost–risk trade-off framework.

8. Contribution to Knowledge

This study demonstrates the real-world consequences of marginal binder overdesign, highlights the tension between empirical and mechanistic frameworks, and reframes asphalt mix design as a risk management decision rather than a routine laboratory exercise. It also provides a practical decision framework for method selection under varying traffic and climatic conditions.

9. Limitations

This research did not include full rheological laboratory testing, and rutting assessment remained theoretical rather than experimentally validated. The single case study limits generalisability. Future research should incorporate dynamic modulus testing, repeated load permanent deformation testing, and full experimental Superpave validation.

10. Conclusion

The investigated roadway illustrates that small deviations in binder optimisation can produce significant long-term structural consequences. Marshall analysis identified an improved optimum binder content of approximately 5.6%, which could have mitigated rut severity. However, Superpave more effectively addresses climatic and traffic variability and provides improved rutting prediction capability.

Empirical design methods remain appropriate for moderate traffic conditions but should evolve toward performance-informed frameworks in high-load urban environments.

REFERENCES

1. Asphalt Institute: Mix Design Methods for Asphalt Concrete, MS-2. Asphalt Institute (1993)
2. American Association of State Highway and Transportation Officials (AASHTO): Standard Method of Test for Marshall Stability and Flow of Asphalt Mixtures (T245). AASHTO (1993)
3. ASTM International: Standard Test Method for Resistance to Plastic Flow of Bituminous Mixtures Using Marshall Apparatus (D1559). ASTM (1993)
4. Roberts, F.L., Kandhal, P.S., Brown, E.R., Lee, D.Y., Kennedy, T.W.: Hot Mix Asphalt Materials, Mixture Design and Construction. National Asphalt Pavement Association Research and Education Foundation (1991)
5. Strategic Highway Research Program (SHRP): Superpave Mix Design Manual for Asphalt Pavements. SHRP-A-407 (1994)
6. Asphalt Institute: Performance Graded Asphalt Binder Specification and Testing. Asphalt Institute (2003)
7. Huang, Y.H.: Pavement Analysis and Design, 2nd edn. Pearson Prentice Hall (2004)
8. AASHTO: Standard Specification for Performance-Graded Asphalt Binder (M320). AASHTO (2017)