TECH SNAPSHOT

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Implementing High RAP Asphalt Mixtures: A Staged Approach

This document provides information to facilitate better understanding of how to effectively use asphalt mixtures with varying levels of reclaimed asphalt pavement (RAP). It highlights key practices employed by several State Departments of Transportation (DOTs) to achieve engineering, economic and environmental benefits when using high RAP mixtures. Additionally, it presents a staged approach based on the identified key practices and strategies for reliably increasing RAP content.

Introduction

Reclaimed asphalt pavement (RAP) has been used in pavement rehabilitation and reconstruction for decades. Positive engineering, economic, and environmental benefits have been documented by the Federal Highway Administration (FHWA), the National Asphalt Pavement Association (NAPA), State DOTs, and others.[1–4] The Nebraska DOT (NDOT) has reported annual savings of $60 million from using RAP in their about 2-million ton annual program.[5,6] National and state studies show that asphalt mixtures with low to high RAP contents can perform as well as those mixtures without RAP when properly designed, produced, and constructed. This can be achieved through key practices employed by select State DOTs, including a staged approach to reliably increase RAP content. Strategies for high RAP asphalt mixtures consider several parameters related to asphalt binder quantity and quality, mixture mechanical tests, and quality assurance (QA).

Advancement and Challenges in RAP Usage

The asphalt industry is the most diligent recycler in the U.S. with more than 99 percent of RAP being put back to use, of which 87 percent is used in asphalt mixtures.[2] However, the average RAP content in asphalt mixtures has only increased from about 15 percent to 22 percent over the last 15 years. During this time, the number of State DOTs updating specifications to allow higher RAP usage has steadily increased by employing various strategies. As a result, several states now allow between 20 and 30 percent RAP, with some allowing up to 50 percent.

Rutting of asphalt pavements was a key performance concern during the development of the Superpave[1] mix design method. A national study linked increased rutting to the transition from bias ply to radial tires on commercial trucks.[7]

[1]Superpave system was developed under the 5-year, $150 million Strategic Highway Research Program (SHRP) authorized by the Surface Transportation and Uniform Relocation Act of 1987, with $50 million dedicated to Superpave.

The Superpave mix design[2,3] method integrated asphalt binder, aggregate, and mixture properties into a single system and introduced compaction levels based on design traffic. These changes led in general to more rut-resistant asphalt mixtures. In the mid 1990's, during the Superpave implementation, the national focus on rutting prompted mix designers to minimize asphalt binder content while still meeting volumetric requirements.

In the early 2000's, renewed interest in the use of RAP in asphalt mixtures prompted research and the development of guidelines.[8,9] Mix designers assumed 100 percent of the RAP binder was effective and fully blended with the virgin binder. National Cooperative Research Program (NCHRP) studies supported this assumption, providing guidelines for selecting virgin asphalt binder grades based on RAP levels. Consequently, this forced the selection of softer virgin binder grades as RAP content increased. While this approach resulted in more economical mixtures with improved rutting resistance, it inadvertently decreased the effective binder content, which compromised cracking resistance and long-term durability.

In the late 2000's, crude oil prices surged by over 300 percent, leading to a rapid and substantial escalation in asphalt binder prices. This rise increased the focus on the use of RAP in asphalt mixtures since it contains asphalt binder that could replace virgin binder.[10] At the time, the prevailing assumption of 100 percent RAP binder availability (RBA) and complete blending of RAP with virgin binders was still being applied. Unfortunately, this contributed to poor asphalt mixture performance. Over time, it became evident that actual RBA values are less than 100 percent. Additionally, the blended RAP and virgin binders were found to be brittle, likely leading to asphalt mixtures with reduced durability and increased susceptibility to cracking and other issues.

- In 2023, an estimated 96.1 million tons of RAP was used in asphalt mixtures, conserving 4.8 million tons (26.4 million barrels) of asphalt binder and replacing more than 91 million tons of virgin aggregates.[2]
- The combined savings of asphalt binder and aggregate from using RAP in asphalt mixtures is estimated at more than $4.5 billion, along with the conservation of more than 67 million cubic yards of landfill space.[2]

State DOTs Success

Some State DOTs have had challenges specifying, designing, and controlling the quality of asphalt mixtures containing RAP, while others have had positive experiences. Six State DOTs with successful performance using 35 to 50 percent RAP shared their practices.[11] The following common key practices were identified:

- ***Project selection criteria.*** Although high RAP content was allowed, it was not always permitted in all asphalt mixtures. Allowance for RAP is based on mixture type, traffic level, mixture location within the pavement structure, binder type, and/or geographic location.
- ***Quality Assurance.*** QA comprises planned and systematic actions necessary to provide confidence that a product or facility will perform satisfactorily in service. This includes mix design, contractor's quality control (QC), and agency acceptance. Several key QA practices commonly observed include:
  - Specifying RAP by percent dry weight (mass) of the mixture or by reclaimed asphalt pavement binder ratio (RBR).
  - Implementing a separate pay item for asphalt binder to incentivize the use of appropriate binder content and prevent it from being treated merely as a cost to minimize.

[2]AASHTO M 323 Standard Specification for Superpave Volumetric Mix Design. American Association of State Highway and Transportation Officials, Washington, D.C., 2024. Use of this AASHTO specification is not a federal requirement.

[3]AASHTO R 35 Standard Practice for Superpave Volumetric Design for Asphalt Mixtures. American Association of State Highway and Transportation Officials, Washington, D.C., 2024. Use of this AASHTO practice is not a federal requirement.

  - Ensuring RAP stockpile uniformity through QC measures by using either fractionation requirements or standard contractor practices to optimize RAP consistency and content.
  - Applying effective mixture acceptance requirements such as the percent within limits (PWL) and pay factor incentives/disincentives.

- ***Binder quality.*** RAP binder tends to be aged and stiffer than the virgin binder. To address this, softer virgin binders are specified by bumping the binders' low and high temperature grades down. Additionally, some strategies use warm mix asphalt (WMA) additives or recycling agents (RA) to improve the compatibility and performance of the blended asphalt binder.

- ***Binder quantity.*** Not all aged RAP binder is available to blend with the virgin binder. Methods to increase the amount of virgin binder in asphalt mixtures include:
  - Reducing the gyration compaction level and/or lowering design air voids level.
  - Increasing minimum voids in mineral aggregate (VMA) requirements in design and/or acceptance.
  - Using RAP aggregate bulk specific gravity (Gsb) instead of effective specific gravity (Gse) for VMA calculation.
  - Employing the Corrected Optimum Asphalt Content (COAC) technique to adjust the optimum asphalt content up to account for less than 100 percent binder availability in RAP.[12] This technique ensures adequate effective binder in the mixture by supplementing with virgin binder.

- ***Asphalt mixture.*** Mechanical tests are sometimes employed to evaluate the effectiveness of RAs and the anticipated performance of high RAP content mixtures. Specifications for some specialty asphalt mixtures (e.g., stone matrix asphalt, interlayer, thinlay) limit the dose or use of RAP.

Table 1 summarizes the successful State DOT requirements for RAP use. It is important to note that not every State DOT uses every requirement listed in the table, and some use a combination of strategies. The last three columns of the table indicate which State DOT requirements are applicable to the three staged approached described below. Specific DOT examples can be found in Hand and Aschenbrener.[11]

A Staged Approach

A staged approach to reliably increase RAP content in asphalt mixtures involves assessing RAP binder quality and compatibility with virgin binder. The goal is to ensure that mixture's rutting and cracking performance is not compromised as RAP content increases. The staged approach needs to consider the following:

I. ***RAP usage thresholds.*** Determine the maximum RAP content that can be used before a grade bump is necessary, both with and without accounting for RBA or COAC.

II. ***Integration of RBA/COAC with grade bumping.*** If grade bumping is used, assess how much RAP can be incorporated while integrating RBA or COAC before considering the addition of a recycling agent (RA).

III. ***Beyond grade bumping considerations.*** Explore alternative approaches to binder adjustment, beyond simply grade bumping with or without RBA or COAC. This may involve using a RA in conjunction with a mixture cracking test or applying a Balanced Mix Design (BMD)[4] concept to evaluate the overall performance of the mixture.

While methods for estimating RBA or COAC exist, they are often too complex for practical application in high-production mix design and QC laboratories. A more effective approach is to compare the mechanical test properties of virgin and RAP mixtures across a range of RAP content levels and aging conditions. These comparisons should include testing with binder grade adjustments (both dropping and bumping) and the addition of RA, as outlined in the staged approach (Table 1).

[4]AASHTO PP 105 Standard Practice for Balanced Design of Asphalt Mixtures. American Association of State Highway and Transportation Officials, Washington, D.C., 2024. Use of this AASHTO specification is not a federal requirement.

Table 1. State DOT RAP Use Requirements Related to Staged Approaches.

DOT RAP Use Requirements	State DOT[a]						Staged Approach[b]		
	FL	NE	NJ	SC	WA	WI	I	II	III
Project Selection Criteria									
Lift Location Criteria	✓[c]	✓	✓	✓	–[d]	✓	⊗	⊗	⊗
Traffic Criteria	✓	–	–	✓	✓	✓	○	○	○
Quality Assurance									
Percent RAP criteria	✓	✓	✓	–	✓[e]	–	⊗	⊗	○
Reclaimed binder ratio (RBR) criteria	✓[f]	–	–	✓	✓	✓	⊗	⊗	○
Pay for binder separately	–	✓	–	✓	–	–	○	○	○
RAP fractionation	✓[g]	–	–	✓[g]	–	✓[g]	○	⊗	⊗
RAP quality control (QC) plan	✓	–	✓	✓	–	–	○	●	●
Dedicated RAP stockpiles	✓[h]	–	–	✓[i]	–	–	○	○	⊗
Agency acceptance with percent within limits (PWL)	✓	–	–	–	✓	✓	⊗	⊗	⊗
Binder Quality									
Binder type criteria	✓	✓	–	✓	✓	–	●	●	●
Softer binder by grade bump	✓	✓	✓[j]	–	–	–	–	⊗	○
Softer binder by blending chart	–	–	✓[j]	–	✓	✓	–	⊗	○
Softer binder by Performance Grade (PG) of actual blend	–	–	✓[j]	–	✓	✓	–	⊗	○
Warm mix asphalt (WMA) additive	✓	✓	✓[j]	✓	✓	✓	○	○	⊗
Recycling Agent (RA) additive	–	✓	✓[j]	-	✓	–	–	–	⊗
Binder Quantity									
Additional asphalt at design (e.g., gyrations, VMA, regressed air voids, COAC)	✓	✓	✓	✓	–	✓	○	●	○
Acceptance VMA equal to or greater than design value	–	–	✓	✓	–	✓	○	–	○
Gsb for RAP aggregates	–	–	–	–	✓	✓	⊗	–	●
Asphalt Mixture									
Mixture Performance Test(s)	–	–	✓	✓[k]	✓	–	○	○	●
Specialty Mixture Criteria	✓	–	✓	✓	✓	✓	○	○	●

Notes: [a] FL = Florida; NE = Nebraska; NJ = New Jersey; SC = South Carolina; WA = Washington; WI = Wisconsin.

[a] ● Necessary for the Stage; ⊗ Necessary or optional for the Stage; ○ Optional for the Stage.

[c] Applicable.

[d] Not applicable.

[e] RAP percent specified but could be overruled by RBR.

[f] Contractor option for RAP over 20 percent, but RBR may not exceed 0.20.

[g] Contractor option, use may be greater for fractionated RAP (FRAP) than RAP.

[h] Contractor option.

[i] If not fractionated.

[j] Contractor option to meet performance test criteria.

[k] Asphalt Pavement Analyzer (APA) rutting test only.

It is important to note that proper aging of asphalt mixtures for mechanical testing should be conducted, especially for cracking tests, to assess the mixture's long-term durability. This comprehensive testing approach will provide a better understanding of the effects of varying RAP content and binder adjustments on overall mixture performance.

Summary & Path Forward

While the U.S. asphalt industry is diligent in recycling efforts, the broader use of RAP in mixtures remains limited by performance concerns and specification constraints. Early assumptions regarding RAP binder availability and blending with virgin binder have led to unintended durability issues. However, recent research and successful state practices demonstrate that high RAP content mixtures can perform well when properly designed and produced. A staged approach based on realistic RAP binder availability assumptions, binder grade adjustments, and mechanical testing offers a clear path to reliably increase RAP use. Moving forward, continued collaboration, specification updates, and implementation of tools like separate binder pay item and BMD will be key for expanding RAP utilization without compromising pavement longevity.

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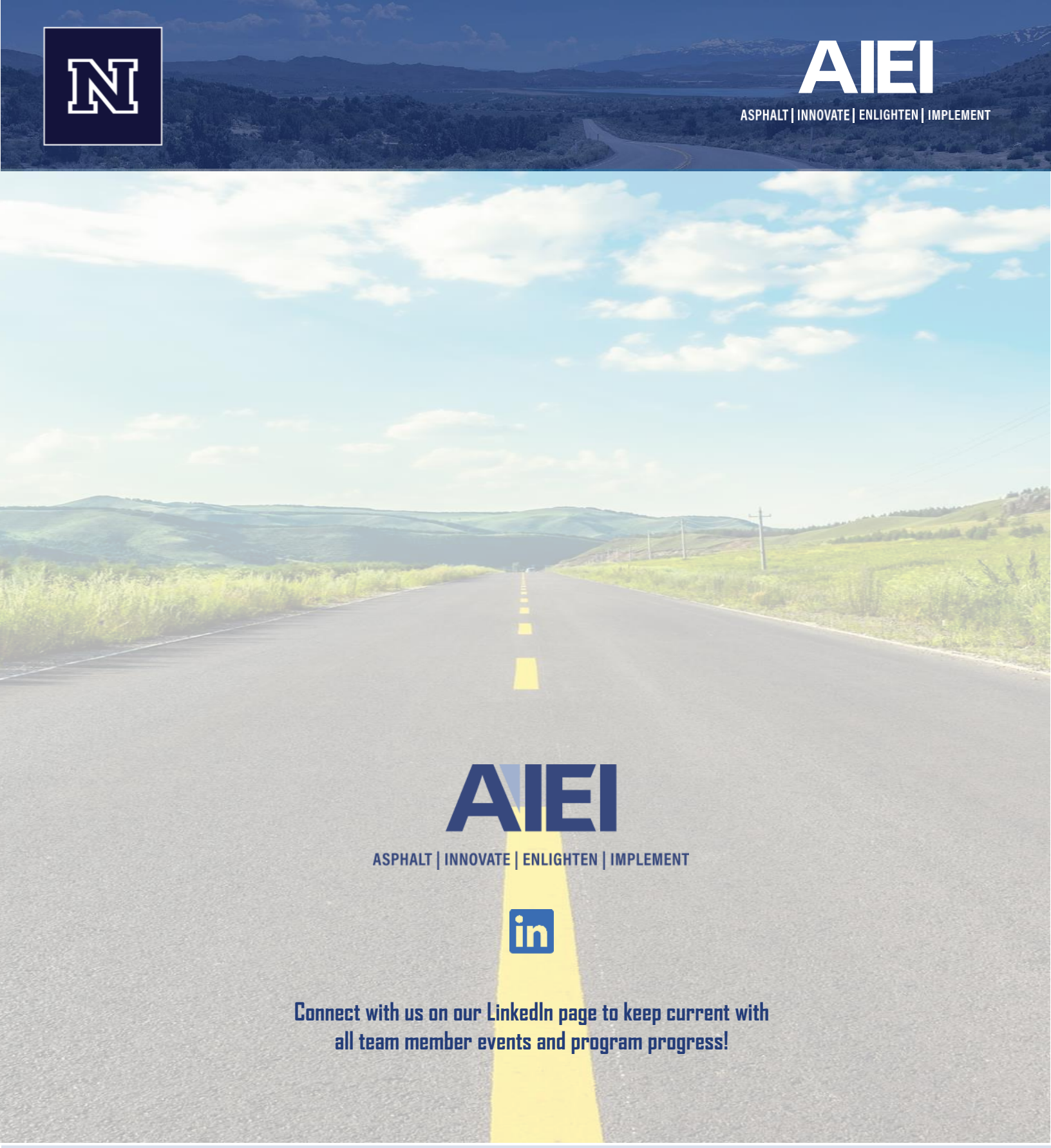

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