**Improving HMA, Bullfrog – May 6, 2016**
**Meeting Minutes**

| Present | Name | Company | Present | Name | Company | Present | Name | Company |
|---|---|---|---|---|---|---|---|---|
| x | Bell, Dave | Lakeside | x | DeVol, Joe | WSDOT | x | Pederson, Chris | CTL |
| | Brickey, Bill | Granite | x | Dyer, Bob | WSDOT | x | Russell, Mark | WSDOT |
| | Byrd, Andrew | WSDOT | x | Erickson, Dave | WSDOT | x | Schofield, Dave | CWA |
| x | Cantrell, Logan | Granite | x | Gent, David | WAPA | | Shearer, Tim | ICON |
| x | Chapman, Josh | Granite | | Gribner, Mike | WSDOT | | Shippy, Ron | Inland Asphalt |
| | Clayton, E. J. | Granite | x | Hill, Kentin | Granite | | Siegel, Roy | FHWA |
| | Costello, Mike | Pyramid | X | Johnson, Torrey | Tucci & Sons | | Uhlmeyer, Jeff | WSDOT |
| x | Dempsey, Bill | Lakeside | x | Mathis, Jerome | Inland Asphalt | | Williams, Kurt | WSDOT |
| | | | x | McDuffee, Steve | Watson | | | |

## OLD BUSINESS

**12-01 Streamline WMA certification paperwork**

- October 26, 2012 - TJ Morgan requested WSDOT consider. Bob Dyer agreed to follow up.
- May 8, 2015, 2015 – No action.
- October 9, 2015 – Very little or no warm mix used in last few years. A one-page submittal is all that is currently required and all present appeared to be aware of the written criteria WSDOT created several years ago. Bob Dyer will create a form that captures the info WSDOT needs so it can be referenced in the specs.
- May 6, 2016 – Bob Dyer reported that a new form, DOT-350-076 (attach #12-01) is in the Specs now, Item Closed.

**13-07 High RAP/RAS**

- May 9, 2013 – Industry expressed concerns of not enough room for stockpiles
- May 9, 2014 - RAP subcommittee reported that we are currently waiting for the industry members of the subcommittee to develop a draft spec for review and discussion. Primary points of discussion have been (a) timing and extent of additional testing currently required when the amount of RAP exceeds 20% or any amount of RAS, and (b) determining the type and timing of testing of RAP and RAS in stockpile needed to make prudent decisions on how variations affect the service life of the end product.
- October 9, 2014 – Update – This subcommittee is looking at increasing the threshold for not requiring the RAP oil to be blended into the mix design for approval, from its present 20%, to 30%. In order to make sure this is a decision that will not jeopardize length of service life, the committee is looking for Washington State test data to support the increase.
- May 8, 2015 – Dave Gent provided a copy (See Attachment #1) of the letter sent to WSDOT summarizing his understanding of the agreement in principle, between WSDOT and WAPA folks on the RAP Subcommittee, which creates a new RAP category for binder bumping in lieu of blending, for RAP between 20% and 25%. It was agreed that the goal is to finalize this into a spec to be published in the January 2016 Amendments.
- October 9, 2015 – Update from Kurt Williams – We need to reconvene the subcommittee to work out a few details. Need more discussion on the proposed changes to RAP between 20% and 25%. Dave Gent and Kurt will get the RAP subcommittee going on this.
- May 6, 2016 –Dave Gent handed out a draft a spec (attach #13-07a) which provides for a new “Medium RAP/No RAS” mix designation, and provided a handout of a report by Shane Buchanan titled “Washington State RAP Blending ‘What If’ Scenarios” (attach #13-07b). Further discussion of that spec will be done by the RAP/RAS subcommittee.

**14-13 Fine Aggregate Angularity (FAA) aka Uncompacted Void Content**

- October 9, 2014 – Bob Dyer reported he is evaluating the enforcement of this spec on projects back to the 2010 spec book, but not done yet. Several contractors expressed that this test is weighted too high in the statistical evaluation and suggested that WSDOT reduce its relative importance in the future, that the test is not very reproducible, and that there is no mechanism to challenge the WSDSOT test results. WSDOT responded that it is part of superpave.
- May 8, 2015 – Continued discussion, led by Dave Gent. Agreed that WAPA would develop a proposal for revisions to the spec.
- October 9, 2015 – Update from Dave Gent, who handed out a draft proposal (attached) to change the spec. The key changes Dave is seeking are a) reduce the size of the financial disincentive, which industry believes is disproportionally high, b) an ability for the contractor to challenge the WSDOT test results, and c) a sliding scale for the severity of the out-of-specness. Other test methods were discussed. Finally agreed that Granite will do some computer experimentation on the

effect on the CPF of changing the statistical parameters so that the mixture CPF includes the PF for SE, coarse fracture, and FAA, and report results by next meeting.

- May 6, 2016 – Dave Gent provided a draft spec (attach #14-13a) and excerpts from NCHRP Report 539 "Aggregate Properties and the Performance of Superpave-Designed Hot Mix Asphalt" (attach #14-13b). The gist of the draft spec is to: a) move the FAA, Fracture, and SE related incentive/disincentive out of Spec 1-06 and into Spec 5-04, combine it with the statistical evaluation of the hot mixture properties, and "soften" the effect of the incentive/disincentive, and b) provide for challenges to the FAA test results possibly looking to real-time Hamburg testing as a referee in challenges. The ball is now in WSDOT court to consider the draft spec, with a target of having any resulting revisions to the Standard Specs in the January 2017 Amendments.

**14-16 Concerns with SAM**

- October 9, 2014 - Dave Gent noted that SAM set-up is often cumbersome. He also suggested adding a "time stamp" for when documentation is entered (not shown currently) & add an "auto-notification" for producers / pavers (whether GC or sub.) to allow for timely review in case of challenges. Kurt Williams agreed to follow up.
- May 8, 2015 – Update from Kurt Williams. The lab has added a portal to SAM for all to use. A new field will be added to the database to record when each test data is input into SAM. "Auto-notification" to the contractor when data in SAM has been updated is in the process of being created, but has not happened yet. (MATS already has the ability to "auto-send".)
- October 9, 2015 – Update from Kurt Williams – MATS program has the ability to auto-email results to the contractor if the Paving contractor so requests the PE, but SAM does not. Bob Dyer agreed to modify Construction Manual to require PE to email MATS results when so requested by the contractor.
- May 6, 2016 – Dave Gent noted that there are still (this spring) delays by some WSDOT offices in getting the WSDOT acceptance test data into SAM. Bob Dyer provided a copy of excerpts from the new 5-04 Standard Spec (attach #14-16) showing the aspirational timeliness goals for WSDOT to provide WSDOT's test results to the contractor. Bill Dempsey volunteered to draft a revision to the WSDOT Construction Manual for WSDOT inspectors to directly and immediately provide test results to the Contractor.

**15-00 Trackless Tack**

- May 8, 2015 – Andrew Byrd reported that SC Region has a project this summer (ad date in a few weeks) that will require the use of paving grade asphalt for tack; they have proposed to allow trackless tack as an option. Jeff Uhlmeyer asked if WAPA had any concerns over two types of tack in one project, such that trackless tack could be used as an experimental feature?
- October 9, 2015 – Update from Dave Gent. We need a draft spec and a project to allow it experimentally. WSDOT agreed that Bob Dyer will revise the spec to allow STE-1 for tack because it was deleted from the 2014 Std Spec Book because we didn't think anyone was using it anymore, not because there is anything wrong with it.
- May 6, 2016 –Bob Dyer confessed that he forgot to get STE-1 back in the Standard Specs list of products acceptable for tack, and committed to get it into the August Amendments. Regarding trackless tack, WSDOT expressed a need for data that demonstrates an acceptable bond. Process now is for the Contractor to propose a no-cost change order. It was suggested that Louisiana has a good spec worth looking at. Possibly put approved products on the QPL. Ball in WAPA court to propose criteria by which WSDOT can evaluate, approve, and put these products on the QPL.

**15-01 Increasing RAP % in <u>aggregates</u>**

- May 8, 2015 – (i.e., using RAP in stuff other than HMA, i.e. discuss updating (9-03.21(1) E table) – Dave Gent brought up this item, and said the RAP subcommittee will take up this issue. Need to look at 9-03.21 to consider increasing RAP percent. A concern was noted that using RAP in untreated aggregates creates difficulties with measuring compaction with a nuke gage, which will need to be overcome.
- October 9, 2015 – Update from Dave Gent – there is still some industry desire to pursue this issue, but the obstacle has been how to deal with nuke gauge density measurement difficulties created by the asphalt. Chris Pederson will put together data on how this has been handled by other states and get it to Dave Gent.
- May 6, 2016 – Dave Gent provided handouts of NCHRP Synthesis 445 (attach 15-01a) and the abstract from a U of W research paper (attach 15-01b). WAPA is requesting to change the table in Standard Spec table in 9-03.21 from the current spec of 20% max RAP in aggregates to 25% max. WSDOT concerns are density testing and possible long-term effects of stripping. Joe DeVol agreed to review the literature and consider the proposed increase. Goal is that a final decision be reflected in the Jan 2017 amendments.

**15-02 HMA Spec Improvements Phase 1**

- May 8, 2015 – Rewriting 5-04 to make it easier to understand – Bob Dyer
    - A Jeff Carpenter initiative

  - Strategies incorporated in draft (draft will be emailed out a few days before the May 8 meeting)
    - Move Warm Mix to its own section 5-04A
    - Move Commercial to its own Section 5-04B
    - Move non-statistical acceptance into its own section 5-04C
    - Reorganize 5-04 so that subheadings are logical subcategories of the headings
    - Take a shot at active voice imperative mood
  - Desired Milestones
    - May 6, 2015 Distribute Draft to Regions and WAPA
    - May 8, 2015 Early Feedback at Improving HMA meeting
    - May 22, 2015 Deadline for Feedback
    - June 12, 2015 Submit to FHWA for Approval
    - June 30, 2015 Send to printer to solicit bids
    - August 2015 – DO NOT include the new spec in the August 2015 Amendments
    - January 1, 2016 New Spec printed in 2016 Spec Book
    - January 1, 2016 Clean Up problems in the 2016 Amendments to Std Spec
- October 9, 2015 – The latest draft is attached. General discussion and a few questions. Bob Dyer needs comments (in writing) back by the end of October. The new spec did not meet the deadline for the 2016 spec book, so new target is to be an Amendment to the 2016 Std Spec, effective on Jan 1, 2016. Bob explained that a change that will be made to the attached draft is, for High RAP/Any RAS mixes, the blended grade of binder from RAP, RAS, virgin oil, etc, must meet the AASHTO M-320 requirements for the required PG grade, and no PG grade other than the required PG grade. Also attached is the new test procedure for running mixture tests when the sample is taken by coring.
- May 6, 2016 – Bob Dyer provided a handout that provides an unofficial one-page summary of the changes (attach #15-02) Item closed.

**15-04 Specs on dilution of tack**

- October 9, 2015 – Bob Dyer- Is a table of tack rates needed? Dave Gent - Also really like the standard of thin film of residual rather than a target to be measured. A good tack coat is easy to recognize, but a hassle to measure. Continue educational efforts across the board. – This item was tabled without discussion owing to the full agenda.
- May 6, 2016 – Consensus was that a table is not the way to go. Item closed.

**15-05 Use of CSS-1h for tack**

- October 9, 2015 – Dave E explained that he would like to see "h" used because it is less prone to wheel-tracking. Dave Gent agreed to check with the oil suppliers to make sure it is readily available. Joe DeVol will bring up the same issue at the oil suppliers meeting in January 2016. Further discussion tabled until availability from the suppliers is verified.
- May 6, 2016 - Dave Erickson reported that CSS-1h is in the current spec (attach #15-05). Anecdotal problems were reported of separation during storage. Consensus was that it's an acceptable product. Item closed.

**15-07 The 3 months limit prior to submitting mix design approval to 6 months.**

- October 9, 2015 – Is this enough time? Kurt Williams agreed to consider increasing to something more than 3 months but needs time to do so.
- May 6, 2016 - Bob Dyer reported that the spec has been changed to say 6 months (attach #15-07). Item closed.

**15-09 Optional allowance for submitting RAP with the zero to 20% RAP QPL mix designs**

- October 9, 2015 - Dave Gent - WAPA members would like this option to be allowed, if not in the specs., then by agreement with the Materials Lab. WSDOT agreed to Implement. Kurt and Joe agreed they would get it done.
- May 6, 2016 –Joe DeVol agreed to draft a spec implementing this and get it to Greg Morehouse for processing.

**15-10 Is WSDOT still evaluating/considering electro-magnetic asphalt density gauges.**

- October 9, 2015 Dave Gent - Many WAPA members would like to move to new style gauges and away from nuke gauges, but would like WSDOT's current view. Steve McDuffee reported his experience has been that they are sensitive to hot HMA and provide more accurate results when pavement is cooled. WAPA reported that small local agencies don't have nuke gages. Current WSDOT investment in nukes will make this a difficult change, particularly because even if there was established and accepted accuracy of the electric gages, they don't yet work on soils so WSDOT would have to use both technologies.

- May 6, 2016 – WSDOT wants to get out of the nuke gage business and is considering other technology, but given the status of alternatives to the nuke don't expect to make any changes for at least two years. Dave Erickson and Bob Dyer agreed to provide for alternate technology as a pilot spec sometime soon.

**15-11 Legislative Update – Laws Passed Spring 2015 Legislative Session**

- October 9, 2015 - Dave Erickson reported a) a there will be a new requirement on every contract for the prime contractor to report the amount of recycled concrete used on the project, or provide cost data if it didn't meet the new 25% recycled concrete requirement for those materials in the Table in Section 9-03.21. b) Prime will be soon be required, on every contract, to create a report every month on payments made and withheld to subs. c) Contractor will be required, on every Connecting Washington contract, to report dollars spent on peds, bicycles, and transit.
- May 6, 2016 – Nothing to report. Item closed.

## NEW BUSINESS

**16-01 Core Lock device and AASHTO T-166 Density on high absorption (> 2%) water cores for nuke gauge correlations**

- May 6, 2016 - Joe DeVol reported that approx. 17% of samples exceeded 2% absorption in a study, mostly in mixes with low compaction. Each Region now has a core-lock, to keep us in compliance with test method T-166. Its use is required only when questionable results occur. Item closed.

**16-02 Better define the dates to be used for the Current Reference Price for Asphalt Cost Price Adjustments spec**

- May 6, 2016 – Dave Gent reported that WAPA believes the dates for making the calculations are ill-defined in the current spec. He will send a draft spec to Dave Erickson pointing out where he thinks the ambiguities are.

**16-03 Challenge regime for FAA whether it is moved to HMA or not.**

- May 6, 2016 – No discussion here, as was already addressed in item 14-13. Close item 16-03 and continue tracking under 14-13.

**16-04 Clarify QPL design costs / process/ rebates**

- May 6, 2016 – Discussion focused on WAPA's concerns regarding getting Commercial HMA mix designs on the QPL. a) WSDOT review cost seems excessive. Joe DeVol agreed to review and report back. b) WSDOT's requirement for advance payment seems antiquated and has caused delays. Dave Jones is working on developing a solution that provides more ways to pay than a check in advance. C) it was pointed out that the old system of dealing with approval of commercial mix designs was at no cost to the contractor, and frustration was expressed that the change to the QPL was what brought about the need for contractor payment. WSDOT reported that when pay is received timely, turn-around time has been 1 or 2 days.

**16-05 Location of HMA automatic sampler**

- May 6, 2016 – Dave Gent questioned why is location required to be between silo and truck? He expressed that WAPA believes other locations would be suitable, and this is the case at some plants and no issue has been raised. Why not allow auto sampler location to be anywhere after final mixing? Bob Dyer pointed out that the currently required location, although recently put in the Standard Spec, has been in the sampling procedure for years. (current spec attach #16-05) WSDOT explained that locations other than between the silo and truck introduce uncertainty of whether the sample truly represents the presumed sublot. Leave the spec as-is. If WAPA elects to pursue further, Dave Gent will provide a draft of a proposed spec change. Close this item for now.

**16-06 GSP for binder content on jobs with state-provided aggregate source**

- May 6, 2016 – Dave Gent - Will the old GSP be preserved, modified, or deleted? The QPL mix design process would be post-bid and an expensive process for one job ($8,500) that is of little use to the Contractor after the job is complete. Without the GSP there is no way for bidders to accurately estimate the binder contact before the bid and before crushing the aggregate. The GSP has been temporarily rendered on the red shirt list, but Bob Dyer will activate it again. Item closed.

**16-07 MTD/V approval process**

- May 6, 2016 – Dave Gent - Is there a way a process can be developed wherein WSDOT specifically approves make and models or the like? The group concurred that WSDOT should not be in the business of preapproving any equipment. Item closed.

**16-08 The MSCR test and proposed changes to binder grades**

- May 6, 2016 – Joe DeVol provided a handout (attach #16-08) and explained that MSCR grading is the direction the national standard is headed, and will likely go into effect for WSDOT contracts about 2018.

**16-09 Closure of ramps on consecutive interchanges is ~~not allowed~~ no longer specifically addressed in new Section 5-04.3(17)**.

- May 6, 2016 – This spec was deleted from 5-04.3(17) with the re-write of 5-04. Dave Erickson provided a handout showing the old spec (attach 16-09a) and a proposed spec (attach 16-09b) inserting this requirement into 1-10.1(2) . This will be addressed in an upcoming amendment to the Std Specs. No objections. Item closed.

**16-10 Elimination of HMA mix designs from GSP for suspension of time charges for critical materials procurement processes**

- May 6, 2016 – Bob Dyer provided a handout of the old GSP (attach #16-10) and noted that this GSP has been deleted owing to the current requirement for all mix designs to be on the QPL. Consensus was that this GSP should be reinstated. Bob Dyer will follow up and make it so.

**16-11 How to allow for project generated RAP to be used in the project**

- May 6, 2016 – Dave Gent noted that the requirement for sequestering RAP stockpiles prior to mix design submittal prohibits the use of RAP generated on a project from being used in the HMA on that project and urged that this be overcome somehow. WSDOT reinforced its concern that the RAP properties in this case are unknown. Perhaps provision for real-time RAP testing? More next time.

**16-12 Nonstatistical evaluation, mixture and compaction**

- May 6, 2016 – Bob Dyer pointed out that the provision for nonstatistical evaluation of mixture complicates the specs, and asked why we couldn't eliminate it? Consensus was that it would be OK to eliminate. Only concern is that Local Agencies like nonstatistical, but they write their own specs anyway. Bob Dyer will draft the revisions and send to Dave Gent for comment.

**16-13 Discussion on a process to modify the "sequestered" RAP and RAS stockpiles rules/ wording**

May 6, 2016 – No discussion on this item. Similar to item 16-11.

**16-14 WAQTC – Implementation Plan**

May 6, 2016 – Joe DeVol provided a handout (attach 16-14) regarding approximate dates for implementing the requirement for testers to be WAQTC certified. This will initially apply to all WSDOT folks and eventually to Contractor QA personnel. WSDOT has set a target that by 2020 industry will be trained and doing QA, with WSDOT doing QV.

**16-15 MSCR asphalt binder specification implementation plans**

May 6, 2016 – This is a duplicate of item 16-08. Close this item.

**16-16 Plans to change in-place density test procedure**

May 6, 2016 - Joe DeVol noted that WSDOT has been buying 3450 gauges recently, and will soon be going to backscatter only for HMA density testing. Apparently WSDOT and Georgia are the only states still using any direct transmission on HMA. No objections from industry. Item closed.

**16-17 QPL Mix Design – Chance for feedback from WAPA**

May 6, 2016 - Discussed under item 16-04. Item closed.

**16-18 Proposal to Vary Number of Hamburg Passes Based on Number of Gyrations**

May 6, 2016 - Dave Gent handed out a proposal (attach 16-18). Joe DeVol will look at it and provide feedback at the next meeting.

**16-19 Proposal to allow a Test Section Verification Process**

May 6, 2016 - Dave Gent proposed that the Test Section process be modified toward the direction of the way it was in the 2006 specs (attach 16-19). More discussion next time.

NEXT MEETING – Friday, November 4, 2016

Washington State Department of Transportation

# Warm Mix Asphalt Submittal

Attach #12-01

Contract Number ______________________

HMA mix design ID number(s) to be used for production of WMA ______________________

## WMA Technology Description

Name of WMA additive manufacturer or producer ______________________

Description of project or process ______________________

☐ Water/Foaming ☐ Organic Additive ☐ Chemical Additive ☐ Other ______________________

Manufacturer or producer's recommended WMA additive dosage rate ______________________

Contractor's target WMA additive dosage rate ______________________

| Manufacturer or Producer's Recommendation | Temperature (°F) |
|---|---|
| Maximum mixing temperature for HMA when using WMA additive | |
| Maximum discharge temperature for HMA when using WMA additive | |
| Maximum asphalt binder temperature when using WMA additive | |

*The Contractor's maximum mixing temperature cannot exceed the maximum mixing temperature recommended by the manufacturer of the WMA additive nor the optimum mixing temperature +25°F per Section 5-04.3(8).

Submitted by ______________________

Paving Contractor

Paving Contractor Representative - Signature

Approved by

Contracting Agency Representative - Signature

Reminder: The truck ticket shall identify the material produced as "WMA" when using WMA products or processes.

Required Attachments: WMA Additive Manufacturer's catalog cuts
WMA Additive Manufacturer's Recommendations for production

attach 13-07a

### 5-04.2(1)A Mix Designs Containing RAP and/or RAS

Mix designs are classified by the RAP and/or RAS content as shown in Table 2.

**Table 2**
**Mix Design Classification Based on RAP/RAS Content**

| RAP/RAS Classification | RAP/RAS Content (note 1) |
|---|---|
| No RAP/No RAS | RAP% = 0 and RAS% = 0 |
| Low RAP/No RAS | 0% < RAP% ≤ 20% and RAS% = 0% |
| Medium RAP/No RAS | 20% < RAP% ≤ 25% and RAS% = 0% |
| High RAP/Any RAS | 25% < RAP% ≤ Maximum Allowable RAP (note 2) or 0% < RAS ≤ Maximum Allowable RAS (note 2) |

Note 1: Percentages in this table are by total weight of HMA
Note 2: See Table 4 to determine the limits on the maximum amount RAP and/or RAS.

### 5-04.2(1) A2 Medium RAP/No RAS - Mix Design Submittals

For Medium RAP/No RAS mixes, comply with the requirements of Section 5-04.2(1) and the following:

1. The Contractor may develop the mix design with or without the inclusion of RAP.
2. Submit the RAP with the mix design if the design was developed with that option. Do not submit samples of RAP with these mix designs if the design was developed using only virgin aggregates.
3. In order to enable WSDOT to create a database of RAP binder variation, perform the following and report the results to the WSDOT Headquarters Materials Lab (*note: need to develop this system*). While constructing and adding to the RAP stockpile, sample the RAP once for every 5,000 tons placed into the RAP stockpile. Perform asphalt recovery on each sample in accordance with AASHTO R 59 or ASTM D 1856. Test the asphalt recovered from each sample in accordance with ASHTO M 320 and determine the PG grade.
4. Bump the asphalt binder grade (from the grade indicated in the bid item name) as shown in Table 3 or as otherwise required by the contract.

**Table 3**
**Medium RAP/No RAS Binder Bumping Requirements**

| Change the PG Binder Grade as Indicated Below | | |
|---|---|---|
| Project Location | Average 7-Day Max Pavement Design Temperature, °C (note 1) | Minimum Pavement Design Temperature, °C (note 1) |
| Western WA & Eastern WA | All binders - Reduce by 6° C | Non-ER Binders<br>Retain or reduce by 6° C (note 2)<br>ER Binders<br>Reduce by Reduce by 6° C |

Note 1: As specified in AASHTO M 320
Note 2: Low temp. sensitivity is not as critical at 25% RAP for non-polymer extended binders. Example, for PG 64-22, use either PG 58-22 or PG 58-28 when bumping the binder for RAP percentage from 20% to 25%. For ER binders, always binder bump at both the Avg. 7-day max pavement design temp. and the minimum pavement design temp.
Note: 5-04 Table 8 for Medium RAP/ No RAS – Update to include as equal to Low RAP/ No RAS criteria (no test section required – Contractor's Option.

Attach #13-07b

# Washington State
# RAP Blending "What If" Scenarios

Shane Buchanan
Oldcastle Materials
November 2015

13-07b

## Analysis Steps

1. Obtain RAP continuous (critical) grading data from Eastern and Western Washington (Table 1)

Table 1 RAP Continuous (Critical) Grades From 2014

**EASTERN WASHINGTON**

| Location | PG | Year | Average |
|---|---|---|---|
| Baker Flats - Wenatchee | 89-19 | 2012 | 91-16 |
| | 87-17 | 2013 | |
| | 97-13 | 2014 | |
| Dallesport | 91-18 | 2012 | 95-14 |
| | 96-15 | 2013 | |
| | 98-8 | 2014 | |
| ECP - Ellensburg | 91-20 | 2013 | 89-21 |
| | 86-22 | 2014 | |
| Hanford | 95-11 | 2012 | 92-15 |
| | 88-20 | 2013 | |
| Hermiston | 99-10 | 2013 | 97-13 |
| | 94-15 | 2013 | |
| Moses Lake | 97-16 | 2013 | 97-16 |
| Selah | 92-17 | 2011 | 92-16 |
| | 89-18 | 2013 | |
| | 96-11 | 2013 | |
| | 88-24 | 2013 | |

DG Note: Highest high = 99, lowest low = -8. Critical low temps. for "worse case" blending in the tables below = 100 & -8.

**WESTERN WASHINGTON**

| Location | PG | Year | Avg. |
|---|---|---|---|
| Belfair | 88-17 | 2013 | 88-16 |
| | 87-16 | 2014 | |
| Martin - Olympia | 89-17 | 2010 | 88-16 |
| | 86-17 | 2013 | |
| | 86-17 | 2013 | |
| | 88-13 | 2014 | |
| | 90-15 | 2014 | |
| Singer - Bellingham | 87-17 | 2010 | 90-16 |
| | 90-16 | 2010 | |
| | 89-18 | 2013 | |
| | 92-13 | 2014 | |
| Smith Island - Everett | 87-29 | 2010 | 87-21 |
| | 89-21 | 2010 | |
| | 84-21 | 2012 | |
| | 90-20 | 2013 | |
| | 83-21 | 2013 | |
| | 91-14 | 2014 | |
| Silverdale | 87-17 | 2012 | 87-17 |
| Vancouver | 91-17 | 2010 | 91-15 |
| | 88-18 | 2013 | |
| | 92-11 | 2014 | |
| | 93-15 | 2014 | |
| Issaquah | [illegible]17 | 2014 | |
| Bellevue | 91-14 | 2014 | |
| Vancouver | 91-18 | 2014 | |

[illegible] Note: Highest high = 93, lowest low = -11. Critical temps. used for "worse case" blending in the tables below = 95 & -10.

2. Perform blending analysis results using the Oldcastle binder blending tool to determine the resultant composite PG binder grade for blends of RAP and virgin binders.
3. Conduct the "what if" blending scenarios as outlined in Table 2 and described below.
4. For Eastern Washington
    a. Evaluate the PG low temperature (LT) grade using the range of obtained RAP critical LT grades along with PG -28 and -34 virgin binders. For the analyses, the critical temperatures for the -28 and -34 binders were assumed to be -31 and -37, respectively. Analyses conducted to maintain a -28 LT PG grade
        i. **Scenarios 1 and 2 (Tables 3 and 4)**
    b. Evaluate the PG high temperature (HT) grade using the range of obtained RAP critical HT grades along with PG 58 and 64 virgin binders. For the analyses, the critical temperatures for the 58 and 64 binders were assumed to be 61 and 67, respectively. Analyses conducted to maintain a 64 HT PG grade (max temp of 70).
        i. **Scenarios 3 and 4 (Tables 5 and 6)**
5. For Western Washington
    a. Evaluate the PG low temperature (LT) grade using the range of obtained RAP critical LT grades along with PG -22 and -28 virgin binders. For the analyses, the critical

13-07 b

temperatures for the -22 and -28 binders were assumed to be -25 and -31, respectively. Analyses conducted to maintain a -22 LT PG grade

i. **Scenarios 5 and 6 (Tables 7 and 8)**

b. Evaluate the PG high temperature (HT) grade using the range of obtained RAP critical HT grades along with PG 58 and 64 virgin binders. For the analyses, the critical temperatures for the 58 and 64 binders were assumed to be 61 and 67, respectively. Analyses conducted to maintain a 64 HT PG grade (max temp of 70).

i. **Scenarios 7 and 8 (Tables 9 and 10)**

6. Provide summary what if table results which show the resultant PG temperature as a function of the RAP % addition and the RAP critical grading. For all tables, results in green indicate PG temperatures which meet the desired PG temperature.

Table 2 Blending Scenario Summary

| Scenario | Location | Temp Analysis | Virgin PG Grade | Virgin PG Critical Temp, C | Desired PG Resultant Grade |
|---|---|---|---|---|---|
| 1 | Eastern Washington | Low | -28 | -31 | -28 |
| 2 | Eastern Washington | Low | -34 | -37 | -28 |
| 3 | Eastern Washington | High | 64 | 67 | 64 |
| 4 | Eastern Washington | High | 58 | 61 | 64 |
| 5 | Western Washington | Low | -22 | -25 | -22 |
| 6 | Western Washington | Low | -28 | -31 | -22 |
| 7 | Western Washington | High | 64 | 67 | 64 |
| 8 | Western Washington | High | 58 | 61 | 64 |

13-076

Table 3 Eastern Washington Scenario 1

| Achieved PG Low Temperature What If Table w/ Virgin LT Critical Temp | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | PG Temp | RAP Stockpile Critical Low Temperature, C | | | | | | | | | | | | | | | |
| | -28.4 | -8.0 | -9.0 | -10.0 | -11.0 | -12.0 | -13.0 | -14.0 | -15.0 | -16.0 | -17.0 | -18.0 | -19.0 | -20.0 | -21.0 | -22.0 | -23.0 |
| RAP, % | 0 | #DIV/0! | ###### | ###### | ###### | ###### | ###### | ###### | ###### | ###### | ###### | ###### | ###### | ###### | ###### | ###### | ###### |
| | 1 | -30.8 | -30.8 | -30.8 | -30.8 | -30.8 | -30.8 | -30.9 | -30.9 | -30.9 | -30.9 | -30.9 | -30.9 | -30.9 | -30.9 | -30.9 | -30.9 |
| | 2 | -30.6 | -30.6 | -30.6 | -30.7 | -30.7 | -30.7 | -30.7 | -30.7 | -30.7 | -30.8 | -30.8 | -30.8 | -30.8 | -30.8 | -30.8 | -30.9 |
| | 3 | -30.4 | -30.4 | -30.5 | -30.5 | -30.5 | -30.5 | -30.6 | -30.6 | -30.6 | -30.6 | -30.7 | -30.7 | -30.7 | -30.7 | -30.8 | -30.8 |
| | 4 | -30.2 | -30.2 | -30.3 | -30.3 | -30.3 | -30.4 | -30.4 | -30.4 | -30.5 | -30.5 | -30.5 | -30.6 | -30.6 | -30.7 | -30.7 | -30.7 |
| | 5 | -30.0 | -30.0 | -30.1 | -30.1 | -30.2 | -30.2 | -30.3 | -30.3 | -30.3 | -30.4 | -30.4 | -30.5 | -30.5 | -30.6 | -30.6 | -30.7 |
| | 6 | -29.8 | -29.9 | -29.9 | -30.0 | -30.0 | -30.1 | -30.1 | -30.2 | -30.2 | -30.3 | -30.3 | -30.4 | -30.4 | -30.5 | -30.5 | -30.6 |
| | 7 | -29.6 | -29.7 | -29.7 | -29.8 | -29.8 | -29.9 | -30.0 | -30.0 | -30.1 | -30.1 | -30.2 | -30.3 | -30.3 | -30.4 | -30.5 | -30.5 |
| | 8 | -29.4 | -29.5 | -29.5 | -29.6 | -29.7 | -29.8 | -29.8 | -29.9 | -30.0 | -30.0 | -30.1 | -30.2 | -30.2 | -30.3 | -30.4 | -30.4 |
| | 9 | -29.2 | -29.3 | -29.4 | -29.4 | -29.5 | -29.6 | -29.7 | -29.8 | -29.8 | -29.9 | -30.0 | -30.1 | -30.1 | -30.2 | -30.3 | -30.4 |
| | 10 | -29.0 | -29.1 | -29.2 | -29.3 | -29.4 | -29.4 | -29.5 | -29.6 | -29.7 | -29.8 | -29.9 | -30.0 | -30.0 | -30.1 | -30.2 | -30.3 |
| | 11 | -28.8 | -28.9 | -29.0 | -29.1 | -29.2 | -29.3 | -29.4 | -29.5 | -29.6 | -29.7 | -29.8 | -29.9 | -29.9 | -30.0 | -30.1 | -30.2 |
| | 12 | -28.6 | -28.7 | -28.8 | -28.9 | -29.0 | -29.1 | -29.2 | -29.3 | -29.4 | -29.5 | -29.6 | -29.8 | -29.9 | -30.0 | -30.1 | -30.2 |
| | 13 | -28.4 | -28.5 | -28.6 | -28.7 | -28.9 | -29.0 | -29.1 | -29.2 | -29.3 | -29.4 | -29.5 | -29.6 | -29.8 | -29.9 | -30.0 | -30.1 |
| | 14 | -28.2 | -28.3 | -28.4 | -28.6 | -28.7 | -28.8 | -28.9 | -29.1 | -29.2 | -29.3 | -29.4 | -29.5 | -29.7 | -29.8 | -29.9 | -30.0 |
| | 15 | -28.0 | -28.1 | -28.3 | -28.4 | -28.5 | -28.7 | -28.8 | -28.9 | -29.0 | -29.2 | -29.3 | -29.4 | -29.6 | -29.7 | -29.8 | -30.0 |
| | 16 | -27.8 | -27.9 | -28.1 | -28.2 | -28.4 | -28.5 | -28.6 | -28.8 | -28.9 | -29.1 | -29.2 | -29.3 | -29.5 | -29.6 | -29.8 | -29.9 |
| | 17 | -27.6 | -27.8 | -27.9 | -28.0 | -28.2 | -28.3 | -28.5 | -28.6 | -28.8 | -28.9 | -29.1 | -29.2 | -29.4 | -29.5 | -29.7 | -29.8 |
| | 18 | -27.4 | -27.6 | -27.7 | -27.9 | -28.0 | -28.2 | -28.3 | -28.5 | -28.7 | -28.8 | -29.0 | -29.1 | -29.3 | -29.4 | -29.6 | -29.8 |
| | 19 | -27.2 | -27.4 | -27.5 | -27.7 | -27.9 | -28.0 | -28.2 | -28.4 | -28.5 | -28.7 | -28.9 | -29.0 | -29.2 | -29.4 | -29.5 | -29.7 |
| | 20 | -27.0 | -27.2 | -27.4 | -27.5 | -27.7 | -27.9 | -28.0 | -28.2 | -28.4 | -28.6 | -28.7 | -28.9 | -29.1 | -29.3 | -29.4 | -29.6 |
| | 21 | -26.8 | -27.0 | -27.2 | -27.4 | -27.5 | -27.7 | -27.9 | -28.1 | -28.3 | -28.4 | -28.6 | -28.8 | -29.0 | -29.2 | -29.4 | -29.5 |
| | 22 | -26.6 | -26.8 | -27.0 | -27.2 | -27.4 | -27.6 | -27.8 | -27.9 | -28.1 | -28.3 | -28.5 | -28.7 | -28.9 | -29.1 | -29.3 | -29.5 |
| | 23 | -26.4 | -26.6 | -26.8 | -27.0 | -27.2 | -27.4 | -27.6 | -27.8 | -28.0 | -28.2 | -28.4 | -28.6 | -28.8 | -29.0 | -29.2 | -29.4 |
| | 24 | -26.2 | -26.4 | -26.6 | -26.8 | -27.0 | -27.3 | -27.5 | -27.7 | -27.9 | -28.1 | -28.3 | -28.5 | -28.7 | -28.9 | -29.1 | -29.3 |
| | 25 | -26.0 | -26.2 | -26.4 | -26.7 | -26.9 | -27.1 | -27.3 | -27.5 | -27.7 | -28.0 | -28.2 | -28.4 | -28.6 | -28.8 | -29.0 | -29.3 |
| | 26 | -25.8 | -26.0 | -26.3 | -26.5 | -26.7 | -26.9 | -27.2 | -27.4 | -27.6 | -27.8 | -28.1 | -28.3 | -28.5 | -28.7 | -29.0 | -29.2 |
| | 27 | -25.6 | -25.8 | -26.1 | -26.3 | -26.5 | -26.8 | -27.0 | -27.3 | -27.5 | -27.7 | -28.0 | -28.2 | -28.4 | -28.7 | -28.9 | -29.1 |
| | 28 | -25.4 | -25.7 | -25.9 | -26.1 | -26.4 | -26.6 | -26.9 | -27.1 | -27.4 | -27.6 | -27.8 | -28.1 | -28.3 | -28.6 | -28.8 | -29.1 |
| | 29 | -25.2 | -25.5 | -25.7 | -26.0 | -26.2 | -26.5 | -26.7 | -27.0 | -27.2 | -27.5 | -27.7 | -28.0 | -28.2 | -28.5 | -28.7 | -29.0 |
| | 30 | -25.0 | -25.3 | -25.5 | -25.8 | -26.1 | -26.3 | -26.6 | -26.8 | -27.1 | -27.4 | -27.6 | -27.9 | -28.1 | -28.4 | -28.7 | -28.9 |
| | 31 | -24.8 | -25.1 | -25.3 | -25.6 | -25.9 | -26.2 | -26.4 | -26.7 | -27.0 | -27.2 | -27.5 | -27.8 | -28.0 | -28.3 | -28.6 | -28.8 |
| | 32 | -24.6 | -24.9 | -25.2 | -25.4 | -25.7 | -26.0 | -26.3 | -26.6 | -26.8 | -27.1 | -27.4 | -27.7 | -27.9 | -28.2 | -28.5 | -28.8 |
| | 33 | -24.4 | -24.7 | -25.0 | -25.3 | -25.6 | -25.8 | -26.1 | -26.4 | -26.7 | -27.0 | -27.3 | -27.6 | -27.8 | -28.1 | -28.4 | -28.7 |
| | 34 | -24.2 | -24.5 | -24.8 | -25.1 | -25.4 | -25.7 | -26.0 | -26.3 | -26.6 | -26.9 | -27.2 | -27.5 | -27.8 | -28.0 | -28.3 | -28.6 |
| | 35 | -24.0 | -24.3 | -24.6 | -24.9 | -25.2 | -25.5 | -25.8 | -26.1 | -26.4 | -26.7 | -27.1 | -27.4 | -27.7 | -28.0 | -28.3 | -28.6 |
| | 36 | -23.8 | -24.1 | -24.4 | -24.8 | -25.1 | -25.4 | -25.7 | -26.0 | -26.3 | -26.6 | -26.9 | -27.3 | -27.6 | -27.9 | -28.2 | -28.5 |
| | 37 | -23.6 | -23.9 | -24.3 | -24.6 | -24.9 | -25.2 | -25.5 | -25.9 | -26.2 | -26.5 | -26.8 | -27.1 | -27.5 | -27.8 | -28.1 | -28.4 |
| | 38 | -23.4 | -23.7 | -24.1 | -24.4 | -24.7 | -25.1 | -25.4 | -25.7 | -26.1 | -26.4 | -26.7 | -27.0 | -27.4 | -27.7 | -28.0 | -28.4 |
| | 39 | -23.2 | -23.6 | -23.9 | -24.2 | -24.6 | -24.9 | -25.2 | -25.6 | -25.9 | -26.3 | -26.6 | -26.9 | -27.3 | -27.6 | -28.0 | -28.3 |
| | 40 | -23.0 | -23.4 | -23.7 | -24.1 | -24.4 | -24.8 | -25.1 | -25.4 | -25.8 | -26.1 | -26.5 | -26.8 | -27.2 | -27.5 | -27.9 | -28.2 |
| | 41 | -22.8 | -23.2 | -23.5 | -23.9 | -24.2 | -24.6 | -25.0 | -25.3 | -25.7 | -26.0 | -26.4 | -26.7 | -27.1 | -27.4 | -27.8 | -28.2 |
| | 42 | -22.6 | -23.0 | -23.3 | -23.7 | -24.1 | -24.4 | -24.8 | -25.2 | -25.5 | -25.9 | -26.3 | -26.6 | -27.0 | -27.4 | -27.7 | -28.1 |
| | 43 | -22.4 | -22.8 | -23.2 | -23.5 | -23.9 | -24.3 | -24.7 | -25.0 | -25.4 | -25.8 | -26.1 | -26.5 | -26.9 | -27.3 | -27.6 | -28.0 |
| | 44 | -22.2 | -22.6 | -23.0 | -23.4 | -23.7 | -24.1 | -24.5 | -24.9 | -25.3 | -25.7 | -26.0 | -26.4 | -26.8 | -27.2 | -27.6 | -27.9 |
| | 45 | -22.0 | -22.4 | -22.8 | -23.2 | -23.6 | -24.0 | -24.4 | -24.8 | -25.1 | -25.5 | -25.9 | -26.3 | -26.7 | -27.1 | -27.5 | -27.9 |
| | 46 | -21.8 | -22.2 | -22.6 | -23.0 | -23.4 | -23.8 | -24.2 | -24.6 | -25.0 | -25.4 | -25.8 | -26.2 | -26.6 | -27.0 | -27.4 | -27.8 |
| | 47 | -21.6 | -22.0 | -22.4 | -22.8 | -23.2 | -23.7 | -24.1 | -24.5 | -24.9 | -25.3 | -25.7 | -26.1 | -26.5 | -26.9 | -27.3 | -27.7 |
| | 48 | -21.4 | -21.8 | -22.3 | -22.7 | -23.1 | -23.5 | -23.9 | -24.3 | -24.8 | -25.2 | -25.6 | -26.0 | -26.4 | -26.8 | -27.3 | -27.7 |
| | 49 | -21.2 | -21.6 | -22.1 | -22.5 | -22.9 | -23.3 | -23.8 | -24.2 | -24.6 | -25.0 | -25.5 | -25.9 | -26.3 | -26.7 | -27.2 | -27.6 |
| | 50 | -21.0 | -21.5 | -21.9 | -22.3 | -22.8 | -23.2 | -23.6 | -24.1 | -24.5 | -24.9 | -25.4 | -25.8 | -26.2 | -26.7 | -27.1 | -27.5 |

DG Note: At worse case and up to -18, 25% RAP would result in marginally non-compliant low temp. blends

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**Table 4 Eastern Washington Scenario 2**

| *Achieved PG Low Temperature What If Table w/ Virgin LT Critical Temp* | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ***PG Temp*** | **RAP Stockpile Critical Low Temperature, C** | | | | | | | | | | | | | | | |
| *-33.4* | **-8.0** | **-9.0** | **-10.0** | **-11.0** | **-12.0** | **-13.0** | **-14.0** | **-15.0** | **-16.0** | **-17.0** | **-18.0** | **-19.0** | **-20.0** | **-21.0** | **-22.0** | **-23.0** |
| **RAP, %** | | | | | | | | | | | | | | | | |
| **0** | #DIV/0! | ###### | ###### | ###### | ###### | ###### | ###### | ###### | ###### | ###### | ###### | ###### | ###### | ###### | ###### | ###### |
| **1** | -36.7 | -36.8 | -36.8 | -36.8 | -36.8 | -36.8 | -36.8 | -36.8 | -36.8 | -36.8 | -36.8 | -36.8 | -36.9 | -36.9 | -36.9 | -36.9 |
| **2** | -36.5 | -36.5 | -36.5 | -36.5 | -36.6 | -36.6 | -36.6 | -36.6 | -36.6 | -36.7 | -36.7 | -36.7 | -36.7 | -36.7 | -36.7 | -36.8 |
| **3** | -36.2 | -36.3 | -36.3 | -36.3 | -36.3 | -36.4 | -36.4 | -36.4 | -36.5 | -36.5 | -36.5 | -36.5 | -36.6 | -36.6 | -36.6 | -36.6 |
| **4** | -36.0 | -36.0 | -36.1 | -36.1 | -36.1 | -36.2 | -36.2 | -36.2 | -36.3 | -36.3 | -36.3 | -36.4 | -36.4 | -36.4 | -36.5 | -36.5 |
| **5** | -35.7 | -35.8 | -35.8 | -35.9 | -35.9 | -36.0 | -36.0 | -36.0 | -36.1 | -36.1 | -36.2 | -36.2 | -36.3 | -36.3 | -36.3 | -36.4 |
| **6** | -35.5 | -35.5 | -35.6 | -35.6 | -35.7 | -35.8 | -35.8 | -35.9 | -35.9 | -36.0 | -36.0 | -36.1 | -36.1 | -36.2 | -36.2 | -36.3 |
| **7** | -35.2 | -35.3 | -35.4 | -35.4 | -35.5 | -35.5 | -35.6 | -35.7 | -35.7 | -35.8 | -35.8 | -35.9 | -36.0 | -36.0 | -36.1 | -36.1 |
| **8** | -35.0 | -35.1 | -35.1 | -35.2 | -35.3 | -35.3 | -35.4 | -35.5 | -35.5 | -35.6 | -35.7 | -35.8 | -35.8 | -35.9 | -36.0 | -36.0 |
| **9** | -34.7 | -34.8 | -34.9 | -35.0 | -35.0 | -35.1 | -35.2 | -35.3 | -35.4 | -35.4 | -35.5 | -35.6 | -35.7 | -35.8 | -35.8 | -35.9 |
| **10** | -34.5 | -34.6 | -34.7 | -34.7 | -34.8 | -34.9 | -35.0 | -35.1 | -35.2 | -35.3 | -35.4 | -35.4 | -35.5 | -35.6 | -35.7 | -35.8 |
| **11** | -34.2 | -34.3 | -34.4 | -34.5 | -34.6 | -34.7 | -34.8 | -34.9 | -35.0 | -35.1 | -35.2 | -35.3 | -35.4 | -35.5 | -35.6 | -35.7 |
| **12** | -34.0 | -34.1 | -34.2 | -34.3 | -34.4 | -34.5 | -34.6 | -34.7 | -34.8 | -34.9 | -35.0 | -35.1 | -35.2 | -35.3 | -35.4 | -35.5 |
| **13** | -33.7 | -33.8 | -34.0 | -34.1 | -34.2 | -34.3 | -34.4 | -34.5 | -34.6 | -34.7 | -34.9 | -35.0 | -35.1 | -35.2 | -35.3 | -35.4 |
| **14** | -33.5 | -33.6 | -33.7 | -33.8 | -34.0 | -34.1 | -34.2 | -34.3 | -34.4 | -34.6 | -34.7 | -34.8 | -34.9 | -35.1 | -35.2 | -35.3 |
| **15** | -33.2 | -33.4 | -33.5 | -33.6 | -33.7 | -33.9 | -34.0 | -34.1 | -34.3 | -34.4 | -34.5 | -34.7 | -34.8 | -34.9 | -35.0 | -35.2 |
| **16** | -33.0 | -33.1 | -33.3 | -33.4 | -33.5 | -33.7 | -33.8 | -33.9 | -34.1 | -34.2 | -34.4 | -34.5 | -34.6 | -34.8 | -34.9 | -35.1 |
| **17** | -32.7 | -32.9 | -33.0 | -33.2 | -33.3 | -33.5 | -33.6 | -33.8 | -33.9 | -34.0 | -34.2 | -34.3 | -34.5 | -34.6 | -34.8 | -34.9 |
| **18** | -32.5 | -32.6 | -32.8 | -32.9 | -33.1 | -33.3 | -33.4 | -33.6 | -33.7 | -33.9 | -34.0 | -34.2 | -34.3 | -34.5 | -34.7 | -34.8 |
| **19** | -32.2 | -32.4 | -32.5 | -32.7 | -32.9 | -33.0 | -33.2 | -33.4 | -33.5 | -33.7 | -33.9 | -34.0 | -34.2 | -34.4 | -34.5 | -34.7 |
| **20** | -32.0 | -32.1 | -32.3 | -32.5 | -32.7 | -32.8 | -33.0 | -33.2 | -33.4 | -33.5 | -33.7 | -33.9 | -34.0 | -34.2 | -34.4 | -34.6 |
| **21** | -31.7 | -31.9 | -32.1 | -32.3 | -32.4 | -32.6 | -32.8 | -33.0 | -33.2 | -33.4 | -33.5 | -33.7 | -33.9 | -34.1 | -34.3 | -34.4 |
| **22** | -31.5 | -31.7 | -31.8 | -32.0 | -32.2 | -32.4 | -32.6 | -32.8 | -33.0 | -33.2 | -33.4 | -33.6 | -33.8 | -33.9 | -34.1 | -34.3 |
| **23** | -31.2 | -31.4 | -31.6 | -31.8 | -32.0 | -32.2 | -32.4 | -32.6 | -32.8 | -33.0 | -33.2 | -33.4 | -33.6 | -33.8 | -34.0 | -34.2 |
| **24** | -31.0 | -31.2 | -31.4 | -31.6 | -31.8 | -32.0 | -32.2 | -32.4 | -32.6 | -32.8 | -33.0 | -33.3 | -33.5 | -33.7 | -33.9 | -34.1 |
| **25** | -30.7 | -30.9 | -31.1 | -31.4 | -31.6 | -31.8 | -32.0 | -32.2 | -32.4 | -32.7 | -32.9 | -33.1 | -33.3 | -33.5 | -33.7 | -34.0 |
| **26** | -30.5 | -30.7 | -30.9 | -31.1 | -31.4 | -31.6 | -31.8 | -32.0 | -32.3 | -32.5 | -32.7 | -32.9 | -33.2 | -33.4 | -33.6 | -33.8 |
| **27** | -30.2 | -30.4 | -30.7 | -30.9 | -31.1 | -31.4 | -31.6 | -31.8 | -32.1 | -32.3 | -32.5 | -32.8 | -33.0 | -33.3 | -33.5 | -33.7 |
| **28** | -30.0 | -30.2 | -30.4 | -30.7 | -30.9 | -31.2 | -31.4 | -31.7 | -31.9 | -32.1 | -32.4 | -32.6 | -32.9 | -33.1 | -33.4 | -33.6 |
| **29** | -29.7 | -30.0 | -30.2 | -30.5 | -30.7 | -31.0 | -31.2 | -31.5 | -31.7 | -32.0 | -32.2 | -32.5 | -32.7 | -33.0 | -33.2 | -33.5 |
| **30** | -29.4 | -29.7 | -30.0 | -30.2 | -30.5 | -30.8 | -31.0 | -31.3 | -31.5 | -31.8 | -32.1 | -32.3 | -32.6 | -32.8 | -33.1 | -33.4 |
| **31** | -29.2 | -29.5 | -29.7 | -30.0 | -30.3 | -30.5 | -30.8 | -31.1 | -31.3 | -31.6 | -31.9 | -32.2 | -32.4 | -32.7 | -33.0 | -33.2 |
| **32** | -28.9 | -29.2 | -29.5 | -29.8 | -30.1 | -30.3 | -30.6 | -30.9 | -31.2 | -31.4 | -31.7 | -32.0 | -32.3 | -32.6 | -32.8 | -33.1 |
| **33** | -28.7 | -29.0 | -29.3 | -29.6 | -29.8 | -30.1 | -30.4 | -30.7 | -31.0 | -31.3 | -31.6 | -31.8 | -32.1 | -32.4 | -32.7 | -33.0 |
| **34** | -28.4 | -28.7 | -29.0 | -29.3 | -29.6 | -29.9 | -30.2 | -30.5 | -30.8 | -31.1 | -31.4 | -31.7 | -32.0 | -32.3 | -32.6 | -32.9 |
| **35** | -28.2 | -28.5 | -28.8 | -29.1 | -29.4 | -29.7 | -30.0 | -30.3 | -30.6 | -30.9 | -31.2 | -31.5 | -31.8 | -32.1 | -32.4 | -32.7 |
| **36** | -27.9 | -28.3 | -28.6 | -28.9 | -29.2 | -29.5 | -29.8 | -30.1 | -30.4 | -30.8 | -31.1 | -31.4 | -31.7 | -32.0 | -32.3 | -32.6 |
| **37** | -27.7 | -28.0 | -28.3 | -28.7 | -29.0 | -29.3 | -29.6 | -29.9 | -30.3 | -30.6 | -30.9 | -31.2 | -31.5 | -31.9 | -32.2 | -32.5 |
| **38** | -27.4 | -27.8 | -28.1 | -28.4 | -28.8 | -29.1 | -29.4 | -29.7 | -30.1 | -30.4 | -30.7 | -31.1 | -31.4 | -31.7 | -32.1 | -32.4 |
| **39** | -27.2 | -27.5 | -27.9 | -28.2 | -28.5 | -28.9 | -29.2 | -29.6 | -29.9 | -30.2 | -30.6 | -30.9 | -31.2 | -31.6 | -31.9 | -32.3 |
| **40** | -26.9 | -27.3 | -27.6 | -28.0 | -28.3 | -28.7 | -29.0 | -29.4 | -29.7 | -30.1 | -30.4 | -30.8 | -31.1 | -31.4 | -31.8 | -32.1 |
| **41** | -26.7 | -27.0 | -27.4 | -27.7 | -28.1 | -28.5 | -28.8 | -29.2 | -29.5 | -29.9 | -30.2 | -30.6 | -31.0 | -31.3 | -31.7 | -32.0 |
| **42** | -26.4 | -26.8 | -27.2 | -27.5 | -27.9 | -28.3 | -28.6 | -29.0 | -29.3 | -29.7 | -30.1 | -30.4 | -30.8 | -31.2 | -31.5 | -31.9 |
| **43** | -26.2 | -26.6 | -26.9 | -27.3 | -27.7 | -28.0 | -28.4 | -28.8 | -29.2 | -29.5 | -29.9 | -30.3 | -30.7 | -31.0 | -31.4 | -31.8 |
| **44** | -25.9 | -26.3 | -26.7 | -27.1 | -27.5 | -27.8 | -28.2 | -28.6 | -29.0 | -29.4 | -29.7 | -30.1 | -30.5 | -30.9 | -31.3 | -31.7 |
| **45** | -25.7 | -26.1 | -26.5 | -26.8 | -27.2 | -27.6 | -28.0 | -28.4 | -28.8 | -29.2 | -29.6 | -30.0 | -30.4 | -30.8 | -31.1 | -31.5 |
| **46** | -25.4 | -25.8 | -26.2 | -26.6 | -27.0 | -27.4 | -27.8 | -28.2 | -28.6 | -29.0 | -29.4 | -29.8 | -30.2 | -30.6 | -31.0 | -31.4 |
| **47** | -25.2 | -25.6 | -26.0 | -26.4 | -26.8 | -27.2 | -27.6 | -28.0 | -28.4 | -28.8 | -29.2 | -29.7 | -30.1 | -30.5 | -30.9 | -31.3 |
| **48** | -24.9 | -25.3 | -25.8 | -26.2 | -26.6 | -27.0 | -27.4 | -27.8 | -28.3 | -28.7 | -29.1 | -29.5 | -29.9 | -30.3 | -30.8 | -31.2 |
| **49** | -24.7 | -25.1 | -25.5 | -25.9 | -26.4 | -26.8 | -27.2 | -27.6 | -28.1 | -28.5 | -28.9 | -29.3 | -29.8 | -30.2 | -30.6 | -31.0 |
| **50** | -24.4 | -24.8 | -25.3 | -25.7 | -26.2 | -26.6 | -27.0 | -27.5 | -27.9 | -28.3 | -28.8 | -29.2 | -29.6 | -30.1 | -30.5 | -30.9 |

DG Note: A low temp. grade bump down -6°C easily complies with the low temp. target at 25% RAP.

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Table 5 Eastern Washington Scenario 3

| Achieved PG High Temperature What If Table w/ Virgin HT Critical Temp | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *PG Temp* | RAP Stockpile Critical High Temperature, C | | | | | | | | | | | | | | | |
| *70.4* | **100.0** | **99.0** | **98.0** | **97.0** | **96.0** | **95.0** | **94.0** | **93.0** | **92.0** | **91.0** | **90.0** | **89.0** | **88.0** | **87.0** | **86.0** | **85.0** |
| **RAP, %** | | | | | | | | | | | | | | | | |
| **0** | #DIV/0! | ###### | ###### | ###### | ###### | ###### | ###### | ###### | ###### | ###### | ###### | ###### | ###### | ###### | ###### | ###### |
| **1** | 67.3 | 67.3 | 67.3 | 67.3 | 67.3 | 67.2 | 67.2 | 67.2 | 67.2 | 67.2 | 67.2 | 67.2 | 67.2 | 67.2 | 67.2 | 67.2 |
| **2** | 67.6 | 67.6 | 67.5 | 67.5 | 67.5 | 67.5 | 67.5 | 67.5 | 67.4 | 67.4 | 67.4 | 67.4 | 67.4 | 67.3 | 67.3 | 67.3 |
| **3** | 67.9 | 67.8 | 67.8 | 67.8 | 67.8 | 67.7 | 67.7 | 67.7 | 67.7 | 67.6 | 67.6 | 67.6 | 67.5 | 67.5 | 67.5 | 67.5 |
| **4** | 68.1 | 68.1 | 68.1 | 68.0 | 68.0 | 68.0 | 67.9 | 67.9 | 67.9 | 67.8 | 67.8 | 67.8 | 67.7 | 67.7 | 67.7 | 67.6 |
| **5** | 68.4 | 68.4 | 68.3 | 68.3 | 68.3 | 68.2 | 68.2 | 68.1 | 68.1 | 68.0 | 68.0 | 68.0 | 67.9 | 67.9 | 67.8 | 67.8 |
| **6** | 68.7 | 68.7 | 68.6 | 68.6 | 68.5 | 68.5 | 68.4 | 68.4 | 68.3 | 68.2 | 68.2 | 68.1 | 68.1 | 68.0 | 68.0 | 67.9 |
| **7** | 69.0 | 68.9 | 68.9 | 68.8 | 68.8 | 68.7 | 68.6 | 68.6 | 68.5 | 68.5 | 68.4 | 68.3 | 68.3 | 68.2 | 68.2 | 68.1 |
| **8** | 69.3 | 69.2 | 69.2 | 69.1 | 69.0 | 68.9 | 68.9 | 68.8 | 68.7 | 68.7 | 68.6 | 68.5 | 68.5 | 68.4 | 68.3 | 68.2 |
| **9** | 69.6 | 69.5 | 69.4 | 69.3 | 69.3 | 69.2 | 69.1 | 69.0 | 69.0 | 68.9 | 68.8 | 68.7 | 68.6 | 68.6 | 68.5 | 68.4 |
| **10** | 69.9 | 69.8 | 69.7 | 69.6 | 69.5 | 69.4 | 69.3 | 69.3 | 69.2 | 69.1 | 69.0 | 68.9 | 68.8 | 68.7 | 68.6 | 68.6 |
| **11** | 70.2 | 70.1 | 70.0 | 69.9 | 69.8 | 69.7 | 69.6 | 69.5 | 69.4 | 69.3 | 69.2 | 69.1 | 69.0 | 68.9 | 68.8 | 68.7 |
| **12** | 70.4 | 70.3 | 70.2 | 70.1 | 70.0 | 69.9 | 69.8 | 69.7 | 69.6 | 69.5 | 69.4 | 69.3 | 69.2 | 69.1 | 69.0 | 68.9 |
| **13** | 70.7 | 70.6 | 70.5 | 70.4 | 70.3 | 70.2 | 70.0 | 69.9 | 69.8 | 69.7 | 69.6 | 69.5 | 69.4 | 69.3 | 69.1 | 69.0 |
| **14** | 71.0 | 70.9 | 70.8 | 70.6 | 70.5 | 70.4 | 70.3 | 70.2 | 70.0 | 69.9 | 69.8 | 69.7 | 69.6 | 69.4 | 69.3 | 69.2 |
| **15** | 71.3 | 71.2 | 71.0 | 70.9 | 70.8 | 70.6 | 70.5 | 70.4 | 70.3 | 70.1 | 70.0 | 69.9 | 69.7 | 69.6 | 69.5 | 69.3 |
| **16** | 71.6 | 71.4 | 71.3 | 71.2 | 71.0 | 70.9 | 70.7 | 70.6 | 70.5 | 70.3 | 70.2 | 70.1 | 69.9 | 69.8 | 69.6 | 69.5 |
| **17** | 71.9 | 71.7 | 71.6 | 71.4 | 71.3 | 71.1 | 71.0 | 70.8 | 70.7 | 70.5 | 70.4 | 70.2 | 70.1 | 70.0 | 69.8 | 69.7 |
| **18** | 72.2 | 72.0 | 71.8 | 71.7 | 71.5 | 71.4 | 71.2 | 71.1 | 70.9 | 70.7 | 70.6 | 70.4 | 70.3 | 70.1 | 70.0 | 69.8 |
| **19** | 72.4 | 72.3 | 72.1 | 71.9 | 71.8 | 71.6 | 71.5 | 71.3 | 71.1 | 71.0 | 70.8 | 70.6 | 70.5 | 70.3 | 70.1 | 70.0 |
| **20** | 72.7 | 72.6 | 72.4 | 72.2 | 72.0 | 71.9 | 71.7 | 71.5 | 71.3 | 71.2 | 71.0 | 70.8 | 70.6 | 70.5 | 70.3 | 70.1 |
| **21** | 73.0 | 72.8 | 72.7 | 72.5 | 72.3 | 72.1 | 71.9 | 71.7 | 71.6 | 71.4 | 71.2 | 71.0 | 70.8 | 70.6 | 70.5 | 70.3 |
| **22** | 73.3 | 73.1 | 72.9 | 72.7 | 72.5 | 72.3 | 72.2 | 72.0 | 71.8 | 71.6 | 71.4 | 71.2 | 71.0 | 70.8 | 70.6 | 70.4 |
| **23** | 73.6 | 73.4 | 73.2 | 73.0 | 72.8 | 72.6 | 72.4 | 72.2 | 72.0 | 71.8 | 71.6 | 71.4 | 71.2 | 71.0 | 70.8 | 70.6 |
| **24** | 73.9 | 73.7 | 73.5 | 73.2 | 73.0 | 72.8 | 72.6 | 72.4 | 72.2 | 72.0 | 71.8 | 71.6 | 71.4 | 71.2 | 71.0 | 70.7 |
| **25** | 74.2 | 73.9 | 73.7 | 73.5 | 73.3 | 73.1 | 72.9 | 72.6 | 72.4 | 72.2 | 72.0 | 71.8 | 71.6 | 71.3 | 71.1 | 70.9 |
| **26** | 74.4 | 74.2 | 74.0 | 73.8 | 73.5 | 73.3 | 73.1 | 72.9 | 72.6 | 72.4 | 72.2 | 72.0 | 71.7 | 71.5 | 71.3 | 71.1 |
| **27** | 74.7 | 74.5 | 74.3 | 74.0 | 73.8 | 73.6 | 73.3 | 73.1 | 72.9 | 72.6 | 72.4 | 72.2 | 71.9 | 71.7 | 71.5 | 71.2 |
| **28** | 75.0 | 74.8 | 74.5 | 74.3 | 74.0 | 73.8 | 73.6 | 73.3 | 73.1 | 72.8 | 72.6 | 72.3 | 72.1 | 71.9 | 71.6 | 71.4 |
| **29** | 75.3 | 75.1 | 74.8 | 74.6 | 74.3 | 74.0 | 73.8 | 73.5 | 73.3 | 73.0 | 72.8 | 72.5 | 72.3 | 72.0 | 71.8 | 71.5 |
| **30** | 75.6 | 75.3 | 75.1 | 74.8 | 74.6 | 74.3 | 74.0 | 73.8 | 73.5 | 73.2 | 73.0 | 72.7 | 72.5 | 72.2 | 71.9 | 71.7 |
| **31** | 75.9 | 75.6 | 75.3 | 75.1 | 74.8 | 74.5 | 74.3 | 74.0 | 73.7 | 73.5 | 73.2 | 72.9 | 72.7 | 72.4 | 72.1 | 71.8 |
| **32** | 76.2 | 75.9 | 75.6 | 75.3 | 75.1 | 74.8 | 74.5 | 74.2 | 73.9 | 73.7 | 73.4 | 73.1 | 72.8 | 72.6 | 72.3 | 72.0 |
| **33** | 76.5 | 76.2 | 75.9 | 75.6 | 75.3 | 75.0 | 74.7 | 74.4 | 74.2 | 73.9 | 73.6 | 73.3 | 73.0 | 72.7 | 72.4 | 72.2 |
| **34** | 76.7 | 76.4 | 76.1 | 75.9 | 75.6 | 75.3 | 75.0 | 74.7 | 74.4 | 74.1 | 73.8 | 73.5 | 73.2 | 72.9 | 72.6 | 72.3 |
| **35** | 77.0 | 76.7 | 76.4 | 76.1 | 75.8 | 75.5 | 75.2 | 74.9 | 74.6 | 74.3 | 74.0 | 73.7 | 73.4 | 73.1 | 72.8 | 72.5 |
| **36** | 77.3 | 77.0 | 76.7 | 76.4 | 76.1 | 75.7 | 75.4 | 75.1 | 74.8 | 74.5 | 74.2 | 73.9 | 73.6 | 73.2 | 72.9 | 72.6 |
| **37** | 77.6 | 77.3 | 77.0 | 76.6 | 76.3 | 76.0 | 75.7 | 75.3 | 75.0 | 74.7 | 74.4 | 74.1 | 73.7 | 73.4 | 73.1 | 72.8 |
| **38** | 77.9 | 77.6 | 77.2 | 76.9 | 76.6 | 76.2 | 75.9 | 75.6 | 75.2 | 74.9 | 74.6 | 74.3 | 73.9 | 73.6 | 73.3 | 72.9 |
| **39** | 78.2 | 77.8 | 77.5 | 77.2 | 76.8 | 76.5 | 76.1 | 75.8 | 75.5 | 75.1 | 74.8 | 74.4 | 74.1 | 73.8 | 73.4 | 73.1 |
| **40** | 78.5 | 78.1 | 77.8 | 77.4 | 77.1 | 76.7 | 76.4 | 76.0 | 75.7 | 75.3 | 75.0 | 74.6 | 74.3 | 73.9 | 73.6 | 73.2 |
| **41** | 78.7 | 78.4 | 78.0 | 77.7 | 77.3 | 77.0 | 76.6 | 76.3 | 75.9 | 75.5 | 75.2 | 74.8 | 74.5 | 74.1 | 73.8 | 73.4 |
| **42** | 79.0 | 78.7 | 78.3 | 77.9 | 77.6 | 77.2 | 76.8 | 76.5 | 76.1 | 75.7 | 75.4 | 75.0 | 74.7 | 74.3 | 73.9 | 73.6 |
| **43** | 79.3 | 78.9 | 78.6 | 78.2 | 77.8 | 77.4 | 77.1 | 76.7 | 76.3 | 76.0 | 75.6 | 75.2 | 74.8 | 74.5 | 74.1 | 73.7 |
| **44** | 79.6 | 79.2 | 78.8 | 78.5 | 78.1 | 77.7 | 77.3 | 76.9 | 76.5 | 76.2 | 75.8 | 75.4 | 75.0 | 74.6 | 74.3 | 73.9 |
| **45** | 79.9 | 79.5 | 79.1 | 78.7 | 78.3 | 77.9 | 77.5 | 77.2 | 76.8 | 76.4 | 76.0 | 75.6 | 75.2 | 74.8 | 74.4 | 74.0 |
| **46** | 80.2 | 79.8 | 79.4 | 79.0 | 78.6 | 78.2 | 77.8 | 77.4 | 77.0 | 76.6 | 76.2 | 75.8 | 75.4 | 75.0 | 74.6 | 74.2 |
| **47** | 80.5 | 80.1 | 79.6 | 79.2 | 78.8 | 78.4 | 78.0 | 77.6 | 77.2 | 76.8 | 76.4 | 76.0 | 75.6 | 75.2 | 74.8 | 74.3 |
| **48** | 80.7 | 80.3 | 79.9 | 79.5 | 79.1 | 78.7 | 78.2 | 77.8 | 77.4 | 77.0 | 76.6 | 76.2 | 75.7 | 75.3 | 74.9 | 74.5 |
| **49** | 81.0 | 80.6 | 80.2 | 79.8 | 79.3 | 78.9 | 78.5 | 78.1 | 77.6 | 77.2 | 76.8 | 76.4 | 75.9 | 75.5 | 75.1 | 74.7 |
| **50** | 81.3 | 80.9 | 80.5 | 80.0 | 79.6 | 79.2 | 78.7 | 78.3 | 77.8 | 77.4 | 77.0 | 76.5 | 76.1 | 75.7 | 75.2 | 74.8 |

DG Note: Without a grade bump, 25% RAP will be unlikely to comply with the contract base grade for PG 64-28

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Table 6 Eastern Washington Scenario 4

| Achieved PG High Temperature What If Table w/ Virgin HT Critical Temp | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PG Temp | | RAP Stockpile Critical High Temperature, C | | | | | | | | | | | | | | | |
| 65.2 | | 100.0 | 99.0 | 98.0 | 97.0 | 96.0 | 95.0 | 94.0 | 93.0 | 92.0 | 91.0 | 90.0 | 89.0 | 88.0 | 87.0 | 86.0 | 85.0 |
| RAP, % | 0 | #DIV/0! | ###### | ###### | ###### | ###### | ###### | ###### | ###### | ###### | ###### | ###### | ###### | ###### | ###### | ###### | ###### |
| | 1 | 61.3 | 61.3 | 61.3 | 61.3 | 61.3 | 61.3 | 61.3 | 61.3 | 61.3 | 61.3 | 61.3 | 61.2 | 61.2 | 61.2 | 61.2 | 61.2 |
| | 2 | 61.7 | 61.7 | 61.6 | 61.6 | 61.6 | 61.6 | 61.6 | 61.6 | 61.5 | 61.5 | 61.5 | 61.5 | 61.5 | 61.5 | 61.4 | 61.4 |
| | 3 | 62.0 | 62.0 | 62.0 | 61.9 | 61.9 | 61.9 | 61.9 | 61.8 | 61.8 | 61.8 | 61.8 | 61.7 | 61.7 | 61.7 | 61.7 | 61.6 |
| | 4 | 62.4 | 62.3 | 62.3 | 62.2 | 62.2 | 62.2 | 62.1 | 62.1 | 62.1 | 62.0 | 62.0 | 62.0 | 61.9 | 61.9 | 61.9 | 61.8 |
| | 5 | 62.7 | 62.6 | 62.6 | 62.6 | 62.5 | 62.5 | 62.4 | 62.4 | 62.3 | 62.3 | 62.3 | 62.2 | 62.2 | 62.1 | 62.1 | 62.0 |
| | 6 | 63.0 | 63.0 | 62.9 | 62.9 | 62.8 | 62.8 | 62.7 | 62.7 | 62.6 | 62.6 | 62.5 | 62.5 | 62.4 | 62.4 | 62.3 | 62.2 |
| | 7 | 63.4 | 63.3 | 63.2 | 63.2 | 63.1 | 63.1 | 63.0 | 62.9 | 62.9 | 62.8 | 62.8 | 62.7 | 62.6 | 62.6 | 62.5 | 62.5 |
| | 8 | 63.7 | 63.6 | 63.6 | 63.5 | 63.4 | 63.4 | 63.3 | 63.2 | 63.2 | 63.1 | 63.0 | 62.9 | 62.9 | 62.8 | 62.7 | 62.7 |
| | 9 | 64.0 | 64.0 | 63.9 | 63.8 | 63.7 | 63.7 | 63.6 | 63.5 | 63.4 | 63.3 | 63.3 | 63.2 | 63.1 | 63.0 | 63.0 | 62.9 |
| | 10 | 64.4 | 64.3 | 64.2 | 64.1 | 64.0 | 64.0 | 63.9 | 63.8 | 63.7 | 63.6 | 63.5 | 63.4 | 63.3 | 63.3 | 63.2 | 63.1 |
| | 11 | 64.7 | 64.6 | 64.5 | 64.4 | 64.3 | 64.2 | 64.2 | 64.1 | 64.0 | 63.9 | 63.8 | 63.7 | 63.6 | 63.5 | 63.4 | 63.3 |
| | 12 | 65.1 | 65.0 | 64.9 | 64.7 | 64.6 | 64.5 | 64.4 | 64.3 | 64.2 | 64.1 | 64.0 | 63.9 | 63.8 | 63.7 | 63.6 | 63.5 |
| | 13 | 65.4 | 65.3 | 65.2 | 65.1 | 64.9 | 64.8 | 64.7 | 64.6 | 64.5 | 64.4 | 64.3 | 64.2 | 64.0 | 63.9 | 63.8 | 63.7 |
| | 14 | 65.7 | 65.6 | 65.5 | 65.4 | 65.3 | 65.1 | 65.0 | 64.9 | 64.8 | 64.6 | 64.5 | 64.4 | 64.3 | 64.2 | 64.0 | 63.9 |
| | 15 | 66.1 | 65.9 | 65.8 | 65.7 | 65.6 | 65.4 | 65.3 | 65.2 | 65.0 | 64.9 | 64.8 | 64.6 | 64.5 | 64.4 | 64.3 | 64.1 |
| | 16 | 66.4 | 66.3 | 66.1 | 66.0 | 65.9 | 65.7 | 65.6 | 65.4 | 65.3 | 65.2 | 65.0 | 64.9 | 64.7 | 64.6 | 64.5 | 64.3 |
| | 17 | 66.8 | 66.6 | 66.5 | 66.3 | 66.2 | 66.0 | 65.9 | 65.7 | 65.6 | 65.4 | 65.3 | 65.1 | 65.0 | 64.8 | 64.7 | 64.5 |
| | 18 | 67.1 | 66.9 | 66.8 | 66.6 | 66.5 | 66.3 | 66.2 | 66.0 | 65.8 | 65.7 | 65.5 | 65.4 | 65.2 | 65.1 | 64.9 | 64.7 |
| | 19 | 67.4 | 67.3 | 67.1 | 66.9 | 66.8 | 66.6 | 66.4 | 66.3 | 66.1 | 65.9 | 65.8 | 65.6 | 65.5 | 65.3 | 65.1 | 65.0 |
| | 20 | 67.8 | 67.6 | 67.4 | 67.2 | 67.1 | 66.9 | 66.7 | 66.6 | 66.4 | 66.2 | 66.0 | 65.9 | 65.7 | 65.5 | 65.3 | 65.2 |
| | 21 | 68.1 | 67.9 | 67.7 | 67.6 | 67.4 | 67.2 | 67.0 | 66.8 | 66.7 | 66.5 | 66.3 | 66.1 | 65.9 | 65.7 | 65.6 | 65.4 |
| | 22 | 68.4 | 68.3 | 68.1 | 67.9 | 67.7 | 67.5 | 67.3 | 67.1 | 66.9 | 66.7 | 66.5 | 66.3 | 66.2 | 66.0 | 65.8 | 65.6 |
| | 23 | 68.8 | 68.6 | 68.4 | 68.2 | 68.0 | 67.8 | 67.6 | 67.4 | 67.2 | 67.0 | 66.8 | 66.6 | 66.4 | 66.2 | 66.0 | 65.8 |
| | 24 | 69.1 | 68.9 | 68.7 | 68.5 | 68.3 | 68.1 | 67.9 | 67.7 | 67.5 | 67.2 | 67.0 | 66.8 | 66.6 | 66.4 | 66.2 | 66.0 |
| | 25 | 69.5 | 69.2 | 69.0 | 68.8 | 68.6 | 68.4 | 68.2 | 67.9 | 67.7 | 67.5 | 67.3 | 67.1 | 66.9 | 66.6 | 66.4 | 66.2 |
| | 26 | 69.8 | 69.6 | 69.3 | 69.1 | 68.9 | 68.7 | 68.4 | 68.2 | 68.0 | 67.8 | 67.5 | 67.3 | 67.1 | 66.9 | 66.6 | 66.4 |
| | 27 | 70.1 | 69.9 | 69.7 | 69.4 | 69.2 | 69.0 | 68.7 | 68.5 | 68.3 | 68.0 | 67.8 | 67.6 | 67.3 | 67.1 | 66.9 | 66.6 |
| | 28 | 70.5 | 70.2 | 70.0 | 69.7 | 69.5 | 69.3 | 69.0 | 68.8 | 68.5 | 68.3 | 68.0 | 67.8 | 67.6 | 67.3 | 67.1 | 66.8 |
| | 29 | 70.8 | 70.6 | 70.3 | 70.1 | 69.8 | 69.6 | 69.3 | 69.1 | 68.8 | 68.6 | 68.3 | 68.0 | 67.8 | 67.5 | 67.3 | 67.0 |
| | 30 | 71.2 | 70.9 | 70.6 | 70.4 | 70.1 | 69.9 | 69.6 | 69.3 | 69.1 | 68.8 | 68.6 | 68.3 | 68.0 | 67.8 | 67.5 | 67.2 |
| | 31 | 71.5 | 71.2 | 71.0 | 70.7 | 70.4 | 70.1 | 69.9 | 69.6 | 69.3 | 69.1 | 68.8 | 68.5 | 68.3 | 68.0 | 67.7 | 67.5 |
| | 32 | 71.8 | 71.6 | 71.3 | 71.0 | 70.7 | 70.4 | 70.2 | 69.9 | 69.6 | 69.3 | 69.1 | 68.8 | 68.5 | 68.2 | 67.9 | 67.7 |
| | 33 | 72.2 | 71.9 | 71.6 | 71.3 | 71.0 | 70.7 | 70.5 | 70.2 | 69.9 | 69.6 | 69.3 | 69.0 | 68.7 | 68.4 | 68.2 | 67.9 |
| | 34 | 72.5 | 72.2 | 71.9 | 71.6 | 71.3 | 71.0 | 70.7 | 70.4 | 70.1 | 69.9 | 69.6 | 69.3 | 69.0 | 68.7 | 68.4 | 68.1 |
| | 35 | 72.8 | 72.5 | 72.2 | 71.9 | 71.6 | 71.3 | 71.0 | 70.7 | 70.4 | 70.1 | 69.8 | 69.5 | 69.2 | 68.9 | 68.6 | 68.3 |
| | 36 | 73.2 | 72.9 | 72.6 | 72.2 | 71.9 | 71.6 | 71.3 | 71.0 | 70.7 | 70.4 | 70.1 | 69.7 | 69.4 | 69.1 | 68.8 | 68.5 |
| | 37 | 73.5 | 73.2 | 72.9 | 72.6 | 72.2 | 71.9 | 71.6 | 71.3 | 71.0 | 70.6 | 70.3 | 70.0 | 69.7 | 69.3 | 69.0 | 68.7 |
| | 38 | 73.9 | 73.5 | 73.2 | 72.9 | 72.5 | 72.2 | 71.9 | 71.6 | 71.2 | 70.9 | 70.6 | 70.2 | 69.9 | 69.6 | 69.2 | 68.9 |
| | 39 | 74.2 | 73.9 | 73.5 | 73.2 | 72.8 | 72.5 | 72.2 | 71.8 | 71.5 | 71.2 | 70.8 | 70.5 | 70.1 | 69.8 | 69.5 | 69.1 |
| | 40 | 74.5 | 74.2 | 73.8 | 73.5 | 73.2 | 72.8 | 72.5 | 72.1 | 71.8 | 71.4 | 71.1 | 70.7 | 70.4 | 70.0 | 69.7 | 69.3 |
| | 41 | 74.9 | 74.5 | 74.2 | 73.8 | 73.5 | 73.1 | 72.7 | 72.4 | 72.0 | 71.7 | 71.3 | 71.0 | 70.6 | 70.3 | 69.9 | 69.5 |
| | 42 | 75.2 | 74.9 | 74.5 | 74.1 | 73.8 | 73.4 | 73.0 | 72.7 | 72.3 | 71.9 | 71.6 | 71.2 | 70.8 | 70.5 | 70.1 | 69.7 |
| | 43 | 75.6 | 75.2 | 74.8 | 74.4 | 74.1 | 73.7 | 73.3 | 72.9 | 72.6 | 72.2 | 71.8 | 71.4 | 71.1 | 70.7 | 70.3 | 70.0 |
| | 44 | 75.9 | 75.5 | 75.1 | 74.7 | 74.4 | 74.0 | 73.6 | 73.2 | 72.8 | 72.5 | 72.1 | 71.7 | 71.3 | 70.9 | 70.5 | 70.2 |
| | 45 | 76.2 | 75.8 | 75.5 | 75.1 | 74.7 | 74.3 | 73.9 | 73.5 | 73.1 | 72.7 | 72.3 | 71.9 | 71.5 | 71.2 | 70.8 | 70.4 |
| | 46 | 76.6 | 76.2 | 75.8 | 75.4 | 75.0 | 74.6 | 74.2 | 73.8 | 73.4 | 73.0 | 72.6 | 72.2 | 71.8 | 71.4 | 71.0 | 70.6 |
| | 47 | 76.9 | 76.5 | 76.1 | 75.7 | 75.3 | 74.9 | 74.5 | 74.1 | 73.6 | 73.2 | 72.8 | 72.4 | 72.0 | 71.6 | 71.2 | 70.8 |
| | 48 | 77.2 | 76.8 | 76.4 | 76.0 | 75.6 | 75.2 | 74.7 | 74.3 | 73.9 | 73.5 | 73.1 | 72.7 | 72.2 | 71.8 | 71.4 | 71.0 |
| | 49 | 77.6 | 77.2 | 76.7 | 76.3 | 75.9 | 75.5 | 75.0 | 74.6 | 74.2 | 73.8 | 73.3 | 72.9 | 72.5 | 72.1 | 71.6 | 71.2 |
| | 50 | 77.9 | 77.5 | 77.1 | 76.6 | 76.2 | 75.8 | 75.3 | 74.9 | 74.5 | 74.0 | 73.6 | 73.2 | 72.7 | 72.3 | 71.8 | 71.4 |

DG Note: With a high temp. grade bump, even at the extremes of the RAP binder grades, 25% RAP result in a compliant final binder grade. Very little practical risk of the high end grade being out of spec. at 25%.

13-07b

Table 7 Western Washington Scenario 1

| Achieved PG Low Temperature What If Table w/ Virgin LT Critical Temp | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **PG Temp** | **RAP Stockpile Critical Low Temperature, C** | | | | | | | | | | | | | | | |
| | -22.6 | **-10.0** | **-11.0** | **-12.0** | **-13.0** | **-14.0** | **-15.0** | **-16.0** | **-17.0** | **-18.0** | **-19.0** | **-20.0** | **-21.0** | **-22.0** | **-23.0** | **-24.0** | **-25.0** |
| **RAP, %** | **0** | #DIV/0! | ###### | ###### | ###### | ###### | ###### | ###### | ###### | ###### | ###### | ###### | ###### | ###### | ###### | ###### | ###### |
| | **1** | -24.9 | -24.9 | -24.9 | -24.9 | -24.9 | -24.9 | -24.9 | -24.9 | -24.9 | -24.9 | -25.0 | -25.0 | -25.0 | -25.0 | -25.0 | -25.0 |
| | **2** | -24.7 | -24.8 | -24.8 | -24.8 | -24.8 | -24.8 | -24.8 | -24.9 | -24.9 | -24.9 | -24.9 | -24.9 | -24.9 | -25.0 | -25.0 | -25.0 |
| | **3** | -24.6 | -24.6 | -24.7 | -24.7 | -24.7 | -24.7 | -24.8 | -24.8 | -24.8 | -24.8 | -24.9 | -24.9 | -24.9 | -24.9 | -25.0 | -25.0 |
| | **4** | -24.5 | -24.5 | -24.5 | -24.6 | -24.6 | -24.7 | -24.7 | -24.7 | -24.8 | -24.8 | -24.8 | -24.9 | -24.9 | -24.9 | -25.0 | -25.0 |
| | **5** | -24.3 | -24.4 | -24.4 | -24.5 | -24.5 | -24.6 | -24.6 | -24.7 | -24.7 | -24.7 | -24.8 | -24.8 | -24.9 | -24.9 | -25.0 | -25.0 |
| | **6** | -24.2 | -24.3 | -24.3 | -24.4 | -24.4 | -24.5 | -24.5 | -24.6 | -24.6 | -24.7 | -24.7 | -24.8 | -24.8 | -24.9 | -24.9 | -25.0 |
| | **7** | -24.1 | -24.1 | -24.2 | -24.3 | -24.3 | -24.4 | -24.5 | -24.5 | -24.6 | -24.6 | -24.7 | -24.8 | -24.8 | -24.9 | -24.9 | -25.0 |
| | **8** | -24.0 | -24.0 | -24.1 | -24.2 | -24.2 | -24.3 | -24.4 | -24.4 | -24.5 | -24.6 | -24.7 | -24.7 | -24.8 | -24.9 | -24.9 | -25.0 |
| | **9** | -23.8 | -23.9 | -24.0 | -24.1 | -24.1 | -24.2 | -24.3 | -24.4 | -24.5 | -24.5 | -24.6 | -24.7 | -24.8 | -24.8 | -24.9 | -25.0 |
| | **10** | -23.7 | -23.8 | -23.9 | -24.0 | -24.0 | -24.1 | -24.2 | -24.3 | -24.4 | -24.5 | -24.6 | -24.7 | -24.7 | -24.8 | -24.9 | -25.0 |
| | **11** | -23.6 | -23.7 | -23.8 | -23.9 | -23.9 | -24.0 | -24.1 | -24.2 | -24.3 | -24.4 | -24.5 | -24.6 | -24.7 | -24.8 | -24.9 | -25.0 |
| | **12** | -23.4 | -23.5 | -23.6 | -23.8 | -23.9 | -24.0 | -24.1 | -24.2 | -24.3 | -24.4 | -24.5 | -24.6 | -24.7 | -24.8 | -24.9 | -25.0 |
| | **13** | -23.3 | -23.4 | -23.5 | -23.6 | -23.8 | -23.9 | -24.0 | -24.1 | -24.2 | -24.3 | -24.4 | -24.5 | -24.7 | -24.8 | -24.9 | -25.0 |
| | **14** | -23.2 | -23.3 | -23.4 | -23.5 | -23.7 | -23.8 | -23.9 | -24.0 | -24.1 | -24.3 | -24.4 | -24.5 | -24.6 | -24.8 | -24.9 | -25.0 |
| | **15** | -23.0 | -23.2 | -23.3 | -23.4 | -23.6 | -23.7 | -23.8 | -24.0 | -24.1 | -24.2 | -24.3 | -24.5 | -24.6 | -24.7 | -24.9 | -25.0 |
| | **16** | -22.9 | -23.1 | -23.2 | -23.3 | -23.5 | -23.6 | -23.8 | -23.9 | -24.0 | -24.2 | -24.3 | -24.4 | -24.6 | -24.7 | -24.9 | -25.0 |
| | **17** | -22.8 | -22.9 | -23.1 | -23.2 | -23.4 | -23.5 | -23.7 | -23.8 | -24.0 | -24.1 | -24.3 | -24.4 | -24.6 | -24.7 | -24.9 | -25.0 |
| | **18** | -22.7 | -22.8 | -23.0 | -23.1 | -23.3 | -23.4 | -23.6 | -23.8 | -23.9 | -24.1 | -24.2 | -24.4 | -24.5 | -24.7 | -24.8 | -25.0 |
| | **19** | -22.5 | -22.7 | -22.9 | -23.0 | -23.2 | -23.4 | -23.5 | -23.7 | -23.8 | -24.0 | -24.2 | -24.3 | -24.5 | -24.7 | -24.8 | -25.0 |
| | **20** | -22.4 | -22.6 | -22.7 | -22.9 | -23.1 | -23.3 | -23.4 | -23.6 | -23.8 | -24.0 | -24.1 | -24.3 | -24.5 | -24.7 | -24.8 | -25.0 |
| | **21** | -22.3 | -22.4 | -22.6 | -22.8 | -23.0 | -23.2 | -23.4 | -23.5 | -23.7 | -23.9 | -24.1 | -24.3 | -24.5 | -24.6 | -24.8 | -25.0 |
| | **22** | -22.1 | -22.3 | -22.5 | -22.7 | -22.9 | -23.1 | -23.3 | -23.5 | -23.7 | -23.9 | -24.0 | -24.2 | -24.4 | -24.6 | -24.8 | -25.0 |
| | **23** | -22.0 | -22.2 | -22.4 | -22.6 | -22.8 | -23.0 | -23.2 | -23.4 | -23.6 | -23.8 | -24.0 | -24.2 | -24.4 | -24.6 | -24.8 | -25.0 |
| | **24** | -21.9 | -22.1 | -22.3 | -22.5 | -22.7 | -22.9 | -23.1 | -23.3 | -23.5 | -23.8 | -24.0 | -24.2 | -24.4 | -24.6 | -24.8 | -25.0 |
| | **25** | -21.7 | -22.0 | -22.2 | -22.4 | -22.6 | -22.8 | -23.0 | -23.3 | -23.5 | -23.7 | -23.9 | -24.1 | -24.3 | -24.6 | -24.8 | -25.0 |
| | **26** | -21.6 | -21.8 | -22.1 | -22.3 | -22.5 | -22.7 | -23.0 | -23.2 | -23.4 | -23.6 | -23.9 | -24.1 | -24.3 | -24.5 | -24.8 | -25.0 |
| | **27** | -21.5 | -21.7 | -22.0 | -22.2 | -22.4 | -22.7 | -22.9 | -23.1 | -23.4 | -23.6 | -23.8 | -24.1 | -24.3 | -24.5 | -24.8 | -25.0 |
| | **28** | -21.4 | -21.6 | -21.8 | -22.1 | -22.3 | -22.6 | -22.8 | -23.1 | -23.3 | -23.5 | -23.8 | -24.0 | -24.3 | -24.5 | -24.8 | -25.0 |
| | **29** | -21.2 | -21.5 | -21.7 | -22.0 | -22.2 | -22.5 | -22.7 | -23.0 | -23.2 | -23.5 | -23.7 | -24.0 | -24.2 | -24.5 | -24.7 | -25.0 |
| | **30** | -21.1 | -21.4 | -21.6 | -21.9 | -22.1 | -22.4 | -22.7 | -22.9 | -23.2 | -23.4 | -23.7 | -24.0 | -24.2 | -24.5 | -24.7 | -25.0 |
| | **31** | -21.0 | -21.2 | -21.5 | -21.8 | -22.0 | -22.3 | -22.6 | -22.8 | -23.1 | -23.4 | -23.7 | -23.9 | -24.2 | -24.5 | -24.7 | -25.0 |
| | **32** | -20.8 | -21.1 | -21.4 | -21.7 | -21.9 | -22.2 | -22.5 | -22.8 | -23.1 | -23.3 | -23.6 | -23.9 | -24.2 | -24.4 | -24.7 | -25.0 |
| | **33** | -20.7 | -21.0 | -21.3 | -21.6 | -21.8 | -22.1 | -22.4 | -22.7 | -23.0 | -23.3 | -23.6 | -23.9 | -24.1 | -24.4 | -24.7 | -25.0 |
| | **34** | -20.6 | -20.9 | -21.2 | -21.5 | -21.8 | -22.0 | -22.3 | -22.6 | -22.9 | -23.2 | -23.5 | -23.8 | -24.1 | -24.4 | -24.7 | -25.0 |
| | **35** | -20.4 | -20.7 | -21.1 | -21.4 | -21.7 | -22.0 | -22.3 | -22.6 | -22.9 | -23.2 | -23.5 | -23.8 | -24.1 | -24.4 | -24.7 | -25.0 |
| | **36** | -20.3 | -20.6 | -20.9 | -21.3 | -21.6 | -21.9 | -22.2 | -22.5 | -22.8 | -23.1 | -23.4 | -23.8 | -24.1 | -24.4 | -24.7 | -25.0 |
| | **37** | -20.2 | -20.5 | -20.8 | -21.1 | -21.5 | -21.8 | -22.1 | -22.4 | -22.8 | -23.1 | -23.4 | -23.7 | -24.0 | -24.4 | -24.7 | -25.0 |
| | **38** | -20.1 | -20.4 | -20.7 | -21.0 | -21.4 | -21.7 | -22.0 | -22.4 | -22.7 | -23.0 | -23.4 | -23.7 | -24.0 | -24.3 | -24.7 | -25.0 |
| | **39** | -19.9 | -20.3 | -20.6 | -20.9 | -21.3 | -21.6 | -22.0 | -22.3 | -22.6 | -23.0 | -23.3 | -23.6 | -24.0 | -24.3 | -24.7 | -25.0 |
| | **40** | -19.8 | -20.1 | -20.5 | -20.8 | -21.2 | -21.5 | -21.9 | -22.2 | -22.6 | -22.9 | -23.3 | -23.6 | -24.0 | -24.3 | -24.7 | -25.0 |
| | **41** | -19.7 | -20.0 | -20.4 | -20.7 | -21.1 | -21.4 | -21.8 | -22.2 | -22.5 | -22.9 | -23.2 | -23.6 | -23.9 | -24.3 | -24.6 | -25.0 |
| | **42** | -19.5 | -19.9 | -20.3 | -20.6 | -21.0 | -21.4 | -21.7 | -22.1 | -22.4 | -22.8 | -23.2 | -23.5 | -23.9 | -24.3 | -24.6 | -25.0 |
| | **43** | -19.4 | -19.8 | -20.1 | -20.5 | -20.9 | -21.3 | -21.6 | -22.0 | -22.4 | -22.8 | -23.1 | -23.5 | -23.9 | -24.3 | -24.6 | -25.0 |
| | **44** | -19.3 | -19.7 | -20.0 | -20.4 | -20.8 | -21.2 | -21.6 | -21.9 | -22.3 | -22.7 | -23.1 | -23.5 | -23.9 | -24.2 | -24.6 | -25.0 |
| | **45** | -19.1 | -19.5 | -19.9 | -20.3 | -20.7 | -21.1 | -21.5 | -21.9 | -22.3 | -22.7 | -23.0 | -23.4 | -23.8 | -24.2 | -24.6 | -25.0 |
| | **46** | -19.0 | -19.4 | -19.8 | -20.2 | -20.6 | -21.0 | -21.4 | -21.8 | -22.2 | -22.6 | -23.0 | -23.4 | -23.8 | -24.2 | -24.6 | -25.0 |
| | **47** | -18.9 | -19.3 | -19.7 | -20.1 | -20.5 | -20.9 | -21.3 | -21.7 | -22.1 | -22.6 | -23.0 | -23.4 | -23.8 | -24.2 | -24.6 | -25.0 |
| | **48** | -18.8 | -19.2 | -19.6 | -20.0 | -20.4 | -20.8 | -21.3 | -21.7 | -22.1 | -22.5 | -22.9 | -23.3 | -23.8 | -24.2 | -24.6 | -25.0 |
| | **49** | -18.6 | -19.0 | -19.5 | -19.9 | -20.3 | -20.7 | -21.2 | -21.6 | -22.0 | -22.4 | -22.9 | -23.3 | -23.7 | -24.1 | -24.6 | -25.0 |
| | **50** | -18.5 | -18.9 | -19.4 | -19.8 | -20.2 | -20.7 | -21.1 | -21.5 | -22.0 | -22.4 | -22.8 | -23.3 | -23.7 | -24.1 | -24.6 | -25.0 |

DG Note: For the low end temp., there is only a very marginal risk of being out of compliance at the extremes of the historic stockpile recovered RAP binder grades. The vast majority of low temp. grades were above the -11°C extreme.

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Table 8 Western Washington Scenario 2

| Achieved PG Low Temperature What If Table w/ Virgin LT Critical Temp | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | PG Temp | RAP Stockpile Critical Low Temperature, C | | | | | | | | | | | | | | | |
| | -27.5 | -10.0 | -11.0 | -12.0 | -13.0 | -14.0 | -15.0 | -16.0 | -17.0 | -18.0 | -19.0 | -20.0 | -21.0 | -22.0 | -23.0 | -24.0 | -25.0 |
| RAP, % | 0 | #DIV/0! | ###### | ###### | ###### | ###### | ###### | ###### | ###### | ###### | ###### | ###### | ###### | ###### | ###### | ###### | ###### |
| | 1 | -30.8 | -30.8 | -30.8 | -30.8 | -30.9 | -30.9 | -30.9 | -30.9 | -30.9 | -30.9 | -30.9 | -30.9 | -30.9 | -30.9 | -30.9 | -30.9 |
| | 2 | -30.6 | -30.7 | -30.7 | -30.7 | -30.7 | -30.7 | -30.7 | -30.8 | -30.8 | -30.8 | -30.8 | -30.8 | -30.8 | -30.9 | -30.9 | -30.9 |
| | 3 | -30.5 | -30.5 | -30.5 | -30.5 | -30.6 | -30.6 | -30.6 | -30.6 | -30.7 | -30.7 | -30.7 | -30.7 | -30.8 | -30.8 | -30.8 | -30.8 |
| | 4 | -30.3 | -30.3 | -30.3 | -30.4 | -30.4 | -30.4 | -30.5 | -30.5 | -30.5 | -30.6 | -30.6 | -30.7 | -30.7 | -30.7 | -30.8 | -30.8 |
| | 5 | -30.1 | -30.1 | -30.2 | -30.2 | -30.3 | -30.3 | -30.3 | -30.4 | -30.4 | -30.5 | -30.5 | -30.6 | -30.6 | -30.7 | -30.7 | -30.7 |
| | 6 | -29.9 | -30.0 | -30.0 | -30.1 | -30.1 | -30.2 | -30.2 | -30.3 | -30.3 | -30.4 | -30.4 | -30.5 | -30.5 | -30.6 | -30.6 | -30.7 |
| | 7 | -29.7 | -29.8 | -29.8 | -29.9 | -30.0 | -30.0 | -30.1 | -30.1 | -30.2 | -30.3 | -30.3 | -30.4 | -30.5 | -30.5 | -30.6 | -30.6 |
| | 8 | -29.5 | -29.6 | -29.7 | -29.8 | -29.8 | -29.9 | -30.0 | -30.0 | -30.1 | -30.2 | -30.2 | -30.3 | -30.4 | -30.4 | -30.5 | -30.6 |
| | 9 | -29.4 | -29.4 | -29.5 | -29.6 | -29.7 | -29.8 | -29.8 | -29.9 | -30.0 | -30.1 | -30.1 | -30.2 | -30.3 | -30.4 | -30.5 | -30.5 |
| | 10 | -29.2 | -29.3 | -29.4 | -29.4 | -29.5 | -29.6 | -29.7 | -29.8 | -29.9 | -30.0 | -30.0 | -30.1 | -30.2 | -30.3 | -30.4 | -30.5 |
| | 11 | -29.0 | -29.1 | -29.2 | -29.3 | -29.4 | -29.5 | -29.6 | -29.7 | -29.8 | -29.9 | -29.9 | -30.0 | -30.1 | -30.2 | -30.3 | -30.4 |
| | 12 | -28.8 | -28.9 | -29.0 | -29.1 | -29.2 | -29.3 | -29.4 | -29.5 | -29.6 | -29.8 | -29.9 | -30.0 | -30.1 | -30.2 | -30.3 | -30.4 |
| | 13 | -28.6 | -28.7 | -28.9 | -29.0 | -29.1 | -29.2 | -29.3 | -29.4 | -29.5 | -29.6 | -29.8 | -29.9 | -30.0 | -30.1 | -30.2 | -30.3 |
| | 14 | -28.4 | -28.6 | -28.7 | -28.8 | -28.9 | -29.1 | -29.2 | -29.3 | -29.4 | -29.5 | -29.7 | -29.8 | -29.9 | -30.0 | -30.1 | -30.3 |
| | 15 | -28.3 | -28.4 | -28.5 | -28.7 | -28.8 | -28.9 | -29.0 | -29.2 | -29.3 | -29.4 | -29.6 | -29.7 | -29.8 | -30.0 | -30.1 | -30.2 |
| | 16 | -28.1 | -28.2 | -28.4 | -28.5 | -28.6 | -28.8 | -28.9 | -29.1 | -29.2 | -29.3 | -29.5 | -29.6 | -29.8 | -29.9 | -30.0 | -30.2 |
| | 17 | -27.9 | -28.0 | -28.2 | -28.3 | -28.5 | -28.6 | -28.8 | -28.9 | -29.1 | -29.2 | -29.4 | -29.5 | -29.7 | -29.8 | -30.0 | -30.1 |
| | 18 | -27.7 | -27.9 | -28.0 | -28.2 | -28.3 | -28.5 | -28.7 | -28.8 | -29.0 | -29.1 | -29.3 | -29.4 | -29.6 | -29.8 | -29.9 | -30.1 |
| | 19 | -27.5 | -27.7 | -27.9 | -28.0 | -28.2 | -28.4 | -28.5 | -28.7 | -28.9 | -29.0 | -29.2 | -29.4 | -29.5 | -29.7 | -29.8 | -30.0 |
| | 20 | -27.4 | -27.5 | -27.7 | -27.9 | -28.0 | -28.2 | -28.4 | -28.6 | -28.7 | -28.9 | -29.1 | -29.3 | -29.4 | -29.6 | -29.8 | -30.0 |
| | 21 | -27.2 | -27.4 | -27.5 | -27.7 | -27.9 | -28.1 | -28.3 | -28.4 | -28.6 | -28.8 | -29.0 | -29.2 | -29.4 | -29.5 | -29.7 | -29.9 |
| | 22 | -27.0 | -27.2 | -27.4 | -27.6 | -27.8 | -27.9 | -28.1 | -28.3 | -28.5 | -28.7 | -28.9 | -29.1 | -29.3 | -29.5 | -29.7 | -29.9 |
| | 23 | -26.8 | -27.0 | -27.2 | -27.4 | -27.6 | -27.8 | -28.0 | -28.2 | -28.4 | -28.6 | -28.8 | -29.0 | -29.2 | -29.4 | -29.6 | -29.8 |
| | 24 | -26.6 | -26.8 | -27.0 | -27.3 | -27.5 | -27.7 | -27.9 | -28.1 | -28.3 | -28.5 | -28.7 | -28.9 | -29.1 | -29.3 | -29.5 | -29.8 |
| | 25 | -26.4 | -26.7 | -26.9 | -27.1 | -27.3 | -27.5 | -27.7 | -28.0 | -28.2 | -28.4 | -28.6 | -28.8 | -29.0 | -29.3 | -29.5 | -29.7 |
| | 26 | -26.3 | -26.5 | -26.7 | -26.9 | -27.2 | -27.4 | -27.6 | -27.8 | -28.1 | -28.3 | -28.5 | -28.7 | -29.0 | -29.2 | -29.4 | -29.6 |
| | 27 | -26.1 | -26.3 | -26.5 | -26.8 | -27.0 | -27.3 | -27.5 | -27.7 | -28.0 | -28.2 | -28.4 | -28.7 | -28.9 | -29.1 | -29.4 | -29.6 |
| | 28 | -25.9 | -26.1 | -26.4 | -26.6 | -26.9 | -27.1 | -27.4 | -27.6 | -27.8 | -28.1 | -28.3 | -28.6 | -28.8 | -29.1 | -29.3 | -29.5 |
| | 29 | -25.7 | -26.0 | -26.2 | -26.5 | -26.7 | -27.0 | -27.2 | -27.5 | -27.7 | -28.0 | -28.2 | -28.5 | -28.7 | -29.0 | -29.2 | -29.5 |
| | 30 | -25.5 | -25.8 | -26.1 | -26.3 | -26.6 | -26.8 | -27.1 | -27.4 | -27.6 | -27.9 | -28.1 | -28.4 | -28.7 | -28.9 | -29.2 | -29.4 |
| | 31 | -25.3 | -25.6 | -25.9 | -26.2 | -26.4 | -26.7 | -27.0 | -27.2 | -27.5 | -27.8 | -28.0 | -28.3 | -28.6 | -28.8 | -29.1 | -29.4 |
| | 32 | -25.2 | -25.4 | -25.7 | -26.0 | -26.3 | -26.6 | -26.8 | -27.1 | -27.4 | -27.7 | -27.9 | -28.2 | -28.5 | -28.8 | -29.1 | -29.3 |
| | 33 | -25.0 | -25.3 | -25.6 | -25.8 | -26.1 | -26.4 | -26.7 | -27.0 | -27.3 | -27.6 | -27.8 | -28.1 | -28.4 | -28.7 | -29.0 | -29.3 |
| | 34 | -24.8 | -25.1 | -25.4 | -25.7 | -26.0 | -26.3 | -26.6 | -26.9 | -27.2 | -27.5 | -27.8 | -28.0 | -28.3 | -28.6 | -28.9 | -29.2 |
| | 35 | -24.6 | -24.9 | -25.2 | -25.5 | -25.8 | -26.1 | -26.4 | -26.7 | -27.1 | -27.4 | -27.7 | -28.0 | -28.3 | -28.6 | -28.9 | -29.2 |
| | 36 | -24.4 | -24.8 | -25.1 | -25.4 | -25.7 | -26.0 | -26.3 | -26.6 | -26.9 | -27.3 | -27.6 | -27.9 | -28.2 | -28.5 | -28.8 | -29.1 |
| | 37 | -24.3 | -24.6 | -24.9 | -25.2 | -25.5 | -25.9 | -26.2 | -26.5 | -26.8 | -27.1 | -27.5 | -27.8 | -28.1 | -28.4 | -28.8 | -29.1 |
| | 38 | -24.1 | -24.4 | -24.7 | -25.1 | -25.4 | -25.7 | -26.1 | -26.4 | -26.7 | -27.0 | -27.4 | -27.7 | -28.0 | -28.4 | -28.7 | -29.0 |
| | 39 | -23.9 | -24.2 | -24.6 | -24.9 | -25.2 | -25.6 | -25.9 | -26.3 | -26.6 | -26.9 | -27.3 | -27.6 | -28.0 | -28.3 | -28.6 | -29.0 |
| | 40 | -23.7 | -24.1 | -24.4 | -24.8 | -25.1 | -25.4 | -25.8 | -26.1 | -26.5 | -26.8 | -27.2 | -27.5 | -27.9 | -28.2 | -28.6 | -28.9 |
| | 41 | -23.5 | -23.9 | -24.2 | -24.6 | -25.0 | -25.3 | -25.7 | -26.0 | -26.4 | -26.7 | -27.1 | -27.4 | -27.8 | -28.2 | -28.5 | -28.9 |
| | 42 | -23.3 | -23.7 | -24.1 | -24.4 | -24.8 | -25.2 | -25.5 | -25.9 | -26.3 | -26.6 | -27.0 | -27.4 | -27.7 | -28.1 | -28.4 | -28.8 |
| | 43 | -23.2 | -23.5 | -23.9 | -24.3 | -24.7 | -25.0 | -25.4 | -25.8 | -26.1 | -26.5 | -26.9 | -27.3 | -27.6 | -28.0 | -28.4 | -28.8 |
| | 44 | -23.0 | -23.4 | -23.7 | -24.1 | -24.5 | -24.9 | -25.3 | -25.7 | -26.0 | -26.4 | -26.8 | -27.2 | -27.6 | -27.9 | -28.3 | -28.7 |
| | 45 | -22.8 | -23.2 | -23.6 | -24.0 | -24.4 | -24.8 | -25.1 | -25.5 | -25.9 | -26.3 | -26.7 | -27.1 | -27.5 | -27.9 | -28.3 | -28.7 |
| | 46 | -22.6 | -23.0 | -23.4 | -23.8 | -24.2 | -24.6 | -25.0 | -25.4 | -25.8 | -26.2 | -26.6 | -27.0 | -27.4 | -27.8 | -28.2 | -28.6 |
| | 47 | -22.4 | -22.8 | -23.2 | -23.7 | -24.1 | -24.5 | -24.9 | -25.3 | -25.7 | -26.1 | -26.5 | -26.9 | -27.3 | -27.7 | -28.1 | -28.6 |
| | 48 | -22.3 | -22.7 | -23.1 | -23.5 | -23.9 | -24.3 | -24.8 | -25.2 | -25.6 | -26.0 | -26.4 | -26.8 | -27.3 | -27.7 | -28.1 | -28.5 |
| | 49 | -22.1 | -22.5 | -22.9 | -23.3 | -23.8 | -24.2 | -24.6 | -25.0 | -25.5 | -25.9 | -26.3 | -26.7 | -27.2 | -27.6 | -28.0 | -28.4 |
| | 50 | -21.9 | -22.3 | -22.8 | -23.2 | -23.6 | -24.1 | -24.5 | -24.9 | -25.4 | -25.8 | -26.2 | -26.7 | -27.1 | -27.5 | -28.0 | -28.4 |

DG Note: With a binder bump for the lower temperature grades, there is no risk of being out-of-spec. at 25% RAP.

13-07 b

Table 9 Western Washington Scenario 3

| Achieved PG High Temperature What If Table w/ Virgin HT Critical Temp | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PG Temp | | RAP Stockpile Critical High Temperature, C | | | | | | | | | | | | | | | |
| | 72.2 | 95.0 | 94.0 | 93.0 | 92.0 | 91.0 | 90.0 | 89.0 | 88.0 | 87.0 | 86.0 | 85.0 | 84.0 | 83.0 | 82.0 | 81.0 | 80.0 |
| RAP, % | 0 | #DIV/0! | ###### | ###### | ###### | ###### | ###### | ###### | ###### | ###### | ###### | ###### | ###### | ###### | ###### | ###### | ###### |
| | 1 | 67.2 | 67.2 | 67.2 | 67.2 | 67.2 | 67.2 | 67.2 | 67.2 | 67.2 | 67.2 | 67.2 | 67.1 | 67.1 | 67.1 | 67.1 | 67.1 |
| | 2 | 67.5 | 67.5 | 67.5 | 67.4 | 67.4 | 67.4 | 67.4 | 67.4 | 67.3 | 67.3 | 67.3 | 67.3 | 67.3 | 67.3 | 67.2 | 67.2 |
| | 3 | 67.7 | 67.7 | 67.7 | 67.7 | 67.6 | 67.6 | 67.6 | 67.5 | 67.5 | 67.5 | 67.5 | 67.4 | 67.4 | 67.4 | 67.4 | 67.3 |
| | 4 | 68.0 | 67.9 | 67.9 | 67.9 | 67.8 | 67.8 | 67.8 | 67.7 | 67.7 | 67.7 | 67.6 | 67.6 | 67.6 | 67.5 | 67.5 | 67.5 |
| | 5 | 68.2 | 68.2 | 68.1 | 68.1 | 68.0 | 68.0 | 68.0 | 67.9 | 67.9 | 67.8 | 67.8 | 67.7 | 67.7 | 67.7 | 67.6 | 67.6 |
| | 6 | 68.5 | 68.4 | 68.4 | 68.3 | 68.2 | 68.2 | 68.1 | 68.1 | 68.0 | 68.0 | 67.9 | 67.9 | 67.8 | 67.8 | 67.7 | 67.7 |
| | 7 | 68.7 | 68.6 | 68.6 | 68.5 | 68.5 | 68.4 | 68.3 | 68.3 | 68.2 | 68.2 | 68.1 | 68.0 | 68.0 | 67.9 | 67.9 | 67.8 |
| | 8 | 68.9 | 68.9 | 68.8 | 68.7 | 68.7 | 68.6 | 68.5 | 68.5 | 68.4 | 68.3 | 68.2 | 68.2 | 68.1 | 68.0 | 68.0 | 67.9 |
| | 9 | 69.2 | 69.1 | 69.0 | 69.0 | 68.9 | 68.8 | 68.7 | 68.6 | 68.6 | 68.5 | 68.4 | 68.3 | 68.2 | 68.2 | 68.1 | 68.0 |
| | 10 | 69.4 | 69.3 | 69.3 | 69.2 | 69.1 | 69.0 | 68.9 | 68.8 | 68.7 | 68.6 | 68.6 | 68.5 | 68.4 | 68.3 | 68.2 | 68.1 |
| | 11 | 69.7 | 69.6 | 69.5 | 69.4 | 69.3 | 69.2 | 69.1 | 69.0 | 68.9 | 68.8 | 68.7 | 68.6 | 68.5 | 68.4 | 68.3 | 68.2 |
| | 12 | 69.9 | 69.8 | 69.7 | 69.6 | 69.5 | 69.4 | 69.3 | 69.2 | 69.1 | 69.0 | 68.9 | 68.8 | 68.7 | 68.6 | 68.5 | 68.4 |
| | 13 | 70.2 | 70.0 | 69.9 | 69.8 | 69.7 | 69.6 | 69.5 | 69.4 | 69.3 | 69.1 | 69.0 | 68.9 | 68.8 | 68.7 | 68.6 | 68.5 |
| | 14 | 70.4 | 70.3 | 70.2 | 70.0 | 69.9 | 69.8 | 69.7 | 69.6 | 69.4 | 69.3 | 69.2 | 69.1 | 68.9 | 68.8 | 68.7 | 68.6 |
| | 15 | 70.6 | 70.5 | 70.4 | 70.3 | 70.1 | 70.0 | 69.9 | 69.7 | 69.6 | 69.5 | 69.3 | 69.2 | 69.1 | 69.0 | 68.8 | 68.7 |
| | 16 | 70.9 | 70.7 | 70.6 | 70.5 | 70.3 | 70.2 | 70.1 | 69.9 | 69.8 | 69.6 | 69.5 | 69.4 | 69.2 | 69.1 | 68.9 | 68.8 |
| | 17 | 71.1 | 71.0 | 70.8 | 70.7 | 70.5 | 70.4 | 70.2 | 70.1 | 70.0 | 69.8 | 69.7 | 69.5 | 69.4 | 69.2 | 69.1 | 68.9 |
| | 18 | 71.4 | 71.2 | 71.1 | 70.9 | 70.7 | 70.6 | 70.4 | 70.3 | 70.1 | 70.0 | 69.8 | 69.7 | 69.5 | 69.3 | 69.2 | 69.0 |
| | 19 | 71.6 | 71.5 | 71.3 | 71.1 | 71.0 | 70.8 | 70.6 | 70.5 | 70.3 | 70.1 | 70.0 | 69.8 | 69.6 | 69.5 | 69.3 | 69.1 |
| | 20 | 71.9 | 71.7 | 71.5 | 71.3 | 71.2 | 71.0 | 70.8 | 70.6 | 70.5 | 70.3 | 70.1 | 70.0 | 69.8 | 69.6 | 69.4 | 69.3 |
| | 21 | 72.1 | 71.9 | 71.7 | 71.6 | 71.4 | 71.2 | 71.0 | 70.8 | 70.6 | 70.5 | 70.3 | 70.1 | 69.9 | 69.7 | 69.6 | 69.4 |
| | 22 | 72.3 | 72.2 | 72.0 | 71.8 | 71.6 | 71.4 | 71.2 | 71.0 | 70.8 | 70.6 | 70.4 | 70.2 | 70.1 | 69.9 | 69.7 | 69.5 |
| | 23 | 72.6 | 72.4 | 72.2 | 72.0 | 71.8 | 71.6 | 71.4 | 71.2 | 71.0 | 70.8 | 70.6 | 70.4 | 70.2 | 70.0 | 69.8 | 69.6 |
| | 24 | 72.8 | 72.6 | 72.4 | 72.2 | 72.0 | 71.8 | 71.6 | 71.4 | 71.2 | 71.0 | 70.7 | 70.5 | 70.3 | 70.1 | 69.9 | 69.7 |
| | 25 | 73.1 | 72.9 | 72.6 | 72.4 | 72.2 | 72.0 | 71.8 | 71.6 | 71.3 | 71.1 | 70.9 | 70.7 | 70.5 | 70.3 | 70.0 | 69.8 |
| | 26 | 73.3 | 73.1 | 72.9 | 72.6 | 72.4 | 72.2 | 72.0 | 71.7 | 71.5 | 71.3 | 71.1 | 70.8 | 70.6 | 70.4 | 70.2 | 69.9 |
| | 27 | 73.6 | 73.3 | 73.1 | 72.9 | 72.6 | 72.4 | 72.2 | 71.9 | 71.7 | 71.5 | 71.2 | 71.0 | 70.7 | 70.5 | 70.3 | 70.0 |
| | 28 | 73.8 | 73.6 | 73.3 | 73.1 | 72.8 | 72.6 | 72.3 | 72.1 | 71.9 | 71.6 | 71.4 | 71.1 | 70.9 | 70.6 | 70.4 | 70.2 |
| | 29 | 74.0 | 73.8 | 73.5 | 73.3 | 73.0 | 72.8 | 72.5 | 72.3 | 72.0 | 71.8 | 71.5 | 71.3 | 71.0 | 70.8 | 70.5 | 70.3 |
| | 30 | 74.3 | 74.0 | 73.8 | 73.5 | 73.2 | 73.0 | 72.7 | 72.5 | 72.2 | 71.9 | 71.7 | 71.4 | 71.2 | 70.9 | 70.6 | 70.4 |
| | 31 | 74.5 | 74.3 | 74.0 | 73.7 | 73.5 | 73.2 | 72.9 | 72.7 | 72.4 | 72.1 | 71.8 | 71.6 | 71.3 | 71.0 | 70.8 | 70.5 |
| | 32 | 74.8 | 74.5 | 74.2 | 73.9 | 73.7 | 73.4 | 73.1 | 72.8 | 72.6 | 72.3 | 72.0 | 71.7 | 71.4 | 71.2 | 70.9 | 70.6 |
| | 33 | 75.0 | 74.7 | 74.4 | 74.2 | 73.9 | 73.6 | 73.3 | 73.0 | 72.7 | 72.4 | 72.2 | 71.9 | 71.6 | 71.3 | 71.0 | 70.7 |
| | 34 | 75.3 | 75.0 | 74.7 | 74.4 | 74.1 | 73.8 | 73.5 | 73.2 | 72.9 | 72.6 | 72.3 | 72.0 | 71.7 | 71.4 | 71.1 | 70.8 |
| | 35 | 75.5 | 75.2 | 74.9 | 74.6 | 74.3 | 74.0 | 73.7 | 73.4 | 73.1 | 72.8 | 72.5 | 72.2 | 71.9 | 71.6 | 71.3 | 70.9 |
| | 36 | 75.7 | 75.4 | 75.1 | 74.8 | 74.5 | 74.2 | 73.9 | 73.6 | 73.2 | 72.9 | 72.6 | 72.3 | 72.0 | 71.7 | 71.4 | 71.1 |
| | 37 | 76.0 | 75.7 | 75.3 | 75.0 | 74.7 | 74.4 | 74.1 | 73.7 | 73.4 | 73.1 | 72.8 | 72.5 | 72.1 | 71.8 | 71.5 | 71.2 |
| | 38 | 76.2 | 75.9 | 75.6 | 75.2 | 74.9 | 74.6 | 74.3 | 73.9 | 73.6 | 73.3 | 72.9 | 72.6 | 72.3 | 71.9 | 71.6 | 71.3 |
| | 39 | 76.5 | 76.1 | 75.8 | 75.5 | 75.1 | 74.8 | 74.4 | 74.1 | 73.8 | 73.4 | 73.1 | 72.8 | 72.4 | 72.1 | 71.7 | 71.4 |
| | 40 | 76.7 | 76.4 | 76.0 | 75.7 | 75.3 | 75.0 | 74.6 | 74.3 | 73.9 | 73.6 | 73.2 | 72.9 | 72.6 | 72.2 | 71.9 | 71.5 |
| | 41 | 77.0 | 76.6 | 76.3 | 75.9 | 75.5 | 75.2 | 74.8 | 74.5 | 74.1 | 73.8 | 73.4 | 73.0 | 72.7 | 72.3 | 72.0 | 71.6 |
| | 42 | 77.2 | 76.8 | 76.5 | 76.1 | 75.7 | 75.4 | 75.0 | 74.7 | 74.3 | 73.9 | 73.6 | 73.2 | 72.8 | 72.5 | 72.1 | 71.7 |
| | 43 | 77.4 | 77.1 | 76.7 | 76.3 | 76.0 | 75.6 | 75.2 | 74.8 | 74.5 | 74.1 | 73.7 | 73.3 | 73.0 | 72.6 | 72.2 | 71.9 |
| | 44 | 77.7 | 77.3 | 76.9 | 76.5 | 76.2 | 75.8 | 75.4 | 75.0 | 74.6 | 74.3 | 73.9 | 73.5 | 73.1 | 72.7 | 72.3 | 72.0 |
| | 45 | 77.9 | 77.5 | 77.2 | 76.8 | 76.4 | 76.0 | 75.6 | 75.2 | 74.8 | 74.4 | 74.0 | 73.6 | 73.2 | 72.9 | 72.5 | 72.1 |
| | 46 | 78.2 | 77.8 | 77.4 | 77.0 | 76.6 | 76.2 | 75.8 | 75.4 | 75.0 | 74.6 | 74.2 | 73.8 | 73.4 | 73.0 | 72.6 | 72.2 |
| | 47 | 78.4 | 78.0 | 77.6 | 77.2 | 76.8 | 76.4 | 76.0 | 75.6 | 75.2 | 74.8 | 74.3 | 73.9 | 73.5 | 73.1 | 72.7 | 72.3 |
| | 48 | 78.7 | 78.2 | 77.8 | 77.4 | 77.0 | 76.6 | 76.2 | 75.7 | 75.3 | 74.9 | 74.5 | 74.1 | 73.7 | 73.2 | 72.8 | 72.4 |
| | 49 | 78.9 | 78.5 | 78.1 | 77.6 | 77.2 | 76.8 | 76.4 | 75.9 | 75.5 | 75.1 | 74.7 | 74.2 | 73.8 | 73.4 | 73.0 | 72.5 |
| | 50 | 79.2 | 78.7 | 78.3 | 77.8 | 77.4 | 77.0 | 76.5 | 76.1 | 75.7 | 75.2 | 74.8 | 74.4 | 73.9 | 73.5 | 73.1 | 72.6 |

DG Note: Grade bump on the top end of the binder spec. is necessary at 25% RAP even though the predominance of RAP binder grades in Western Washington fall in the 88°C range.

13-07b

Table 10 Western Washington Scenario 4

| Achieved PG High Temperature What If Table w/ Virgin HT Critical Temp | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PG Temp | | RAP Stockpile Critical High Temperature, C | | | | | | | | | | | | | | | |
| | 67.5 | 95.0 | 94.0 | 93.0 | 92.0 | 91.0 | 90.0 | 89.0 | 88.0 | 87.0 | 86.0 | 85.0 | 84.0 | 83.0 | 82.0 | 81.0 | 80.0 |
| RAP, % | 0 | #DIV/0! | ###### | ###### | ###### | ###### | ###### | ###### | ###### | ###### | ###### | ###### | ###### | ###### | ###### | ###### | ###### |
| | 1 | 61.3 | 61.3 | 61.3 | 61.3 | 61.3 | 61.3 | 61.2 | 61.2 | 61.2 | 61.2 | 61.2 | 61.2 | 61.2 | 61.2 | 61.2 | 61.2 |
| | 2 | 61.6 | 61.6 | 61.6 | 61.5 | 61.5 | 61.5 | 61.5 | 61.5 | 61.5 | 61.4 | 61.4 | 61.4 | 61.4 | 61.4 | 61.3 | 61.3 |
| | 3 | 61.9 | 61.9 | 61.8 | 61.8 | 61.8 | 61.8 | 61.7 | 61.7 | 61.7 | 61.7 | 61.6 | 61.6 | 61.6 | 61.5 | 61.5 | 61.5 |
| | 4 | 62.2 | 62.1 | 62.1 | 62.1 | 62.0 | 62.0 | 62.0 | 61.9 | 61.9 | 61.9 | 61.8 | 61.8 | 61.8 | 61.7 | 61.7 | 61.7 |
| | 5 | 62.5 | 62.4 | 62.4 | 62.3 | 62.3 | 62.3 | 62.2 | 62.2 | 62.1 | 62.1 | 62.0 | 62.0 | 62.0 | 61.9 | 61.9 | 61.8 |
| | 6 | 62.8 | 62.7 | 62.7 | 62.6 | 62.6 | 62.5 | 62.5 | 62.4 | 62.4 | 62.3 | 62.2 | 62.2 | 62.1 | 62.1 | 62.0 | 62.0 |
| | 7 | 63.1 | 63.0 | 62.9 | 62.9 | 62.8 | 62.8 | 62.7 | 62.6 | 62.6 | 62.5 | 62.5 | 62.4 | 62.3 | 62.3 | 62.2 | 62.2 |
| | 8 | 63.4 | 63.3 | 63.2 | 63.2 | 63.1 | 63.0 | 62.9 | 62.9 | 62.8 | 62.7 | 62.7 | 62.6 | 62.5 | 62.5 | 62.4 | 62.3 |
| | 9 | 63.7 | 63.6 | 63.5 | 63.4 | 63.3 | 63.3 | 63.2 | 63.1 | 63.0 | 63.0 | 62.9 | 62.8 | 62.7 | 62.6 | 62.6 | 62.5 |
| | 10 | 64.0 | 63.9 | 63.8 | 63.7 | 63.6 | 63.5 | 63.4 | 63.3 | 63.3 | 63.2 | 63.1 | 63.0 | 62.9 | 62.8 | 62.7 | 62.6 |
| | 11 | 64.2 | 64.2 | 64.1 | 64.0 | 63.9 | 63.8 | 63.7 | 63.6 | 63.5 | 63.4 | 63.3 | 63.2 | 63.1 | 63.0 | 62.9 | 62.8 |
| | 12 | 64.5 | 64.4 | 64.3 | 64.2 | 64.1 | 64.0 | 63.9 | 63.8 | 63.7 | 63.6 | 63.5 | 63.4 | 63.3 | 63.2 | 63.1 | 63.0 |
| | 13 | 64.8 | 64.7 | 64.6 | 64.5 | 64.4 | 64.3 | 64.2 | 64.0 | 63.9 | 63.8 | 63.7 | 63.6 | 63.5 | 63.4 | 63.3 | 63.1 |
| | 14 | 65.1 | 65.0 | 64.9 | 64.8 | 64.6 | 64.5 | 64.4 | 64.3 | 64.2 | 64.0 | 63.9 | 63.8 | 63.7 | 63.6 | 63.4 | 63.3 |
| | 15 | 65.4 | 65.3 | 65.2 | 65.0 | 64.9 | 64.8 | 64.6 | 64.5 | 64.4 | 64.3 | 64.1 | 64.0 | 63.9 | 63.7 | 63.6 | 63.5 |
| | 16 | 65.7 | 65.6 | 65.4 | 65.3 | 65.2 | 65.0 | 64.9 | 64.7 | 64.6 | 64.5 | 64.3 | 64.2 | 64.1 | 63.9 | 63.8 | 63.6 |
| | 17 | 66.0 | 65.9 | 65.7 | 65.6 | 65.4 | 65.3 | 65.1 | 65.0 | 64.8 | 64.7 | 64.5 | 64.4 | 64.2 | 64.1 | 64.0 | 63.8 |
| | 18 | 66.3 | 66.2 | 66.0 | 65.8 | 65.7 | 65.5 | 65.4 | 65.2 | 65.1 | 64.9 | 64.7 | 64.6 | 64.4 | 64.3 | 64.1 | 64.0 |
| | 19 | 66.6 | 66.4 | 66.3 | 66.1 | 65.9 | 65.8 | 65.6 | 65.5 | 65.3 | 65.1 | 65.0 | 64.8 | 64.6 | 64.5 | 64.3 | 64.1 |
| | 20 | 66.9 | 66.7 | 66.6 | 66.4 | 66.2 | 66.0 | 65.9 | 65.7 | 65.5 | 65.3 | 65.2 | 65.0 | 64.8 | 64.6 | 64.5 | 64.3 |
| | 21 | 67.2 | 67.0 | 66.8 | 66.7 | 66.5 | 66.3 | 66.1 | 65.9 | 65.7 | 65.6 | 65.4 | 65.2 | 65.0 | 64.8 | 64.6 | 64.5 |
| | 22 | 67.5 | 67.3 | 67.1 | 66.9 | 66.7 | 66.5 | 66.3 | 66.2 | 66.0 | 65.8 | 65.6 | 65.4 | 65.2 | 65.0 | 64.8 | 64.6 |
| | 23 | 67.8 | 67.6 | 67.4 | 67.2 | 67.0 | 66.8 | 66.6 | 66.4 | 66.2 | 66.0 | 65.8 | 65.6 | 65.4 | 65.2 | 65.0 | 64.8 |
| | 24 | 68.1 | 67.9 | 67.7 | 67.5 | 67.2 | 67.0 | 66.8 | 66.6 | 66.4 | 66.2 | 66.0 | 65.8 | 65.6 | 65.4 | 65.2 | 65.0 |
| | 25 | 68.4 | 68.2 | 67.9 | 67.7 | 67.5 | 67.3 | 67.1 | 66.9 | 66.6 | 66.4 | 66.2 | 66.0 | 65.8 | 65.6 | 65.3 | 65.1 |
| | 26 | 68.7 | 68.4 | 68.2 | 68.0 | 67.8 | 67.5 | 67.3 | 67.1 | 66.9 | 66.6 | 66.4 | 66.2 | 66.0 | 65.7 | 65.5 | 65.3 |
| | 27 | 69.0 | 68.7 | 68.5 | 68.3 | 68.0 | 67.8 | 67.6 | 67.3 | 67.1 | 66.9 | 66.6 | 66.4 | 66.2 | 65.9 | 65.7 | 65.5 |
| | 28 | 69.3 | 69.0 | 68.8 | 68.5 | 68.3 | 68.0 | 67.8 | 67.6 | 67.3 | 67.1 | 66.8 | 66.6 | 66.3 | 66.1 | 65.9 | 65.6 |
| | 29 | 69.6 | 69.3 | 69.1 | 68.8 | 68.6 | 68.3 | 68.0 | 67.8 | 67.5 | 67.3 | 67.0 | 66.8 | 66.5 | 66.3 | 66.0 | 65.8 |
| | 30 | 69.9 | 69.6 | 69.3 | 69.1 | 68.8 | 68.6 | 68.3 | 68.0 | 67.8 | 67.5 | 67.2 | 67.0 | 66.7 | 66.5 | 66.2 | 65.9 |
| | 31 | 70.1 | 69.9 | 69.6 | 69.3 | 69.1 | 68.8 | 68.5 | 68.3 | 68.0 | 67.7 | 67.5 | 67.2 | 66.9 | 66.7 | 66.4 | 66.1 |
| | 32 | 70.4 | 70.2 | 69.9 | 69.6 | 69.3 | 69.1 | 68.8 | 68.5 | 68.2 | 67.9 | 67.7 | 67.4 | 67.1 | 66.8 | 66.6 | 66.3 |
| | 33 | 70.7 | 70.5 | 70.2 | 69.9 | 69.6 | 69.3 | 69.0 | 68.7 | 68.4 | 68.2 | 67.9 | 67.6 | 67.3 | 67.0 | 66.7 | 66.4 |
| | 34 | 71.0 | 70.7 | 70.4 | 70.1 | 69.9 | 69.6 | 69.3 | 69.0 | 68.7 | 68.4 | 68.1 | 67.8 | 67.5 | 67.2 | 66.9 | 66.6 |
| | 35 | 71.3 | 71.0 | 70.7 | 70.4 | 70.1 | 69.8 | 69.5 | 69.2 | 68.9 | 68.6 | 68.3 | 68.0 | 67.7 | 67.4 | 67.1 | 66.8 |
| | 36 | 71.6 | 71.3 | 71.0 | 70.7 | 70.4 | 70.1 | 69.7 | 69.4 | 69.1 | 68.8 | 68.5 | 68.2 | 67.9 | 67.6 | 67.2 | 66.9 |
| | 37 | 71.9 | 71.6 | 71.3 | 71.0 | 70.6 | 70.3 | 70.0 | 69.7 | 69.3 | 69.0 | 68.7 | 68.4 | 68.1 | 67.7 | 67.4 | 67.1 |
| | 38 | 72.2 | 71.9 | 71.6 | 71.2 | 70.9 | 70.6 | 70.2 | 69.9 | 69.6 | 69.2 | 68.9 | 68.6 | 68.3 | 67.9 | 67.6 | 67.3 |
| | 39 | 72.5 | 72.2 | 71.8 | 71.5 | 71.2 | 70.8 | 70.5 | 70.1 | 69.8 | 69.5 | 69.1 | 68.8 | 68.4 | 68.1 | 67.8 | 67.4 |
| | 40 | 72.8 | 72.5 | 72.1 | 71.8 | 71.4 | 71.1 | 70.7 | 70.4 | 70.0 | 69.7 | 69.3 | 69.0 | 68.6 | 68.3 | 67.9 | 67.6 |
| | 41 | 73.1 | 72.7 | 72.4 | 72.0 | 71.7 | 71.3 | 71.0 | 70.6 | 70.3 | 69.9 | 69.5 | 69.2 | 68.8 | 68.5 | 68.1 | 67.8 |
| | 42 | 73.4 | 73.0 | 72.7 | 72.3 | 71.9 | 71.6 | 71.2 | 70.8 | 70.5 | 70.1 | 69.7 | 69.4 | 69.0 | 68.7 | 68.3 | 67.9 |
| | 43 | 73.7 | 73.3 | 72.9 | 72.6 | 72.2 | 71.8 | 71.4 | 71.1 | 70.7 | 70.3 | 70.0 | 69.6 | 69.2 | 68.8 | 68.5 | 68.1 |
| | 44 | 74.0 | 73.6 | 73.2 | 72.8 | 72.5 | 72.1 | 71.7 | 71.3 | 70.9 | 70.5 | 70.2 | 69.8 | 69.4 | 69.0 | 68.6 | 68.3 |
| | 45 | 74.3 | 73.9 | 73.5 | 73.1 | 72.7 | 72.3 | 71.9 | 71.5 | 71.2 | 70.8 | 70.4 | 70.0 | 69.6 | 69.2 | 68.8 | 68.4 |
| | 46 | 74.6 | 74.2 | 73.8 | 73.4 | 73.0 | 72.6 | 72.2 | 71.8 | 71.4 | 71.0 | 70.6 | 70.2 | 69.8 | 69.4 | 69.0 | 68.6 |
| | 47 | 74.9 | 74.5 | 74.1 | 73.6 | 73.2 | 72.8 | 72.4 | 72.0 | 71.6 | 71.2 | 70.8 | 70.4 | 70.0 | 69.6 | 69.2 | 68.8 |
| | 48 | 75.2 | 74.7 | 74.3 | 73.9 | 73.5 | 73.1 | 72.7 | 72.2 | 71.8 | 71.4 | 71.0 | 70.6 | 70.2 | 69.7 | 69.3 | 68.9 |
| | 49 | 75.5 | 75.0 | 74.6 | 74.2 | 73.8 | 73.3 | 72.9 | 72.5 | 72.1 | 71.6 | 71.2 | 70.8 | 70.4 | 69.9 | 69.5 | 69.1 |
| | 50 | 75.8 | 75.3 | 74.9 | 74.5 | 74.0 | 73.6 | 73.2 | 72.7 | 72.3 | 71.8 | 71.4 | 71.0 | 70.5 | 70.1 | 69.7 | 69.2 |

DG Note: With a binder bump, the 25% RAP results in compliance throughout the recovered RAP binder grade range.

***DRAFT V2.0 – Statement of the Issues: WAPA Proposal to move HMA Aggregate Testing out of 3-04 and into 5-04***

The separation of HMA aggregate and HMA mix testing has caused confusion and conflict in the last few years and has even led to potential project delays based on single aggregate tests (generally from uncompacted void content (FAA) testing) without an equitable vehicle for challenging the test or disproving the relevance of the test.

Attach #14-13a

It is WAPA's view that recent specification changes (limited natural sands from secondary sources) and the use of a rutting performance test during mix design evaluation (Hamburg) are serving to greatly reduce mix rutting susceptibility, as was WSDOT's intent. These items have in turn greatly limited the practical usefulness of the FAA test, which is simply an imperfect "indicator" test, at best (see attached excerpts from NCHRP Report 539). The limited natural (blending) sand spec. and the Hamburg tests make the current "pass/ fail" nature of the FAA aggregate specification, and the resulting potential penalties, disproportionate to the true relevance of the test.

WAPA believes that the FAA test should be recognized as somewhat obsolete now that Hamburg testing is in full force. Alternately, its importance should be reduced and the test reporting simplified/ unified as an HMA test. As a way to retain the test (WSDOT's previously voiced preference) but to also make it more indicative of its role in HMA quality, WAPA proposes to eliminate all HMA aggregate testing from 3-04 and move the testing into 5-04 mixture evaluation.

**WAPA Proposed specification updates:**

Eliminate HMA Aggregate Testing from 3-04 Table 1 and move those tests to 5-04.5(1)A as shown below:

| Table of Price Adjustment Factors | |
|---|---|
| Constituent | Factor "f" |
| All aggregate passing: 1 ½", 1", ¾", ½", 3/8", and No. 4 sieves | 2 |
| All aggregate passing No. 8 sieve | 15 |
| All aggregate passing No. 200 sieve | 20 |
| Asphalt Binder | 40 |
| Air Voids (Va) | 20 |
| Sand Equivalent (SE) | 5 |
| Fracture | 5 |
| Uncompacted Void Content (FAA) | 5 |

**Notes:** All the tests in 5-04.5(1)A would be able to be challenged in the same way current HMA component tests are able to be challenged in the existing 5-04 system. Also allow for challenge of FAA specific gravity tests if they appear low vs. historical date and recalculate FAA with the proper SG.

Additionally, as the direct link between FAA and rutting stability is tenuous in many circumstances, the Contractor should have the option to challenge the Uncompacted Void Content penalty through Hamburg evaluation of pavement cores in a system similar to compaction challenges by coring. (Added/ better option) – HMA challenge samples (to produce Hamburg pucks for Hamburg testing) could be collected in parallel with FAA testing and disposed of as FAA testing passes or challenge time windows expire. Testing costs to be borne by the prevailing party (i.e. Contractor pays if Hamburg fails, WSDOT pays if Hamburg passes).

Allow the project to progress with low FAA if it has demonstrated stability in the Hamburg test, with no on-going penalites.

The frequency of the aggregate tests would not change under this proposal. Each aggregate test would be posted to represent two HMA lots in SAM.

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Attach #14-13b

NCHRP REPORT 539

# Aggregate Properties and the Performance of Superpave-Designed Hot Mix Asphalt

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SUBJECT AREAS
Materials and Construction

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relationship exists for 20 to 40% exceeding a 3:1 ratio. The test for uncompacted voids in fine aggregate is a reasonable measure of fine aggregate angularity (FAA), but the present FAA criteria are likely too restrictive. No relationship can be corroborated between the presence of clay-like particles in aggregate (as measured by the sand equivalent) and HMA performance, but this lack may be related to the inadequacy of the present test method. Similar mixed results were found for the aggregate source properties specified in the Superpave mix design method. No relationship could be established between the Los Angeles abrasion test results and long-term wear of HMA pavement surfaces. The magnesium sulfate soundness and Micro-Deval abrasion loss tests are highly correlated, and there is a demonstrated relationship between Micro-Deval results and pavement particle abrasion. Finally, available experiment results do not demonstrate any difference in rutting resistance between coarse- and fine-graded Superpave mix designs.

The project final report presents the detailed results of the critical review and analysis in seven chapters and an appendix; this published report contains the complete final report.

This report has been referred to the TRB Mixtures and Aggregate Expert Task Group for its review and possible recommendation to the AASHTO Highway Subcommittees on Materials as support for revision of selected specifications and methods.

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**TABLE 6 Precision of ASTM D4791 F&E tests from AMRL Proficiency Samples 117 and 118 (*43*)**

| Particle Size, mm | Number of Labs | Sample 1 Multilaboratory Precision | | | Sample 2 Multilaboratory Precision | | | Single Operator Precision | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | Sample 1 | | Sample 2 | |
| | | Avg. | 1S% | D2S% | Avg. | 1S% | D2S% | 1S% | D2S% | 1S% | D2S% |
| 19.0 to 12.5 | 128 | 14.4 | 51.0 | 144.3 | 13.1 | 53.4 | 151.0 | 26.6 | 75.3 | 29.1 | 82.2 |
| 12.5 to 9.5 | 123 | 17.6 | 43.9 | 124.1 | 17.3 | 42.1 | 119.2 | 22.7 | 64.2 | 23.1 | 65.2 |
| 9.5 to 4.75 | 122 | 24.9 | 45.7 | 129.3 | 23.3 | 46.4 | 131.2 | 18.3 | 51.8 | 19.6 | 55.4 |

near the existing specification level of 10% particles exceeding the 5:1 ratio of maximum-to-minimum particle dimension. The research conducted to date generally supports the following:

- Percentage of F&E changes with handling of the stockpile and mixing.
- Aggregate breakdown during compaction increases for higher percentages of F&E.
- VMA generally increases with increasing percent F&E.
- There does not be appear to be a relationship between the percentage of F&E exceeding the 3:1 ratio—in the range of approximately 10% to 40%—and performance.
- ASTM D4791 is a highly variable test procedure. Alternative methods of determining the percentage of F&E should be developed. This variability may mask relationships with performance.

## 2.4 METHODS OF MEASURING FAA AND THEIR RELATIONSHIP TO PERFORMANCE

### 2.4.1 Introduction

It has long been recognized that the characteristics of the fine aggregate component of HMA can have a significant and sometimes dominant influence on mixture rutting and fatigue cracking resistance (*2, 34, 44,* and *45*). Kandhal et al. (*46*) have classified the test methods to describe aggregate angularity into two broad categories: direct and indirect. *Direct* methods are defined as those wherein particle shape or texture are measured and described qualitatively or quantitatively through direct measurement of individual particles. In *indirect* methods, particle shape and texture are determined based on measurements of bulk properties.

### 2.4.2 Uncompacted Voids Content in Fine Aggregate

The Superpave method specifies AASHTO T304 (ASTM C1252), "Uncompacted Void Content in Fine Aggregate, Method A," to ensure that the *blend* of fine aggregates in an HMA mixture has sufficient internal friction to provide rutresistance in an HMA mixture (*47*). The amount of friction depends on the aggregate particle shape and texture. Higher internal friction is associated with increased rutting resistance. AASHTO T304 is commonly referred to as the FAA test. FAA levels used in the Superpave method are below 40, 40 to 45, and above 45. The higher values are specified for layers near the pavement surface and for higher traffic levels. AASHTO T304 was to be used in conjunction with the restricted zone to limit the amount of rounded natural sand in high traffic mixes.

The angularity and texture of the fine aggregate also affect the packing characteristics of the HMA and, therefore, the VMA of the compacted HMA. More angular or poorly shaped particles or particles having a high degree of texture may not pack as tightly as rounded or smooth particles and, therefore, may provide greater VMA in the compacted HMA.

The FAA test is an indirect measure of particle shape, angularity, and texture. The FAA test is based on the National Aggregate Association Flow Test (Method A) that is used to evaluate the effect of the fine aggregate on the finish ability of Portland cement concrete. The FAA value is defined as the percent air voids in a loosely compacted sample of fine aggregate. The FAA test assumes that more angular particles or particles with more surface texture will not pack together as tightly as rounded or smooth particles would.

In AASHTO T304, a 190-g sample of fine aggregate of a prescribed gradation is allowed to flow through the orifice of a funnel and fill a 100-cm$^3$ calibrated cylinder. Excess material is struck off, and the cylinder with aggregate is weighed. The uncompacted void content of the sample is then computed using the loosely compacted weight of the aggregate, the bulk dry specific gravity of the aggregate, and the calibrated volume of the receiving cylinder.

There are three methods for running AASHTO T304: Methods A, B, and C. The mass of the sample for all three methods is fixed at 190 g. Method A specifies a known gradation ranging from material passing the 2.36-mm sieve to material retained on the 0.150-mm sieve. Method B specifies that the test be run on three individual size fractions: 2.36 to 1.18 mm, 1.18 to 0.600 mm, and 0.600 to 0.300 mm. The reported void content for Method B is the average of the results from the three individual size fractions. In Method C, the test is run on the as-received gradation (*48*).

The Superpave researchers chose Method A to limit the effect of gradation, particularly material passing the 0.075-mm sieve on the test result. For example, if one were to test a washed manufactured sand with a –0.075 mm sieve content of 8% and a crushed screening produced from the same aggregate and crushed with the same crusher settings with a –0.075 mm sieve content of 14% under Method C, the crushed screening would produce a lower FAA value than would the washed manufactured sand even though the two materials have identical particle shape and texture.

Several studies have been conducted to compare Methods A, B, and C (*49–53*). The studies have indicated a strong relationship between Methods B and C, with Method B producing uncompacted void contents almost 5 points higher (*49, 51–53*). Hossain et al. (*49*) observed that the uncompacted void contents were generally higher for smaller sized particles. Hudson (*50*) stated that, based on visual observation, particle shape appeared to be constant with size. Thus, particle texture may have a greater effect for smaller particles. Roque et al. (*51*) noted the strong effect of texture in AASHTO T304 tests. Hudson (*50*) states:

> Test method C relates to the materials "as-is," or "in-situ." Little or no shape information can be determined from this method as the reduction in voids content that would be attributed to improved particle shape cannot be separated due to the influence of the sample gradation.

Researchers have also investigated the effects of alternate gradations. Hossain et al. (*49*) evaluated a gradation typical of dense-graded HMA that included material passing the 4.75-mm sieve and retained on the 2.35-mm sieve. Alternate gradations are strongly correlated with the Method A gradation (*49, 51*). The blended uncompacted voids contents were on average 2.4% lower when the material retained on the 2.36-mm sieve was included (*49*). Hudson (*50*) stated that the current AASHTO T304 equipment was not suitable for testing the material passing the 4.75-mm sieve and retained on the 2.36-mm sieve because the outlet orifice and the receiving container were both too small. Virginia Test Method 5, which uses an enlarged version of the AASHTO T304 apparatus, produced identical uncompacted void contents when the Method A grading was tested in both devices (*53*). Based on the preceding research, altering the AASHTO T304 Method A gradation or fixtures would appear to shift uniformly the uncompacted void contents for all aggregates.

Several concerns have been expressed regarding the use of the FAA test as a screening tool for rutting resistance of fine aggregate. There is concern that some 100% crushed particles do not meet the minimum requirements (>45) for mixes used in the upper 100 mm of the pavement structure with traffic levels in excess of 3 million ESALs during the design life (*54*). Typically, these particles are extremely cubical in nature. A second concern is that particles passing the 4.75-mm sieve but retained on the 2.36-mm sieve are not evaluated for angularity or shape under the current Superpave aggregate properties (*52*). Work by Hudson (*50*) indicates that the current AASHTO T304 apparatus may not be appropriate for testing particles in this size range. A third concern is related to the variability of the test procedure and its dependence on the fine aggregate dry bulk specific gravity (*52*).

Finally, there is concern that the FAA test may not be related to the rutting propensity of the HMA mixture. These concerns led to numerous studies evaluating the FAA test as well as alternative tests to relate FAA, shape, and texture to the rutting performance of HMA mixtures. Commonly used alternative tests will be discussed prior to efforts to relate FAA to HMA performance.

### 2.4.3 Alternative Methods of Measuring FAA

#### *2.4.3.1 Direct Tests (Digital Imaging Methods)*

In the past few years, digital image processing technique has been introduced into the HMA industry to analyze macro- and microstructures of HMA, aggregates, air voids, gradation, and so on. Several researchers have attempted to use image analysis to measure the FAA. Particle shape from image analysis, automated image analysis, and morphology analysis from profile images and from 3-D images are some of the image analysis methods being used actively in recent years.

**Particle Shape from Image Analysis:** This automated technique was developed at the University of Arkansas for FHWA (*55*). The fine aggregate is spread on a glass plate, and a high-resolution video camera is used to capture the image of each particle. Modern digital imaging hardware, image analysis techniques, and computerized analysis were used to quantify aggregate shape. EAAP (ellipse-based area of the object divided by the perimeter squared) Index and Roundness Index were found to have the most potential for predicting rutting performance.

**Automated Image Analysis:** The automated image analysis approach was developed by Massad et al. (*56*). Two procedures—surface erosion-dilation technique and fractal-behavior technique—were used to quantify FAA. The surface erosion-dilation technique consists of subjecting the aggregate surface to a smoothing effect that causes the angularity elements to disappear from the image. The aggregate angularity is measured in terms of a surface parameter, which is defined as the area lost during the erosion-dilation process as a percentage of the total area of the original image.

The fractal-behavior technique uses image-analysis techniques to capture the aggregate boundary. Fractal length of the boundary is the slope of effective-width-to-number-of-cycles relationship. The fractal length increases with aggregate angularity.

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**Morphology Analysis from Profile Images and 3-D Images:** Similar techniques have been applied by Wang and Mohammad (*57*) and Kecham and Shashidhar (*58*) to evaluate particle size, shape, angularity, and texture of aggregate.

*2.4.3.2 Indirect Tests*

**Standard Test Method for Index of Aggregate Particle Shape and Texture (ASTM D3398):** In this test method, the sample is first broken down into individual sieve fractions. Thus, the gradation of the sample is determined. Each size of material is then separately compacted in a cylindrical mold using a tamping rod at 10 and 50 drops from a height of 2 in. The mold is filled completely by adding extra material so that it levels off with the top of the mold. The weight of the material in the mold at each compactive effort is determined, and the percent voids is computed. A particle index for each size fraction is then computed, and, using the gradation of the sample, a weighted average particle index for the entire sample is also calculated (*16*).

**Direct Shear Test (ASTM D 3080):** The direct shear test (DST) method is used to measure the angle of internal fraction of a fine aggregate under different normal stress conditions. A prepared sample of the aggregate under consideration is consolidated in a shear mold. The sample is then placed in a direct shear device and sheared by a horizontal force while known normal stress is applied (*16*). DST is probably the most straightforward way to determine the stress-dependent shear strength of fine aggregate. Research conducted by Fernandes et al. (*59*) found that direct shear strength may provide a more relevant parameter to evaluate fine aggregates. The researchers also stated that the DST is significantly more complex and less repeatable than the FAA test, and its relation to the performance of fine aggregates needs to be further verified and developed.

**CAR Test:** The CAR test method was developed to evaluate shear resistance of compacted fine aggregate (*60, 61*). It is similar to the Florida bearing ratio test (*61*). In this method, fine aggregates are compacted in a 100-mm mold following the Marshall hammer method using 50 blows applied to only one face of the specimen. The compacted sample height was maintained as 63.5 mm. The CAR stability was measured by applying a compressive load using the Marshall test machine. The compacted sample, while still in the mold, is placed in the Marshall test machine in the upright position. A load of 50 mm/min is transmitted through a 37.5-mm-diameter steel cylinder on the plane surface of the compacted sample. The highest load that one specimen can carry was reported as the CAR stability value. This test is believed to be a performance-related method of measuring FAA (*61*).

### 2.4.4 Relationships Between Fine Aggregate Shape, Angularity, and Texture and HMA Performance

*2.4.4.1 Introduction*

The following section describes 12 studies relating FAA to HMA performance. Because of the controversy over the fine aggregate uncompacted voids test, the studies are discussed individually and in some detail.

*2.4.4.2 NCAT National Rutting Study by Cross and Brown*

Cross and Brown (*17*) reported relationships between aggregate properties and field rut depth obtained from a national rutting study. The study indicated the aggregate properties had little relationship with rutting when the in-place air voids of the pavement section were less than 2.5%; however, relationships between aggregate properties and field rut depths were observed for pavement sections with in-place air void contents in excess of 2.5%. A relationship with an $R^2 = 0.67$ was determined between the National Aggregate Association (NAA) Flow Test Method A, which is the basis of AASHTO T304, and the pavement rut depth divided by the square root of the applied ESAL. The relationship was developed from the analysis of data from 13 pavements. The pavement rut depth divided by the square root of ESALs was used to account for the fact that greater truck traffic was likely to produce greater pavement rut depths.

A rutting model with an $R^2 = 0.77$ was developed between rate of rutting and aggregate properties with data from pavements with in-place air voids in excess of 2.5%. The aggregate properties considered included coarse aggregate crushed faces, uncompacted voids in fine aggregate, gradation parameters, and both nominal and maximum aggregate size divided by lift thickness (*17*). Only two factors—percent of coarse aggregate with two or more crushed faces and uncompacted voids in fine aggregate—were included in the model (Equation 1).

$$P = 0.080038 - 0.00008(CF) - 0.00151(NAA) \quad (1)$$

where

$P$ = predicted rate of rutting, rut depth (mm)/square root ESAL;
$CF$ = two or more crushed faces in coarse aggregate (%); and
$NAA$ = NAA uncompacted voids, (%).

In 1992, Cross and Brown (*10*) reported that a rutting rate of 0.005842 mm per square root ESALs delineated good performing pavements from rutted pavements. Using this criterion and the relationship between the NAA flow test and rutting rate (*17*), Kandhal et al. (*20*) determined a minimum uncompacted voids content of 43.3%. Cross and Brown (*17*) developed several additional models relating uncompacted voids content and air void contents of recompacted specimens using various compaction methods.

#### *2.4.4.3 Evaluation of Particle Shape and Texture of Mineral Aggregates Used in Pennsylvania by Kandhal et al.*

Kandhal et al. (*20*) evaluated 18 sources (8 natural and 10 manufactured) of fine aggregate from Pennsylvania using ASTM D3398 and both Methods A and B of the NAA uncompacted voids test. They observed an overlap between the natural and manufactured sands in that one manufactured sand, a limestone, produced both a particle index (12.8) and an NAA uncompacted void contents (Method A = 43.1) that were lower than those of several natural sands. The authors concluded that a minimum particle index of 14 and NAA uncompacted voids content Method A of 44.5 separated between natural and manufactured sands with confidence levels of 86% and 82%, respectively.

During the development of the Superpave method, an expert panel using a modified Delphi process determined the consensus aggregate properties (*1*). During the fifth round of questionnaires used as part of the Delphi process, the expert panel recommended minimum uncompacted voids of 42.8% for pavements with design traffic levels less than 300,000 ESALs and 44.2 for pavements with design traffic levels less than 10 million ESALs. These values represented the expert panel's average recommendations for pavement layers in the top 50 mm of the pavement structure. The recommended uncompacted void levels were reduced to 41.4% and 42.8%, respectively, for layers at a depth of 127 mm.

#### *2.4.4.4 Evaluation of Natural Sands Used in Asphalt Mixtures by Stuart and Mogawer*

Stuart and Mogawer (*62*) conducted a study to evaluate different methods of measuring fine aggregate shape and texture. Twelve materials were evaluated in the study: five natural sands with a poor performance history, four natural sands with a good performance history, and three manufactured (crushed) sands with a good performance history. Five methods were used to characterize the sands: NAA uncompacted voids Method A, DST, ASTM D3398, Michigan Test Method 118-90, and a flow rate method. Michigan test method 118-90 is similar to the NAA uncompacted voids test in that the volume of voids in a loosely compacted sample is used to determine the air voids–to–solids ratio and, in turn, an angularity index. The volume of voids is determined in water in a graduated cylinder, which eliminates the need for a bulk specific gravity; however, the results are affected by the aggregate absorption. Based on Michigan DOT's survey responses, this test method has been replaced by AASHTO T304. The flow rate test uses the NAA apparatus. The flow rate is determined by dividing the volume of a 500-g sample of fine aggregate by the time it takes to flow through the NAA orifice. A shape-texture index is calculated from the flow time by dividing the flow time from a standard set of steel balls by the flow time for the fine aggregate. Standardized gradations were used for the study. Previous studies had evaluated the as-received gradations and recommended a standardized gradation for the NAA uncompacted voids test, Michigan Test Method 118-90, and flow rate test (*63*).

The twelve sands were ranked by each of the test methods based on the average test value. The best method of differentiation was the flow time test. This was also the easiest parameter to obtain. ASTM D3398 correctly differentiated all of the poor-quality sands from the good-quality sands. The weighted particle index that divided good- and poor-performing materials was between 11.7 and 13.9. NAA uncompacted voids Method A ranked one of the poor-quality materials the same as one of the good-quality materials. Both had an uncompacted voids content of 44.7%. However, the test procedure for the poor sand was violated because the sand did not have size fractions retained above the 0.600-mm sieve. Thus three size fractions were excluded from the standard. Mogawer and Stuart (*63*) concluded that 44.7% uncompacted voids would divide good- and poor-performing sands for high traffic levels. The remaining methods, Michigan Test Method 118-90 and the DST, did not differentiate the sands as well. The authors noted that the DST was time consuming.

Attempts were made to differentiate between the rutting performance of HMA produced with four of the sands, two of good quality and two of poor quality. Twelve aggregate blends with levels of 10%, 20%, and 30% of each of the sands were tested with the GLWT, the French Laboratorie Central des Ponts et Chaussées (LCPC) Pavement Rutting Tester, and the USACE's Gyratory Testing Machine. The remainder of the mix was made up of a good-quality traprock coarse aggregate and traprock crushed sand. Unfortunately, none of the rutting tests differentiated between the performance of the sands. This was most likely due to the high quality of the other aggregates (crushed traprock) used in the blend (*62*).

Stuart and Mogawer (*62*) presented three additional important conclusions:

1. Methods for measuring shape and texture can only be expected to group sands into performance categories, such as high or low potential for rutting. The performance of a sand depends on its quality, the quantity used, the qualities of the other aggregates, and the traffic level.

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2. Each sand should be tested to determine its rutting potential. The methods are not sensitive enough to evaluate the blend of materials found in a job-mix formula gradation.
3. The discrepancies provided by the NAA and the Michigan DOT methods may be related to gradation. A single, standard gradation should be used in these methods so that the voids that they provide are only a function of shape and texture.

#### 2.4.4.5 *Investigation of the Influence of Aggregate Properties on Performance of Heavy-Duty HMA Pavements by Ahlrich*

Ahlrich (*19*) reported an investigation of aggregate particle shape and texture on the permanent deformation properties of HMA meeting the Federal Aviation Administration's P-401 specification. Eleven blends meeting the P-401 gradation band were produced with varying amounts of crushed coarse aggregate (0%, 30%, 50%, 70%, and 100%) and varying amounts of natural sand (0%, 10%, 20%, 30%, and 40%). The blends were produced using crushed limestone, crushed gravel, and uncrushed gravel. The fine aggregate portion of the blends was evaluated by visual inspection of the percent crushed particles according to CRD-C-171, ASTM D3398 (Particle Index Test), and ASTM C1252 Methods A and C (FAA test). The uncompacted voids contents of the fine aggregate portion of the 11 blends as measured by ASTM C1252 Method A ranged from 38.4% to 47.1%. ASTM D3398 and ASTM C1252 Method A both produced strong correlations ($R^2 = 0.98$) with the percent crushed particles (minimum two fractured faces). ASTM C1252 Method A produced the best correlation with the percent of (rounded) natural sand in the blend ($R^2 = 0.94$). ASTM C1252 Method C produced lower $R^2$ values with both the percent crushed faces and percent natural sand ($R^2 = 0.66$ and $R^2 = 0.71$, respectively).

A volumetric mix design was performed for each of the 11 blends using the USACE's Gyratory Testing Machine. The samples were prepared with AC-20 (approximately PG 64-22). Samples were tested using a triaxial (confined) repeated load creep test at 60°C. Three properties were used to evaluate the rutting propensity of the mixtures: permanent strain, creep modulus, and slope of the deformation curve. The composite (coarse and fine aggregate) particle index measured by ASTM D3398 produced the best correlation with all three parameters ($R^2 = 0.78$, 0.69, and 0.71, respectively). ASTM C1252 Method A produced better correlations with all three parameters than the other two fine aggregate tests (ASTM D3398 and percent crushed particles). The $R^2$ values ranged from 0.29 to 0.41. The better correlation with the composite aggregate index from ASTM D3398 is not unexpected because the coarse aggregate fraction was also varied between the blends. Ahlrich (*19*) concluded.

> On the basis of the strong correlations and simple test procedure, the promising alternatives for specification requirements to characterize aggregate particle shape and texture instead of percent crushed particles are modified ASTM C1252 for the coarse aggregate fraction and ASTM C1252 for the fine aggregate fraction.

#### 2.4.4.6 *Study of the Contribution of FAA and Particle Shape to Superpave Mixture Performance by Huber et al.*

Huber et al. (*34*) conducted a study to assess the contribution of FAA and particle shape to the rutting performance of a Superpave-designed HMA. Four fine aggregates were selected for the study: a Georgia granite; Alabama limestone; Indiana crushed sand (geology not identified, most likely limestone); and Indiana natural sand. The uncompacted void contents (AASHTO T304 Method A) of the four aggregates were measured as 48, 46, 42, and 38, respectively. A reference mixture was prepared with the Georgia granite (coarse and fine aggregate) and a PG 67-22 binder. The other three aggregates were sieved into size fractions and substituted for the granite fine aggregate to produce four mixtures, keeping the gradation constant. All four blends were mixed at the optimum asphalt content determined for the granite blend. No adjustment was made for variances in asphalt absorption between the fine aggregates.

The resulting mixtures were tested in the Couch Wheel Tracker (a modified Hamburg Wheel Tracker), the APA, and the SST using the frequency sweep test. The rutting tests did not appear to differentiate between the blends in a consistent manner or at all in some cases. The authors concluded that the choice of coarse aggregate may have masked the effect of the fine aggregate (*34*). There was not a correlation between any of the tests and the uncompacted void contents. This finding is not unexpected because there were not significant differences between the rutting results.

#### 2.4.4.7 *NCHRP Project 4-19 by Kandhal and Parker*

NCHRP Project 4-19, "Aggregate Tests Related to Asphalt Concrete Performance in Pavements," (*2*) evaluated fine aggregate tests related to rutting performance. Three tests were used in the study: ASTM D3398, AASHTO T304 Method A, and particle shape from image analysis (the University of Arkansas Method). Used in this study were nine fine aggregate sources with a range in uncompacted void contents of 40.3% to 47.5%. Three of the materials were natural sands. The fine aggregates were mixed with an uncrushed gravel coarse aggregate. All of the mixes were produced using the same gradation, above the maximum density line. The coarse aggregate and gradation were chosen to emphasize the response of the fine aggregate. The aggregate was mixed with a PG 64-22 binder. A mix design was conducted for each mixture using an $N_{design}$ level of 119 gyrations to determine optimum asphalt content.

The resulting mixtures were tested using the GLWT and the SST. Simple shear at constant height and frequency sweep at constant height were performed using the SST. Poor correlation coefficients were observed between all three fine aggregate tests and the SST results. The index of aggregate shape and particle texture from ASTM D3398 produced the best correlation with the GLWT rut depths ($R^2$ = 0.67). The uncompacted void contents produced a slightly lower correlation ($R^2$ = 0.60). The authors noted that the uncompacted voids were highly correlated with the aggregate index ($R^2$ = 0.99) and that the uncompacted voids test was much simpler to run. They therefore recommended AASHTO T304 to quantify fine aggregate particle shape, angularity, and surface texture. The Roundness Index from the University of Arkansas digital image analysis produced a fair correlation with the GLWT rut depth ($R^2$ = 0.56).

#### 2.4.4.8 *Study of the Effect of FAA on Asphalt Mixture Performance by Lee et al.*

Lee et al. (*64*) conducted a study on the effect of FAA on HMA performance for the Indiana Department of Transportation. The study included six fine aggregate sources, which were used to produce 18 9.5-mm NMAS mixtures using different gradations and blends of the fine aggregate. Only one of the fine aggregate sources was a natural sand. The coarse aggregate used for all 18 mixtures was a partially crushed (80% one crushed face) gravel. The angularity and texture of the fine aggregate sources were evaluated using ASTM C1252 Method A (FAA test), CAR test, and Florida Bearing Value (Indiana Test Method 201-89). The Florida Bearing Value is a precursor to the CAR test. Instead of using a Marshall press, the sample was loaded through the flow of lead shot into a receiving container. The uncompacted voids content of the fine aggregate ranged from 38.7 to 49.0. Blends of the six sands were prepared to produce uncompacted void contents of 46, 45, and 43. Regression analysis indicates an $R^2$ = 0.70 between the uncompacted voids and CAR peak load. The trend indicated an increase in CAR peak load with an increase in uncompacted voids.

Volumetric mix designs were conducted for each of the 18 mixtures. The first nine mixtures were produced one each with the six sands and three blends of those six sands. Nine additional mixtures were produced, five using a slag sand with varying percentages of natural sand and mineral filler and four with a limestone sand (S gradation mix) and different percentages of natural sand. Rut testing was performed on the mixtures using the PurWheel Laboratory Tracking Device and the SST. The PurWheel device applies loads to the slabs of HMA with a rubber wheel having a contact pressure of 620 kPa. PurWheel testing was conducted on dry slabs at 60°C. SST testing for frequency sweep at constant height and repeated shear at constant height were performed according to AASHTO TP7-94.

Correlation analysis between the three fine aggregate tests and rutting performance based on both repeated shear at constant height and the PurWheel rut depths indicated that the uncompacted voids content was most correlated with rutting performance (*64*). A stepwise regression was performed to predict the rutting performance of the mixtures using the PurWheel. The independent variables considered were uncompacted voids content, asphalt content, air voids content (of the PurWheel samples), dust to asphalt ratio, gradation parameters, the interaction between uncompacted voids and asphalt content, and the number of loading cycles to 2% shear strain from the repeated shear at constant height test. Six of the eight variables were included in the model by the stepwise regression: uncompacted voids, asphalt content, air voids, the interaction between uncompacted voids and asphalt content, cycles to 2% strain in the SST, and gradation. The uncompacted voids content was the most significant parameter ($F$-value = 41.00). Comparing the aggregate properties individually to the rutting results from the PurWheel device and repeated shear at constant height, FAA had the highest correlation with the PurWheel results ($R^2$ = 0.40) and the Florida Bearing Ratio had the highest correlation with the repeated shear at constant height ($R^2$ = 0.29). The authors concluded that uncompacted voids alone may not be sufficient to evaluate the fine aggregate contribution to mixture rutting performance. It was observed that a mixture having an uncompacted voids content of 43 performed as well as a mixture with an uncompacted voids content of 48. The authors note that this may be due to the confounding effects of gradation and compactability (the uncompacted voids content of 48 represents the slag mixtures).

#### 2.4.4.9 *Pooled Fund Study 176*

One of the goals of the National Pooled Fund Study No. 176, "Validation of SHRP Asphalt Mixture Specifications Using Accelerated Testing," was to examine the effect of FAA on the rutting performance of Superpave mixtures. Two coarse aggregates—a limestone and granite—and three fine aggregates—a natural sand, limestone sand, and granite sand—were used in the study (*65*). The fine aggregates had uncompacted void contents of 39, 44, and 50, respectively. The aggregates were combined with a neat PG 64-22 to produce 21 mixture designs: 9 of 9.5-mm NMAS and 12 of 19.0-mm NMAS. A trend was observed between the design asphalt content and the uncompacted voids content. The relationship indicated that for a given gradation shape (above, through, or below the maximum density line), optimum asphalt content increased with increasing uncompacted voids.

The rutting propensities of the mixes were tested with the PurWheel, the SST, and Triaxial Tests and in the APT facility. The APT facility is a full-scale, indoor accelerated loading facility managed by Indiana DOT and Purdue University.

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The primary goal of the Phase I testing was to evaluate the sensitivity of the various test methods to the study factors (*66*). Based on screening tests performed with the PurWheel device in Phase I of the study, four mixtures were selected for APT facility testing. A limestone coarse aggregate was used to produce 19.0-mm NMAS mix designs using all three sands. The natural sand (FAA 39) and limestone sand (FAA 44) were used to produce coarse-graded mixes (below the maximum density line). The limestone sand and granite sand were used to produce fine-graded mixes (above the maximum density line). These four mix designs were placed at both low and high in-place densities.

The results of the APT facility testing are shown in Table 7. It is apparent that both mixtures produced with the limestone sand (FAA 44) had design asphalt contents that were approximately 1 percentage point less than the mixtures produced with the natural or granite sand. For the low-density sections, the crushed limestone sand (FAA 44) produced both the best and worst rutting results in the APT facility; however, the dry PurWheel results ranked both of the limestone sand mixtures as performing the best. For the high-density (low air void) sections, the limestone sand mixtures performed best in both the PurWheel and the APT facility. However, it should be noted that the air void contents of the natural sand and granite fine aggregate sections were close to the 2.5% level identified by Cross and Brown (*10, 17*) below which mixtures were less sensitive to aggregate properties. The air void contents of the limestone fine aggregate sections (FAA 44) were approximately 2.5 percentage points higher than the natural sand and granite fine aggregate sections. These variations were not planned but are part of the variation associated with full-scale test sections. Thus, although the limestone fine aggregate indicated the best rutting performance for the high-density sections, this result may be more related to the higher in-place air voids and lower asphalt contents of those mixtures than to the performance of the fine aggregate. This emphasizes the fact that screening tests for FAA and texture cannot by themselves ensure mixture performance.

In Phase II of Pooled Fund Study 176, an additional 6 mixtures were tested in the APT facility for a total of 10 mixtures and in excess of 20 sections (considering varying densities and asphalt contents). Stiady et al. (*67*) discussed the findings relative to aggregate. Based on Figure 5, the rounded natural sand (FAA 39) produced the worst rutting performance;

**TABLE 7 INDOT/Purdue APT facility results from Phase I of Pooled-Fund Study 176 (*65*)**

| Mixture (FAA, Gradation) | Design Asphalt Content, % | Average As-Constructed Wheel Path Air Voids, % | APT Rut Depth, mm (Adjusted for 76-mm layer thickness) | PURWheel Dry Test Ranking |
|---|---|---|---|---|
| | | *Low Density Sections* | | |
| 44 ARZ | 4.6 | 8.8 | 5.3 | 1 |
| 50 ARZ | 5.9 | 6.4 | 6.3 | 3 |
| 39 BRZ | 5.5 | 5.2 | 9.4 | 4 |
| 44 BRZ | 4.6 | 6.4 | 11.8 | 2 |
| | | *High Density Sections* | | |
| 44 ARZ | 4.6 | 5.3 | 4.3 | 1 |
| 44 BRZ | 4.6 | 5.7 | 8.0 | 2 |
| 50 ARZ | 5.9 | 2.9 | 9.3 | 3 |
| 39 BRZ | 5.5 | 2.6 | 15.7 | 4 |

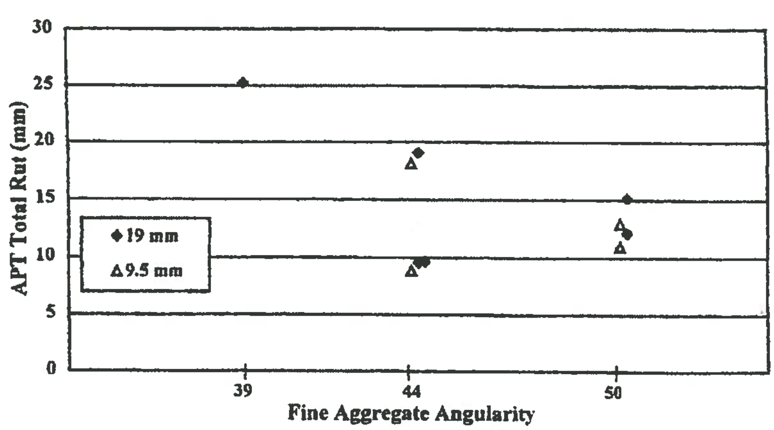


*Figure 5. APT facility rutting versus uncompacted voids content by gradation type (67).*

however, the limestone fine aggregate (FAA 44) performed as well or better than the granite fine aggregate (FAA 50). The mix designs produced with the granite fine aggregate had consistently higher asphalt contents. Analysis of variance (ANOVA) performed on the triaxial shear strength test results from the 21 mixtures indicated that the uncompacted void contents for the fine aggregates in the mixtures were a significant factor (*66*).

### *2.4.4.10 Evaluation of Superpave FAA Specification by Chowdhury et al.*

Chowdhury et al. (*54*) conducted a study to evaluate various measures of FAA and texture and their relationship to rutting performance. The study was conducted for the International Center for Aggregate Research. The study evaluated 23 fine aggregates using seven different procedures: uncompacted voids content (AASHTO T304), DST (ASTM D3080), CAR test, three different methods of digital image analysis, and visual inspection. The image analysis techniques included the Hough Transform by the University of Arkansas, which was discussed previously; unified image analysis by Washington State University; and the VDG-40 Videograder conducted by the Virginia Transportation Research Council.

The samples tested by Washington State University were sieved, and only the material passing the 1.18-mm sieve and retained on the 0.600-mm sieve was used for analysis. The aggregates were stained black to improve their contrast with the background prior to capturing the images. An optical microscope linked to an image analyzer was used to capture images of the fine aggregate. Three techniques were used to analyze the binary image: surface erosion-dilation, fractal behavior, and form factor (*56*). Surface erosion-dilation involves removing layers of image pixels on the fringe of the object (i.e., erosion) followed by replacement of these pixels (i.e., dilation) to simplify the form. The surface parameter is believed to be a measure of angularity and is calculated as the percentage of the particle area lost after six cycles of erosion followed by six cycles of dilation (*56*). Fractal behavior is defined "as the self-similarity exhibited by an irregular boundary when captured at different magnifications" (*56*). Fractal length increases with an increase in aggregate angularity. Form factor describes an object's dimensions, particularly surface irregularity. The form factor of a perfectly circular object is 1; therefore, form factor decreases with increasing surface irregularity.

The VDG-40 Videograder was developed by LCPC, the French national road and bridges laboratory (*68*). The device was developed primarily to measure aggregate grading of particles larger than 1 mm (No. 16 sieve), but it can also measure shape properties. Aggregates are backlit as they fall in front of a linear charged couple device camera, which produces a line scan image of the aggregate. The aggregates fall off a rotating wheel, which prevents them from tumbling as they fall in front of the camera. An ellipse having the same length and area is fit to each particle. The ratio of the length to the width of each particle is reported as the slenderness ratio (*SR*). The *SR* may be determined as a distribution or an average. The flatness factor is a property for the group of aggregates tested; it is related to the ratio of the average width to average thickness of the particles.

Based upon the data presented in the paper (*54*), a correlation matrix was developed between the indices for angularity determined with each test method (Table 8). (See Chowdhury et al. for some of the correlations [*54, 69*].) Regression analysis was performed using Minitab statistical software. The upper number in the cell is the coefficient of determination ($R^2$) and the lower number is the significance level ($p$-value) based on the ANOVA.

**TABLE 8 Correlation matrix for fine aggregate test results using data from Chowdhury et al. (*54*)**

| Test Procedure | UV, AASHTO T304 Method A | Angle of Internal Friction (AIF) ASTM D3080 | Log CAR Stability | University of Arkansas K-index | University of Washington Surface Parameter (SP) | VDG-40 Slenderness Ratio (SR) |
|---|---|---|---|---|---|---|
| UV | 1.00[1]<br>0.000[2] | 0.07<br>0.222 | 0.17<br>0.050 | 0.76<br>0.000 | 0.72<br>0.000 | 0.47<br>0.000 |
| AIF | | 1.00<br>0.000 | 0.53<br>0.000 | 0.06<br>0.244 | 0.05<br>0.292 | 0.22<br>0.028 |
| Log CAR | | | 1.00<br>0.000 | 0.20<br>0.031 | 0.16<br>0.061 | 0.72<br>0.000 |
| K-index | | | | 1.00<br>0.000 | 0.69<br>0.000 | 0.50<br>0.000 |
| SP | | | | | 1.00<br>0.000 | 0.43<br>0.001 |
| SR | | | | | | 1.00<br>0.000 |

[1]Coefficient of determination ($R^2$)
[2]ANOVA level of significance ($p$ value)

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The uncompacted voids content correlated well with two of the digital imaging methods, K-index ($R^2 = 0.76$) and surface parameter ($R^2 = 0.72$), and had a fair correlation with the *SR* ($R^2 = 0.47$). The relationships between uncompacted voids and all three direct measures of fine aggregate particle shape were significant based on the ANOVA. The authors noted that four crushed limestone aggregates that have good field performance histories showed high values of K-index even though their uncompacted voids contents were less than 45 (*54*). Kandhal and Parker (*2*) also found a good relationship between the EAPP (i.e., ellipse-based area of the object divided by the perimeter squared) and uncompacted voids content ($R^2 = 0.76$) as measured by the University of Arkansas Hough Transform. Uncompacted voids content correlated poorly with both angle of internal friction (AIF) and the Log of CAR stability.

There was a fair correlation between the two shear measurements, AIF and Log of CAR stability ($R^2 = 0.53$). AIF did not correlate well with any other test, although the relationship with the VDG-40 *SR* was significant (p-value = 0.028). Log of CAR stability correlated well with the VDG-40 *SR* ($R^2 = 0.72$). There was a fairly good correlation between K-index and surface parameter ($R^2 = 0.69$); both methods had moderate correlations with the VDG-40 *SR*. The authors noted (*54*):

> The CAR test appears to separate uncrushed and crushed aggregates much better than the FAA test. This could be, in part, due to the high filler content of the crushed materials as compared to the sands.

A laboratory rutting study was conducted with four of the fine aggregates: three crushed materials and one natural sand. Two blends of materials were also produced using two of the crushed materials, one with 15% and the other with 30% of the natural sand. A single limestone coarse aggregate and a coarse 19.0-mm NMAS gradation were used for all of the mixtures. The binder grade was not reported. Superpave mix designs were performed for each of the six blends. The mixtures produced using the natural sand and blend with 30% natural sand did not meet the Superpave minimum VMA requirements.

Cylindrical samples at 4 ± 1% air voids were tested in the APA at 64°C with a 445-N (100-lb) vertical load and 694 kPa (100 psi) hose pressure. Regression analysis indicated a fair to poor relationship ($R^2 = 0.37$) between uncompacted voids and APA rut depth (*54*). The mix with 100% natural sand fines (FAA = 39.0) had the highest rut depth (9.2 mm) followed closely by the mix with the crushed river gravel fines (FAA = 44.3, rut depth = 9.1 mm). The mix containing the crushed river gravel had the highest asphalt content of all of the mixes evaluated (tied with granite/natural sand blend). The mix with the granite fines (FAA = 48.0) had the least amount of rutting (4.0 mm), followed closely by the mix with the limestone fines (FAA = 43.5, rut depth = 4.4 mm). This illustrates the concern with the current uncompacted voids specifications. Based on laboratory results, it is possible to design mixes using fine aggregate that fails the uncompacted voids criteria but produces acceptable rutting performance. Regression analysis using data provided by Chowdhury et al. (*54*) did indicate a good relationship between uncompacted voids and VMA ($R^2 = 0.70$). This suggests that uncompacted voids may also identify fine aggregates that will assist in meeting minimum VMA requirements.

Angle of internal friction, as tested by ASTM D3080, produced the best relationship ($R^2 = 0.69$) with the APA rut depths (*54*). Log of CAR stability and the VDG-40 SR produced fair correlations ($R^2 = 0.46$ and 0.42, respectively). No correlation ($R^2 = 0.07$) was found with the Washington State University surface parameter discussed previously, but a fair correlation ($R^2 = 0.58$) was found with a second parameter, fractal length.

#### 2.4.4.11 *Evaluation of Superpave Criteria for VMA and FAA for Florida DOT by Roque et al.*

Roque et al. (*51*) conducted a study on FAA for the Florida DOT. A total of nine fine aggregates were included in the study: six limestone sources, two granite sources, and a gravel source. The fine aggregates were evaluated using AASHTO T304 Methods A, B, and C as discussed previously; using the ASTM D3080 (DST); and visually. Two alternative gradations, other than that specified in AASHTO T304 Method A, were also evaluated (*51, 59*). These gradations were selected to represent the range of fine aggregate gradations used in the study. The authors concluded that "material type had a far greater effect on FAA than did gradation. Furthermore, all three gradations appeared to result in the same relative FAA rankings for the fine aggregates tested" (*51*). A poor correlation ($R^2 = 0.32$) was observed between the uncompacted voids content and direct shear strength when both tests were conducted using the AASHTO T304 Method A gradation. The trend indicates decreasing shear strength with increasing uncompacted voids content. This may be due to the packing characteristics of the fine aggregates with higher uncompacted voids contents. The authors conclude that "although FAA had some influence on the shear strength, aggregate toughness and gradation appeared to overwhelm its effects, confirming that FAA alone was not a good predictor of fine aggregate shear strength" (*51*).

Five of the fine aggregate sources, three limestone sources, a granite source, and a gravel source were used to evaluate the effect of fine aggregate on mixture performance. A single limestone source was used as the coarse aggregate and to develop a reference coarse and fine gradation commonly used in Florida. The four other fine aggregates were used to volumetrically replace the reference aggregate. The material passing the 4.75-mm sieve was replaced for the coarse gradation,

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and the material passing the 2.36-mm sieve was replaced for the fine gradation. Volumetric replacement was done to account for any differences in specific gravities between the materials.

Superpave mixture designs were performed for each of the 10 blends using $N_{design}$ = 109 compaction level. The binder grade was not reported. Six of the ten mix designs failed one or more Superpave criteria. Two of the three limestone sources failed minimum VMA (14% minimum for 12.5-mm NMAS). The granite source failed the voids filled with asphalt (VFA) requirements on the high side because of a high VMA (16%). The authors noted that "the FAA did appear to identify substandard VMA mixtures" (*51*).

Rutting tests were performed with the APA. Test temperature and loads used in the APA were not reported. The results for the fine mixtures are reported by Roque et al. (*51*). The authors state that the rutting results agree with the direct shear results, aggregate toughness, and known field performance. The trend between uncompacted voids and APA rut depths indicated decreased rutting with increasing uncompacted voids. Two fine aggregates with uncompacted voids less than 45 and high toughness (LA abrasion < 35%) exhibited a rut depth equivalent to a fine aggregate with an uncompacted voids content in excess of 45. Roque et al. (*51*) recommend including aggregate toughness as part of the AASHTO T304 acceptance criteria. Aggregates with uncompacted voids between 42 and 50 would be acceptable with LA abrasion values of the parent rock less than 35%. If the LA abrasion of these fine aggregates were to exceed 35%, their rutting performance may not be adequate.

### *2.4.4.12 Evaluation of the Effect of FAA on Compaction and Shearing Resistance of Asphalt Mixtures by Stackston et al.*

Stackston et al. (*70*) conducted a study to evaluate the effect of FAA on compaction effort and rutting resistance. Three aggregate sources were used in the study. Twenty-four Superpave mix designs were developed using blends of the three materials and two gradation shapes: fine and s-shaped. The response of the mixtures was evaluated using Superpave volumetric properties and the gyratory load plate assembly. The gyratory load plate assembly measures the force on the sample at three points. This force is converted to a force per cycle. Testing indicated that the density at $N_{initial}$ decreases with increasing uncompacted voids content. This indicates that mixes with higher uncompacted voids contents would be less likely to be tender mixes. Data from the gyratory load plate assembly indicated that mixes with higher uncompacted voids contents are harder to compact. The authors reported that the effect of uncompacted voids content was not consistent in terms of rutting resistance as measured by the gyratory load plate assembly (*70*).

### *2.4.4.13 NCHRP Project 4-19(2)*

Ongoing research as part of NCHRP Project 4-19(2), "Validation of Performance-Related Tests of Aggregates for Use in Hot-Mix Asphalt Pavements," is examining the relationship between uncompacted voids tests and rutting through accelerated testing using the Indiana prototype APT facility. Six fine aggregates were initially selected for the fine aggregate characterization portion of the study: crushed gravel, granite, dolomite, traprock sands, and two natural sands. The uncompacted void contents (Method A) for these sands ranged from 40.3 to 49.1 (*23*). Later, alternative dolomite and traprock sands were included that produced HMA mixtures with better volumetric properties (uncompacted void contents of 46.8% and 49.2%).

The study tracked the measured uncompacted void contents from the HMA mix design through field construction. On average, a 1.8% reduction in voids was observed between the HMA mix design value and material recovered from HMA samples taken at the asphalt plant. Rismantojo states that "the degradation was significantly correlated with the initial UVA [uncompacted voids] values. Fine aggregates with high initial UVA values appeared to degrade more than those with low UVA values" (*23*).

Mixture designs were performed with all eight fine aggregates using a single uncrushed gravel coarse aggregate to amplify the effect of the fine aggregate. The original dolomite and traprock sources produced VMA values that were excessively high (17.4% and 18.0% at $N_{design}$ = 100 gyrations). This resulted in failing VFA values (exceeding 75%). The mixtures produced using the other original fine aggregates and two replacement aggregates met all of the Superpave criteria. Correlations were performed between the volumetric properties and measured fine aggregate properties. Uncompacted voids produced a significant correlation ($R^2$ = 0.59) with density at $N_{initial}$ (*23*). A model was developed to relate uncompacted voids and dust proportion to VMA. As expected, VMA increased with increasing uncompacted voids and decreasing dust proportion (*23*).

The six mixtures with passing Superpave volumetric properties were tested in the full-scale Indiana APT facility. The results indicate that uncompacted voids Methods A and B as well as the uncompacted voids from Virginia Test Method 5 (VTM 5) were significantly related to the total rut depth after 1,000 passes. The $R^2$ = 0.65 for Method A was slightly less than for the other two methods. AASHTO T304 Method A produced the best relationship with the total rut depth after 20,000 passes ($R^2$ = 0.51); however, the relationship was not significant ($p$-value = 0.286) (*23*). The author noted that the decrease in rut depth with increasing uncompacted voids occurs to a lesser extent above 45% voids. Rismantojo (*23*) concludes that the results of the current study are similar to those reported by Kandhal and Parker (*2*), including that fine-graded mixtures with uncompacted voids contents (Method A) between 42% and 46% demonstrate similar levels of rutting resistance.

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### 2.4.5 Precision of AASHTO T304

AASHTO T304 reports a single-operator standard deviation (Std) of 0.13% voids and a multilaboratory standard deviation of 0.33% voids *(71)*. This means that two properly conducted tests should not differ (D2S) by more than 0.37% and 0.93% voids, respectively, for a single operator and between two different labs. AASHTO T304 testing is included as part of the AASHTO Materials Reference Laboratory (AMRL) proficiency samples testing program. The precision results for the four latest proficiency samples are shown in Table 9. The average uncompacted voids contents for the samples tested in Table 9 ranged from 42.7% to 44.7%. The data in Table 9 indicates that AASHTO T304 is more variable in practice than reported in the test method. The Southeast Asphalt User/Producer Group conducted a round-robin for AASHTO T304 Methods A, B, and C. The study included seven aggregate sources from the southeastern United States: two natural sands, two granite sources, two limestone sources, and standard graded sand. The standard graded sand had been previously used to establish the precision statement for AASHTO T304. Sixteen laboratories participated in the study, although not all of the data were returned for all of the samples. The results indicated that Method C was more variable than Methods A and B, which had similar variability. For Method A, the single operator standard deviation was 0.57% voids and the multilaboratory standard deviation was 0.75% voids, which correspond to D2S limits of 1.61 and 2.12, respectively *(72)*. The variability of the bulk dry specific gravity measurements *(72)* used in the calculations to determine the uncompacted void content significantly increases the test variability. The AMRL results and Southeast Asphalt User/Producer Group Study indicate that the AASHTO T304 precision statement may need to be revised.

### 2.4.6 Summary of Findings on Fine Aggregate Texture and Angularity

The findings on fine aggregate texture and angularity are as follows:

- The results of AASHTO T304 Methods A and B are highly correlated, with Method B producing larger uncompacted void contents. Tests using alternative gradations other than Method A were also highly correlated to the Method A results and maintained the same ranking of fine aggregates. The results from AASHTO T304 Method C are affected by the fine aggregate gradation and are not recommended for comparing particle shape and texture.
- The current Superpave consensus aggregate properties do not address the angularity of the material that pass the No. 4 sieve but are retained on the No. 8 sieve. It is doubtful that the current AASHTO T304 apparatus could accommodate material of this size fraction.
- Numerous test procedures are available to assess fine aggregate texture and angularity. Several of the imaging techniques and the CAR test appear to be promising. Researchers using the DST (ASTM D3080) have indicated that it is difficult to obtain consistent results; however, to date, the majority of the work to correlate fine aggregate shape and texture to performance has been completed using AASHTO T304 Method A.
- The results of studies relating the uncompacted voids content from AASHTO T304 Method A to performance are mixed. Generally, studies indicated a trend between uncompacted voids content and improved rutting performance, but in some cases the trend was weak. Subtle differences in uncompacted voids content can be overwhelmed by the effect of the coarse aggregate or other HMA mixture properties. Several studies supported the 45% uncompacted voids criteria for high traffic, but several also indicated performance was unclear between 43% and 45% (or higher) uncompacted voids. There is clear evidence that good-performing mixes can be designed with uncompacted voids contents between 43% and 45%, but evaluation of these mixes using a rutting performance test is recommended.
- Higher uncompacted void contents generally resulted in higher VMA and lower densities at $N_{initial}$.
- The variability of AASHTO T304 method A appears to be larger than reported in the test method. Much of this variability appears to be related to variability in the fine aggregate specific gravity measurements used to calculate the uncompacted voids. Ongoing research to improve fine aggregate specific gravity measurements may also benefit AASHTO T304.

**TABLE 9 AMRL AASHTO T304 proficiency sample results *(71)***

| Sample Numbers | Number of Labs | Multilaboratory Precision | | | | Single Operator Precision | |
|---|---|---|---|---|---|---|---|
| | | First Sample | | Second Sample | | | |
| | | *Std.* | *D2S* | *Std.* | *D2s* | *Std.* | *D2s* |
| 119 120 | 136 | 0.937 | 2.651 | 1.012 | 2.863 | 0.358 | 1.103 |
| 123 124 | 183 | 1.129 | 3.194 | 1.149 | 3.250 | 0.406 | 1.147 |
| 127 128 | 211 | 1.291 | 3.651 | 1.349 | 3.815 | 0.377 | 1.066 |
| 131 132 | 242 | 0.917 | 2.594 | 0.858 | 2.428 | 0.381 | 1.077 |

Attach # 14-16

### 5-04.3(9)E Mixture Acceptance – Notification of Acceptance Test Results

The results of all mixture acceptance testing and the Composite Pay Factor (CPF) of the lot after three sublots have been tested will be available to the Contractor through The Contracting Agency's website.

The Contracting Agency will endeavor to provide written notification (via email to the Contractor's designee) of acceptance test results through its web-based materials testing system Statistical Analysis of Materials (SAM) within 24 hours of the sample being made available to the Contracting Agency. However, the Contractor agrees:

1. Quality control, defined as the system used by the Contractor to monitor, assess, and adjust its production processes to ensure that the final HMA mixture will meet the specified level of quality, is the sole responsibility of the Contractor.
2. The Contractor has no right to rely on any testing performed by the Contracting Agency, nor does the Contractor have any right to rely on timely notification by the Contracting Agency of the Contracting Agency's test results (or statistical analysis thereof), for any part of quality control and/or for making changes or correction to any aspect of the HMA mixture.
3. The Contractor shall make no claim for untimely notification by the Contracting Agency of the Contracting Agency's test results or statistical analysis.

Attach 15-01a

# NCHRP
## SYNTHESIS 445

NATIONAL
COOPERATIVE
HIGHWAY
RESEARCH
PROGRAM

# Practices for Unbound Aggregate Pavement Layers

*A Synthesis of Highway Practice*

TRANSPORTATION RESEARCH BOARD
OF THE NATIONAL ACADEMIES

# NCHRP

## REPORT 598

NATIONAL
COOPERATIVE
HIGHWAY
RESEARCH
PROGRAM

# Performance-Related Tests of Recycled Aggregates for Use in Unbound Pavement Layers

TRANSPORTATION RESEARCH BOARD
*OF THE NATIONAL ACADEMIES*

# NCHRP

## Web-Only Document 119:

# Appendixes to NCHRP Report 598

**Athar Saeed**
**Applied Research Associates, Inc.**
**Vicksburg, MS**

Appendixes to Contractor's Final Report for NCHRP Project 4-31
Submitted October 2007

**National Cooperative Highway Research Program**
TRANSPORTATION RESEARCH BOARD
*OF THE NATIONAL ACADEMIES*

Resilient modulus tests on 0, 10, 30, and 50 percent RAP in base and subbase mixes used by the Massachusetts Highway Department indicated that the stiffness of the base and subbase mixes increased with an increase in the amount of RAP [46]. An increase in material stiffness increases the layer coefficient and thus the structural number of the layer. This observation is consistent with work conducted by Bennert et al. [16].

The New Jersey DOT evaluated RAP versus a DGAB using a Heavy Weight Deflectometer (HWD) [47]. The objective of this in-situ assessment was to determine if the RAP base will perform equal or better than the DGAB. This evaluation determined that RAP was 1.5 to 1.8 times stiffer than DGAB. The calculated tensile strains at the bottom of the HMA were lower for the pavement with the RAP base than those calculated for the DGAB, which means that the pavement with the RAP base will have a relatively longer fatigue life.

Florida DOT [22] studied the strength and deformation properties of RAP using laboratory tests on four RAP materials from Florida, and made the following conclusions:

- RAP was compacted using the modified Proctor, modified Marshall, vibratory, and static methods during laboratory evaluation; RAP did not display the classic moisture-density behavior for these compaction methods. At moisture contents in excess of 4 percent, the dry density was relatively constant; the slight variations observed were attributed to grinding and sample variations. Free-standing water at moisture contents in excess of 10 percent was observed for all samples (all compaction methods). In the field, RAP should be compacted at moisture contents between 4 to 7 percent.
- The triaxial properties of RAP are not affected by duration of the storage time.
- Triaxial tests conducted at three confining stresses showed an increase in strength with an increase in confining pressure (Figure 17).
- RAP was determined to be a suitable material for base/subbase construction based on its engineering properties.

Table 7. Permeability and CBR test results of RAP and granular blends.

| Blends | Aggregate (%) | | CBR (%) 0.2" Pen | Permeability × $10^{-4}$ (cm/sec) |
|---|---|---|---|---|
| | Coarse | Fine | | |
| Virgin Aggregate | 47.8 | 52.2 | 129.0 | $1.04 \times 10^{-4}$ |
| 20 % RAP | 51.5 | 48.5 | 95.3 | --[a] |
| 40 % RAP | 57.6 | 42.4 | 53.0 | --[a] |
| 60 % RAP | 61.2 | 38.8 | 26.7 | $1.04 \times 10^{-3}$ |
| 80 % RAP | 63.9 | 36.1 | 11.7 | --[a] |
| 100 % RAP | 67.2 | 32.8 | 13.1 | $1.35 \times 10^{-3}$ |

[a] not tested

**Permeability Tests**

MTO [43] conducted permeability tests on virgin aggregate and compared them with a 60 percent RAP blend (40 percent virgin aggregate) and 100 percent RAP. Their results, shown in Table 7, indicated that because of the coarser gradations of RAP blends, they had a higher permeability, as would be expected.

Addition of up to 50 percent RAP has little effect on the permeability of the original base or subbase material [46]. The permeability of the subbase material (containing more than 50 percent RAP) increased by an order of magnitude which is very similar to tests conducted by MTO [43] reported in Table 7.

## SUMMARY OF TESTS CONDUCTED TO EVALUATE RCP PROPERTIES

FHWA reports that, when properly processed and tested for appropriate specification compliance, RCP has demonstrated satisfactory performance as aggregate in unbound base/subbase layers. This performance assessment is based on the results of a 6-year-long study in which RCP aggregate was tested for consistency and was found to fall within a predictable range [7].

Table 10. State DOTs contacted by the NCHRP 4-31 team for phone interviews.

| **Reclaimed Asphalt Pavement** | **Reclaimed Concrete Pavement** |
|---|---|
| Arizona DOT | Florida DOT |
| Florida DOT | Georgia DOT |
| Georgia DOT | Illinois DOT |
| Illinois DOT | Iowa DOT |
| Louisiana DOT | Kansas DOT |
| Maine DOT | Michigan DOT |
| Mississippi DOT | Minnesota DOT |
| Nebraska Department of Roads | Mississippi DOT |
| New Hampshire DOT | Missouri DOT |
| New Jersey DOT | North Dakota DOT |
| North Dakota DOT | Oklahoma DOT |
| Rhode Island DOT | South Dakota DOT |
| South Dakota DOT | Wisconsin DOT |
| Texas DOT | |
| Virginia DOT | |
| Wisconsin DOT | |

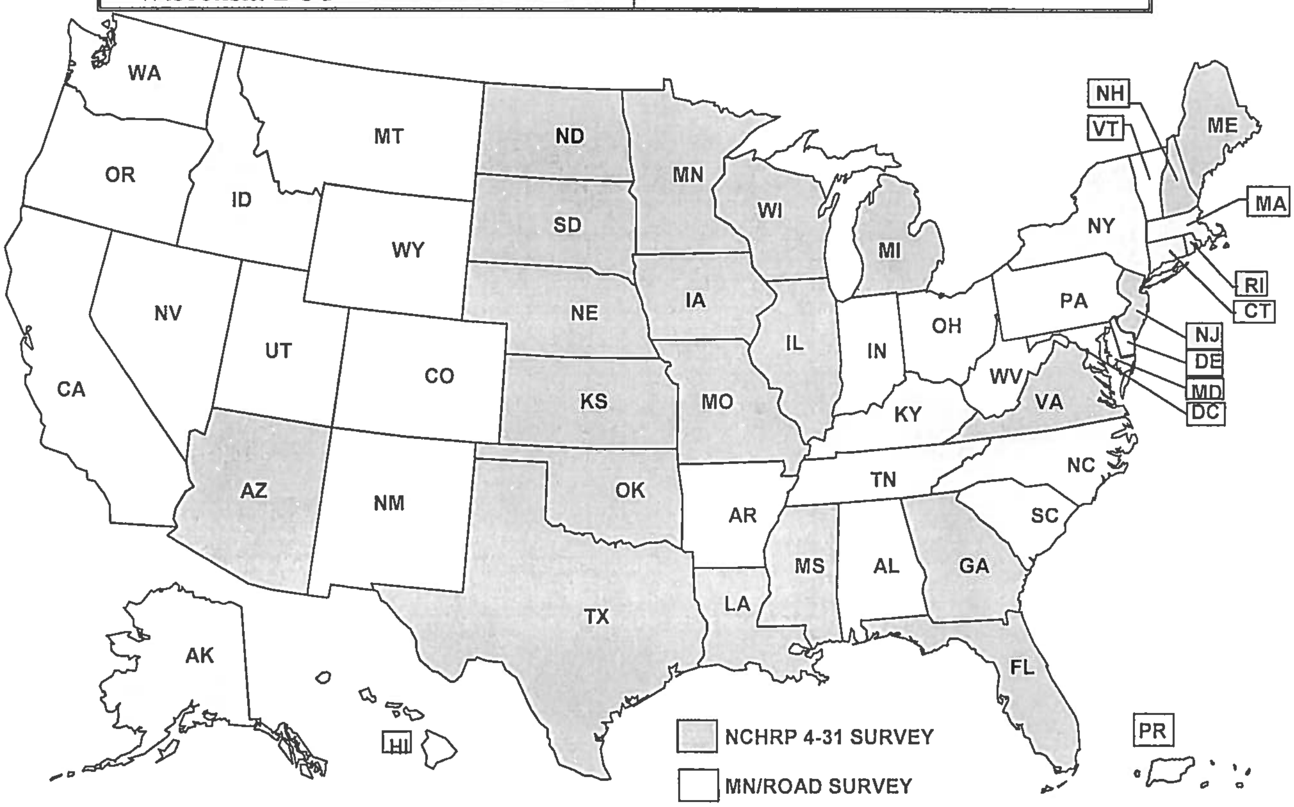
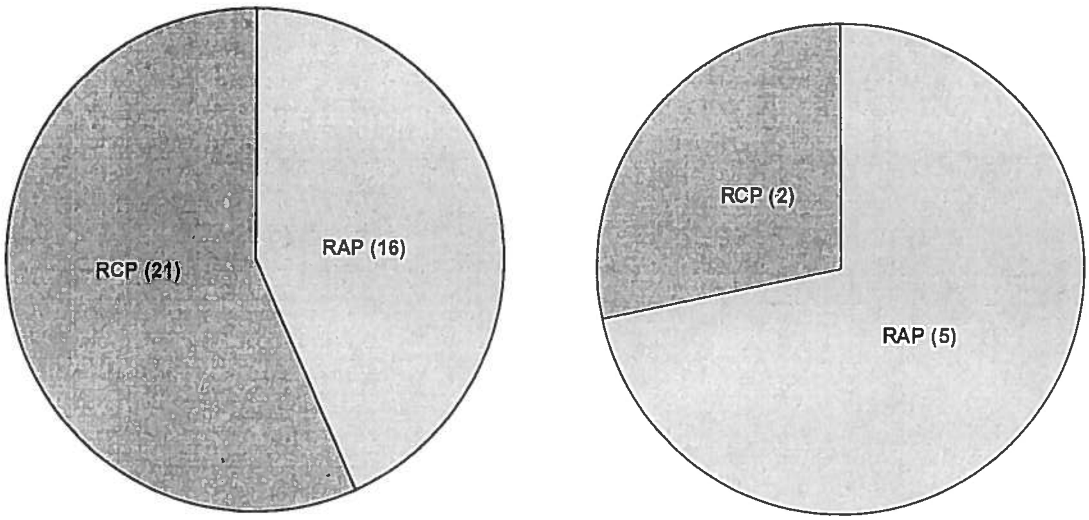



Figure 26. State DOTs included in the final analysis for Subtask 1.B.




100 percent Restricted to 50 percent or less

Figure 29. State DOTs allowing 100 percent and less than 50 percent RAP and RCP.

**Material Specifications**

Twenty-one of the responding state DOTs have specifications for the use of RAP or RCP as aggregate in unbound pavement layers. Two state DOTs use special provisions for RCP modifying the virgin aggregate base course specifications on a project-by-project basis.

Connecticut, Florida, New Jersey and Texas DOTs require environmental tests on RAP. Connecticut, Louisiana, North Dakota, and Texas require that environmental tests be conducted on RCP before use as unbound aggregate in base/subbase pavement layers. Only Illinois DOT requires environmental tests for source approval of virgin aggregate materials. Florida DOT does not allow the use of RAP below the water table. New Jersey requires environmental tests on RAP and virgin aggregate if suspecting petroleum contamination.

**Construction and Constructability Issues**

Most of the state DOTs contacted had no constructability related issues with using either RAP or RCP as aggregate in unbound pavement layers. One state DOT indicated that

## Performance Observations

All state DOTs contacted indicated no problems with the performance of RAP and RCP based on empirical evidence; Figure 31 shows agencies' experience with RAP and RCP as aggregate in unbound pavement layers. A total of eleven respondents (four for RAP and seven for RCP) indicated that they have recently started using RAP and RCP as aggregate in unbound pavement layers; no problems have been noted, but they have no history to make a judgment at this stage.

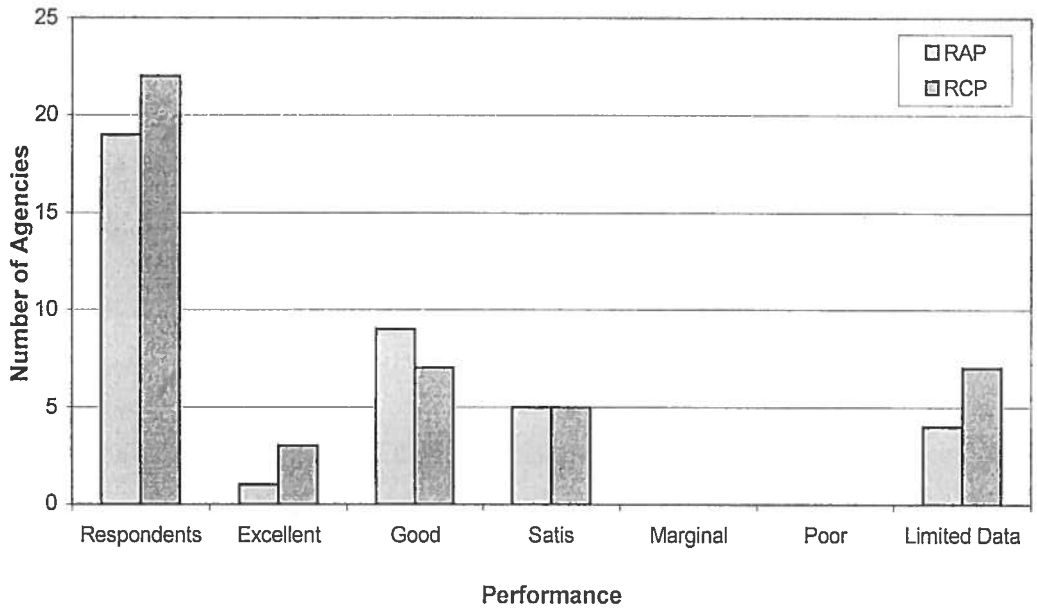



Figure 31. Agencies' experience with RAP and RCP as aggregate in unbound layers.

Attach #15-01b

| 1. REPORT NO. | 2. GOVERNMENT ACCESSION NO. | 3. RECIPIENTS CATALOG NO |
|---|---|---|
| WA-RD 713.1 | | |

| | |
|---|---|
| 4. TITLE AND SUBTITLE<br>**Evaluation of Current Practices of Reclaimed Asphalt Pavement/Virgin Aggregate as Base Course Material** | 5. REPORT DATE<br>December 2007<br>6. PERFORMING ORGANIZATION CODE |
| 7. AUTHOR(S)<br>Eric J. McGarrah | 8. PERFORMING ORGANIZATION REPORT NO. |
| 9. PERFORMING ORGANIZATION NAME AND ADDRESS<br>University of Washington<br>Department of Civil and Environmental Engineering<br>PO Box 352700<br>Seattle, WA 98195-2700 | 10. WORK UNIT NO.<br>11. CONTRACT OR GRANT NO. |
| 12. CO-SPONSORING AGENCY NAME AND ADDRESS<br>Research Office<br>Washington State Department of Transportation<br>PO Box 47372<br>Olympia, WA 98504-7372<br>Project Manager: Kim Willoughby 360.705.7978 | 13. TYPE OF REPORT AND PERIOD COVERED<br>Final Report<br>14. SPONSORING AGENCY CODE |

15. SUPPLEMENTARY NOTES

This study was conducted in cooperation with the U.S. Department of Transportation, Federal Highway Administration.

16. ABSTRACT

Every year Hot Mix Asphalt (HMA) roadways are rehabilitated by milling the existing roadway and replacing the milled portion with new HMA. As a result of this practice, a tremendous amount of reclaimed asphalt pavement (RAP) is created. The Federal Highway Administration estimates that 100 million tons of HMA is milled each year (MAPA, 2007). The Washington State Department of Transportation (WSDOT) currently allows RAP to be recycled into new HMA, but only 20% of the RAP may be used in the new material. Thus, a large portion of the milled asphalt ends up at contractors' pits or landfills. Due to the possible reduction in product and construction cost by using RAP as base course in addition with increasing requests by contractors to do so, WSDOT is investigating the possibility of blending RAP with virgin material for use as a base course material. This report analyzes existing studies that have examined the properties and performances of 100% RAP mixtures as well as RAP/virgin aggregate blends. In addition, this report includes a survey of 12 state DOT's detailing current practices regarding the use of RAP as base course and any corresponding specifications and testing procedures.

| 17. KEY WORDS | 18. DISTRIBUTION STATEMENT |
|---|---|
| reclaimed asphalt pavement (RAP), base course, pavement rehabilitation | |

| 19. SECURITY CLASSIF. (of this report) | 20. SECURITY CLASSIF. (of this page) | 21. NO. OF PAGES | 22. PRICE |
|---|---|---|---|
| None | None | 33 | |

Attach # 15-02

**Amendments to the 2016 Standard Specifications**
**Effective April 4, 2016**

## 5-04 Hot Mix Asphalt

This amendment is a complete rewrite of Section 5-04. This has been done first and foremost to make this section easier to understand. However, there are a few minor changes in meaning and clarifications, such as:

### CHANGE IN MEANING

- Mixture samples may be taken by coring when loose mixture is not available for testing (no method was previously prescribed).
- Mix design development may begin up to 6 months before being submitted for QPL approval (instead of 3 months).
- Aspirational goals are established for WSDOT to provide acceptance test results to the Contractor for mixture and compaction (no timeline was previously identified).
- The Section titled "Preparation of Untreated Roadway" has been deleted (because we don't do that anymore).
- A lump breaker or screen is required for any mix containing RAP or RAS (instead of for High RAP mixes only).
- PG grade oil is allowed to be used as tack (because it's a good idea).
- Depth of "pavement repair" is stipulated as 1.0 feet unless otherwise shown in the plans, subject to final approval by the Engineer (so the contractor knows what to bid).
- Max nominal compacted depth of any layer of class ⅜ mix is increased to 0.15 feet (instead of 0.10).

### CLARIFICATIONS

- Test Section – When one is required, and what must happen to stop test sections.
- Warm Mix processes in relation to mix designs.
- Limits on max allowable RAP and RAS.
- Requirements for managing RAP stockpiles after the mix design process begins.
- New terms are created for "High RAP/Any RAS" and "Low RAP/No RAS".
- The term "Commercial Evaluation" is changed to "Visual Evaluation" (in name only).
- The difference between an MTD and MTV.
- Increased emphasis on the connection from Section 5-04 to Section 3-04 regarding HMA aggregate acceptance.
- Criteria for when HMA mixture is accepted by Visual versus Nonstatistical versus Statistical Evaluation.
- Clarification of what is and is not included when determining sublot size for mixture acceptance and compaction acceptance.

### CHANGE IN WRITING STYLE

An effort has been made to use a writing style known as "Plain Language" in this rewrite of Section 5-04. Plain Language style has been around for many years, is supported by FHWA as a best practice, and is intended to make documents easier to understand. Additional information is available at www.plainlanguage.gov and on the FHWA website. While there are no universally accepted rules for Plain Language, the following are some characteristics which have been attempted in this spec:

1. Use of the "active voice"
2. Use of the "imperative" case
3. Use short simple sentences.
4. Use lists whenever practical.
5. Avoid technical jargon when possible.
6. Use meaningful headings.

Unless otherwise approved by the Engineer, use CSS-1, CSS-1h, or Performance Graded (PG) asphalt for tack coat. The CSS-1 and CSS-1h emulsified asphalt may be diluted with water at a rate not to exceed one part water to one part emulsified asphalt. Do not allow the tack coat material to exceed the maximum temperature recommended by the asphalt supplier.

Attach # 15-05

Attach # 15-07

**5-04.2(1) How to Get an HMA Mix Design on the QPL**

- Develop a mix design no more than 6 months prior to submitting it for QPL 48 evaluation.

Attach # 16-05

**Excerpt from 5-04.3(3)A Mixing Plant**

**4. Provide HMA sampling equipment that complies with WSDOT SOP T-168.**

- Use a mechanical sampling device installed between the discharge of the silo and the truck transport, approved by the Engineer, or

- Platforms or devices to enable sampling from the truck transport without entering the truck transport for sampling HMA

**Excerpt from WSDOT SOP T-168**

**Sampling**

- **General**

1. The material shall be tested to determine variations. The supplier/contractor shall sample the HMA mixture in the presence of the Project Engineer. The supplier/contractor shall provide one of the following for safe and representative sampling:

    a. A mechanical sampling device installed between the discharge of the silo and the truck transport that is approved by the Regional Materials Engineer.

    b. Platforms or devices to enable sampling from the truck transport without entering the truck transport for sampling HMA.

Attach #16-08

- Asphalt Binder Grading - 101

- Current Grading System
  - Base grade (Environment)
  - Grade bump (Traffic/Load)
  - Bump = same stiffness at higher temperature
  - Allows for products & processes that may affect performance

- MSCR Grading System
  - Base grade (Environment)
  - Grade bump (Traffic/Load)
  - Bump = increase stiffness at service temperature
  - Requires products & processes that ensure performance

# Asphalt Binder Grading - 101

- Current Grading System
  - PG58-22
  - PG64-22
  - PG70-22
  - PG64-28
  - PG70-28
  - PG76-28

- MSCR Grading System
  - PG58<u>S</u>-22 (Standard)
  - PG58<u>H</u>-22 (Heavy)
  - PG58<u>V</u>-22 (Very Heavy)
  - PG64<u>S</u>-28
  - PG64<u>H</u>-28
  - PG64<u>V</u>-28

by the Contractor's operations shall be repaired to the satisfaction of the Engineer, at the Contractor's expense.

For mainline planing operations, the equipment shall have automatic controls, with sensors for either or both sides of the equipment. The controls shall be capable of sensing the grade from an outside reference line, or a mat-referencing device. The automatic controls shall have a transverse slope controller capable of maintaining the mandrel at the desired transverse slope (expressed as a percentage) within plus or minus 0.1 percent.

The planings and other debris resulting from the planing operation shall become the property of the Contractor and be disposed of in accordance with Section 2-03.3(7)C. The planings may be utilized as RAP, within the requirements of Sections 5-04.2 or 9-03.21.

### 5-04.3(15) HMA Road Approaches

HMA approaches shall be constructed at the locations shown in the Plans or where staked by the Engineer. The Work shall be performed in accordance with Section 5-04.

### 5-04.3(16) Weather Limitations

HMA for wearing course shall not be placed on any Traveled Way beginning October 1st through March 31st of the following year without written approval from the Engineer.

Asphalt for prime coat shall not be applied when the ground temperature is lower than 50°F without written approval of the Engineer.

HMA shall not be placed on any wet surface, or when the average surface temperatures are less than those specified in the following table, or when weather conditions otherwise prevent the proper handling or finishing of the bituminous mixtures:

| Surface Temperature Limitation | | |
|---|---|---|
| **Compacted Thickness (Feet)** | **Wearing Course** | **Other Courses** |
| Less than 0.10 | 55°F | 45°F |
| 0.10 to 0.20 | 45°F | 35°F |
| More than 0.20 | 35°F | 35°F |

### 5-04.3(17) Paving Under Traffic

When the Roadway being paved is open to traffic, the requirements of this Section shall apply.

The Contractor shall keep on-ramps and off-ramps open to traffic at all times except when paving the ramp or paving across the ramp. During such time, and provided that there has been an advance warning to the public, the ramp may be closed for the minimum time required to place and compact the mixture. In hot weather, the Engineer may require the application of water to the pavement to accelerate the finish rolling of the pavement and to shorten the time required before reopening to traffic.

Before closing a ramp, advance warning signs shall be placed and signs shall also be placed marking the detour or alternate route. Ramps shall not be closed on consecutive interchanges at the same time.

During paving operations, temporary pavement markings shall be maintained throughout the project. Temporary pavement markings shall be installed on the Roadway prior to opening to traffic. Temporary pavement markings shall be in accordance with Section 8-23.

All costs in connection with performing the Work in accordance with these requirements, except the cost of temporary pavement markings, shall be included in the unit Contract prices for the various Bid items involved in the Contract.

attach # 16-09

**1-10.1(2) Description**

The Contractor shall provide flaggers and all other personnel required for labor for traffic control activities and not otherwise specified as being furnished by the Contracting Agency.

The Contractor shall perform all procedures necessary to support the Contract Work.

Unless otherwise permitted by the Contract or approved by the ~~Project~~ Engineer, the Contractor shall keep all existing pedestrian routes and access points (including sidewalks, paths, and crosswalks) open and clear at all times.

The Contractor shall keep lanes, on-ramps, and off-ramps, open to traffic at all times except when Work requires closures. Ramps shall not be closed on consecutive interchanges at the same time, unless approved by the Engineer. ~~The Contractor shall keep lanes, on-ramps, and off-ramps, open to traffic at all times except when Work requires closures.~~ Lanes and ramps shall be closed for the minimum time required to complete the Work. When paving hot mix asphalt the Contractor may apply water to the pavement to shorten the time required before reopening to traffic.

The Contractor shall provide signs and other traffic control devices not otherwise specified as being furnished by the Contracting Agency. The Contractor shall erect and maintain all construction signs, warning signs, detour signs, and other traffic control devices necessary to warn and protect the public at all times from injury or damage as a result of the Contractor's operations, which may occur on or adjacent to Highways, roads, streets, sidewalks, or paths. No Work shall be done on or adjacent to any Traveled Way until all necessary signs and traffic control devices are in place.

The traffic control resources and activities described shall be used for the safety of the public, of the Contractor's employees, and of the Contracting Agency's personnel and to facilitate the movement of the traveling public. Traffic control resources and activities may be used for the separation or merging of public and construction traffic when such use is in accordance with a specific approved traffic control plan.

Upon failure of the Contractor to immediately provide flaggers; erect, maintain, and remove signs; or provide, erect, maintain, and remove other traffic control devices when ordered to do so by the Engineer, the Contracting Agency may, without further notice to the Contractor or the Surety, perform any of the above and deduct all of the costs from the Contractor's payments.

The Contractor shall be responsible for providing adequate labor, sufficient signs, and other traffic control devices, and for performing traffic control procedures needed for the protection of the Work and the public at all times regardless of whether or not the labor, devices or procedures have been ordered by the Engineer, furnished by the Contracting Agency, or paid for by the Contracting Agency.

Wherever possible when performing Contract Work, the Contractor's equipment shall follow normal and legal traffic movements. The Contractor's ingress and egress of the Work area shall be accomplished with as little disruption to traffic as possible. Traffic control devices shall be removed by picking up the devices in a reverse sequence to that used for installation. This may require moving backwards through the work zone. When located behind barrier or at other locations shown on approved traffic control plans, equipment may operate in a direction opposite to adjacent traffic.

The Contractor is advised that the Contracting Agency may have entered into operating agreements with one or more law enforcement organizations for cooperative activities. Under such agreements, at the sole discretion of the Contracting Agency, law enforcement personnel may enter the work zone for enforcement purposes and may participate in the Contractor's traffic control activities. The responsibility under the Contract for all traffic control resides with the Contractor and any such participation by law enforcement personnel in Contractor traffic control activities will be referenced in the Special Provisions or will be preceded by an agreement and, if appropriate, a cost adjustment. Nothing in this Contract is intended to create an entitlement, on the part of the Contractor, to the services or participation of the law enforcement organization.

Attach 16-10

(August 7, 2006)
Section 1-08.6 is supplemented with the following:

Contract time may be suspended for verification of HMA mix designs or for procurement of critical materials (Procurement Suspension). In order to receive a Procurement Suspension, the Contractor shall within 30 calendar days after execution by the Contracting Agency, submit all HMA mix designs according to section 5-04.3(7)A or place purchase orders for all materials deemed critical by the Contracting Agency for physical completion of the contract. The Contractor shall provide a copy of the completed DOT Form 350-042 indicating the date the mix design was submitted, or copies of purchase orders for the critical materials. Such purchase orders shall disclose the purchase order date and estimated delivery dates for such critical material.

The Contractor shall show mix design verification or procurement of the materials listed below as activities in the Progress Schedule. If the approved Progress Schedule indicates that the mix design verification or materials procurement are critical activities, and if the Contractor has provided documentation that mix designs are submitted or purchase orders are placed for the critical materials within the prescribed 30 calendar days, then contract time shall be suspended upon physical completion of all critical work except that work dependent upon the below listed critical materials:

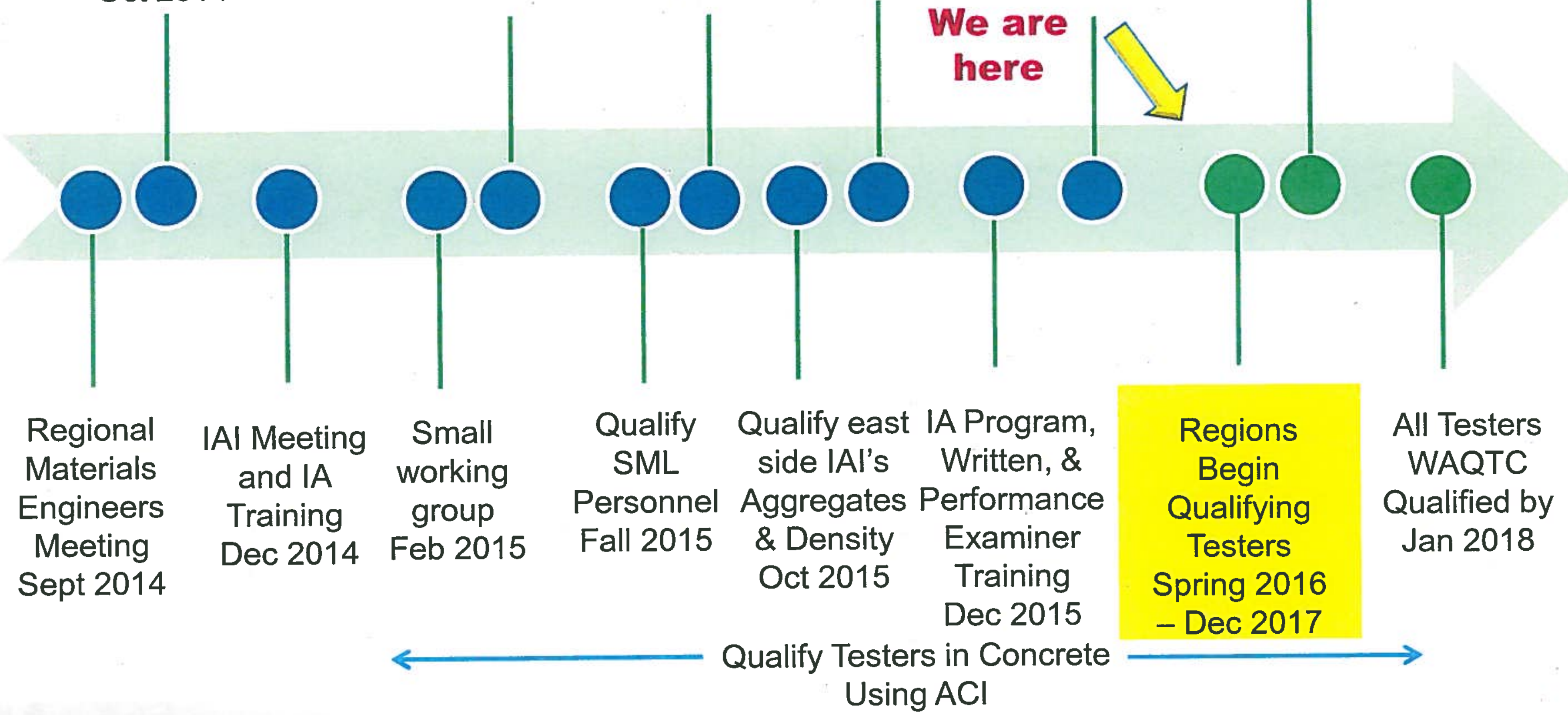
$$1$$

Charging of contract time will resume upon the Contractors' receipt of a mix design verification report, delivery of the critical materials to the Contractor, notification that the critical materials are ready for delivery to the Contractor from the Contracting Agency's Materials Laboratory, or *** $$2$$ *** calendar days after execution by the Contracting Agency, whichever occurs first.

No additional Procurement Suspension will be provided if the Contractors HMA mix designs did not verify and are resubmitted.

Attach # 16-14

# WAQTC Timeline




Washington State Department of Transportation

Attach # 16-18

**Improving HMA Committee – New Business – May 6, 2016 meeting**

**Proposal for revision of Hamburg test for lower gyration mixes**

**Statement of the Issue:**

With running Hamburg tests over the past couple years, an obvious trend was established between the number of design gyrations of a mix and performance in the Hamburg wheel tracker test. It is true that for 50 design gyration mixes, it is nearly impossible to pass the Hamburg test using the current specifications.

**Proposed Specification Revision:**

The correlation between expected traffic level and gyration design levels suggest that lower gyration mixes should be evaluated differently than higher gyration mixes. We propose that WSDOT change the passes of the Hamburg wheel tracker to vary based on gyration design parameters (ESAL level). Instead of the current 15,000 passes for every gyration level, we would propose a drop in the required passes for 50 and 75 gyration mixes. This would be applied for both the stripping inflection point and where the rut depth is calculated.

Proposed Hamburg Criteria for varying design gyrations:

| | Gyrations | Passes for Rut Depth and SIP | Max Rut Depth (mm) |
|---|---|---|---|
| Hamburg Wheel-Track Testing, FOP for AASHTO T 324 | 50 | 10,000 | 10 |
| | 75 | 12,500 | 10 |
| | 100 | 15,000 | 10 |
| | 125 | 15,000 | 10 |

Attech # 16-19



**5-04.3(7)A Mix Design**

1. **General.** Prior to the production of HMA, the Contractor shall determine a design aggregate structure and asphalt binder content in accordance with WSDOT Standard Operating Procedure 732. Once the design aggregate structure and asphalt binder content have been determined, the Contractor shall submit the HMA mix design on DOT form 350-042 demonstrating that the design meets the requirements of Sections 9-03.8(2) and 9-03.8(6). For HMA accepted by commercial evaluation only the first page of DOT form 350-042 and the percent of asphalt binder is required. In no case shall the paving begin before the determination of anti-strip requirements has been made.

   Changes to the aggregate or asphalt binder require approval of the Engineer and may require a new mix design submittal from the contractor. For aggregate this will include changes in the source of material or a change in the percentage of material from a stockpile greater than 5%. Asphalt binder changes include the source of the crude petroleum supplied to the refinery, the refining process and additives or modifiers in the asphalt binder. For mix designs that will be used in more than one calendar year and have not changed the contractor shall submit a certification that the mix design has not changed.

2. **Statistical or Nonstatistical Evaluation.** When the contract calls for either of these evaluation methods, the Contractor shall submit representative samples of the mineral materials that are to be used in the HMA production. The Contracting Agency will use these samples to determine anti-strip requirements, if any, in accordance with WSDOT test method T 718 and will also conduct verification testing of the mix design. Verification testing of HMA mix designs proposed by the contractor that include RAP will be completed without the inclusion of the RAP. Submittal of RAP samples is not required. A mix design verification report will be provided within 25 calendar days after a mix design submittal has been received in the State Materials Laboratory in Tumwater.

   If the results of the verification testing of the mix design by the Contracting Agency are within the tolerances in Section 9-03.8(7) the mix design will be considered verified. HMA requiring nonstatistical evaluation must have a verified mix design before paving will be allowed. Where HMA requires statistical evaluation, and where the mix design did not meet the required tolerances to be verified, the contractor shall have the option to either resubmit a new mix design or proceed to paving the HMA mixture test section.

   The mix design will be the initial job mix formula (JMF) for the class of mix. Any additional adjustments to the JMF will require the approval of the Project Engineer and may be made per Section 9-03.8(7).

3. **Commercial Evaluation.** Verification of the mix design by the Contracting Agency is not required. The Project Engineer will determine anti-strip requirements for the HMA. For commercial HMA, the contractor shall select a class of HMA and design level of Equivalent Single Axle Loads (ESAL's) appropriate for the required use.

**Deviation**

| | |
|---|---|
| U.S. No. 4 sieve and larger | Percent passing ±4.0 |
| U.S. No. 8 sieve | Percent passing ±2.0 |
| U.S. No. 200 sieve | Percent passing ±0.4 |
| Asphalt binder | Percent binder content ±0.3 |
| Va Percent | Va ±0.7 |

If the results of the challenge sample testing are within the allowable deviation established above for each parameter, the acceptance sample test results will be used for acceptance of the HMA. The cost of testing will be deducted from any monies due or that may come due the Contractor under the contract at the rate of $250 per challenge sample. If the results of the challenge sample testing are outside of any one parameter established above, the challenge sample will be used for acceptance of the HMA and the cost of testing will be the Contracting Agency's responsibility.

6. **Test Methods.** Testing of HMA for compliance of volumetric properties (VMA, VFA and Va) will be by WSDOT Standard Operating Procedure SOP 731. Testing for compliance of asphalt binder content will be by WSDOT FOP for AASHTO T 308. Testing for compliance of gradation will be by WAQTC FOP for AASHTO T 27/T 11.

7. **Test Section - HMA Mixture.** A mixture test section shall be constructed for every mix design accepted by Statistical Evaluation. The test section shall be used to determine if the mix meets the requirements of Sections 9-03.8(2) and 9-03.8(6). The HMA mixture test section may be constructed simultaneously with the compaction test section (Section 5-04.3(10)B).

The test section shall be constructed at the beginning of paving and will be at least 600 tons and a maximum of 800 tons or as approved by the Engineer. No further wearing or leveling HMA will be paved the day of or the day following the construction of the test section. The mixture in the test section will be evaluated as a lot with a minimum of three sublots required. If more than one test section is required, each test section shall be a separate lot.

For a test section to be acceptable, with or without a verified mix design, the pay factor (PF) for each of gradation, asphalt binder, VMA and Va shall be 0.95 or greater, and the remaining test requirements in Section 9-03.8(2) (dust/asphalt ratio, sand equivalent, uncompacted void content and fracture) shall conform to the requirements of that Section. When the pay factor for any item is less than 0.95 the Contractor shall make adjustments to the mix in accordance with Section 9-03.8(7) and construct another test section. The Project Engineer may waive the requirement for the construction of another test section.

For all HMA of the same class and PG asphalt binder grade payment for the HMA in the test section(s) will be in accordance with the provisions of 5-04.5(1) Quality Assurance Price Adjustments. The CPF for the HMA represented by the first test section shall be a minimum of 0.75 if the mix design was verified by the Contracting agency. The calculation of the CPF in a test section with a verified mix design will include gradation and asphalt binder content. The calculation of the CPF in a test section with a mix design that did not verify will include gradation, asphalt binder content and percent air voids (Va).

**Improving HMA, Bullfrog – November 4, 2016**
**Meeting Agenda**

| Present | Name | Company | Present | Name | Company | Present | Name | Company |
|---|---|---|---|---|---|---|---|---|
| X | Anderson, Taj | Poe | X | DeVol, Joe | WSDOT | | McDuffee, Steve | Watson |
| | Bell, Dave | Lakeside | X | Dyer, Bob | WSDOT | X | Pederson, Chris | CTL |
| | Byrd, Andrew | WSDOT | | Erickson, Dave | WSDOT | X | Russell, Mark | WSDOT |
| X | Cantrell, Logan | Granite | X | Gent, David | WAPA | X | Schofield, Dave | CWA |
| X | Chapman, Josh | Granite | X | Griffith, Brad | Miles | X | Shearer, Tim | ICON |
| | Clayton, E. J. | Granite | X | Hill, Kentin | Granite | | Shippy, Ron | Inland Asphalt |
| | Costello, Mike | Pyramid | X | Johnson, Torrey | Tucci & Sons | | Siegel, Roy | FHWA |
| X | Damitio, Chris | WSDOT | X | Martin, Preston | Miles | X | Uhlmeyer, Jeff | WSDOT |
| X | Dempsey, Bill | Lakeside | X | Mathis, Jerome | Inland Asphalt | X | Williams, Kurt | WSDOT |

## OLD BUSINESS

**13-07 High RAP/RAS**

- May 9, 2013 – Industry expressed concerns of not enough room for stockpiles.
- May 9, 2014 - RAP subcommittee reported that we are currently waiting for the industry members of the subcommittee to develop a draft spec for review and discussion. Primary points of discussion have been (a) timing and extent of additional testing currently required when the amount of RAP exceeds 20% or any amount of RAS, and (b) determining the type and timing of testing of RAP and RAS in stockpile needed to make prudent decisions on how variations affect the service life of the end product.
- October 9, 2014 – Update – This subcommittee is looking at increasing the threshold for not requiring the RAP oil to be blended into the mix design for approval, from its present 20%, to 30%. In order to make sure this is a decision that will not jeopardize length of service life, the committee is looking for Washington State test data to support the increase.
- May 8, 2015 – Dave Gent provided a copy (See Attachment #1) of the letter sent to WSDOT summarizing his understanding of the agreement in principle, between WSDOT and WAPA folks on the RAP Subcommittee, which creates a new RAP category for binder bumping in lieu of blending, for RAP between 20% and 25%. It was agreed that the goal is to finalize this into a spec to be published in the January 2016 Amendments.
- October 9, 2015 – Update from Kurt Williams – We need to reconvene the subcommittee to work out a few details. Need more discussion on the proposed changes to RAP between 20% and 25%. Dave Gent and Kurt will get the RAP subcommittee going on this.
- May 6, 2016 –Dave Gent handed out a draft a spec (attach #13-07a) which provides for a new “Medium RAP/No RAS” mix designation, and provided a handout of a report by Shane Buchanan titled “Washington State RAP Blending ‘What If’ Scenarios” (attach #13-07b). Further discussion of that spec will be done by the RAP/RAS subcommittee.
- November 4, 2016 – Dave Gent and Joe DeVol discussed the meeting minutes from the WSDOT/WAPA’s subcommittee on RAP meeting of October 4, 2016 (attachment #1, 13-07).

**14-13 Fine Aggregate Angularity (FAA) aka Uncompacted Void Content**

- October 9, 2014 – Bob Dyer reported he is evaluating the enforcement of this spec on projects back to the 2010 spec book, but not done yet. Several contractors expressed that this test is weighted too high in the statistical evaluation and suggested that WSDOT reduce its relative importance in the future, that the test is not very reproducible, and that there is no mechanism to challenge the WSDSOT test results. WSDOT responded that it is part of superpave.
- May 8, 2015 – Continued discussion, led by Dave Gent. Agreed that WAPA would develop a proposal for revisions to the spec.
- October 9, 2015 – Update from Dave Gent, who handed out a draft proposal (attached) to change the spec. The key changes Dave is seeking are a) reduce the size of the financial disincentive, which industry believes is disproportionally high, b) an ability for the contractor to challenge the WSDOT test results, and c) a sliding scale for the severity of the out-of-specness. Other test methods were discussed. Finally agreed that Granite will do some computer experimentation on the effect on the CPF of changing the statistical parameters so that the mixture CPF includes the PF for SE, coarse fracture, and FAA, and report results by next meeting.
- May 6, 2016 – Dave Gent provided a draft spec (attach #14-13a) and excerpts from NCHRP Report 539 “Aggregate Properties and the Performance of Superpave-Designed Hot Mix Asphalt” (attach #14-13b). The gist of the draft spec is to: a) move the FAA, Fracture, and SE related incentive/disincentive out of Spec 1-06 and into Spec 5-04, combine it with the statistical evaluation of the hot mixture properties, and “soften” the effect of the incentive/disincentive, and b) provide for

challenges to the FAA test results possibly looking to real-time Hamburg testing as a referee in challenges. The ball is now in WSDOT court to consider the draft spec, with a target of having any resulting revisions to the Standard Specs in the January 2017 Amendments.

- November 4, 2016 –Dave Gent discussed WAPA's proposed spec change (attachment #2, 14-13). It moves the price adjustment factors for SE, FAA, and Fracture out of Section 3-04 and into the price adjustment factors in Section 5-04. It also provides for challenge samples for failing FAA via Hamburg. The challenge samples would be taken from splits of WSDOT's acceptance samples. Dave's goal is to do two things – (1) make the price adjustment more equitable and (2) provide some basis for the contractor to challenge WSDOT test results. Dyer agreed to look into and respond at the next meeting.

**14-16 Concerns with SAM**

- October 9, 2014 - Dave Gent noted that SAM set-up is often cumbersome. He also suggested adding a "time stamp" for when documentation is entered (not shown currently) & add an "auto-notification" for producers / pavers (whether GC or sub.) to allow for timely review in case of challenges. Kurt Williams agreed to follow up.
- May 8, 2015 – Update from Kurt Williams. The lab has added a portal to SAM for all to use. A new field will be added to the database to record when each test data is input into SAM. "Auto-notification" to the contractor when data in SAM has been updated is in the process of being created, but has not happened yet. (MATS already has the ability to "auto-send".)
- October 9, 2015 – Update from Kurt Williams – MATS program has the ability to auto-email results to the contractor if the Paving contractor so requests the PE, but SAM does not. Bob Dyer agreed to modify Construction Manual to require PE to email MATS results when so requested by the contractor.
- May 6, 2016 – Dave Gent noted that there are still (this spring) delays by some WSDOT offices in getting the WSDOT acceptance test data into SAM. Bob Dyer provided a copy of excerpts from the new 5-04 Standard Spec (attach #14-16) showing the aspirational timeliness goals for WSDOT to provide WSDOT's test results to the contractor. Bill Dempsey volunteered to draft a revision to the WSDOT Construction Manual for WSDOT inspectors to directly and immediately provide test results to the Contractor.
- November 4, 2016 – Nothing to report.

**15-00 Trackless Tack**

- May 8, 2015 – Andrew Byrd reported that SC Region has a project this summer (ad date in a few weeks) that will require the use of paving grade asphalt for tack; they have proposed to allow trackless tack as an option. Jeff Uhlmeyer asked if WAPA had any concerns over two types of tack in one project, such that trackless tack could be used as an experimental feature?
- October 9, 2015 – Update from Dave Gent. We need a draft spec and a project to allow it experimentally. WSDOT agreed that Bob Dyer will revise the spec to allow STE-1 for tack because it was deleted from the 2014 Std Spec Book because we didn't think anyone was using it anymore, not because there is anything wrong with it.
- May 6, 2016 –Bob Dyer confessed that he forgot to get STE-1 back in the Standard Specs list of products acceptable for tack, and committed to get it into the August Amendments. Regarding trackless tack, WSDOT expressed a need for data that demonstrates an acceptable bond. Process now is for the Contractor to propose a no-cost change order. It was suggested that Louisiana has a good spec worth looking at. Possibly put approved products on the QPL. Ball in WAPA court to propose criteria by which WSDOT can evaluate, approve, and put these products on the QPL.
- November 4, 2016 – It was agreed that contractor requests to use trackless tack would be handled on a project-by-project basis, relying on contractor requests. This item is closed for the time being.

**15-01 Increasing RAP % in <u>aggregates</u>**

- May 8, 2015 – (i.e., using RAP in stuff other than HMA, i.e. discuss updating (9-03.21(1) E table) – Dave Gent brought up this item, and said the RAP subcommittee will take up this issue. Need to look at 9-03.21 to consider increasing RAP percent. A concern was noted that using RAP in untreated aggregates creates difficulties with measuring compaction with a nuke gage, which will need to be overcome.
- October 9, 2015 – Update from Dave Gent – there is still some industry desire to pursue this issue, but the obstacle has been how to deal with nuke gauge density measurement difficulties created by the asphalt. Chris Pederson will put together data on how this has been handled by other states and get it to Dave Gent.
- May 6, 2016 – Dave Gent provided handouts of NCHRP Synthesis 445 (attach 15-01a) and the abstract from a U of W research paper (attach 15-01b). WAPA is requesting to change the table in Standard Spec table in 9-03.21 from the current spec of 20% max RAP in aggregates to 25% max. WSDOT concerns are density testing and possible long-term effects of stripping. Joe DeVol agreed to review the literature and consider the proposed increase. Goal is that a final decision be reflected in the Jan 2017 amendments.

- November 4, 2016 – Joe DeVol agreed it would be acceptable to increase to 25% the percentage of those items in the Table in 9-03.21 that are currently 20% (attach #3, 15-01). Will try to get into January 2017 amendments to Standard Specs. Item closed.

**15-09 Optional allowance for submitting RAP with the zero to 20% RAP QPL mix designs**

- October 9, 2015 - Dave Gent - WAPA members would like this option to be allowed, if not in the specs., then by agreement with the Materials Lab. WSDOT agreed to Implement. Kurt and Joe agreed they would get it done.
- May 6, 2016 –Joe DeVol agreed to draft a spec implementing this and get it to Greg Morehouse for processing.
- November 4, 2016 – A draft of the spec allowing RAP to be included as a mandatory part of the mix design for Low RAP mixes is attached. WSDOT will try to get this implemented in the January 2017 amendments to the Standard Specs. (attachment #4, 15-09)

**15-10 Is WSDOT still evaluating/considering electro-magnetic asphalt density gauges.**

- October 9, 2015 - Dave Gent - Many WAPA members would like to move to new style gauges and away from nuke gauges, but would like WSDOT's current view. Steve McDuffee reported his experience has been that they are sensitive to hot HMA and provide more accurate results when pavement is cooled. WAPA reported that small local agencies don't have nuke gages. Current WSDOT investment in nukes will make this a difficult change, particularly because even if there was established and accepted accuracy of the electric gages, they don't yet work on soils so WSDOT would have to use both technologies.
- May 6, 2016 – WSDOT wants to get out of the nuke gage business and is considering other technology, but given the status of alternatives to the nuke don't expect to make any changes for at least two years. Dave Erickson and Bob Dyer agreed to provide for alternate technology as a pilot spec sometime soon.
- November 4, 2016 – Nothing to report.

**16-02 Better define the dates to be used for the Current Reference Price for Asphalt Cost Price Adjustments spec**

- May 6, 2016 – Dave Gent reported that WAPA believes the dates for making the calculations are ill-defined in the current spec. He will send a draft spec to Dave Erickson pointing out where he thinks the ambiguities are.
- November 4, 2016 – Dave Gent provided draft spec changes, but discussion was deferred until the next meeting. (attach #5, 16-02)

**16-04 Clarify QPL design costs / process/ rebates**

- May 6, 2016 – Discussion focused on WAPA's concerns regarding getting Commercial HMA mix designs on the QPL. a) WSDOT review cost seems excessive. Joe DeVol agreed to review and report back. b) WSDOT's requirement for advance payment seems antiquated and has caused delays. Dave Jones is working on developing a solution that provides more ways to pay than a check in advance. C) it was pointed out that the old system of dealing with approval of commercial mix designs was at no cost to the contractor, and frustration was expressed that the change to the QPL was what brought about the need for contractor payment. WSDOT reported that when pay is received timely, turn-around time has been 1 or 2 days.
- November 4, 2016 – Costs have been reduced. WSDOT will accept checks but will wait for the check to clear before beginning review. WSDOT is working on trying to be able to accept credit cards or PayPal but that process is not yet in place. Industry asked if WSDOT could post the rates online; Kurt Williams agreed to look into.

**16-08 The MSCR test and proposed changes to binder grades**

- May 6, 2016 – Joe DeVol provided a handout (attach #16-08) and explained that MSCR grading is the direction the national standard is headed, and will likely go into effect for WSDOT contracts about 2018.
- November 4, 2016 – MSCR stands for Multiple Stress Creep Recovery. Joe DeVol is working with a multi-state task group on developing specs. Joe expects WSDOT implementation will occur in 2018. Dave Gent noted that the Paving Industry's concern is the need for extra storage tanks, and how smoothly the Oil Industry will make the transition. The question was raised on what WSDOT's expectations would be for QPL approvals of mix designs when all the binder changes. Further discussion needed.

**16-10 Elimination of HMA mix designs from GSP for suspension of time charges for critical materials procurement processes**

- May 6, 2016 – Bob Dyer provided a handout of the old GSP (attach #16-10) and noted that this GSP has been deleted owing to the current requirement for all mix designs to be on the QPL. Consensus was that this GSP should be reinstated. Bob Dyer will follow up and make it so.

- November 4, 2016 – Bob Dyer Reported that the GSP allowing for procurement suspension for HMA mix design will be reinstituted, and should be available with the Jan 2017 update to the GSP's. Item closed. (attach #6, 16-10)

**16-11 How to allow for project generated RAP to be used in the project**

- May 6, 2016 – Dave Gent noted that the requirement for sequestering RAP stockpiles prior to mix design submittal prohibits the use of RAP generated on a project from being used in the HMA on that project and urged that this be overcome somehow. WSDOT reinforced its concern that the RAP properties in this case are unknown. Perhaps provision for real-time RAP testing? More next time.
- November 4, 2016 – Dave Gent will draft a proposed spec and present at the next meeting.

**16-12 Nonstatistical evaluation, mixture**

- May 6, 2016 – Bob Dyer pointed out that the provision for nonstatistical evaluation of mixture complicates the specs, and asked why we couldn't eliminate it? Consensus was that it would be OK to eliminate. Only concern is that Local Agencies like nonstatistical, but they write their own specs anyway. Bob Dyer will draft the revisions and send to Dave Gent for comment.
- November 4, 2016 – Bob Dyer provided a draft of the spec changes that will eliminate non-statistical evaluation of HMA mixture. Continuing to hear support from industry and WSDOT, this spec change will be implemented in the January 2017 amendments to the Standard Specs. Item closed. (attach #4, item 16-12)

**16-13 Discussion on a process to modify the "sequestered" RAP and RAS stockpiles rules/ wording**

- May 6, 2016 – No discussion on this item. Similar to item 16-11.
- November 4, 2016 –Dave Gent provided a draft spec change (attach #7, item 16-13). Joe DeVol noted that Dave's proposed spec would provide for testing the addition to the stockpile for binder content and gradation which is good, but he also would need to know about the VMA (which means also need to test for Aggregate sp.gr.). That puts the ball back in WAPA court to provide a draft spec that addresses testing for VMA and aggregate specific gravity.

**16-14 WAQTC – Implementation Plan**

- May 6, 2016 – Joe DeVol provided a handout (attach 16-14) regarding approximate dates for implementing the requirement for testers to be WAQTC certified. This will initially apply to all WSDOT folks and eventually to Contractor QA personnel. WSDOT has set a target that by 2020 industry will be trained and doing QA, with WSDOT doing QV.
- November 4, 2016 – Kurt Williams noted that the target date for getting all WSDOT testers certified is January of 2018. Also, he is working with ACEC to develop the mechanism to qualify folks that are not WSDOT employees.

**16-18 Proposal to Vary Number of Hamburg Passes Based on Number of Gyrations**

- May 6, 2016 – Dave Gent handed out a proposal (attach 16-18). Joe DeVol will look at it and provide feedback at the next meeting.
- November 4, 2016 – Joe DeVol noted that Hamburg results have improved since eliminating blend sand and implementing elastic recovery. He will review Dave Gent's proposal, and Dave Gent will provide supporting data.

**16-19 Proposal to allow a Test Section Verification Process**

- May 6, 2016 - Dave Gent proposed that the Test Section process be modified toward the direction of the way it was in the 2006 specs (attach 16-19). More discussion next time.
- November 4, 2016 – After further discussion, WSDOT is not interested in pursuing this further (attach #8, item 16-19).

## <u>NEW BUSINESS</u>

**16-20 Compaction Testing On Bridge Decks**

- November 4, 2016 – Bob Dyer hit the highlights of upcoming changes to compaction testing frequency on bridge decks - that will be effective in the Jan 2017 amendments to the standard specs. (attach #9 & attach #4, 16-20) – Dave Gent requested that the requirement for pneumatic rollers on decks longer than 125 feet be eliminated. Dyer will try to get bridge office to agree to that. More next time.

**16-21 Equipment Weight Restrictions When Paving Bridge Decks**

- November 4, 2016 – Bob Dyer hit the highlights of amendments to the standard specs that will implemented in Jan 2017 to memorialize what we have been doing for about the last year. (attach #10, 16-21). Item closed.

**16-22 Revisions to specs regarding HMA Overlays and Milling on Bridge Decks**

- November 4, 2016 – No discussion.

**16-23 Revise retesting specification to reflect 2008 procedure:**

- November 4, 2016 - Kentin Hill of Granite **-** There appears to have been a lot of issues this year (as well as in the past) with the state's initial testing of mix samples. When we think that the states testing isn't correct and challenge that test, there is no time frame for the retest to be completed. Some retests have taken <u>over a week</u> to get results back. The majority of the retests have come back in our favor (in Granite's experience) indicating that the test wasn't run correctly initially. Since we have to make plant changes based on the state's test results, this lag time isn't acceptable. We propose reinstating a turnaround time frame on retests?  Also, if the samples come back in our favor we propose that WSDOT pay for the cost of the retest. Proposal: In the 2008 spec book there was language that evaluated a retest sample and if it was outside of the tolerances then the state would pay for the extra testing.  We propose that we return to this standard. Bob Dyer responded that he will look at the aspirational language currently in the specs regarding turn-around time for test results and make sure it addresses retests.

**16-24 Allow mix design a 3rd year on the QPL**

- November 4, 2016 – Dave Gent proposed allowing an approved mix design to remain on the QPL for three years (instead of the current two) if the mix has passed volumetric testing on a WSDOT project at 95% pay factor or greater within one year prior to the extended expiration date for the QPL design.  Joe DeVol responded that binders change over time and so do anti-strips, therefore the WSDOT lab does not support this proposal.  Item closed.

NEXT MEETING – March 24, 2017

Attach #1
Item 13-07

**WSDOT/ WAPA Improving HMA Subcommittee on RAP/ RAS**

Meeting Summary – October 4/ 2016

The meeting was called to clarify the next steps forward:

- Four (4) trial projects (or partial projects) will be selected for demonstration/ testing of 25% RAP with simple binder bump criteria in 2017. Targeting jobs that can get at least a 2-day production run of 25% RAP (2,000 ton minimum trial). Target two jobs from each side of the state.
- WSDOT will develop a proposed "simple binder bump" specification where approved low RAP (20% RAP or less) mix designs will incorporate binder bumps one grade below the binder specified for the project. For instance:
  - Eastside paving – Contract binder PG 64-28, binder bumped to PG 58-34 for the trial section/ evaluation.
  - Westside paving – Contract binder PG 64-22, binder bumped to PG 58-28 for the trial section/ evaluation
- Granite Construction agreed to provide addition recovered binder from their RAP stockpiles to WSDOT for evaluation to be performed by WSDOT. WSDOT's goal is to experiment with the G*/sin Temp(°C) (Delta Temp°C) tests that are being considered to predict end-use binder conditions.
- WSDOT is actively considering two research proposals to further advance understanding of the Delta Temp°C predictive potential

**New Items Discussed –**

- ➢ WSDOT considering strategies to address occurrences of "dry mixes" they have encountered
- ➢ Preliminary results of increased compaction demonstration project were less than satisfactory. Prelim. results were approx. 0.5% density increase, but also lower standard deviation (more consistent testing

Attach #2 Item 14-13

***DRAFT V2.0 – Statement of the Issues: WAPA Proposal to move HMA Aggregate Testing out of 3-04 and into 5-04***

The separation of HMA aggregate and HMA mix testing has caused confusion and conflict in the last few years and has even led to potential project delays based on single aggregate tests (generally from uncompacted void content (FAA) testing) without an equitable vehicle for challenging the test or disproving the relevance of the test.

It is WAPA's view that recent specification changes (limited natural sands from secondary sources) and the use of a rutting performance test during mix design evaluation (Hamburg) are serving to greatly reduce mix rutting susceptibility, as was WSDOT's intent. These items have in turn greatly limited the practical usefulness of the FAA test, which is simply an imperfect "indicator" test, at best (see attached excerpts from NCHRP Report 539). The limited natural (blending) sand spec. and the Hamburg tests make the current "pass/ fail" nature of the FAA aggregate specification, and the resulting potential penalties, disproportionate to the true relevance of the test.

WAPA believes that the FAA test should be recognized as somewhat obsolete now that Hamburg testing is in full force. Alternately, its importance should be reduced and the test reporting simplified/ unified as an HMA test. As a way to retain the test (WSDOT's previously voiced preference) but to also make it more indicative of its role in HMA quality, WAPA proposes to eliminate all HMA aggregate testing from 3-04 and move the testing into 5-04 mixture evaluation.

**WAPA Proposed specification updates:**

Eliminate HMA Aggregate Testing from 3-04 Table 1 and move those tests to 5-04.5(1)A as shown below:

| Table of Price Adjustment Factors | |
|---|---|
| Constituent | Factor "f" |
| All aggregate passing: 1 ½", 1", ¾", ½", 3/8", and No. 4 sieves | 2 |
| All aggregate passing No. 8 sieve | 15 |
| All aggregate passing No. 200 sieve | 20 |
| Asphalt Binder | 40 |
| Air Voids (Va) | 20 |
| Sand Equivalent (SE) | 5 |
| Fracture | 5 |
| Uncompacted Void Content (FAA) | 5 |

**Notes:** All the tests in 5-04.5(1)A would be able to be challenged in the same way current HMA component tests are able to be challenged in the existing 5-04 system.

Additionally, as the direct link between FAA and rutting stability is tenuous in many circumstances, the Contractor should have the option to challenge the Uncompacted Void Content penalty through Hamburg evaluation of pavement cores in a system similar to compaction challenges by coring. (Added option) – Alternately, HMA challenge samples (to produced Hamburg pucks for Hamburg testing) could be collected in parallel with FAA testing and disposed of as FAA testing passes or challenge time windows expire.

The frequency of the aggregate tests would not change under this proposal. Each aggregate test would be posted to represent two HMA lots in SAM.

Item 15-01 attach #3

LRRB

# TRANSPORTATION RESEARCH SYNTHESIS

Local Road Research Board
Minnesota Department of Transportation
Research Services & Library
651-366-3780
www.lrrb.org

TRS 1604
Published September 2016

# Recycled Materials in Unbound Aggregate Base Layers in Minnesota

*The purpose of this TRS is to serve as a synthesis of pertinent completed research to be used for further study and evaluation by MnDOT and the Local Road Research Board. This TRS does not represent the conclusions of MSU Mankato, MnDOT or LRRB.*

## Introduction

The purpose of this Transportation Research Synthesis (TRS) is to provide an overview about the use of recycled materials in the base layers of pavements, and the design of these layers when using recycled materials. While the primary focus is on local streets and county roads, attention was also given to pavements constructed by state highway agencies. This TRS has at least two intended audiences: the Local Road Research Board (to aid in directing further research that may be needed) and engineers at local highway and street agencies (to assist in their immediate needs for guidance regarding recycled materials in maintaining their road networks).

The objectives of this TRS include the following.

- Summarize the current research and practice in the use of recycled materials in pavement base layers.
- Provide information to local agency pavement engineers to encourage the use of recycled materials where appropriate, and to promote realistic expectations of differences in construction and in long-term performance.
- Develop recommendations for the Local Road Research Board and regarding future research and the most effective use of research funding in this topic.

The most common recycled materials for pavement construction are the primary focus of this report, including recycled:

- Asphalt Pavement,
- Concrete Aggregate,
- Pavement Material,
- Roofing shingles, and
- Glass.

*attach #4*

**COLOR CODES FOR PROPOSED CHANGES**

| | | |
|---|---|---|
| (yellow) | Commit to RAP in <20% RAP mix designs | *item 15-09* |
| (blue) | Miscellaneous cleanup | |
| (green) | Eliminate non-statistical acceptance (mixture) | *item 16-12* |
| (purple) | Increased compaction testing on bridge decks | *item 16-20* |

## 5-04 Hot Mix Asphalt

This Section 5-04 is written in a style which, unless otherwise indicated, shall be interpreted as direction to the Contractor.

### 5-04.1 Description

This Work consists of providing and placing one or more layers of plant-mixed hot mix asphalt (HMA) on a prepared foundation or base, in accordance with these Specifications and the lines, grades, thicknesses, and typical cross-sections shown in the Plans. The manufacture of HMA may include warm mix asphalt (WMA) processes in accordance with these Specifications.

HMA shall be composed of asphalt binder and mineral materials as required, and may include reclaimed asphalt pavement (RAP) or reclaimed asphalt shingles (RAS), mixed in the proportions specified to provide a homogeneous, stable, and workable mix.

### 5-04.2 Materials

Provide materials as specified in these sections:

| | |
|---|---|
| Asphalt Binder | 9-02.1(4) |
| Cationic Emulsified Asphalt | 9-02.1(6) |
| Anti-Stripping Additive | 9-02.4 |
| Warm Mix Asphalt Additive | 9-02.5 |
| Aggregates | 9-03.8 |
| Reclaimed Asphalt Pavement (RAP) | 9-03.8(3)B |
| Reclaimed Asphalt Shingles (RAS) | 9-03.8(3)B |
| Mineral Filler | 9-03.8(5) |
| Recycled Material | 9-03.21 |
| Hot Poured Sealant | 9-04.2(1)A |
| Sand Slurry | 9-04.2(1)B |

#### 5-04.2(1) How to Get an HMA Mix Design on the QPL

Comply with each of the following:

- Develop the mix design in accordance with WSDOT SOP 732.
- Develop a mix design that complies with Sections 9-03.8(2) and 9-03.8(6).
- Develop a mix design no more than 6 months prior to submitting it for QPL evaluation.
- Submit mix designs to the WSDOT State Materials Laboratory in Tumwater, including WSDOT Form 350-042.
- Include representative samples of the materials that are to be used in the HMA production as part of the mix design submittal. ~~See Section 5-04.2(1)A to determine when to include samples of RAP or RAS.~~
- Identify the brand, type, and percentage of anti-stripping additive in the mix design submittal.
- Include with the mix design submittal a certification from the asphalt binder supplier that the anti-stripping additive is compatible with the crude source and the formulation of asphalt binder proposed for use in the mix design.
- Do not include warm mix asphalt (WMA) additives when developing a mix design or submitting a mix design for QPL evaluation. The use of warm mix asphalt (WMA) additives is not part of the process for obtaining approval for listing a mix design on the QPL. Refer to Section 5-04.2(2)B.

The Contracting Agency's basis for approving, testing, and evaluating HMA mix designs for approval on the QPL is dependent on the contractual basis for acceptance of the HMA mixture, as shown in Table 1.

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Table 1

| Basis for Contracting Agency Evaluation of HMA Mix Designs for Approval on the QPL | | |
|---|---|---|
| Contractual Basis for Acceptance of HMA Mixture [see Section 5-04.3(9)] | Basis for Contracting Agency Approval of Mix Design for Placement on QPL | Contracting Agency Materials Testing for Evaluation of the Mix Design |
| Statistical Evaluation, ~~or Nonstatistical Evaluation~~ | WSDOT Standard Practice QC-8 | The Contracting Agency will test the mix design materials for compliance with Sections 9-03.8(2) and 9-03.8(6). |
| Visual Evaluation | Review of Form 350-042 for compliance with Sections 9-03.8(2) and 9-03.8(6) | The Contracting Agency may elect to test the mix design materials, or evaluate in accordance with WSDOT Standard Practice QC-8, at its sole discretion. |

If the Contracting Agency approves the mix design, it will be listed on the QPL for 12 consecutive months. The Contracting Agency may extend the 12 month listing provided the Contractor submits a certification letter to the Qualified Products Engineer verifying that the aggregate source and job mix formula (JMF) gradation, and asphalt binder crude source and formulation have not changed. The Contractor may submit the certification no sooner than ~~one~~ three months prior to expiration of the initial 12 month mix design approval. Within 7 calendar days of receipt of the Contractor's certification, the Contracting Agency will update the QPL. The maximum duration for approval of a mix design and listing on the QPL will be 24 months from the date of initial approval or as approved by the Engineer.

### 5-04.2(1)A Mix Designs Containing RAP and/or RAS

Mix designs are classified by the RAP and/or RAS content as shown in Table 2.

Table 2

| Mix Design Classification Based on RAP/RAS Content | |
|---|---|
| RAP/RAS Classification | RAP/RAS Content[1] |
| Low RAP/No RAS | 0% ≤ RAP% ≤ 20% and RAS% = 0% |
| High RAP/Any RAS | 20% < RAP% ≤ Maximum Allowable RAP[2] and/or 0% < RAS% ≤ Maximum Allowable RAS[2] |

[1]Percentages in this table are by total weight of HMA
[2]See Table 4 to determine the limits on the maximum amount RAP and/or RAS.

### 5-04.2(1)A1 Low RAP/No RAS – Mix Design Submittals for Placement on QPL

For Low RAP/No RAS mix designs, comply with the following additional requirements:

1. Develop the mix design with or without the inclusion of RAP.
2. The asphalt binder grade shall be the grade indicated in the Bid item name or as otherwise required by the Contract.
3. ~~Do not s~~Submit samples of RAP if used in development of the~~with these~~ mix designs.
4. Testing RAP or RAS stockpiles is not required for obtaining approval for placing these mix designs on the QPL.

### 5-04.2(1)A2 High RAP/Any RAS – Mix Design Submittals for Placement on QPL

For High RAP/Any RAS mix designs, comply with the following additional requirements:

1. For mix designs with any RAS, test the RAS stockpile (and RAP stockpile if any RAP is in the mix design) in accordance with Table 3.
2. For High RAP mix designs with no RAS, test the RAP stockpile in accordance with Table 3.
3. For mix designs with High RAP/Any RAS, construct a single stockpile for RAP and a single stockpile for RAS and isolate (sequester) these stockpiles from further stockpiling before beginning development of the mix design. Test the RAP and RAS during stockpile construction as required by item 1 and 2 above. Use the test data in developing the mix design, and report the test data to The Contracting Agency on WSDOT Form 350-042 as part of the mix design submittal for approval on the QPL. Account for the reduction in asphalt binder contributed from RAS in accordance with AASHTO PP 78. Do not add to these stockpiles after starting the mix design process.

Table 3

| Test Frequency of RAP/RAS During RAP/RAS Stockpile Construction For Approving a High RAP/Any RAS Mix Design for Placement on the QPL | | |
|---|---|---|
| Test Frequency[1] | Test for | Test Method |
| • 1/1000 tons of RAP (minimum of 10 per mix | Asphalt Binder Content and Sieve Analysis of Fine and | FOP for AASHTO T 308 and |

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| | | |
|---|---|---|
| design) and<br>• 1/100 tons of RAS (minimum of 10 per mix design) | Coarse Aggregate | FOP for WAQTC T 27/T 11 |
| [1]"tons", in this table, refers to tons of the reclaimed material before being incorporated into HMA. | | |

4. Limit the amount of RAP and/or RAS used in a High RAP/Any RAS mix design by the amount of binder contributed by the RAP and/or RAS, in accordance with Table 4.

Table 4

| Maximum Amount of RAP and/or RAS in HMA Mixture | |
|---|---|
| Maximum Amount of Binder Contributed from: | |
| RAP | RAS |
| 40%[1] minus contribution of binder from RAS | 20%[2] |
| [1]Calculated as the weight of asphalt binder contributed from the RAP as a percentage of the total weight of asphalt binder in the mixture.<br>[2]Calculated as the weight of asphalt binder contributed from the RAS as a percentage of the total weight of asphalt binder in the mixture. | |

5. Develop the mix design including RAP, RAS, recycling agent, and new binder.
6. Extract, recover, and test the asphalt residue from the RAP and RAS stockpiles to determine the percent of recycling agent and/or grade of new asphalt binder needed to meet but not exceed the performance grade (PG) of asphalt binder required by the Contract.
   a. Perform the asphalt extraction in accordance with AASHTO T 164 or ASTM D 2172 using reagent grade trichloroethylene.
   b. Perform the asphalt recovery in accordance with AASHTO R 59 or ASTM D 1856.
   c. Test the recovered asphalt residue in accordance with AASHTO R 29 to determine the asphalt binder grade in accordance with Section 9-02.1(4).
   d. After determining the recovered asphalt binder grade, determine the percent of recycling agent and/or grade of new asphalt binder in accordance with ASTM D 4887.
   e. Test the final blend of recycling agent, binder recovered from the RAP and RAS, and new asphalt binder in accordance with AASHTO R 29. The final blended binder shall meet but not exceed the performance grade of asphalt binder required by the Contract and comply with the requirements of Section 9-02.1(4).
7. Include the following test data with the mix design submittal:
   a. All test data from RAP and RAS stockpile construction.
   b. All data from testing the recovered and blended asphalt binder.
8. Include representative samples of the following with the mix design submittal:
   a. RAP and RAS.
   B. ~~100~~ 150 grams of recovered asphalt residue from the RAP and RAS that are to be used in the HMA production.

**5-04.2(1)B Commercial HMA – Mix Design Submittal for Placement on QPL**

For HMA used in the Bid item Commercial HMA, in addition to the requirements of 5-04.2(1) identify the following in the submittal:

1. Commercial HMA
2. Class of HMA
3. Performance grade of binder
4. Equivalent Single Axle Load (ESAL)

The Contracting Agency may elect to approve Commercial HMA mix designs without evaluation.

**5-04.2(1)C Mix Design Resubmittal for QPL Approval**

Develop a new mix design and resubmit for approval on the QPL when any of the following changes occur. When these occur, discontinue using the mix design until after it is reapproved on the QPL.

1. Change in the source of crude petroleum used in the asphalt binder.
2. Changes in the asphalt binder refining process.
3. Changes in additives or modifiers in the asphalt binder.
4. Changes in the anti-strip additive, brand, type or quantity.
5. Changes to the source of material for aggregate.
6. Changes to the job mix formula that exceed the amounts as described in item 2 of Section 9-03.8(7), unless otherwise approved by the Engineer.
7. Changes in the percentage of material from a stockpile, when such changes exceed 5% of the total aggregate weight.
   a. Changes to the percentage of material from a stockpile will be calculated based on the total aggregate weight (not including the weight of

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RAP) for Low RAP/No RAS mix designs developed without RAP.

b. For High RAP/Any RAS mix designs, changes in the percentage of material from a stockpile will be based on total aggregate weight including the weight of RAP (and/or RAS when included in the mixture).

Prior to making any change in the amount of RAS in an approved mix design, notify the Engineer for determination of whether a new mix design is required, and obtain the Engineer's approval prior to implementing such changes.

#### 5-04.2(2) Mix Design – Obtaining Project Approval

Use only mix designs listed on the Qualified Products List (QPL). Submit WSDOT Form 350-041 to the Engineer to request approval to use a mix design from the QPL. Changes to the job mix formula (JMF) that have been approved on other contracts may be included. The Engineer may reject a request to use a mix design if production of HMA using that mix design on any contract is not in compliance with Section 5-04.3(11)D, E, F, and G for mixture or compaction.

#### 5-04.2(2)A Changes to the Job Mix Formula

The approved mix design obtained from the QPL will be considered the starting job mix formula (JMF) and shall be used as the initial basis for acceptance of HMA mixture, as detailed in Section 5-04.3(9).

During production the Contractor may request to adjust the JMF. Any adjustments to the JMF will require approval of the Engineer and shall be made in accordance with item 2 of Section 9-03.8(7). After approval by the Engineer, such adjusted JMF's shall constitute the basis for acceptance of the HMA mixture.

#### 5-04.2(2)B Using Warm Mix Asphalt Processes

The Contractor may, at the Contractor's discretion, elect to use warm mix asphalt (WMA) processes for producing HMA. WMA processes include organic additives, chemical additives, and foaming. The use of WMA is subject to the following:

- Do not use WMA processes in the production of High RAP/Any RAS mixtures.
- Before using WMA processes, obtain the Engineer's approval using WSDOT Form 350-076 to describe the proposed WMA process.

### 5-04.3 Construction Requirements

#### 5-04.3(1) Weather Limitations

Do not place HMA for wearing course on any Traveled Way beginning October 1st through March 31st of the following year, without written concurrence from the Engineer.

Do not place HMA on any wet surface, or when the average surface temperatures are less than those specified in Table 5, or when weather conditions otherwise prevent the proper handling or finishing of the HMA.

Table 5

| Minimum Surface Temperature for Paving | | |
|---|---|---|
| Compacted Thickness (Feet) | Wearing Course | Other Courses |
| Less than 0.10 | 55°F | 45°F |
| 0.10 to 0.20 | 45°F | 35°F |
| More than 0.20 | 35°F | 35°F |

#### 5-04.3(2) Paving Under Traffic

These requirements apply when the Roadway being paved is open to traffic.

In hot weather, the Engineer may require the application of water to the pavement to accelerate the finish rolling of the pavement and to shorten the time required before reopening to traffic.

During paving operations, maintain temporary pavement markings throughout the project. Install temporary pavement markings on the Roadway prior to opening to traffic. Temporary pavement markings shall comply with Section 8-23.

#### 5-04.3(3) Equipment

#### 5-04.3(3)A Mixing Plant

Equip mixing plants as follows:

1. **Use tanks for storage and preparation of asphalt binder which:**
   - Heat the contents by means that do not allow flame to contact the contents or the tank, such as by steam or electricity.

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- Heat and hold contents at the required temperatures.
- Continuously circulate contents to provide uniform temperature and consistency during the operating period.
- Provide an asphalt binder sampling valve, in either the storage tank or the supply line to the mixer.

2. **Provide thermometric equipment:**
   - In the asphalt binder feed line near the charging valve at the mixer unit, capable of detecting temperature ranges expected in the HMA and in a location convenient and safe for access by Inspectors.
   - At the discharge chute of the drier to automatically register or indicate the temperature of the heated aggregates, and situated in full view of the plant operator.
3. **When heating asphalt binder:**
   - Do not exceed the maximum temperature of the asphalt binder recommended by the asphalt binder supplier.
   - Avoid local variations in heating.
   - Provide a continuous supply of asphalt binder to the mixer at a uniform average temperature with no individual variations exceeding 25°F.
4. **Provide a mechanical sampler for sampling mineral materials that:**
   - Meets the crushing or screening requirements of Section 1-05.6.
5. **Provide HMA sampling equipment that complies with WSDOT SOP T-168.**
   - Use a mechanical sampling device installed between the discharge of the silo and the truck transport, approved by the Engineer, or
   - Platforms or devices to enable sampling from the truck transport without entering the truck transport for sampling HMA.
6. **Provide for setup and operation of the Contracting Agency's field testing:**
   - As required in Section 3-01.2(2).
7. **Provide screens or a lump breaker:**
   - When using any RAP or any RAS, to eliminate oversize RAP or RAS particles from entering the pug mill or drum mixer.

**5-04.3(3)B Hauling Equipment**

Provide HMA hauling equipment with tight, clean, smooth metal beds and a cover of canvas or other suitable material of sufficient size to protect the HMA from adverse weather. Securely attach the cover to protect the HMA whenever the weather conditions during the work shift include, or are forecast to include, precipitation or an air temperature less than 45°F.

Prevent HMA from adhering to the hauling equipment. Spray metal beds with an environmentally benign release agent. Drain excess release agent prior to filling hauling equipment with HMA. Do not use petroleum derivatives or other coating material that contaminate or alter the characteristics of the HMA. For hopper trucks, operate the conveyer during the process of applying the release agent.

**5-04.3(3)C Pavers**

Use self-contained, power-propelled pavers provided with an internally heated vibratory screed that is capable of spreading and finishing courses of HMA in lane widths required by the paving section shown in the Plans.

When requested by the Engineer, provide written certification that the paver is equipped with the most current equipment available from the manufacturer for the prevention of segregation of the coarse aggregate particles. The certification shall list the make, model, and year of the paver and any equipment that has been retrofitted to the paver.

Operate the screed in accordance with the manufacturer's recommendations and in a manner to produce a finished surface of the required evenness and texture without tearing, shoving, segregating, or gouging the mixture. Provide a copy of the manufacturer's recommendations upon request by the Contracting Agency. Extensions to the screed will be allowed provided they produce the same results, including ride, density, and surface texture as obtained by the primary screed. In the Travelled Way do not use extensions without both augers and an internally heated vibratory screed.

Equip the paver with automatic screed controls and sensors for either or both sides of the paver. The controls shall be capable of sensing grade from an outside reference line, sensing the transverse slope of the screed, and providing automatic signals that operate the screed to maintain the desired grade and transverse slope. Construct the sensor so it will operate from a reference line or a mat referencing device. The transverse slope controller shall be capable of maintaining the screed at the desired slope within plus or minus 0.1 percent.

Equip the paver with automatic feeder controls, properly adjusted to maintain a uniform depth of material ahead of the screed.

Manual operation of the screed is permitted in the construction of irregularly shaped and minor areas. These areas include, but are not limited to, gore areas, road approaches, tapers and left-turn channelizations.

When specified in the Contract, provide reference lines for vertical control. Place reference lines on both outer edges of the Traveled Way of each Roadway. Horizontal control utilizing the reference line is permitted. Automatically control the grade and slope of intermediate lanes by means of reference lines or a mat referencing device and a slope control device. When the finish of the grade prepared for paving is superior to the established tolerances and when, in the opinion of the Engineer, further improvement to the line, grade, cross-section, and smoothness can best be achieved without the use of the reference line, a mat referencing device may be substituted for the reference line. Substitution of the device will be subject to the continued approval of the Engineer. A joint matcher may be used subject to the approval of the Engineer. The reference line may be removed after completion of the first course of HMA when approved by the Engineer. Whenever the Engineer determines that any of these methods are failing to provide the necessary vertical control, the reference lines will be reinstalled by the Contractor.

Furnish and install all pins, brackets, tensioning devises, wire, and accessories necessary for satisfactory operation of the automatic control

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equipment.

If the paving machine in use is not providing the required finish, the Engineer may suspend Work as allowed by Section 1-08.6.

### 5-04.3(3)D Material Transfer Device or Material Transfer Vehicle

Use a material transfer device (MTD) or material transfer vehicle (MTV) to deliver the HMA from the hauling equipment to the paving machine for any lift in (or partially in) the top 0.30 feet of the pavement section used in traffic lanes. However, an MTD/V is not required for HMA placed in irregularly shaped and minor areas such as tapers and turn lanes, or for HMA mixture that is accepted by Visual Evaluation. At the Contractor's request the Engineer may approve paving without an MTD/V; the Engineer will determine if an equitable adjustment in cost or time is due. If a windrow elevator is used, the Engineer may limit the length of the windrow in urban areas or through intersections.

To be approved for use, an MTV:

1. Shall be self-propelled vehicle, separate from the hauling vehicle or paver.
2. Shall not be connected to the hauling vehicle or paver.
3. May accept HMA directly from the haul vehicle or pick up HMA from a windrow.
4. Shall mix the HMA after delivery by the hauling equipment and prior to placement into the paving machine.
5. Shall mix the HMA sufficiently to obtain a uniform temperature throughout the mixture.

To be approved for use, an MTD:

1. Shall be positively connected to the paver.
2. May accept HMA directly from the haul vehicle or pick up HMA from a windrow.
3. Shall mix the HMA after delivery by the hauling equipment and prior to placement into the paving machine.
4. Shall mix the HMA sufficiently to obtain a uniform temperature throughout the mixture.

### 5-04.3(3)E Rollers

Operate rollers in accordance with the manufacturer's recommendations. When requested by the Engineer, provide a Type 1 Working Drawing of the manufacturer's recommendation for the use of any roller planned for use on the project. Do not use rollers that crush aggregate, produce pickup or washboard, unevenly compact the surface, displace the mix, or produce other undesirable results.

### 5-04.3(4) Preparation of Existing Paved Surfaces

Before constructing HMA on an existing paved surface, the entire surface of the pavement shall be clean. Entirely remove all fatty asphalt patches, grease drippings, and other deleterious substances from the existing pavement to the satisfaction of the Engineer. Thoroughly clean all pavements or bituminous surfaces of dust, soil, pavement grindings, and other foreign matter. Thoroughly remove any cleaning or solvent type liquids used to clean equipment spilled on the pavement before paving proceeds. Fill all holes and small depressions with an appropriate class of HMA. Level and thoroughly compact the surface of the patched area.

Apply a uniform coat of asphalt (tack coat) to all paved surfaces on which any course of HMA is to be placed or abutted. Apply tack coat to cover the cleaned existing pavement with a thin film of residual asphalt free of streaks and bare spots. Apply a heavy application of tack coat to all joints. For Roadways open to traffic, limit the application of tack coat to surfaces that will be paved during the same working shift. Equip the spreading equipment with a thermometer to indicate the temperature of the tack coat material.

Do not operate equipment on tacked surfaces until the tack has broken and cured. Repair tack coat damaged by the Contractor's operation, prior to placement of the HMA.

Unless otherwise approved by the Engineer, use cationic emulsified asphalt CSS-1, CSS-1h, or Performance Graded (PG) asphalt for tack coat. The CSS-1 and CSS-1h ~~emulsified asphalt~~ may be diluted with water at a rate not to exceed one part water to one part emulsified asphalt. Do not allow the tack coat material to exceed the maximum temperature recommended by the asphalt supplier.

When shown in the Plans, prelevel uneven or broken surfaces over which HMA is to be placed by using an asphalt paver, a motor patrol grader, or by hand raking, as approved by the Engineer.

### 5-04.3(4)A Crack Sealing

### 5-04.3(4)A1 General

When the Proposal includes a pay item for crack sealing, seal all cracks ¼ inch in width and greater.

**Cleaning:** Ensure that cracks are thoroughly clean, dry and free of all loose and foreign material when filling with crack sealant material. Use a hot compressed air lance to dry and warm the pavement surfaces within the crack immediately prior to filling a crack with the sealant material. Do not overheat pavement. Do not use direct flame dryers. Routing cracks is not required.

**Sand Slurry:** For cracks that are to be filled with sand slurry, thoroughly mix the components and pour the mixture into the cracks until full. Add additional CSS-1 cationic emulsified asphalt to the sand slurry as needed for workability to ensure the mixture will completely fill the cracks. Strike off the sand slurry flush with the existing pavement surface and allow the mixture to cure. Top off cracks that were not completely filled with additional sand slurry. Do not place the HMA overlay until the slurry has fully cured.

**Hot Poured Sealant:** For cracks that are to be filled with hot poured sealant, apply the material in accordance with these requirements and the manufacturer's recommendations. Furnish ~~a Type 1 Working Drawing of~~ the manufacturer's product information and recommendations to the Engineer prior to the start of work, including the manufacturer's recommended heating time and temperatures, allowable storage time and

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temperatures after initial heating, allowable reheating criteria, and application temperature range. Confine hot poured sealant material within the crack. Clean any overflow of sealant from the pavement surface. If, in the opinion of the Engineer, the Contractor's method of sealing the cracks with hot poured sealant results in an excessive amount of material on the pavement surface, stop and correct the operation to eliminate the excess material.

#### 5-04.3(4)A2 Crack Sealing Areas Prior to Paving

In areas where HMA will be placed, use sand slurry to fill the cracks.

#### 5-04.3(4)A3 Crack Sealing Areas Not to be Paved

In areas where HMA will not be placed, fill the cracks as follows:

1. Cracks ¼ inch to 1 inch in width - fill with hot poured sealant.
2. Cracks greater than 1 inch in width – fill with sand slurry.

#### 5-04.3(4)B Soil Residual Herbicide

Where shown in the Plans, apply one application of an approved soil residual herbicide. Comply with Section 8-02.3(3)B. Complete paving within 48 hours of applying the herbicide.

Use herbicide registered with the Washington State Department of Agriculture for use under pavement. Before use, obtain the Engineer's approval of the herbicide and the proposed rate of application. Include the following information in the request for approval of the material:

1. Brand Name of the Material,
2. Manufacturer,
3. Environmental Protection Agency (EPA) Registration Number,
4. Material Safety Data Sheet, and
5. Proposed Rate of Application.

#### 5-04.3(4)C Pavement Repair

Excavate pavement repair areas and backfill these with HMA in accordance with the details shown in the Plans and as staked. Conduct the excavation operations in a manner that will protect the pavement that is to remain. Repair pavement not designated to be removed that is damaged as a result of the Contractor's operations to the satisfaction of the Engineer at no cost to the Contracting Agency. Excavate only within one lane at a time unless approved otherwise by the Engineer. Do not excavate more area than can be completely backfilled and compacted during the same shift.

Unless otherwise shown in the Plans or determined by the Engineer, excavate to a depth of 1.0 feet. The Engineer will make the final determination of the excavation depth required.

The minimum width of any pavement repair area shall be 40 inches unless shown otherwise in the Plans. Before any excavation, sawcut the perimeter of the pavement area to be removed unless the pavement in the pavement repair area is to be removed by a pavement grinder.

Excavated materials shall be the property of the Contractor and shall be disposed of in a Contractor-provided site off the Right of Way or used in accordance with Sections 2-02.3(3) or 9-03.21.

Apply a heavy application of tack coat to all surfaces of existing pavement in the pavement repair area, in accordance with Section 5-04.3(4).

Place the HMA backfill in lifts not to exceed 0.35-foot compacted depth. Thoroughly compact each lift by a mechanical tamper or a roller.

#### 5-04.3(5) Producing/Stockpiling Aggregates, RAP, & RAS

Produce aggregate in compliance with Section 3-01. Comply with Section 3-02 for preparing stockpile sites, stockpiling, and removing from stockpile each of the following: aggregates, RAP, and RAS. Provide sufficient storage space for each size of aggregate, RAP and RAS. Fine aggregate or RAP may be uniformly blended with the RAS as a method of preventing the agglomeration of RAS particles. Remove the aggregates, RAP and RAS from stockpile(s) in a manner that ensures minimal segregation when being moved to the HMA plant for processing into the final mixture. Keep different aggregate sizes separated until they have been delivered to the HMA plant.

#### 5-04.3(5)A Stockpiling RAP or RAS for High RAP/Any RAS Mixes

Do not place any RAP or RAS into a stockpile which has been sequestered for a High RAP/Any RAS mix design. Do not incorporate any RAP or RAS into a High RAP/Any RAS mixture from any source other than the stockpile which was sequestered for approval of that particular High RAP/Any RAS mix design.

RAP that is used in a Low RAP/No RAS mix is not required to come from a sequestered stockpile.

#### 5-04.3(6) Mixing

The asphalt supplier shall introduce anti-stripping additive, in the amount designated on the QPL for the mix design, into the asphalt binder prior to shipment to the asphalt mixing plant.

Anti-strip is not required for temporary work that will be removed prior to Physical Completion.

Use asphalt binder of the grade, and from the supplier, in the approved mix design.

Prior to introducing reclaimed materials into the asphalt plant, remove wire, nails, and other foreign material. Discontinue use of the reclaimed material if the Engineer, in their sole discretion, determines the wire, nails, or other foreign material to be excessive.

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Size RAP and RAS prior to entering the mixer to provide uniform and thoroughly mixed HMA. If there is evidence of the RAP or RAS not breaking down during the heating and mixing of the HMA, immediately suspend the use of the RAP or RAS until changes have been approved by the Engineer.

After the required amount of mineral materials, RAP, RAS, new asphalt binder and recycling agent have been introduced into the mixer, mix the HMA until complete and uniform coating of the particles and thorough distribution of the asphalt binder throughout the mineral materials, RAP and RAS is ensured.

Upon discharge from the mixer, ensure that the temperature of the HMA does not exceed the optimum mixing temperature shown on the approved Mix Design Report by more than 25°F, or as approved by the Engineer. When a WMA additive is included in the manufacture of HMA, do not heat the WMA additive (at any stage of production including in binder storage tanks) to a temperature higher than the maximum recommended by the manufacturer of the WMA additive.

A maximum water content of 2 percent in the mix, at discharge, will be allowed providing the water causes no problems with handling, stripping, or flushing. If the water in the HMA causes any of these problems, reduce the moisture content.

During the daily operation, HMA may be temporarily held in approved storage facilities. Do not incorporate HMA into the Work that has been held for more than 24 hours after mixing. Provide an easily readable, low bin-level indicator on the storage facility that indicates the amount of material in storage. Waste the HMA in storage when the top level of HMA drops below the top of the cone of the storage facility, except as the storage facility is being emptied at the end of the working shift. Dispose of rejected or waste HMA at no expense to the Contracting Agency.

### 5-04.3(7) Spreading and Finishing

Do not exceed the maximum nominal compacted depth of any layer in any course, as shown in Table 6, unless approved by the Engineer:

Table 6

| Maximum Nominal Compacted Depth of Any Layer | | |
|---|---|---|
| HMA Class | Wearing Course | Other than Wearing Course |
| 1 inch | 0.35 feet | 0.35 feet |
| ¾ and ½ inch | 0.30 feet | 0.35 feet |
| ⅜ inch | 0.15 feet | 0.15 feet |

Use HMA pavers complying with Section 5-04.3(3) to distribute the mix. On areas where irregularities or unavoidable obstacles make the use of mechanical spreading and finishing equipment impractical, the paving may be done with other equipment or by hand.

When more than one JMF is being utilized to produce HMA, place the material produced for each JMF with separate spreading and compacting equipment. Do not intermingle HMA produced from more than one JMF. Each strip of HMA placed during a work shift shall conform to a single JMF established for the class of HMA specified unless there is a need to make an adjustment in the JMF.

### 5-04.3(8) Aggregate Acceptance Prior to Incorporation in HMA

Sample aggregate for meeting the requirements of Section 3-04 prior to being incorporated into HMA. (The acceptance data generated for the Section 3-04 acceptance analysis will not be commingled with the acceptance data generated for the Section 5-04.3(9) acceptance analysis.) Aggregate acceptance samples shall be taken as described in Section 3-04. Aggregate acceptance testing will be performed by the Contracting Agency. Aggregate contributed from RAP and/or RAS will not be evaluated under Section 3-04.

For aggregate that will be used in HMA mixture which will be accepted by ~~either~~ Statistical ~~or Nonstatistical~~ Evaluation, the Contracting Agency's acceptance of the aggregate will be based on:

1. Samples taken prior to mixing with asphalt binder, RAP, or RAS;
2. Testing for the materials properties of fracture, uncompacted void content, and sand equivalent;
3. Evaluation by the Contracting Agency in accordance with Section 3-04, including price adjustments as described therein.

For aggregate that will be used in HMA which will be accepted by Visual Evaluation, evaluation in accordance with items 1, 2, and 3 above is at the discretion of the Engineer.

### 5-04.3(9) HMA Mixture Acceptance

The Contracting Agency will evaluate HMA mixture for acceptance by one of three two methods as determined from the criteria in Table 7.

Table 7

| Basis of Acceptance for HMA Mixture | | | |
|---|---|---|---|
| | Visual Evaluation | ~~Nonstatistical Evaluation~~ | Statistical Evaluation |

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| | | | |
|---|---|---|---|
| Criteria for Selecting the Evaluation Method | • Commercial HMA placed at any location<br>• Any HMA placed in:<br>◦ sidewalks<br>◦ road approaches<br>◦ ditches<br>◦ slopes<br>◦ paths<br>◦ trails<br>◦ gores<br>◦ prelevel<br>◦ temporary pavement[1]<br>◦ pavement repair<br>• Other nonstructural applications of HMA as approved by the Engineer | ~~• All HMA mixture of the same class and PG binder grade with a Proposal quantity less than 4,000 tons. (Exclude the tonnage of HMA mixture accepted by Visual Evaluation.)~~ | • All HMA mixture other than that accepted by Visual ~~or Nonstatistical~~ Evaluation |
| [1]Temporary pavement is HMA that will be removed before Physical Completion of the Contract. | | | |

**5-04.3(9)A Mixture Acceptance – Test Section**

This Section applies to HMA mixture accepted by Statistical Evaluation ~~and mixture accepted by Nonstatistical Evaluation~~. A test section is not allowed for HMA accepted by Visual Evaluation.

The purpose of a test section is to determine, at the beginning of paving, whether or not the Contractor's mix design and production processes will produce HMA meeting the Contract requirements related to mixture.

Use Table 8 to determine when a test section is required, optional, or not allowed, and to determine when test sections may end for an individual mix design. Each mix design will be evaluated independently for the test section requirements.

Construct HMA mixture test sections at the beginning of paving, using at least 600 tons and a maximum of 1,000 tons or as approved by the Engineer. Each test section shall be constructed in one continuous operation. Each test section shall be considered a lot. The mixture in each test section will be evaluated based on the criteria in Table 9 to determine if test sections for that mix design may stop.

If more than one test section is required, each test section shall be separately by the criteria in table 8 and 9.

Table 8

| Criteria for Conducting and Evaluating HMA Mixture Test Sections ~~(For HMA Mixture Accepted by Statistical or Nonstatistical Evaluation)~~ | | |
|---|---|---|
| | High RAP/Any RAS | Low RAP/No RAS |
| Is Mixture Test Section Optional or Mandatory? | Mandatory[1] | At Contractor's Option |
| Waiting period after paving the test section. | 4 calendar days[2] | 4 calendar days[2] |
| What Must Happen to Stop Performing Test Sections? | Meet "Results Required to Stop Performing Test Sections" in Table 9 for High RAP/Any RAS. | Provide samples and respond to WSDOT test results required by Table 9 for Low RAP/No RAS. |
| [1]If a mix design has produced an acceptable test section on a previous contract (paved in the same calendar year, from the same plant, using the same JMF) the test section may be waived if approved by the Engineer.<br>[2]This is to provide time needed by the Contracting Agency to complete testing and the Contractor to adjust the mixture in response to those test results. Paving may resume when this is done.<br>~~For HMA with Low RAP/No RAS which is accepted by Nonstatistical Evaluation, a test section is not allowed.~~ | | |

Table 9

| Results Required to Stop Performing HMA Mixture Test Sections1 ~~(For HMA Mixture Accepted by Statistical or Nonstatistical Evaluation)~~ | | |
|---|---|---|
| Test Property | Type of HMA | |
| | High RAP/Any RAS | Low RAP/No RAS |
| Gradation | Minimum PF of 0.95 based on the criteria in Section 5-04.3(9)B4[2] | None[4] |

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| | | |
|---|---|---|
| Asphalt Binder | Minimum $PF_i$ of 0.95 based on the criteria in Section 5-04.3(9)B4[2] | None[4] |
| $V_a$ | Minimum $PF_i$ of 0.95 based on the criteria in Section 5-04.3(9)B4[2] | None[4] |
| Hamburg Wheel Track<br>Indirect Tensile Strength | Meet requirements of Section 9-03.8(2).[3] | These tests will not be done as part of Test Section |
| Sand Equivalent<br>Uncompacted Void Content<br>Fracture | Meet requirements of Section 9-03.8(2).[3] | None[3] |

[1]In addition to the requirements of this table, acceptance of the HMA mixture used in each test section is subject to the acceptance criteria and price adjustments for Statistical Evaluation ~~or Non-statistical Evaluation~~ (see Table 7.)

[2]Divide the test section lot into three sublots, approximately equal in size. Take one sample from each sublot, and test each sample for all of the properties in the first column.

[3]Take one sample for each test section lot. Test the sample for all of the properties in the first column.

[4]Divide the test section lot into three sublots, approximately equal in size. Take one sample from each sublot, and test each sample for all of the properties in the first column. There are no criteria for discontinuing test sections for these mixes; however, the contractor must comply with Section 5-04.3(11)F before resuming paving.

**5-04.3(9)B Mixture Acceptance – Statistical Evaluation**

**5-04.3(9)B1 Mixture Statistical Evaluation – Lots and Sublots**

HMA mixture which is accepted by Statistical Evaluation will be evaluated by the Contracting Agency dividing that HMA tonnage into mixture lots, and each mixture lot will be evaluated using stratified random sampling by the Contracting Agency sub-dividing each mixture lot into mixture sublots. All mixture in a mixture lot shall be of the same mix design. The mixture sublots will be numbered in the order in which the mixture (of a particular mix design) is paved.

Each mixture lot comprises a maximum of 15 mixture sublots, except:

- The final mixture lot of each mix design on the Contract will comprise a maximum of 25 sublots.
- A mixture lot for a test section, which will consist of the three sublots and corresponding test results used in evaluating the test section for gradation, asphalt binder, and $V_a$.

Each mixture sublot shall be approximately uniform in size with the maximum mixture sublot size as specified in Table 10. The quantity of material represented by the final mixture sublot of the project, for each mix design on the project, may be increased to a maximum of two times the mixture sublot quantity calculated. ~~Should a lot accepted by statistical evaluation contain fewer than three sublots, the HMA will be accepted in accordance with non-statistical evaluation.~~

Table 10

| Maximum HMA Mixture Sublot Size<br>For HMA Accepted by Statistical Evaluation | |
|---|---|
| **HMA Original Plan Quantity (tons)[1]** | **Maximum Sublot Size (tons)[2]** |
| < 20,000 | 1,000 |
| 20,000 to 30,000 | 1,500 |
| >30,000 | 2,000 |

[1]"Plan quantity" means the plan quantity of all HMA of the same class and binder grade which is accepted by Statistical Evaluation.

[2]The maximum sublot size for each combination of HMA class and binder grade shall be calculated separately.

- For a mixture lot in progress with a mixture CPF less than 0.75, a new mixture lot will begin at the Contractor's request after the Engineer is satisfied that material conforming to the Specifications can be produced. See also Section 5-04.3(11)F.
- If, before completing a mixture lot, the Contractor requests a change to the JMF which is approved by the Engineer, the mixture produced in that lot after the approved change will be evaluated on the basis of the changed JMF, and the mixture produced in that lot before the approved change will be evaluated on the basis of the unchanged JMF; however, the mixture before and after the change will be evaluated in the same lot. Acceptance of subsequent mixture lots will be evaluated on the basis of the changed JMF.

**5-04.3(9)B2 Mixture Statistical Evaluation – Sampling**

Comply with Section 1-06.2(1).

Samples of HMA mixture which is accepted by Statistical Evaluation will be randomly selected from within each sublot, with one sample per

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sublot. The Engineer will determine the random sample location using WSDOT Test Method T 716. The Contractor shall obtain the sample when ordered by the Engineer. The Contractor shall sample the HMA mixture in the presence of the Engineer and in accordance with FOP for WAQTC T 168.

### 5-04.3(9)B3 Mixture Statistical Evaluation – Acceptance Testing

Comply with Section 1-06.2(1).

The Contracting Agency will test the mixture sample from each sublot (including sublots in a test section) for the properties shown in Table 11.

Table 11

| Testing Required for each HMA Mixture Sublot | | |
|---|---|---|
| **Test** | **Procedure** | **Performed by** |
| $V_a$ | WSDOT SOP 731 | Engineer |
| Asphalt Binder Content | FOP for AASHTO T 308 | Engineer |
| Gradation: Percent Passing 1½", 1", ¾", ½", ⅜", No. 4, No. 8, No. 200 | FOP for WAQTC T 27/T 11 | Engineer |

The mixture samples and tests taken for the purpose of determining acceptance of the test section (as described in Section 5-04.3(9)A) shall also be used as the test results for acceptance of the mixture described in 5-04.3(9)B3, 5-04.3(9)B4, 5-04.3(9)B5, and 5-04.3(9)B6.

### 5-04.3(9)B4 Mixture Statistical Evaluation – Pay Factors

Comply with Section 1-06.2(2).

The Contracting Agency will determine a pay factor (PFi) for each of the properties in Table 11, for each mixture lot, using the quality level analysis in Section 1-06.2(2)D. For Gradation, a pay factor will be calculated for each of the sieve sizes listed in Table 11 which is equal to or smaller than the maximum allowable aggregate size (100 percent passing sieve) of the HMA mixture. The USL and LSL shall be calculated using the Job Mix Formula Tolerances (for Statistical Evaluation) in Section 9-03.8(7).

If a constituent is not measured in accordance with these Specifications, its individual pay factor will be considered 1.00 in calculating the Composite Pay Factor (CPF).

### 5-04.3(9)B5 Mixture Statistical Evaluation – Composite Pay Factors (CPF)

Comply with Section 1-06.2(2).

In accordance with Section 1-06.2(2)D4, the Contracting Agency will determine a Composite Pay Factor (CPF) for each mixture lot from the pay factors calculated in Section 5-04.3(9)B4, using the price adjustment factors in Table 12. Unless otherwise specified, the maximum CPF for HMA mixture shall be 1.05.

Table 12

| HMA Mixture Price Adjustment Factors | |
|---|---|
| **Constituent** | **Factor "f"** |
| All aggregate passing: 1½", 1", ¾", ½", ⅜" and No.4 sieves | 2 |
| All aggregate passing No. 8 sieve | 15 |
| All aggregate passing No. 200 sieve | 20 |
| Asphalt binder | 40 |
| Air Voids ($V_a$) | 20 |

### 5-04.3(9)B6 Mixture Statistical Evaluation – Price Adjustments

For each HMA mixture lot, a Job Mix Compliance Price Adjustment will be determined and applied, as follows:

JMCPA = [0.60 x (CPF – 1.00)] x Q x UP

Where

JMCPA = Job Mix Compliance Price Adjustment for a given lot of mixture ($)

CPF = Composite Pay Factor for a given lot of mixture (maximum is 1.05)

Q = Quantity in a given lot of mixture (tons)

UP = Unit price of the HMA in a given lot of mixture ($/ton)

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### 5-04.3(9)B7 Mixture Statistical Evaluation – Retests

The Contractor may request that a mixture sublot be retested. To request a retest, submit a written request to the Contracting Agency within 7 calendar days after the specific test results have been posted to the website or emailed to the Contractor, whichever occurs first. The Contracting Agency will send a split of the original acceptance sample for testing by the Contracting Agency to either the Region Materials Laboratory or the State Materials Laboratory as determined by the Engineer. The Contracting Agency will not test the split of the sample with the same equipment or by the same tester that ran the original acceptance test. The sample will be tested for a complete gradation analysis, asphalt binder content, and $V_a$, and the results of the retest will be used for the acceptance of the HMA mixture in place of the original mixture sublot sample test results. The cost of testing will be deducted from any monies due or that may come due the Contractor under the Contract at the rate of $250 per sample.

### ~~5-04.3(9)C Mixture Acceptance – Nonstatistical Evaluation~~

### ~~5-04.3(9)C1 Mixture Nonstatistical Evaluation – Lots, Sublots, Sampling, Test Section, Testing, Retests~~

~~For HMA mixture accepted by Nonstatistical Evaluation, comply with the requirements in Table 13:~~

~~Table 13~~

| ~~Nonstatistical Evaluation Lots, Sublots, Sampling, Test Section, Testing, Retests~~ | | |
|---|---|---|
| ~~Comply with the Specifications Below~~ | | ~~Comply with the Requirements of the Section for:~~ |
| ~~Test Section~~ | ~~Section 5-04.3(9)A~~ | ~~Nonstatistical Evaluation~~ |
| ~~Lots and Sublots~~ | ~~Section 5-04.3(9)B1~~ | ~~Statistical Evaluation~~ |
| ~~Sampling~~ | ~~Section 5-04.3(9)B2~~ | ~~Statistical Evaluation~~ |
| ~~Acceptance Tests~~ | ~~Section 5-04.3(9)B3~~ | ~~Statistical Evaluation~~ |
| ~~Retests~~ | ~~Section 5-04.3(9)B7~~ | ~~Statistical Evaluation~~ |

### ~~5-04.3(9)C2 Mixture Nonstatistical Evaluation – Acceptance~~

~~Each mixture lot of HMA produced under Nonstatistical Evaluation, for which all sublot acceptance test results (required by Table 13) fall within the Job Mix Formula Tolerances for Nonstatistical Evaluation in Section 9-03.8(7), will be accepted at the unit Contract price with no further evaluation.~~

### ~~5-04.3(9)C3 Mixture Nonstatistical Evaluation – Out of Tolerance Procedures~~

~~Each mixture lot of HMA produced under Nonstatistical Evaluation, for which any sublot acceptance test result (required by Table 13) falls outside of the Job Mix Formula Tolerances for Nonstatistical Evaluation in Section 9-03.8(7), shall be evaluated in accordance with Section 1-06.2 and Table 14 to determine a Job Mix Compliance Price Adjustment.~~

~~Table 14~~

| ~~Nonstatistical Evaluation – Out of Tolerance Procedures~~ | |
|---|---|
| ~~Comply with the Following:~~ | |
| ~~Pay Factors~~[1] | ~~Section 5-04.3(9)B4~~ |
| ~~Composite Pay Factors~~[2] | ~~Section 5-04.3(9)B5~~ |
| ~~Price Adjustments~~ | ~~Section 5-04.3(9)B6~~ |

~~[1]When less than three mixture sublots exist, backup samples of the existing mixture sublots shall be tested to provide a minimum of three sets of results for evaluation. If enough backup samples are not available, the Contracting Agency will select core sample locations from the Roadway in accordance with WSDOT Test Method T 716, take cores from the roadway in accordance with WSDOT SOP 734, and test the cores in accordance with WSDOT SOP 736.~~

~~[1]The Nonstatistical Evaluation tolerance limits in Section 9-03.8(7) will be used in the calculation of the PF.~~

~~[2]The maximum CPF shall be 1.00.~~

### 5-04.3(9)D Mixture Acceptance – Visual Evaluation

Visual Evaluation of HMA mixture will be by visual inspection by the Engineer or, in the sole discretion of the Engineer, the Engineer may sample and test the mixture.

### 5-04.3(9)D1 Mixture Visual Evaluation – Lots, Sampling, Testing, Price Adjustments

HMA mixture accepted by Visual Evaluation will not be broken into lots unless the Engineer determines that testing is required. When that occurs, the Engineer will identify the limits of the questionable HMA mixture, and that questionable HMA mixture shall constitute a lot. Then, the

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Contractor will take samples from the truck, or the Engineer will take core samples from the roadway at a minimum of three random locations from within the lot, selected in accordance with WSDOT Test Method T 716, taken from the roadway in accordance with WSDOT SOP 734, and tested in accordance with WSDOT SOP 737. The Engineer will test one of the samples for all constituents in Section 5-04.3(9)B3. If all constituents from that test fall within the Job Mix Formula Tolerances (for Visual Evaluation) in Section 9-03.8(7), the lot will be accepted at the unit Contract price with no further evaluation.

When one or more constituents fall outside those tolerance limits, the other samples will be tested for all constituents in Section 5-04.3(9)B3, and a Job Mix Compliance Price Adjustment will be calculated in accordance with Table 15.

Table 15

| Visual Evaluation – Out of Tolerance Procedures | |
|---|---|
| Comply with the Following[1] | |
| Pay Factors[1] | Section 5-04.3(9)B4 |
| Composite Pay Factors[2] | Section 5-04.3(9)B5 |
| Price Adjustments | Section 5-04.3(9)B6 |
| [1]The Visual Evaluation tolerance limits in Section 9-03.8(7) will be used in the calculation of the PF. [2]The maximum CPF shall be 1.00. | |

### 5-04.3(9)E Mixture Acceptance – Notification of Acceptance Test Results

The results of all mixture acceptance testing and the Composite Pay Factor (CPF) of the lot after three sublots have been tested will be available to the Contractor through The Contracting Agency's website.

The Contracting Agency will endeavor to provide written notification (via email to the Contractor's designee) of acceptance test results through its web-based materials testing system Statistical Analysis of Materials (SAM) within 24 hours of the sample being made available to the Contracting Agency. However, the Contractor agrees:

1. Quality control, defined as the system used by the Contractor to monitor, assess, and adjust its production processes to ensure that the final HMA mixture will meet the specified level of quality, is the sole responsibility of the Contractor.
2. The Contractor has no right to rely on any testing performed by the Contracting Agency, nor does the Contractor have any right to rely on timely notification by the Contracting Agency of the Contracting Agency's test results (or statistical analysis thereof), for any part of quality control and/or for making changes or correction to any aspect of the HMA mixture.
3. The Contractor shall make no claim for untimely notification by the Contracting Agency of the Contracting Agency's test results or statistical analysis.

### 5-04.3(10) HMA Compaction Acceptance

For all HMA, the Contractor shall comply with the General Compaction Requirements in Section 5-04.3(10)A. The Contracting Agency will evaluate all HMA for compaction compliance with one of the following - Statistical Evaluation, Visual Evaluation, or Test Point Evaluation - determined by the criteria in Table 16:

Table 16

| Criteria for Determining Method of Evaluation for HMA Compaction[1] | | |
|---|---|---|
| Statistical Evaluation of HMA Compaction Is Required For: | Visual Evaluation of HMA Compaction Is Required For: | Test Point Evaluation of HMA Compaction Is Required For: |
| • Any HMA for which the specified course thickness is greater than 0.10 feet, and the HMA is in:<br>• traffic lanes, including but not limited to:<br>• ramp lanes<br>• truck climbing lanes<br>• weaving lanes<br>• speed change lanes | • "HMA for Preleveling…"<br>• "HMA for Pavement Repair…" | • Any HMA not meeting the criteria for Statistical Evaluation or Visual Evaluation |
| [1]This table applies to all HMA, and shall be the sole basis for determining the acceptance method for compaction. | | |

The Contracting Agency may, at its sole discretion, evaluate any HMA for compliance with the Cyclic Density requirements of Section 5-04.3(10)B.

### 5-04.3(10)A HMA Compaction – General Compaction Requirements

Immediately after the HMA has been spread and struck off, and after surface irregularities have been adjusted, thoroughly and uniformly compact the mix. The completed course shall be free from ridges, ruts, humps, depressions, objectionable marks, and irregularities and shall conform to the line, grade, and cross-section shown in the Plans. If necessary, alter the JMF in accordance with Section 9-03.8(7) to achieve desired results.

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Compact the mix when it is in the proper condition so that no undue displacement, cracking, or shoving occurs. Compact areas inaccessible to large compaction equipment by mechanical or hand tampers. Remove HMA that becomes loose, broken, contaminated, shows an excess or deficiency of asphalt, or is in any way defective. Replace the removed material with new HMA, and compact it immediately to conform to the surrounding area.

The type of rollers to be used and their relative position in the compaction sequence shall generally be the Contractor's option, provided the specified densities are attained. An exception shall be that pneumatic tired rollers shall be used for compaction of the wearing course beginning October 1st of any year through March 31st of the following year. Coverage with a steel wheel roller may precede pneumatic tired rolling. Unless otherwise approved by the Engineer, operate rollers in the static mode when the internal temperature of the mix is less than 175°F. Regardless of mix temperature, do not operate a roller in a mode that results in checking or cracking of the mat.

On bridge decks and on the five feet of roadway approach immediately adjacent to the end of bridge/back of pavement seat, operate rollers in static mode only. On bridges of a total length of 125 feet or more, at least one roller in the paving compaction train shall be a pneumatic roller.

### 5-04.3(10)B HMA Compaction – Cyclic Density

Low cyclic density areas are defined as spots or streaks in the pavement that are less than 90 percent of the theoretical maximum density. At the Engineer's discretion, the Engineer may evaluate the HMA pavement for low cyclic density, and when doing so will follow WSDOT SOP 733. A $500 Cyclic Density Price Adjustment will be assessed for any 500-foot section with two or more density readings below 90 percent of the theoretical maximum density.

### 5-04.3(10)C HMA Compaction Acceptance – Statistical Evaluation

HMA compaction which is accepted by Statistical Evaluation will be based on acceptance testing performed by the Contracting Agency, and statistical analysis of those acceptance tests results. This will result in a Compaction Price Adjustment.

### 5-04.3(10)C1 HMA Compaction Statistical Evaluation – Lots and Sublots

HMA compaction which is accepted by Statistical Evaluation will be evaluated by the Contracting Agency dividing the project into compaction lots, and each compaction lot will be evaluated using stratified random sampling by the Contracting Agency sub-dividing each compaction lot into compaction sublots. All mixture in any individual compaction lot shall be of the same mix design. The compaction sublots will be numbered in the order in which the mixture (of a particular mix design) is paved.

Each compaction lot comprises a maximum of 15 compaction sublots, except for the final compaction lot of each mix design on the Contract, which comprises a maximum of 25 sublots.

Each compaction sublot shall be uniform in size as shown in Table 17, except that the last compaction sublot of each day may be increased to a maximum of two times the compaction sublot quantity calculated. Minor variations in the size of any sublot shall not be cause to invalidate the associated test result.

Table 17

| HMA Compaction Sublot Size | |
|---|---|
| HMA Original Plan Quantity (tons)[1] | Compaction Sublot Size (tons)[2] |
| <20,000 | 100 |
| 20,000 to 30,000 | 150 |
| >30,000 | 200 |

[1]In determining the plan quantity tonnage, do not include any tons accepted by test point evaluation.

The following will cause one compaction lot to end prematurely and a new compaction lot to begin:

- For a compaction lot in progress with a compaction CPF less than 0.75, a new compaction lot will begin at the Contractor's request after the Engineer is satisfied that material conforming to the Specifications can be produced. See also Section 5-04.3(11)F.

All HMA which is paved on a bridge and accepted for compaction by Statistical Evaluation will comprise a bridge compaction lot. If the contract includes such HMA on more than one bridge, compaction will be evaluated on each bridge individually, as separate bridge compaction lots.

Bridge compaction sublots will be determined by the Engineer subject to the following:

- All sublots on a given bridge will be approximately the same size.
- Sublots will be stratified from the lot.
- In no case will there be less than 3 sublots in each bridge compaction lot.
- No sublot will exceeds 50 tons.
- Compaction test locations will be determined by the Engineer in accordance with WSDOT FOP for AASHTO T166.

### 5-04.3(10)C2 HMA Compaction Statistical Evaluation – Acceptance Testing

Comply with Section 1-06.2(1).

The location of HMA compaction acceptance tests will be randomly selected by the Contracting Agency from within each sublot, with one test per sublot. The Contracting Agency will determine the random sample location using WSDOT Test Method T 716.

Use Table 18 to determine compaction acceptance test procedures and to allocate compaction acceptance sampling and testing responsibilities between the Contractor and the Contracting Agency. HMA cores Roadway cores shall be taken or nuclear density testing shall occur after completion of the finish rolling, prior to opening to traffic, and on the same day that the mix is placed

Table 18

| HMA Compaction Acceptance Testing Procedures and Responsibilities | | | |
|---|---|---|---|
| | When Contract Includes Bid Item HMA Core – Roadway[4] Roadway Cores[1] | When Contract Does Not Include Bid Item HMA Core – Roadway[4] Roadway Cores[1] | |
| Basis for Test: | Roadway Cores | Roadway Cores[3] | Nuclear Density Gauge[3] |
| In-Place Density Determined by: | Contractor shall take cores[1] using WSDOT SOP 734[2]<br>Contracting Agency will determine core density using FOP for AASHTO T 166 | Contracting Agency will take cores[1] using WSDOT SOP 734<br>Contracting Agency will determine core density using FOP for AASHTO T 166 | Contracting Agency, using FOP for WAQTC TM 8 |
| Theoretical Maximum Density Determined by: | Contracting Agency, using FOP for AASHTO T 209 | | |
| Rolling Average of Theoretical Maximum Densities Determined by: | Contracting Agency, using WSDOT SOP 729 | | |
| Percent Compaction in Each Sublot Determined by: | Contracting Agency, using WSDOT SOP 736 | Contracting Agency, using WSDOT SOP 736 | Contracting Agency, using FOP for WAQTC TM 8 |

[1]The core diameter shall be 4-inches unless otherwise approved by the Engineer.
[2]The Contractor shall take the core samples in the presence of the Engineer, at locations designated by the Engineer, and deliver the core samples to the Contracting Agency.
[3]The Contracting Agency will determine, in its sole discretion, whether it will take cores or use the nuclear density gauge to determine in-place density. Exclusive reliance on cores for density acceptance is generally intended for small paving projects and is not intended as a replacement for nuclear gauge density testing on typical projects.
[4]The basis for test of all compaction sublots in a bridge compaction lot shall be cores. These cores shall be taken by the Contractor when the Proposal includes the bid item "HMA Cores – Bridge Deck". When there is no bid item for "HMA Cores – Bridge Deck", the Engineer will be responsible for taking HMA cores for all compaction sublots in a bridge compaction lot. In either case, the Engineer will determine core location, in-place density of the core, theoretical maximum density, rolling average of theoretical maximum density, and percent compaction using the procedure called for in this Section.

When using the nuclear density gauge for acceptance testing of pavement density, the Engineer will follow WSDOT SOP 730 for correlating the nuclear gauge with HMA cores. When cores are required for the correlation, coring and testing will be by the Contracting Agency. When a core is taken for gauge correlation at the location of a sublot, the relative density of the core will be used for the sublot test result and is exempt from retesting.

**5-04.3(10)C3 HMA Statistical Compaction – Price Adjustments**

For each HMA compaction lot (that is accepted by Statistical Evaluation) which has less than three compaction sublots, for which all compaction sublots attain a minimum of 91 percent compaction determined in accordance with FOP for WAQTC TM 8 (or WSDOT SOP 736 when provided by the Contract), the HMA will be accepted at the unit Contract price with no further evaluation.

For each HMA compaction lot (that is accepted by Statistical Evaluation) which does not meet the criteria in the preceding paragraph, the compaction lot shall be evaluated in accordance with Section 1-06.2(2) to determine the appropriate Compaction Price Adjustment (CPA). All of the test results obtained from the acceptance samples from a given compaction lot shall be evaluated collectively. Additional testing by either a nuclear density gauge or cores will be completed as required to provide a minimum of three tests for evaluation.

For the statistical analysis in Section 1-06.2, use the following values:

x = Percent compaction of each sublot
USL = 100
LSL = 91

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Each CPA will be determined as follows:

CPA = [0.40 x (CPF – 1.00)] x Q x UP

Where

CPA = Compaction Price Adjustment for the compaction lot ($)

CPF = Composite Pay Factor for the compaction lot (maximum is 1.05)

Q = Quantity in the compaction lot (tons)

UP = Unit price of the HMA in the compaction lot ($/ton)

### 5-04.3(10)C4 HMA Statistical Compaction – Requests for Retesting

For a compaction sublot that has been tested with a nuclear density gauge that did not meet the minimum of 91 percent of the theoretical maximum density in a compaction lot with a CPF below 1.00 and thus subject to a price reduction or rejection, the Contractor may request that a core, taken at the same location as the nuclear density test, be used for determination of the relative density of the compaction sublot. The relative density of the core will replace the relative density determined by the nuclear density gauge for the compaction sublot and will be used for calculation of the CPF and acceptance of HMA compaction lot. When cores are taken by the Contracting Agency at the request of the Contractor, they shall be requested by noon of the next workday after the test results for the compaction sublot have been provided or made available to the Contractor. Traffic control shall be provided by the Contractor as requested by the Engineer. Failure by the Contractor to provide the requested traffic control will result in forfeiture of the request for retesting. When the CPF for the compaction lot based on the results of the cores is less than 1.00, the Contracting Agency will deduct the cost for the coring from any monies due or that may become due the Contractor under the Contract at the rate of $200 per core and the Contractor shall pay for the cost of the traffic control.

### 5-04.3(10)D HMA Compaction – Visual Evaluation

Visual Evaluation will be the basis of acceptance for compaction of the Bid items "HMA for Pavement Repair Cl. ___ PG ___" and "HMA for Prelevelling Class___ PG___". This HMA shall be thoroughly compacted to the satisfaction of the Engineer. HMA that is used to prelevel wheel ruts shall be compacted with a pneumatic tire roller.

### 5-04.3(10)E HMA Compaction – Test Point Evaluation

When compaction acceptance is by Test Point Evaluation, compact HMA based on a test point evaluation of the compaction train. Perform the test point evaluation in accordance with instructions from the Engineer. The number of passes with an approved compaction train, required to attain the maximum test point density, shall be used on all subsequent paving.

### 5-04.3(10)F HMA Compaction Acceptance – Notification of Acceptance Test Results

The obligations and responsibilities for notifying the Contractor of compaction acceptance test results are the same as for mixture acceptance test results. See Section 5-04.3(9)E.

### 5-04.3(11) Reject Work

This Section applies to HMA and all requirements related to HMA (except aggregates prior to being incorporated into HMA). For rejection of aggregate prior to its incorporation into HMA refer to Section 3-04.

### 5-04.3(11)A Reject Work – General

Work that is defective or does not conform to Contract requirements shall be rejected.

### 5-04.3(11)B Rejection by Contractor

The Contractor may, prior to acceptance sampling and testing, elect to remove any defective material and replace it with new material. Any such new material will be sampled, tested, and evaluated for acceptance.

### 5-04.3(11)C Rejection Without Testing (Mixture or Compaction)

The Engineer may, without sampling, reject any batch, load, or section of Roadway that appears defective. Material rejected before placement shall not be incorporated into the pavement.

No payment will be made for the rejected materials or the removal of the materials unless the Contractor requests the rejected material to be tested. If the Contractor requests testing, acceptance will be by Statistical Evaluation, and a minimum of three samples will be obtained and tested. When uncompacted material is required for testing but not available, the Engineer will determine random sample locations on the roadway in accordance with WSDOT Test Method T 716, take cores in accordance with WSDOT SOP 734, and test the cores in accordance with WSDOT SOP 737.

If the CPF for the rejected material is less than 0.75, no payment will be made for the rejected material; in addition, the cost of sampling and testing shall be borne by the Contractor. If the CPF is greater than or equal to 0.75, the cost of sampling and testing will be borne by the Contracting Agency. If the material is rejected before placement and the CPF is greater than or equal to 0.75, compensation for the rejected material will be at a CPF of 0.75. If rejection occurs after placement and the CPF is greater than or equal to 0.75, compensation for the rejected material will be at the calculated CPF with an addition of 25 percent of the unit Contract price added for the cost of removal and disposal.

*attach #4*

**5-04.3(11)D Rejection – A Partial Sublot (Mixture or Compaction)**

In addition to the random acceptance sampling and testing, the Engineer may also isolate from a mixture or compaction sublot any material that is suspected of being defective in relative density, gradation or asphalt binder content. Such isolated material will not include an original sample location. The Contracting Agency will obtain a minimum of three random samples of the suspect material and perform the testing. When uncompacted material is required for testing but is not available, the Engineer will select random sample locations on the roadway in accordance with WSDOT Test Method T 716, take cores samples in accordance with WSDOT SOP 734, and test the material in accordance with WSDOT SOP 737. The material will then be statistically evaluated as an independent lot in accordance with Section 1-06.2(2).

**5-04.3(11)E Rejection – An Entire Sublot (Mixture or Compaction)**

An entire mixture or compaction sublot that is suspected of being defective may be rejected. When this occurs, a minimum of two additional random samples from this sublot will be obtained. When uncompacted material is required for the additional samples but the material has been compacted, the Contracting Agency will take and test cores from the roadway as described in Section 5-04.3(11)D. The additional samples and the original sublot will be evaluated as an independent lot in accordance with Section 1-06.2(2).

**5-04.3(11)F Rejection - A Lot in Progress (Mixture or Compaction)**

The Contractor shall shut down operations and shall not resume HMA placement until such time as the Engineer is satisfied that material conforming to the Specifications can be produced when:

1. the Composite Pay Factor (CPF) of a mixture or compaction lot in progress drops below 1.00 and the Contractor is taking no corrective action, or
2. the Pay Factor ($PF_i$) for any constituent of a mixture or compaction lot in progress drops below 0.95 and the Contractor is taking no corrective action, or
3. either the $PF_i$ for any constituent (or the CPF) of a mixture or compaction lot in progress is less than 0.75.

**5-04.3(11)G Rejection – An Entire Lot (Mixture or Compaction)**

An entire lot with a CPF of less than 0.75 will be rejected.

**5-04.3(12) Joints**

**5-04.3(12)A Transverse Joints**

Conduct operations such that the placement of the top or wearing course is a continuous operation or as close to continuous as possible. Unscheduled transverse joints will be allowed, but the roller may pass over the unprotected end of the freshly laid HMA only when the placement of the course is discontinued for such a length of time that the HMA will cool below compaction temperature. When the Work is resumed, cut back the previously compacted HMA to produce a slightly beveled edge for the full thickness of the course.

Construct a temporary wedge of HMA on a 50H:1V where a transverse joint as a result of paving or planing is open to traffic. Separate the HMA in the temporary wedge from the permanent HMA upon which it is placed by strips of heavy wrapping paper or other methods approved by the Engineer. Remove the wrapping paper and trim the joint to a slightly beveled edge for the full thickness of the course prior to resumption of paving.

Waste the material that is cut away and place new HMA against the cut. Use rollers or tamping irons to seal the joint.

**5-04.3(12)B Longitudinal Joints**

Offset the longitudinal joint in any one course from the course immediately below by not more than 6 inches nor less than 2 inches. Locate all longitudinal joints constructed in the wearing course at a lane line or an edge line of the Traveled Way. Construct a notched wedge joint along all longitudinal joints in the wearing surface of new HMA unless otherwise approved by the Engineer. The notched wedge joint shall have a vertical edge of not less than the maximum aggregate size nor more than ½ of the compacted lift thickness, and then taper down on a slope not steeper than 4H:1V. Uniformly compact the sloped portion of the HMA notched wedge joint.

On one-lane ramps a longitudinal joint may be constructed at the center of the traffic lane, subject to approval by the Engineer, if:

1. The ramp must remain open to traffic, or
2. The ramp is closed to traffic and a hot-lap joint is constructed.
   a. Two paving machines shall be used to construct the hot-lap joint.
   b. The pavement within 6 inches of the hot-lap joint will not be excluded from random location selection for compaction testing.
   c. Construction equipment other than rollers shall not operate on any uncompacted HMA.

When HMA is placed adjacent to cement concrete pavement, construct longitudinal joints between the HMA and the cement concrete pavement. Saw the joint to the dimensions shown on Standard Plan A-40.10 and fill with joint sealant meeting the requirements of Section 9-04.2.

**5-04.3(13) Surface Smoothness**

The completed surface of all courses shall be of uniform texture, smooth, uniform as to crown and grade, and free from defects of all kinds. The completed surface of the wearing course shall not vary more than ⅛ inch from the lower edge of a 10-foot straightedge placed on the surface parallel to the centerline. The transverse slope of the completed surface of the wearing course shall vary not more than ¼ inch in 10 feet from the rate of

attach #4

transverse slope shown in the Plans.

When deviations in excess of the above tolerances are found that result from a high place in the HMA, correct the pavement surface by one of the following methods:

1. Remove material from high places by grinding with an approved grinding machine, or
2. Remove and replace the wearing course of HMA, or
3. By other method approved by the Engineer.

Correct defects until there are no deviations anywhere greater than the allowable tolerances.

Deviations in excess of the above tolerances that result from a low place in the HMA and deviations resulting from a high place where corrective action, in the opinion of the Engineer, will not produce satisfactory results will be accepted with a price adjustment. The Engineer shall deduct from monies due or that may become due to the Contractor the sum of $500.00 for each and every section of single traffic lane 100 feet in length in which any excessive deviations described above are found.

When portland cement concrete pavement is to be placed on HMA, the surface tolerance of the HMA shall be such that no surface elevation lies above the Plan grade minus the specified Plan depth of portland cement concrete pavement. Prior to placing the portland cement concrete pavement, bring any such irregularities to the required tolerance by grinding or other means approved by the Engineer.

When utility appurtenances such as manhole covers and valve boxes are located in the Traveled Way, pave the Roadway before the utility appurtenances are adjusted to the finished grade.

#### 5-04.3(14) Planing Bituminous Pavement

Plane in such a manner that the underlying pavement is not torn, broken, or otherwise damaged by the planing operation. Delamination or raveling of the underlying pavement will not be construed as damage due to the Contractor's operations. Pavement outside the limits shown in the Plans or designated by the Engineer that is damaged by the Contractor's operations shall be repaired to the satisfaction of the Engineer at no additional cost to the Contracting Agency.

For mainline planing operations, use equipment with automatic controls and with sensors for either or both sides of the equipment. The controls shall be capable of sensing the grade from an outside reference line, or a mat-referencing device. The automatic controls shall have a transverse slope controller capable of maintaining the mandrel at the desired transverse slope (expressed as a percentage) within plus or minus 0.1 percent.

Remove all loose debris from the planed surface before opening the planed surface to traffic. The planings and other debris resulting from the planing operation shall become the property of the Contractor and be disposed of in accordance with Section 2-03.3(7)C, or as otherwise allowed by the Contract.

#### 5-04.3(15) Sealing Pavement Surfaces

Apply a fog seal where shown in the Plans. Construct the fog seal in accordance with Section 5-02.3. Unless otherwise approved by the Engineer, apply the fog seal prior to opening to traffic.

#### 5-04.3(16) HMA Road Approaches

Construct HMA approaches at the locations shown in the Plans or where staked by the Engineer, in accordance with Section 5-04.

### 5-04.4 Measurement

HMA Cl. ___ PG ___, HMA for ___ Cl. ___ PG ___, and Commercial HMA will be measured by the ton in accordance with Section 1-09.2, with no deduction being made for the weight of asphalt binder, mineral filler, or any other component of the HMA. If the Contractor elects to remove and replace HMA as allowed by Section 5-04.3(11), the material removed will not be measured.

Roadway cores will be measured per each for the number of cores taken.

Crack Sealing-LF will be measured by the linear foot along the line of the crack.

Soil residual herbicide will be measured by the mile for the stated width to the nearest 0.01 mile or by the square yard, whichever is designated in the Proposal.

Pavement repair excavation will be measured by the square yard of surface marked prior to excavation.

Asphalt for fog seal will be measured by the ton, as provided in Section 5-02.4.

Longitudinal joint seals between the HMA and cement concrete pavement will be measured by the linear foot along the line and slope of the completed joint seal.

Planing bituminous pavement will be measured by the square yard.

Temporary pavement marking will be measured by the linear foot as provided in Section 8-23.4.

Water will be measured by the M gallon as provided in Section 2-07.4.

### 5-04.5 Payment

Payment will be made for each of the following Bid items that are included in the Proposal:

"HMA Cl. ___ PG ___", per ton.

*attach #4*

"HMA for Approach Cl. ___ PG ___", per ton.

"HMA for Preleveling Cl. ___ PG ___", per ton.

"HMA for Pavement Repair Cl. ___ PG ___", per ton.

"Commercial HMA", per ton.

The unit Contract price per ton for "HMA Cl. ___ PG ___", "HMA for Approach Cl. ___ PG ___", "HMA for Preleveling Cl. ___ PG ___", "HMA for Pavement Repair Cl. ___ PG ___", and "Commercial HMA" shall be full compensation for all costs, including anti-stripping additive, incurred to carry out the requirements of Section 5-04 except for those costs included in other items which are included in this Subsection and which are included in the Proposal.

"Crack Sealing-FA", by force account.

"Crack Sealing-FA" will be paid for by force account as specified in Section 1-09.6. For the purpose of providing a common Proposal for all Bidders, the Contracting Agency has entered an amount in the Proposal to become a part of the total Bid by the Contractor.

"Crack Sealing-LF", per linear foot.

The unit Contract price per linear foot for "Crack Sealing-LF" shall be full payment for all costs incurred to perform the Work described in Section 5-04.3(4)A.

"Soil Residual Herbicide ____ ft. Wide", per mile, or

"Soil Residual Herbicide", per square yard.

The unit Contract price per mile or per square yard for "Soil Residual Herbicide" shall be full payment for all costs incurred to obtain, provide and install herbicide in accordance with Section 5-04.3(4)B.

"Pavement Repair Excavation Incl. Haul", per square yard.

The unit Contract price per square yard for "Pavement Repair Excavation Incl. Haul" shall be full payment for all costs incurred to perform the Work described in Section 5-04.3(4)C with the exception, however, that all costs involved in the placement of HMA shall be included in the unit Contract price per ton for "HMA for Pavement Repair Cl. ___ PG ___", per ton.

"Asphalt for Fog Seal", per ton.

Payment for "Asphalt for Fog Seal" is described in Section 5-02.5.

"Longitudinal Joint Seal", per linear foot.

The unit Contract price per linear foot for "Longitudinal Joint Seal" shall be full payment for all costs incurred to construct the longitudinal joint between HMA and cement concrete pavement, as described in Section 5-04.3(12)B.

"Planing Bituminous Pavement", per square yard.

The unit Contract price per square yard for "Planing Bituminous Pavement" shall be full payment for all costs incurred to perform the Work described in Section 5-04.3(14).

"Temporary Pavement Marking", per linear foot.

Payment for "Temporary Pavement Marking" is described in Section 8-23.5.

"Water", per M gallon.

Payment for "Water" is described in Section 2-07.5.

"Job Mix Compliance Price Adjustment", by calculation.

"Job Mix Compliance Price Adjustment" will be calculated and paid for as described in Section 5-04.3(9)B6, 5-04.3(9)C3, and 5-04.3(9)D1.

"Compaction Price Adjustment", by calculation.

"Compaction Price Adjustment" will be calculated and paid for as described in Section 5-04.3(10)C3.

~~"Roadway Core", per each.~~

~~The Contractor's costs for all other Work associated with the coring (e.g., traffic control) shall be incidental and included within the unit Bid price per each and no additional payments will be made.~~

"HMA Core – Bridge Deck", per each.

The unit Contract price per each for "HMA Core – Bridge Deck" shall be full payment for all costs, including traffic control, associated with taking HMA density cores in pavement that is on a bridge deck.

"HMA Core – Roadway", per each.

The unit Contract price per each for "HMA Core – Roadway" shall be full payment for all costs, including traffic control, associated with taking HMA density cores in pavement that is not on a bridge deck.

"Cyclic Density Price Adjustment", by calculation.

"Cyclic Density Price Adjustment" will be calculated and paid for as described in Section 5-04.3(10)B.

item 16-02
attach #5

From: Dave Gent - WAPA
To: "Dyer, Bob"
Cc: "Erickson, Dave"
Subject: RE: Improving HMA meeting
Date: Thursday, October 6, 2016 9:24:00 AM

I thought we had clarified, but the written word is stronger than my memory.

The issue revolved around how often the price adjustment would be calculated since it is updated twice per month. I believe that Dave clarified that WSDOT would only perform the adjustment calculation once per month and it would be based on the "Date Effective" date, NOT the End Period Date. As you can see from my clip and paste below, the "Date Effective" sometimes lags the "End Period" date for some reason. The current specification only says "posted", but it seems to me that the "Date Effective" should mean just that.

**Asphalt binder reference costs get posted at the end of the period .**

| Date Effective | Begin Period | End Period | Eastern | Western |
|---|---|---|---|---|
| | 4/1/2012 | 4/15/2012 | $607.50 | $602.50 |
| | 3/1/2012 | 3/15/2012 | $562.50 | $591.25 |
| | 3/16/2012 | 3/31/2012 | $582.50 | $595.00 |
| | 2/1/2012 | 2/15/2012 | $555.00 | $566.25 |
| | 2/16/2012 | 2/29/2012 | $555.00 | $570.00 |
| | 1/1/2012 | 1/15/2012 | $547.50 | $553.75 |
| | 1/16/2012 | 1/31/2012 | $550.00 | $557.50 |
| | 12/1/2011 | 12/15/2011 | $547.50 | $528.75 |
| | 12/16/2011 | 12/31/2011 | $547.50 | $534.17 |
| | 11/1/2011 | 11/15/2011 | $552.50 | $531.25 |
| | 11/16/2011 | 11/30/2011 | $547.50 | $525.00 |
| . . | . . | . . | . | . |
| 05/05/2015 | 04/16/2015 | 04/30/2015 | $505.00 | $471.25 |
| 05/18/2015 | 05/01/2015 | 05/15/2015 | $505.00 | $455.00 |
| 06/01/2015 | 05/16/2015 | 05/31/2015 | $505.00 | $445.00 |
| 06/15/2015 | 06/01/2015 | 06/15/2015 | $498.75 | $442.50 |
| 07/06/2015 | 06/16/2015 | 06/30/2015 | $492.50 | $425.83 |
| 07/20/2015 | 07/01/2015 | 07/15/2015 | $492.50 | $430.00 |

The specification now reads (existing spec. segment):

"Adjustments will be based on the most current reference cost for Western Washington or Eastern Washington as posted on the Agency website, depending on where the work is performed. For work completed after all authorized working days are used, the adjustment will be based on the posted reference cost during which contract time was exhausted. The adjustment will be calculated as follows:".....

I think it would be clarifying to say....

## Updated Spec. Proposal - WAPA

"Adjustments will be based on the most current reference cost for Western Washington or Eastern Washington as posted on the Agency website, depending on where the work is performed. The "Date Effective" reference cost last posted prior to the pay period close date will be the basis for adjustments and adjustments will be calculated only once per pay period. For work completed after all authorized working days are used, the adjustment will be based on the posted reference cost during which contract time was exhausted. The adjustment will be calculated as follows:".....

The confusion and differing calculations came from the Contractor wanting to segment the month of work into two price points because the reference costs are posted twice per month. Further confusion was added when the "Date Effective) is several days later than the End Period. The pay period ended on 7/5 but the Date Effective was posted as 7/6. The reference number should be the one "Date Effective" on 6/15 as it was the last posted "Date Effective" before the pay period closed.

Dave will be able to interpret my ham-fisted attempt to explain the nuance.

This is really only an issue with prices are sliding (or rising) very rapidly.

Thanks for the reminder!

*Dave Gent*
David Gent, P.E.
Executive Director / Technical Director
Washington Asphalt Pavement Assoc. (WAPA)
*451 SW 10th Street Suite 110A Renton WA 98057*
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Dave.Gent@AsphaltWA.com

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**From:** Dyer, Bob [mailto:DyerB@wsdot.wa.gov]
**Sent:** Thursday, October 6, 2016 8:38 AM
**To:** dave.gent@asphaltwa.com
**Cc:** Erickson, Dave <EricksD@wsdot.wa.gov>
**Subject:** Improving HMA meeting

Mr Erickson tells me he has not received the info you were going to send him related to agenda item 16-02

**16-02 Better define the dates to be used for the Current Reference Price for Asphalt Cost Price Adjustments spec**

- May 6, 2016 – Dave Gent reported that WAPA believes the dates for making the calculations are ill-defined in the current spec. He will send a draft spec to Dave Erickson pointing out where he thinks the ambiguities are.

Attach 16-10

Attach #6

not already on the QPL

5-04.2(1)

(August 7, 2006)

Section 1-08.6 is supplemented with the following:

Contract time may be suspended for verification of HMA mix designs or for procurement of critical materials (Procurement Suspension). In order to receive a Procurement Suspension, the Contractor shall within 30 calendar days after execution by the Contracting Agency, submit all HMA mix designs according to section 5-04.3(7)A or place purchase orders for all materials deemed critical by the Contracting Agency for physical completion of the contract. The Contractor shall provide a copy of the completed DOT Form 350-042 indicating the date the mix design was submitted, or copies of purchase orders for the critical materials. Such purchase orders shall disclose the purchase order date and estimated delivery dates for such critical material.

The Contractor shall show mix design verification or procurement of the materials listed below as activities in the Progress Schedule. If the approved Progress Schedule indicates that the mix design verification or materials procurement are critical activities, and if the Contractor has provided documentation that mix designs are submitted or purchase orders are placed for the critical materials within the prescribed 30 calendar days, then contract time shall be suspended upon physical completion of all critical work except that work dependent upon the below listed critical materials:

$$1$$

Charging of contract time will resume upon the Contractors' receipt of a mix design verification report, delivery of the critical materials to the Contractor, notification that the critical materials are ready for delivery to the Contractor from the Contracting Agency's Materials Laboratory, or *** $$2$$ *** calendar days after execution by the Contracting Agency, whichever occurs first.

No additional Procurement Suspension will be provided if the Contractors HMA mix designs did not verify and are resubmitted.

item 16-13

Attach # 7

**WSDOT/WAPA Improving HMA Committee – 11/4/2016**

**WAPA Proposal for Updating RAP Stockpile Sequestering Rules – Item 16-13 -**

## CURRENT SPECIFICATION

**5-04.2(1)A2 High RAP/Any RAS - Mix Design Submittals for Placement on QPL**

For High RAP/Any RAS mixes, comply with the requirements of Section 5-04.2(1) and all of the following that apply:

1. For mixes with any RAS, test the RAS stockpile (and RAP stockpile if any RAP is in the mix) in accordance with Table 4.
2. For mixes with no RAS, test the RAP stockpile in accordance with Table 4.
3. For mixes with High RAP/Any RAS, complete constructing a single stockpile for RAP and a single stockpile for RAS and isolate these stockpiles from further stockpiling before beginning development of the mix design. Test the RAP and RAS stockpile during their construction as required by item 1) or 2) above. Use the test data in developing the mix design, and report the test data to WSDOT as part of the mix design submittal for approval on the QPL. Do not add to these stockpiles after starting the mix design process.
4. Comply with 5-04.3(5)A for stockpiling RAP and/or RAS after sequestering the RAP/RAS stockpiles for mix design approval on the QPL.

**Table 4**
**Test Frequency of RAP and RAS During RAP and RAS Stockpile Construction**
**For the Purpose of Approving a Mix Design for Placement in the QPL**

| Test Frequency | Test for | Test method |
|---|---|---|
| • 1/1000 tons of RAP (minimum of 10 per mix design) and<br>• 1/100 tons of RAS (minimum of 10 per mix design) | Asphalt Binder content | FOP for AASHTO T 308 |
| | Aggregate Gradation | FOP for WAQTC T 27/T 11 |

## SUPPLIMENTAL LANGUAGE

5. The initial RAP or RAS stockpile(s), as defined above, may be supplemented in volume with additional RAP or RAS when:
   a. The RAP or RAS is processed in the same manner as the original stockpile(s) resulting in RAP or RAS of the same general quality as in the initial stockpile(s) and
   b. Testing of the supplemental RAP or RAS, as outlined in Table 4 and above, is certified to have been performed at a minimum of ½ the frequency defined in the Table. Testing documentation shall be maintained and be available for review.
   c. OK if gradation & binder test results are w/i certain limits, DeVol's concern is VMA - would include VMA in acceptance decision, but would have to also test agg for sp. gr. DeVol will consider a proposal that addresses VMA, agg sp. gr.

5-04.3(7)A Mix Design

1. **General.** Prior to the production of HMA, the Contractor shall determine a design aggregate structure and asphalt binder content in accordance with WSDOT Standard Operating Procedure 732. Once the design aggregate structure and asphalt binder content have been determined, the Contractor shall submit the HMA mix design on DOT form 350-042 demonstrating that the design meets the requirements of Sections 9-03.8(2) and 9-03.8(6). For HMA accepted by commercial evaluation only the first page of DOT form 350-042 and the percent of asphalt binder is required. In no case shall the paving begin before the determination of anti-strip requirements has been made.

   Changes to the aggregate or asphalt binder require approval of the Engineer and may require a new mix design submittal from the contractor. For aggregate this will include changes in the source of material or a change in the percentage of material from a stockpile greater than 5%. Asphalt binder changes include the source of the crude petroleum supplied to the refinery, the refining process and additives or modifiers in the asphalt binder. For mix designs that will be used in more than one calendar year and have not changed the contractor shall submit a certification that the mix design has not changed.

2. **Statistical or Nonstatistical Evaluation.** When the contract calls for either of these evaluation methods, the Contractor shall submit representative samples of the mineral materials that are to be used in the HMA production. The Contracting Agency will use these samples to determine anti-strip requirements, if any, in accordance with WSDOT test method T 718 and will also conduct verification testing of the mix design. Verification testing of HMA mix designs proposed by the contractor that include RAP will be completed without the inclusion of the RAP. Submittal of RAP samples is not required. A mix design verification report will be provided within 25 calendar days after a mix design submittal has been received in the State Materials Laboratory in Tumwater.

   If the results of the verification testing of the mix design by the Contracting Agency are within the tolerances in Section 9-03.8(7) the mix design will be considered verified. HMA requiring nonstatistical evaluation must have a verified mix design before paving will be allowed. Where HMA requires statistical evaluation, and where the mix design did not meet the required tolerances to be verified, the contractor shall have the option to either resubmit a new mix design or proceed to paving the HMA mixture test section.

   The mix design will be the initial job mix formula (JMF) for the class of mix. Any additional adjustments to the JMF will require the approval of the Project Engineer and may be made per Section 9-03.8(7).

3. **Commercial Evaluation.** Verification of the mix design by the Contracting Agency is not required. The Project Engineer will determine anti-strip requirements for the HMA. For commercial HMA, the contractor shall select a class of HMA and design level of Equivalent Single Axle Loads (ESAL's) appropriate for the required use.

**Deviation**

| | |
|---|---|
| U.S. No. 4 sieve and larger | Percent passing ±4.0 |
| U.S. No. 8 sieve | Percent passing ±2.0 |
| U.S. No. 200 sieve | Percent passing ±0.4 |
| Asphalt binder | Percent binder content ±0.3 |
| Va Percent | Va ±0.7 |

If the results of the challenge sample testing are within the allowable deviation established above for each parameter, the acceptance sample test results will be used for acceptance of the HMA. The cost of testing will be deducted from any monies due or that may come due the Contractor under the contract at the rate of $250 per challenge sample. If the results of the challenge sample testing are outside of any one parameter established above, the challenge sample will be used for acceptance of the HMA and the cost of testing will be the Contracting Agency's responsibility.

6. **Test Methods.** Testing of HMA for compliance of volumetric properties (VMA, VFA and Va) will be by WSDOT Standard Operating Procedure SOP 731. Testing for compliance of asphalt binder content will be by WSDOT FOP for AASHTO T 308. Testing for compliance of gradation will be by WAQTC FOP for AASHTO T 27/T 11.
7. **Test Section - HMA Mixture.** A mixture test section shall be constructed for every mix design accepted by Statistical Evaluation. The test section shall be used to determine if the mix meets the requirements of Sections 9-03.8(2) and 9-03.8(6). The HMA mixture test section may be constructed simultaneously with the compaction test section (Section 5-04.3(10)B).

The test section shall be constructed at the beginning of paving and will be at least 600 tons and a maximum of 800 tons or as approved by the Engineer. No further wearing or leveling HMA will be paved the day of or the day following the construction of the test section. The mixture in the test section will be evaluated as a lot with a minimum of three sublots required. If more than one test section is required, each test section shall be a separate lot.

For a test section to be acceptable, with or without a verified mix design, the pay factor (PF) for each of gradation, asphalt binder. VMA and Va shall be 0.95 or greater, and the remaining test requirements in Section 9-03.8(2) (dust/asphalt ratio, sand equivalent, uncompacted void content and fracture) shall conform to the requirements of that Section. When the pay factor for any item is less than 0.95 the Contractor shall make adjustments to the mix in accordance with Section 9-03.8(7) and construct another test section. The Project Engineer may waive the requirement for the construction of another test section.

For all HMA of the same class and PG asphalt binder grade payment for the HMA in the test section(s) will be in accordance with the provisions of 5-04.5(1) Quality Assurance Price Adjustments. The CPF for the HMA represented by the first test section shall be a minimum of 0.75 if the mix design was verified by the Contracting agency. The calculation of the CPF in a test section with a verified mix design will include gradation and asphalt binder content. The calculation of the CPF in a test section with a mix design that did not verify will include gradation, asphalt binder content and percent air voids (Va).

attach #9 item 16-20

**Washington State Department of Transportation**

# CONSTRUCTION BULLETIN

State Construction Office
Engineering and Regional Operations

**HMA Paving on Bridge Decks:**
**HMA Compaction**
Bulletin #2016-05
Date: October 28, 2016

**Purpose**

1. To explain the reasoning behind recently implemented contract requirements which increase the number of compaction tests to be taken on HMA paving on bridge decks.
2. To request Region feedback on the attached draft Amendment to the Standard Specifications (attachment 1).

**Background**

It is a certainty that HMA overlays on bridge decks haven't been lasting as long as they could, as evidenced by lower HMA performance (raveling, delamination, and potholes) when compared to adjacent HMA off of bridges. It is also a certainty that one of the major causes of this has been lower-than-desired HMA compaction.

Several things are occurring that individually are minor but collectively have exacerbated the trend in lower than desired HMA compaction on bridge decks.

1) The Standard Specifications disallow the vibration mode of rollers on bridge decks.

2) An industry-wide trend in roller equipment technology has been to increase the energy for compaction from vibration and amplitude, with a commensurate reduction in the gross static weight of rollers.

3) Our current Standard Specification for HMA does not specifically target testing on the bridge deck for percent compaction - instead, such testing only happens when a random test location happens to fall on the deck.

4) With statistical evaluation as the basis of acceptance for most of WSDOT's projects, for those instances when a random test location does fall on a deck, it is statistically evaluated with 15 other sublots. This can tend to mask compaction test results that are on the low end of desirable.

5) For about the last year, we have had contracts which (a) restricted the weight of, and (b) stipulated minimum spacing of equipment in the paving train. (This will be addressed in a separate Construction Bulletin.) Each of the above will have a tendency to make achieving the specified compaction more difficult.

When these factors are viewed together, lower than desired compaction is not an unforeseeable outcome, and lower than desired compaction is a well-recognized cause of reduced service life of HMA.

**Is Obtaining the Desired Compaction Achievable Under these Circumstances?**

Yes, because it has been done successfully on many projects. Things Contractors have done or could do are:

- Use warm mix technology.
- Use optimal amount of asphalt binder in the mixture.
- Make more roller passes on bridges.
- Use a heavier roller.
- Use a pneumatic roller with preheated tires.
- Adhere to best practices to keep HMA temperature up.
    - Pave during off-peak hours to minimize haul time.
    - Tarp trucks.
- Adhere to best practices to apply compactive effort as soon as possible.
    - Keep rollers as close to the paver as possible consistent with the contract.
    - Add another roller.

Things WSDOT can do to facilitate increased HMA compaction on bridge deck overlays are:

- Specify 3/8 inch Nominal Maximum Aggregate Size (NMAS) for use on bridge decks in order to increase the ratio of depth/NMAS.
- Modify volumetric property specifications such as voids in mineral aggregate (VMA), air voids ($V_a$), and dust-to-asphalt ratio during production to ensure optimum binder content is provided.
- Eliminate use of reclaimed asphalt pavement (RAP) and recycled asphalt shingles (RAS) in the HMA used to pave bridge decks to ensure full benefit of asphalt binder in mixture
- Specify polymer modified asphalt binders to provide rut and crack resistance.
- Consider using 3/8 inch HMA for an entire paving project, particularly where a project encompasses several bridges. The use of a single 3/8 inch mix, rather than using ½ inch off bridges and 3/8 inch on bridges, would simplify design and construction.

**The Problem and the Solution**

The problem is that compaction on bridge decks is generally not meeting the intended requirements of the Standard Specifications, which is a compaction Pay Factor of 1.00 or greater. The solution is to increase the asphalt compaction on bridge decks by specifically targeting mix design modifications and compaction testing on bridge decks.

**The Current Process**

Most contracts advertised in fall 2015/spring 2016 which included HMA paving on a bridge deck included the following language in a GSP for bridge deck overlays:

> ***HMA Overlay on Bridge Deck***
>
> *"HMA overlay shall be placed on the bridge deck in accordance with Section 5-04.3(7), and compacted in accordance with Section 5-04.3(10) and the following specific bridge and Structure requirements:"*
>
> > *"Pneumatic rollers are required for bridges with a total length of 125-feet or more."*
> >
> > *"HMA compaction on bridges will be evaluated collectively as a separate lot. Sublots on bridges shall not exceed 50-tons with at least one sublot per lane. Compaction on bridges will be evaluated by using random core samples of the lot in accordance with WSDOT Test Method T 716 where the relative density of the core in accordance with WSDOT FOP for*

> *AASHTO T 166 will be used for acceptance of the HMA compaction and the calculation of the CPF."*

A few changes are needed to the above language to address concerns that have surfaced during its use. Regions have been swamped with coring requests as a result of this spec and therefore have asked that the cores be taken by the contractor. Projects with multiple bridges have sometimes produced illogical results because the specification calls for all bridges to be evaluated with one collective pay factor; a separate pay factor is needed for each bridge. And finally, since this spec is intended to apply to all bridge decks, and owing to the complexity of the bridge deck HMA overlay GSP, it makes sense to take this language out of the GSP and make it an amendment to the Standard Specifications. The proposed language for insertion into the Standard Specifications on January 1, 2017 is attachment 1.

**HMA Compaction – Why So Many Tests, and Why Cores?**

It's already been said that one of the chosen solutions is to increase frequency of density testing on bridge decks. Along with the difficulty of achieving the compaction requirements on bridge decks comes the increased risk of failing compaction tests. This, in turn, increases the likelihood of requests for retests (which is always by cores) and the requirement to evaluate failing results by statistical evaluation (requiring a minimum of 3 sublots). Therefore, it is felt that in the long run or at least until there is a few year's data, it will be less work to go straight to cores and statistical evaluation.

**HMA Compaction – Doesn't Coring Create a Risk of Damaging the Deck?**

Using Cores for density testing on bridge decks does increase the risk of damage to the waterproofing membrane and the bridge deck. Occasionally, damage the membrane or the bridge deck concrete will occur, but changes will be made by January 2017 to WSDOT SOP 734 (Sampling Hot Mix Asphalt After Compaction (Obtaining Cores)) to require the bottom of the core hole to be swabbed with asphalt binder before being backfilled to help mitigate any damage. More importantly, the issue of low density is of such a concern to the Bridge and Structures Office that it's felt that the risk and consequences of coring damage is overshadowed by the benefit of increased compaction.

**Other Future Changes to the Process**

- The Bridge and Structures Office and HQ Construction are working with WAPA to consider allowing "oscillatory" rollers on decks. These purportedly create motion in a plane parallel to the deck which is reported to impose less force into the structure, as opposed to "vibratory" rollers which impose vertical forces on the structure.
- Implement training on these changes in our processes, which will rely on this Construction Bulletin for content.

**Additional Information Contact:**

- HQ Bridge & Structures Office - DeWayne Wilson and Dick Stoddard
- HQ Construction – Bob Dyer
- Pavement Design – Jeff Uhlmeyer

**Send Comments on the Proposed Amendment to the Standard Specifications (attachment 1):**

Bob Dyer

Draft Amendment to the Standard Specifications

To Increase HMA Density Testing on ALL Bridge Decks

***Add the following to 5-04.3(10)A HMA Compaction – General Compaction Requirements***

On bridges of a total length of 125 feet or more, at least one roller in the paving compaction train shall be a pneumatic roller.

***Add the following to 5-04.3(10)C1 HMA Compaction Statistical Evaluation–Lots and Sublots***

All HMA which is paved on a bridge and accepted for compaction by Statistical Evaluation will compose a bridge compaction lot. If the contract includes such HMA on more than one bridge, compaction will be evaluated on each bridge individually, as separate bridge compaction lots.

Bridge compaction sublots will be determined by the Engineer subject to the following.

- All sublots on a given bridge will be approximately the same size.
- Sublots will be stratified from the lot.
- In no case will there be less than 3 sublots in each bridge compaction lot.
- No sublot will exceeds 50 tons.
- Compaction test locations will be determined by the Engineer in accordance with WSDOT FOF for AASHTO T166.

***In Section 5-04.5, delete the following:***

"Roadway Core" – per each.

The Contractor's costs for all other Work associated with the coring (e.g., traffic control) shall be incidental and included within the unit Bid price per each and no additional payments will be made."

***In Section 5-04.5, add the following***

"HMA Core – Bridge Deck", per each.

The unit Contract price per each for "HMA Core – Bridge Deck" shall be full payment for all costs, including traffic control, associated with taking HMA density cores in pavement that is on a bridge deck.

"HMA Core – Roadway", per each.

The unit Contract price per each for "HMA Core – Roadway" shall be full payment for all costs, including traffic control, associated with taking HMA density cores in pavement that is not on a bridge deck.

***Replace Section 5-04.3(10)C2 with the following:***

### 5-04.3(10)C2 HMA Compaction Statistical Evaluation – Acceptance Testing

Comply with Section 1-06.2(1).

The location of HMA compaction acceptance tests will be randomly selected by the Contracting Agency from within each sublot, with one test per sublot. The Contracting Agency will determine the random sample location using WSDOT Test Method T 716.

Use Table 18 to determine compaction acceptance test procedures and to allocate compaction acceptance sampling and testing responsibilities between the Contractor and the Contracting Agency. HMA cores ~~Roadway cores~~ shall be taken or nuclear density testing shall occur after completion of the finish rolling, prior to opening to traffic, and on the same day that the mix is placed

Table 18

**HMA Compaction Acceptance Testing Procedures and Responsibilities**

| | When Contract Includes Bid Item "HMA Core – Roadway" [4] ~~Roadway Core~~ | When Contract Does Not Include Bid Item "HMA Core – Roadway" [4] ~~Roadway Core~~ | |
|---|---|---|---|
| Basis for Test: | ~~Roadway~~ Cores | ~~Roadway~~ Cores [3] | Nuclear Density Gauge[3] |
| In-Place Density Determined by: | Contractor shall take cores[1] using WSDOT SOP 734[2]<br>Contracting Agency will determine core density using FOP for AASHTO T 166 | Contracting Agency will take cores[1] using WSDOT SOP 734<br>Contracting Agency will determine core density using FOP for AASHTO T 166 | Contracting Agency, using FOP for WAQTC TM 8 |
| Theoretical Maximum Density Determined by: | Contracting Agency, using FOP for AASHTO T 209 | | |
| Rolling Average of Theoretical Maximum Densities Determined by: | Contracting Agency, using WSDOT SOP 729 | | |
| Percent Compaction in Each Sublot Determined by: | Contracting Agency, using WSDOT SOP 736 | Contracting Agency, using WSDOT SOP 736 | Contracting Agency, using FOP for WAQTC TM 8 |

[1]The core diameter shall be 4-inches unless otherwise approved by the Engineer.

[2]The Contractor shall take the core samples in the presence of the Engineer, at locations designated by the Engineer, and deliver the core samples to the Contracting Agency.

[3]The Contracting Agency will determine, in its sole discretion, whether it will take cores or use the nuclear density gauge to determine in-place density. Exclusive reliance on cores for density acceptance is generally intended for small paving projects and is not intended as a replacement for nuclear gauge density testing on typical projects.

[4] The basis for test of all compaction sublots in a bridge compaction lot shall be cores. These cores shall be taken by the Contractor when the Proposal includes the bid item "HMA Cores – Bridge Deck". When there is no bid item for "HMA Cores – Bridge Deck", the Engineer will be responsible for taking HMA cores for all compaction sublots in a bridge compaction lot. In either case, the Engineer will determine core location, in-place density of the core, theoretical maximum density, rolling average of theoretical maximum density, and percent compaction using the procedure called for in this Section.

When using the nuclear density gauge for acceptance testing of pavement density, the Engineer will follow WSDOT SOP 730 for correlating the nuclear gauge with HMA cores. When cores are required for the correlation, coring and testing will be by the Contracting Agency. When a core is taken for gauge correlation at the location of a sublot, the relative density of the core will be used for the sublot test result and is exempt from retesting.

Attach #10 item 16-21

# CONSTRUCTION BULLETIN

Washington State
Department of Transportation

State Construction Office
Engineering and Regional Operations

HMA Paving on Bridge Decks:
Restrictions on Equipment Weight & Spacing
Bulletin #2016-04
Date: October 28, 2016

## Purpose

(1) To explain the reasoning behind recently implemented contract requirements for restricting the weight and spacing of equipment in the Contractor's HMA paving and milling trains when working on a bridge deck.
(2) To request Regional feedback on the current General Special Provision (GSP) and plan sheet (Attach. 1A and 1B).

## What Are These "Restrictions on Paving/Milling Train Weights/Spacing on Bridge Decks"?

The restrictions are defined in a GSP and plan sheet which together make sure the contractor's paving/milling equipment is not too heavy, and that this heavy equipment doesn't get too close together, ensuring the continued structural integrity of the bridge. This equipment could include pavers, MTD/V, hauling vehicles, milling machines, rollers, etc. See Attachment 1A and 1B for a sample of the GSP and plan sheet. Features of this GSP/plan sheet are:

1. They would be included in any project that places heavy equipment on a bridge deck, if the bridge is identified by the Bridge and Structures Office as requiring load restrictions on paving or milling equipment.
2. They do not require the paving contractor to do any structural analysis because they provide a pre-approved (by the Bridge and Structures Office) weight and spacing on a plan sheet.
3. Equipment weights on the plan sheet will have been vetted with industry to assure reasonable availability and functionality.
4. The GSP allows each bidder to submit a maximum of 2 contractor-specific paving trains to the Bridge and Structures Office for review and approval prior to submitting a bid.
5. After contract execution, even though the GSP does not explicitly state as much, the Contractor may propose changes to the WSDOT preapproved plan sheet by submitting working drawings showing the Plan and Elevation views of the equipment train that includes axle weights and spacing between all axles. Axle weights must be reflective of a fully loaded vehicle. Track loads may be represented by contact length, width, and gross weight. This proposal requires review and approval by the Bridge and Structures Office.

## Are These Restrictions the Same for Every Project?

These restrictions are not the same for every project. Allowable equipment weights may vary from one project to another, equipment spacing may vary, or MTD/V's may or may not be allowed.

Most projects will not include the restricted equipment weight GSP. That's because, for the time being, the Bridge and Structures Office evaluates only those bridges considered to have a high potential for being at risk. The bridges identified as having the high potential for being at risk are structurally evaluated to determine whether the need to restrict paving equipment loads exists, and if so, what those restrictions are. Experience has shown that not all of the bridges evaluated ultimately require equipment weight restrictions in the contract. For those bridges that are not evaluated, at the present time they are assumed to have capacity to support modern paving equipment based on past experience.

Of the 43 HMA paving projects placed on Ad by WSDOT from September 2015 through August 2016 for the 2016 paving season, 25 included paving on bridge decks requiring bridge deck repair, membrane, and/or overlay profile revision. Of those 25, nine included a plan sheet outlining a milling train and/or paving train arrangement, and another 5 included specifications outlining load restrictions on bridges within the paving limits (some being paved and others not paved).

A very rough forecast from review of the list of projects for the 2017 season looks to have 17 projects with some form of bridge deck paving, out of 43 HMA paving projects overall. Of the 17 that will have paving on bridge decks, it has not yet been determined how many will require restricting the weight of paving equipment.

## Why Now?

Several factors happening at the same time have made it necessary for WSDOT to consider whether our bridges, and in particular our older bridges, are being overstressed during HMA milling and paving operations. Some of these factors have been happening for decades, and some are recent developments. For example, highway bridges age, and as a natural result they deteriorate. Causes of this deterioration include concrete shrinkage cracking, ground settlement, seismic ground movement, rebar corrosion, structural steel corrosion, vehicle damage, insect infestation (timber), tire wear, fatigue cracking, and a myriad of other causes. These in turn cause the load capacity to diminish from the original design intent. At the same time, bridge design loads have increased to accommodate the need for heavier truck loads. Also at the same time the size, capacity, and weight of HMA paving equipment has increased in order to optimize efficiency and increase quality. More recently, new technology such as transfer vehicles and pavement grinders have appeared on the scene that further increase the overall weight of the paving train.

It turns out that some of our bridges are being overstressed by HMA paving and grinding operations as determined by bridge-specific calculations that take into consideration weights and spacing of typical, modern, paving and milling equipment.

The primary goal of this effort is to prevent structural damage to a bridge as a result of the HMA paving operation.

## Doesn't Standard Specification 1-07.7 "Load Limits" Already Address This Issue?

Not really. The 35% axle overload no longer complies with the code so it will be removed from the Standard Specs soon.

**Isn't The Proposed Spec More Restrictive Than Legal Load Limits?**

After all, if legal loads can be up to 80,000 or 105,500 lbs., how does it make sense to restrict a truck and pup to less than 80,000 pounds? The short answer is that the code and the law address more than merely gross vehicle weight. The longer answer is that pavers, grinders, and MTD/V's of the size typically used on WSDOT projects almost never meet the requirements of a legal load. When any piece of construction equipment exceeds legal loads or axle spacing (such as a paver, MTD/V, or milling machine) you cannot locate an 80,000 truck just adjacent to it merely because the 80,000 truck is a "legal" load; once one piece of equipment is known to exceed the legal load criteria, the structural effect of all equipment in the vicinity must be considered. Then, the type, size and geometry of the bridge can affect the size of truck the bridge can carry. Therefore, a structural analysis is required, based on axle spacing (i.e., concentration of loads), proximity of adjacent heavy equipment, bridge type, bridge size, and bridge geometry.

For example, an MTD/V might weigh 100,000 lbs., but because its axle spacing is so close and it has tracks instead of wheels, it doesn't meet the code or the law for vehicle weight. Only a bridge-specific structural analysis can determine if the bridge can withstand the specific MTD/V loads, and that analysis must also evaluate the weight and geometry of other heavy equipment (such as 10-wheelers) that might be in the vicinity. If it can, the analysis will show where the bridge will overstress first and what influence the adjacent equipment has on the overstress. If it's the deck, maybe adjacent equipment must stay farther away. If it's the superstructure, perhaps a lighter combination of adjacent equipment is the only solution between the piers. There is a complex matrix of weight/spacing/structural support that need to be considered.

Refer to Attachments 2, 3, and 4 for a brief summary of Washington legal loads, Washington permit loads, and the AASHTO Bridge Design Code.

**Project Scoping and PS&E Process to Determine Paving/Grinding Equipment Weight Restrictions**

As part of project programming the HQ Bridge Asset Management unit creates Bridge Condition Reports (BCR) that state the paving design and identify bridge conditions that could limit or impact construction procedures. Beginning in 2016, if the bridge Operating Load Rating is 42 tons or less, the BCR automatically includes a statement that equipment weight restrictions might be required in the PS&E. For BCR's that were developed before 2016, an update should be requested before finalizing a PS&E.

During PS&E development, the Bridge Design Office will use the existing Bridge Load Rating models and software that are maintained by the Bridge Preservation Office to investigate equipment limitations. Also, the Bridge Design Office is working with the Washington Asphalt Paving Association (WAPA) to establish two paving train models that will be used as "bookends" to define the limits of heaviest-typical and lightest-practical paving trains. These will be used in the initial analysis of the potential for load restrictions. These bookends - the WAPA Heavy Paving Train and WAPA Light Paving Train - will be evaluated using Overload Permit vehicle criteria, which allows heavier vehicle loads for occasional live loads. If the analysis calculates a Load Rating Factor less than 1.0, the Bridge Capacity is judged to be inadequate to resist the equipment loads. When that happens, additional analysis is performed to determine if increasing equipment spacing will help or if equipment weights need to be reduced. In many cases, the MTV must be lightened or eliminated to produce a Load Rating of 1.0 or greater. The objective is to provide potential contractors with paving equipment diagrams that show the allowable maximum weights and minimum spacing.

Contractor-proposed configurations will be considered during the bidding phase and after contract award. The Bridge Design Office will have the structural models and spreadsheet available and ready to go in order to provide timely responses.

**Here's A Way to Increase Max Allowable Weight of Some Equipment**

In doing the structural analysis, the more certainty the Bridge and Structures Office has about what the maximum equipment weights will be, the higher the maximum allowable equipment weights can be. Known as "load validation", this reduces the uncertainty of the equipment weights and allows the structural engineer to reduce conservatism in the load rating analysis. Use of on-site, certified scales will typically result in a 15% increase in maximum allowable equipment weight when compared to what has been allowed in projects in the last year. The process that will be used to convey this information to the Bridge and Structures Office, and the process WSDOT inspectors will play in validating actual equipment weights, is being worked out as this is written (and by this Construction Bulletin Region input is requested as to how this can best be accomplished), but is expected to be in the January 2017 spec and Construction Manual.

**Future Changes to the Process**

- The Standard Specification that allows WSDOT Contractors to increase construction equipment weights to 35% over legal will be removed from the specifications because it is no longer valid.
- Bridge and Structures Office is working with WAPA on defining the lightest practical and heaviest typical equipment weights.
- Update the GSP and Construction Manual to designate how equipment weights will be verified.
- Certainty of actual loads and actual axle spacing will reduce load factors, which in turn will increase the allowable equipment weights. Establish inspection and documentation procedures to this effect.
- Implement training, which will rely largely on this Construction Bulletin.

**Additional Information or to Comment on the GSP/Plan Sheet:**

- HQ Bridge Preservation – Harvey Coffman
- HQ Bridge Design – Dick Stoddard
- HQ Construction – Bob Dyer
- Pavement Design – Jeff Uhlmeyer

# GSP FOR WEIGHT AND SPACING RESTRICTIONS ON HMA PAVING/MILLING ON BRIDGES

(current a/o September 20, 2016)

**Planing Bituminous Pavement**

The gross vehicle weight (GVW) of the planer and haul truck allowed on the bridges shall not exceed the maximum GVW specified in the Plans, and the spacing of the vehicles shall not be less than that specified in the Plans unless otherwise accepted as described in this Special Provision.

After planing, the Contractor shall remove all loose and unsound surfacing not firmly bonded to the bridge deck, as specified by the Engineer, using methods and equipment that do not damage the bonded layer of surfacing to remain.

**HMA Overlay on Bridge Deck**

HMA overlay shall be placed on the bridge deck in accordance with Section 5- 04.3(9), and compacted in accordance with Section 5-04.3(10) and the following specific bridge and Structure requirements:

> Use of an MTD/V on Bridge Nos. 107/5 and 107/6 will not be allowed. The Contractor may directly transfer HMA from the hauling equipment to the paving machine for paving of Bridge Nos. 107/5 and 107/6.
>
> The gross vehicle weight (GVW) of the paving train vehicles (haul truck, asphalt paver, and breakdown pneumatic, intermediate, and finish rollers) allowed on the bridges shall not exceed the maximum GVW specified in the Plans, and the spacing of the vehicles shall not be less than that specified in the Plans unless otherwise accepted as described in this Special Provision.
>
> Static mode compaction is required for all compaction equipment operating over the bridges and 5-feet of Roadway approach immediately adjacent to the end of bridge/back of pavement seat. At least one roller in the paving compaction train shall be a pneumatic roller.
>
> HMA compaction on bridges will be evaluated collectively as a separate lot. Sublets on bridges shall not exceed 50-tons with at least one sublet per lane. Compaction on bridges will be evaluated by using random core samples of the lot in accordance with WSDOT Test Method T 716 where the relative density of the core in accordance with WSDOT FOP for AASHTO T 166 will be used for acceptance of the HMA compaction and the calculation of the CPF.

**Submittal of Alternative Asphalt Removal and Paving Trains**

During the Bid period, prospective Bidders may submit a maximum of two asphalt removal trains and two asphalt paving trains for review and comment. The submittal shall contain the maximum gross vehicle weights including loaded weights for haul trucks, paver, material transfer vehicle, etc., the axle spacing of the equipment and the minimum spacing between adjacent pieces of equipment. Submittals must be received by the Contracting Agency's representative identified in the Notice to All Plan holders by April 26, 2016 at 5:00 PM. Electronic submittals will be accepted. All submittals received by the required date and time, both accepted and not accepted, will be posted on the Contract Ad & Award information page no later than the Friday prior to Bid opening.

***Replace Section 5-04.3(10)C2 with the following:***

### 5-04.3(10)C2 HMA Compaction Statistical Evaluation – Acceptance Testing

Comply with Section 1-06.2(1).

The location of HMA compaction acceptance tests will be randomly selected by the Contracting Agency from within each sublot, with one test per sublot. The Contracting Agency will determine the random sample location using WSDOT Test Method T 716.

Use Table 18 to determine compaction acceptance test procedures and to allocate compaction acceptance sampling and testing responsibilities between the Contractor and the Contracting Agency. HMA cores ~~Roadway cores~~ shall be taken or nuclear density testing shall occur after completion of the finish rolling, prior to opening to traffic, and on the same day that the mix is placed

Table 18

| HMA Compaction Acceptance Testing Procedures and Responsibilities | | | |
|---|---|---|---|
| | When Contract Includes Bid Item For "HMA Cores ~~1~~ Roadway" or "HMA Cores – Bridge" | When Contract Does Not Include Bid Item "HMA Core – Roadway" or "HMA Core – Bridge" [4] | |
| Basis for Test: | ~~Roadway~~ Cores | ~~Roadway~~ Cores [3] | Nuclear Density Gauge[3] |
| In-Place Density Determined by: | Contractor shall take cores[1] using WSDOT SOP 734[2]<br>Contracting Agency will determine core density using FOP for AASHTO T 166 | Contracting Agency will take cores[1] using WSDOT SOP 734<br>Contracting Agency will determine core density using FOP for AASHTO T 166 | Contracting Agency, using FOP for WAQTC TM 8 |
| Theoretical Maximum Density Determined by: | Contracting Agency, using FOP for AASHTO T 209 | | |
| Rolling Average of Theoretical Maximum Densities Determined by: | Contracting Agency, using WSDOT SOP 729 | | |
| Percent Compaction in Each Sublot Determined by: | Contracting Agency, using WSDOT SOP 736 | Contracting Agency, using WSDOT SOP 736 | Contracting Agency, using FOP for WAQTC TM 8 |

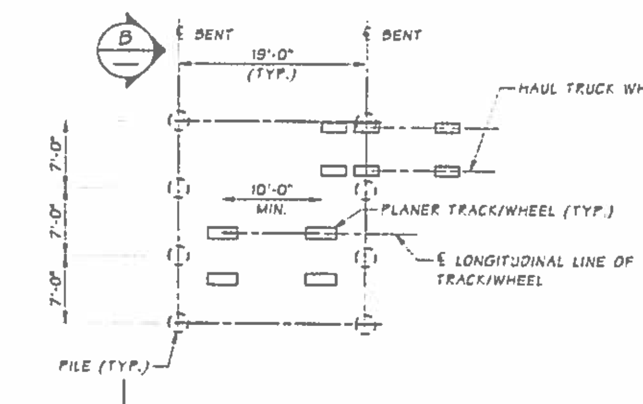
[1]The core diameter shall be 4-inches unless otherwise approved by the Engineer.
[2]The Contractor shall take the core samples in the presence of the Engineer, at locations designated by the Engineer, and deliver the core samples to the Contracting Agency.
[3]The Contracting Agency will determine, in its sole discretion, whether it will take cores or use the nuclear density gauge to determine in-place density. Exclusive reliance on cores for density acceptance is generally intended for small paving projects and is not intended as a replacement for nuclear gauge density testing on typical projects.
[4] The basis for test of all compaction sublots in a bridge compaction lot shall be cores. These cores shall be taken by the Contractor when the Proposal includes the bid item "HMA Cores – Bridge Deck". When there is no bid item for "HMA Cores – Bridge Deck", the Engineer will be responsible for taking HMA cores for all compaction sublots in a bridge compaction lot. In either case, the Engineer will determine core location, in-place density of the core, theoretical maximum density, rolling average of theoretical maximum density, and percent compaction using the procedure called for in this Section.

When using the nuclear density gauge for acceptance testing of pavement density, the Engineer will follow WSDOT SOP 730 for correlating the nuclear gauge with HMA cores. When cores are required for the correlation, coring and testing will be by the Contracting Agency. When a core is taken for gauge correlation at the location of a sublot, the relative density of the core will be used for the sublot test result and is exempt from retesting.

**ATTACHMENT 1B**

| ITEM | MAXIMUM GROSS WEIGHT (LBS) |
|---|---|
| HAUL TRUCK | 45,000.0 * |
| LIGHT PLANER WITH LOCATIONS UNRESTRICTED | 26,000.0* |
| HEAVY PLANER WITH LOCATIONS RESTRICTED | 45,000.0* |

* FULLY LOADED TOTAL WEIGHT




PLAN VIEW

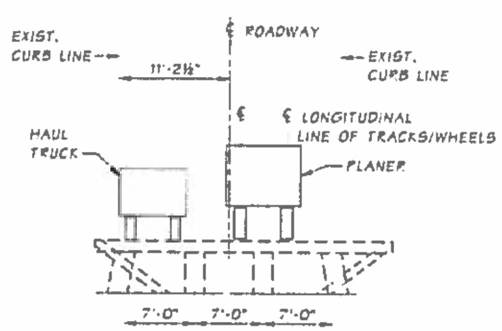

## ASPHALT REMOVAL TRAIN

## FOR BRIDGES 107/5 AND 107/6

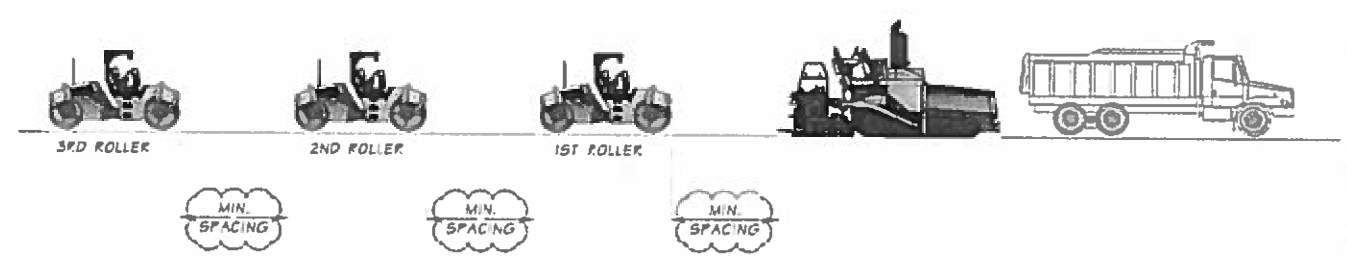
REMOVAL EQUIPMENT LIMITS ARE BASED ON EXPECTED AXLE WEIGHTS AND GROSS VEHICLE WEIGHTS BUT DO NOT SPECIFY EQUIPMENT MODELS OR MANUFACTURERS.

FOR EACH BENT:

THE HEAVY PLANER SHALL BE POSITIONED SUCH THAT ONLY ONE LONGITUDINAL LINE OF TRACKS/WHEELS IS LOCATED BETWEEN ANY PAIR OF ADJACENT PILES OF THE BENT. SEE "PLAN VIEW" AND SECTION B. THE HAUL TRUCK SHALL BE POSITIONED IN AN ADJACENT LANE SUCH THAT NO ONE LONGITUDINAL LINE OF WHEELS IS BETWEEN THE SAME PILES AS A LONGITUDINAL LINE OF PLANER TRACKS/WHEELS.




SECTION B




## ASPHALT PAVING TRAIN

VIBRATION MODE IS NOT ALLOWED FOR ANY ROLLERS.

## FOR BRIDGES 107/5 AND 107/6

PAVING TRAIN LIMITS ARE BASED ON EXPECTED AXLE WEIGHTS BUT DO NOT SPECIFY EQUIPMENT MODELS OR MANUFACTURERS.

A THREE ROLLER PAVING TRAIN IS SHOWN TO ILLUSTRATE EQUIPMENT SPACING ADDITIONAL ROLLERS MAY BE USED IF EQUIPMENT SPACING IS MAINTAINED.

MINIMUM SPACING FOR EACH PIECE OF EQUIPMENT SHALL BE MAINTAINED IN FRONT OF AND BEHIND THE EQUIPMENT. THE SPACING BETWEEN A LIGHT ROLLER AND A HEAVY ROLLER SHALL NOT BE LESS THAN PRESCRIBED FOR THE HEAVY ROLLER.

| ITEM | MAXIMUM GROSS WEIGHT (LBS) | MIN. SPACING |
|---|---|---|
| ASPHALT PAVER & HAUL TRUCK COMBINED | 60,000 LBS ** | - |
| LIGHT ROLLER | 30,000 LBS | 20 FT. |
| HEAVY ROLLER | 45,000 LBS | 30 FT |

** COMBINED TOTAL WEIGHT OF HAUL TRUCK, ASPHALT PAVER AND HMA SHALL NOT EXCEED THE MAXIMUM GROSS WEIGHT.

SR ___ FILE NO. ___ SHEET 1

| | | |
|---|---|---|
| Bridge Design Engr. | Khaleghi, B | |
| Supervisor | Stoddard, RB | |
| Designed By | Stoddard, RB | 01/16 |
| Checked By | Chu, A | 03/16 |
| Detailed By | Andreotti, L | 01/16 |
| Bridge Projects Engr. | | |
| Prelim. Plan By | | |
| Architect/Specialist | | |

M:\RAIL RETROFITS\1-OVERLAYS\XL4868_SR8-SR107_PAVING TRAIN\window files\A001-HMA PAVING TRAIN.wnd

| DATE | REVISION | BY | APP'D |
|---|---|---|---|
| 4/15/16 | CHANGED MAXIMUM GROSS WEIGHT & MIN. SPACING | BK | |

REGION NO. 10 | STATE WASH | FED. AID PROJ. NO. | SHEET NO. | TOTAL SHEETS

JOB NUMBER 5C916

CONTRACT NO.

BRIDGE AND STRUCTURES OFFICE

Apr 19 2016 9:31 AM

**Washington State Department of Transportation**

SR 8 & SR 107
MCCLEARY & MONTESANO VIC
PAVING

PLANER & PAVING EQUIPMENT WEIGHTS AND SPACING

BRIDGE SHEET NO. 1

SHEET 8 OF 18 SHEETS

***Legal Loads in Washington State***

Legal weight limits in Washington State, which are found in RCW 46.44, are based on Federal regulation 23 CFR 658.17 which was enacted into law by Congress in 1974. The federal regulation limits the gross vehicle weight on the National System of Interstate and Defense Highways to a maximum of 80,000 pounds. When the RCW was enacted in 1975-76, the state legislature increased the maximum gross vehicle weight to 105,500 pounds and the weight on the steer axle was limited to the lesser of 20,000 pounds or 600 pounds per inch width.

The maximum gross weight is calculated based on the Federal Formula, which is known as Formula B:

$$W = 500(\frac{LN}{N-1} + 12N + 36)$$

Where *L* is the total length between a group of axles in feet and *N* is the number of axles.

As an example, a 60 foot long configuration with 6 axles will carry:

$$W = 500\left(\frac{60 * 6}{6-1} + (12 * 6) + 36\right) = 90{,}000 \text{ pounds}$$

Additionally, the maximum load on a single axle is 20,000 pounds. The weight is controlled by the width of tire where it is limited to 500 pounds per inch of width except for the steer axle where it is limited to the lesser of the 20,000 pounds or manufacturer rating.

Tandem axles are limited to 34,000 pounds and are defined as two or more consecutive axles where the distance between the first and last axle is over 40 inches and less or equal to 8 feet.

The lesser of the above calculations will govern the gross weight of the configuration.

The Washington State Legislature adopted the federal regulation in 1975-76 per RCW 46.44.042. At the same time our Legislature of tire.

## *Permit Loads in Washington State*

There is no national standard to regulate permit loads, so each state has its own laws that govern the permitting of overloads. In Washington State, permits for weight are regulated under RCW 46.44.091. Permit loads are defined as non-divisible loads or those that can't be reduced in a reasonable amount of time.

Permit loads are limited by the following:

- 600 pounds per inch of tire width
- 22,000 pounds on a single axle; this limit can be exceeded if the tire has a rim width greater than 20 inches and a diameter greater than 24 inches.
- 43,000 pounds on a tandem axle

Additionally, the maximum load on a group of axles is limited by the following formulas:

- Length of the group is from 7 feet to less than 10 feet: $L$*6500
- Length of the group is from 10 feet to less than 30 feet: ($L$+20)*2200
- Length of the group is from 30 feet and greater: ($L$+40)*1600

Where $L$ is the length of the combination

The lesser of any of these calculations or axle weight limits will control the maximum gross weight on a combination.

Permits for over-legal loads can always be considered on a WSDOT contract.

## AASHTO LRFD Allowed Loads

Pavement removal equipment and paving equipment will be evaluated by the same structural Load Rating Criteria that is used by the Bridge Preservation Office to evaluate overload truck permits. They require a moving load analysis of the equipment, including tire sizes, axle spacing, gross and net vehicle weight, and stresses with various relative locations of equipment to evaluate equipment spacing. The structural analysis reviews all components of the bridge to see what controls the failure mechanism. The objective of the analysis is to find the heaviest allowable scenario that does not overstress the structure.

The paving removal equipment with haul trucks and the paving training are analyzed as a single overload truck with axle loads and spacing that match the proposed equipment weights and equipment spacing. Spreading the paving loads longitudinally in a lane and transversely into adjacent lanes are techniques that can help reduce the maximum stresses in the bridge. However, when a capacity limit is exceeded by a single axle load from one of the pieces of equipment, the only solution is to look for lighter equipment to reduce the load.