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Subject: S.O.P. LOT DENSITY ACCEPTANCE OF HMA			Distribution A, B, C, D, E
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PURPOSE: To Establish Standard Procedures For The Determining of Lot Densities and Acceptance of Lots Based on Specified Density Requirements (Refer to Chapter 7 of MDOT “Field Manual For Hot Mix Asphalt (HMA)” latest edition).

1. Definitions

- 1.1. Gauge Bias - The average of the individual bias values determined during one day of production testing and all previous update determinations for the project.
- 1.2. Pavement Cores - Pavement cores shall be obtained using a 4.0 to 6.0 inch inside diameter coring bit. For a “25 mm” mixture, a 6.0 inch inside diameter coring bit shall be used. Sawed samples, if used, shall have a surface area approximately equivalent to the cores.
- 1.3. Random Density Testing Sites - The testing sites for density determination selected at random from each lot in accordance with the Table of Random Numbers as set out in S.O.P. No. SA II-3-31. The random numbers selected shall be recorded.
- 1.4. Unit Weight Constant - The value of 62.24 pcf is used to convert from specific gravity to unit weight.

2. Roadway Density Measurements

- 2.1. The primary method to determine roadway density is by measurement with a calibrated nuclear gauge adjusted for testing bias.
- 2.2. On the first day of production and once each production week (a production week is defined as - six (6) days of mixture production or 5,000 tons of mixture, whichever comes later), cores will be obtained from the roadway to measure density and to establish the nuclear gauge bias (correction factor). The engineer may use cores to verify the nuclear gauge results at any time.
- 2.3 Cores will be used to verify lot compaction penalties and to identify the limits for pavement removal.

3. First Production Day

- 3.1. The production will be divided into lots according to the procedures as defined in Subsection S-401.02.6.4 of the Standard Specifications.
- 3.2. Select one random density site for each density lot as defined in Subsection 1.3 above.

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3.3. Nuclear Density Testing

- 3.3.1. Select a nuclear gauge testing location within the allowable tolerance specified in S.O.P. No. S.A. II-3-31 from the previously established random density test site.
- 3.3.2. Place the nuclear gauge with the sides of the gauge parallel to the centerline of roadway. Mark the outline of the gauge on the pavement.
- 3.3.3. Irregularities in the area of the test site shall be filled with dry fine sand, native fines, cement, fly ash, or other similar dry material.
- 3.3.4. Take one (1) four minute density count and record the wet density in the space provided on Form TMD-004.

3.4. Core Density Testing

- 3.4.1. Core the pavement at the approximate center of the nuclear gauge test location for each testing site.
- 3.4.2. Damaged cores will not be used for testing. Take a replacement core(s) for any core(s) damaged during the coring process.
- 3.4.3. Determine the core density according to AASHTO T 166 Method C (or AASHTO T 275 when the water absorption exceeds two (2) percent of the sample volume).

3.5. Calculating the Nuclear Gauge Bias

- 3.5.1. Subtract the nuclear gauge density from the core density for each test site to determine the bias (this value should generally be a positive number).
- 3.5.2. If any of the individual bias values differ from the gauge bias by more than the allowable bias variation given in Table 7-1 below, any individual bias that exceeds the tolerance shall be discarded and a new bias shall be determined from the original density test site. Select a new gauge location within the allowable tolerance specified in MDOT S.O.P. No. CSD-50-70-54-000 of the test site location. A new gauge bias shall be calculated and used to replace the original value using the procedures outlined above.

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Table 7-1
Allowable Variation from Average for Individual Bias Values

Gauge Bias Value, pcf	Allowable Individual Bias Variation, pcf
-3.0 to -0.1	1.5
0.0 to 3.0	1.5
3.1 to 6.0	3.0

Example:

The following test results are from the first day of production:

The contractor produced 2000 tons of HMA. Based on the requirements of Subsection S-401.02.6.4 of the Standard Specifications, the production is divided into 5 equal lots of 400 tons each. The Engineer selects two test sites in each lot using appropriate procedures for determining the random density test sites. The test results are as follows:

Lot	Core Density, pcf	Nuclear Density, pcf	Bias, pcf
1	138.2	135.1	3.1
2	136.6	134.0	2.6
3	137.4	135.5	1.9
4	142.0	135.4	6.6
5	138.7	135.5	3.2
Average			3.5

Based on the above data, the gauge bias is calculated by averaging the individual bias values.

$$\text{Gauge Bias} = 3.5 \text{ pcf}$$

$$\text{Allowable Individual Bias Variation (Table 1)} = 3.5 \pm 3.0 \text{ pcf}$$

Therefore, the acceptable range of individual bias values = 0.5 to 6.5 pcf

A review of the individual bias values in the above table indicates that the test result for Lot 4 exceeds the allowable bias deviation from the average.

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Select a new gauge location within the allowable tolerance specified in MDOT S.O.P. No. CSD-50-70-54-000 of the test site for location 4. Determine new test values for nuclear density and core density using the above procedures. The new test results are as follows:

	Core Density, pcf	Nuclear Density, pcf	Bias, pcf
Lot 4	141.3	137.3	4.0

Substitute the new bias (4.0) for the original Lot 4 result.

$$\begin{aligned} \text{The corrected Gauge Bias} &= (3.1+2.6+1.9+4.0+3.2)/5 \\ &= 3.0 \text{ pcf} \end{aligned}$$

The acceptable range of individual bias values now becomes = 1.5 to 4.5 pcf

The bias values determined for each individual test site are within the allowable difference. Therefore the gauge bias update of 3.0 pcf should be used for further testing until a bias update is required.

3.6. Roadway Density Acceptance for the First Day of Production.

- 3.6.1. Calculate the percent compaction payment according to the procedures contained in Subsection S-401.02.6.4.1 of the Standard Specifications.
- 3.6.2. Any lot, or portion thereof with a density below the requirement and not allowed to remain in place at a reduced pay in accordance with the specifications shall be removed and replaced at no additional cost to the project.
- 3.6.3. When the density of a lot does not meet the requirement to remain in place, the limits of the lot to be removed and replaced will be established by testing the pavement as set out in Section 8 below. A corrected lot will be retested for acceptance as set out in Section 9 below.

4. Compactive Effort for Lot to Lot Operations

Once the contractor establishes a compaction process that produces an acceptable roadway density, that process should be used for daily compaction operations and should only be changed when conditions under which the original process was established have changed.

5. Nuclear Density Procedure for Determining Acceptance of Lots

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- 5.1. In all cases except when a nuclear gauge bias is being established, the nuclear gauge will be used to determine roadway density.
- 5.2. A lot is equal to the quantity of mixture as defined in Subsection S-401.02.6.4 of the Standard Specifications.
- 5.3. Two nuclear density test sites will be selected at random from each lot in accordance with the procedures set out in Section 6 below. The two density test results will be averaged to determine compliance with the compaction requirements for the lot.
- 5.4. When the difference between the two (2) nuclear density readings exceeds 3 pounds per cubic foot (pcf) and either or both readings indicate less than the required density (92% or 93%, as specified) test an additional three (3) random sites in the lot and average all five(5) readings to determine compliance with the compaction requirements for the lot. When the difference between the two (2) nuclear density readings exceeds 3 pounds per cubic foot (pcf) and both readings indicate meeting the required density (92% or 93%), no further testing in the lot is required. The lot density will be the average of the two (2) nuclear density readings.
- 5.5. If the nuclear gauge testing indicates that a lot is in penalty or requires removal and replacement for compaction, the Contractor is required to obtain a core from each of the original nuclear density test sites in the lot within 24 hours of being notified of the need for such cores. The Engineer will test the cores according to the above procedures. The results of the cores will be averaged and used for the determination of payment for compaction.
- 5.6. When the average core density for a lot does not meet the requirements to remain in place, the limits of the lot to be removed and replaced will be established by testing the pavement as set out in Section 8 below. A corrected lot will be retested for acceptance as set out in Section 9 below.

Example

The Contractor produces 1,460 tons of HMA for the day in a 12-foot wide lane that resulted in a total of 10,000 feet of paving. The project was a single lift construction with a MT mixture (Target Compaction from Subsection S-401.02.6.4.1 = 92 percent). The specifications require the production to be divided into four Lots each 2,500 feet long. Using random numbers, the Engineer selects two locations in each Lot and measures the density using MT-16, Method C, for the nuclear gauge. The test results in pcf and the results corrected for bias (3.0 pcf from previous example) are as follows:

	Site 1	Site 2	Average	Adjusted
Lot 1	132.2	134.6	133.4	136.4
Lot 2	131.1	132.1	131.6	134.6
Lot 3	130.4	128.6	129.5	132.5
Lot 4	134.6	130.4	132.5	135.5

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Prior to calculating pay factors, the individual tests from each lot must be tested for uniformity according to Subsection 5.4 above. The maximum deviation between the two individual gauge readings for a lot is 3 pcf.

	Allowable Deviation, pcf	Actual Deviation, pcf	Result
Lot 1	3.0	2.4	Okay
Lot 2	3.0	1.0	Okay
Lot 3	3.0	1.8	Okay
Lot 4	3.0	4.2	Retest

Because the variation between the two samples for Lot 4 exceeds the allowable deviation, the Engineer will locate three additional test sites in the Lot and test for density with the nuclear gauge. The three new readings and the two original readings in pcf will be averaged to represent the lot density.

	Site 1	Site 2	Site 3	Site 4	Site 5	Average	Adjusted
Lot 4	134.6	130.4	131.5	131.9	133.0	132.3	135.3

Based on the above data, the Engineer can determine the compaction payment for each of the Lots. The mixture quality control testing at the plant indicated that average maximum specific gravity (density) for the day was 2.356 (146.6 pcf).

For Lot 1, the percent compaction = $(136.4/146.6) \times 100 = 93.0\%$.

	Average Lot Density, pcf	Percent Compaction	Pay Factor
Lot 1	136.4	93.0	1.00
Lot 2	134.6	91.8	0.90
Lot 3	132.5	90.4	0.70
Lot 4	135.3	92.3	1.00

Based on the above density testing, the Contractor will receive 100 percent of the unit price per ton for the material represented by Lots 1 and 4. Because Lots 2 and 3 are in penalty, a core testing program must be conducted to determine the final pay factors.

6. Nuclear Gauge Bias Update

- 6.1. The bias for the nuclear gauge will be updated as required in Subsection 2.2 above.
- 6.2. Compaction acceptance for the bias update lots shall be based on cores.

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- 6.3. The day's production will be divided into lots according to the procedures as defined in Subsection S-401.02.6.4 of the Standard Specifications (for the bias update, a minimum of four lots shall be tested).
- 6.4. A new gauge bias number will be established according to the procedures outlined in Subsection 3.5 above; except, if any of the individual bias values differ from the gauge bias by more than the allowable bias variation given in Table 7-1 above, a new bias update shall be conducted on the next paving day.
- 6.5. The new gauge bias value will be compared to the average of all previous gauge bias value(s) that have met the following criteria.
- 6.6. If the deviation between the new gauge bias value and the average of all previous gauge bias value(s) is less than or equal to the limits in Table 7-2 below, the new gauge bias should be averaged with all previous gauge bias values that have met the above criteria and the new average value shall be used for future density testing on the project.
- 6.7. If the deviation between the new gauge bias value and the average of all previous gauge bias value(s) exceeds the limits in Table 7-2 below, a new bias update shall be conducted on the next paving day. The nuclear gauge shall not be used to accept density on the project until a bias within the above limits can be established or reasons for the variation can be explained. Construction can continue using cores to accept density until the problem with the gauge bias has been corrected. Bias values exceeding the above limits will not be used in calculations for density or average gauge bias values.

Table 7-2
Allowable Variation Between New Gauge Bias Value
and Average of Previous Gauge Bias Values

Average Previous Gauge Bias Values, pcf	Allowable Bias Variation, pcf
-3.0 to -0.1	1.5
0.0 to 3.0	1.5
3.1 to 6.0	3.0

Example

On the seventh day of paving, the Contractor produced 2,400 tons of mixture. The specifications require that the day's production be divided into 6 lots. Total production for the project to date was 10,000 tons. Therefore, a bias update is required on the seventh day of paving. Compaction acceptance for the day will be based on one randomly selected core from each lot. The test results are as follows:

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Lot	Core Density	Nuclear Density	Lot Bias
1	138.7	135.2	3.5
2	137.9	136.0	1.9
3	135.8	133.3	2.5
4	136.2	133.5	2.7
5	134.1	131.0	3.1
6	137.7	135.3	2.4
Average			2.7

Based on the data the gauge bias = 2.7 pcf.

The Allowable Individual Bias Variation (Table 1) = $2.7 \pm 1.5 = 1.2$ to 4.2 pcf.

The results indicate that all test results were within the allowable bias difference.

Next, the bias value just determined (2.7 pcf) is compared to the previous Gauge Bias Values using the procedures in Subsection 6.7 above..

Allowable Gauge Bias Deviation (Table 2) = 1.5 pcf.

The actual deviation between the new gauge bias (2.7 pcf) and the previous average gauge bias (3.0 pcf) is 0.3 pcf. This value is less than the maximum deviation allowed. Therefore, the gauge bias value used for future nuclear gauge testing is the average of 2.7 pcf and 3.0 pcf (all previously acceptable values), which equals 2.9 pcf.

Payment for compaction is calculated using the core test results for the paving day used for updating the bias value.

7. Limits On Daily Compaction

At any time the average daily compaction (the total of the percent compaction for the lots produced in one day divided by the total number of lots for the day) does not meet the minimum percent compaction requirement for 100 percent pay for two consecutive days, the Contractor shall notify the Engineer of proposed changes to the compactive effort. If the average daily compaction does not meet the minimum percent compaction requirement for 100 percent pay for a third consecutive day, the Contractor shall stop production and determine the cause of the problem.

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Example:

The Contractor is producing a mixture that has a 92 percent minimum compaction requirement for 100% payment.

	Compaction Results, percent		
	Day 1	Day 2	Day 3
Lot 1	93.2	92.4	91.8
Lot 2	92.0	91.2	92.2
Lot 3	90.6	90.4	91.7
Lot 4	92.5	92.3	
Lot 5		91.9	
Average	92.1	91.6	91.9

The above results indicate that the Contractor has failed to meet the minimum requirement for average daily compaction for two consecutive days. The Contractor is required to notify the Engineer of proposed changes to the compaction process. If the average percent compaction for the fourth day of production does not equal 92.0 percent or more, the contractor is required to stop production.

8. Procedure For Determining Limits For Removing Lot(s) or Part Thereof Not Allowed To Remain In Place

After determining that the lot compaction is below the lower limit allowed for the mixture to remain in place, proceed to establish limits for removal of this lot or portion thereof as follows:

- 8.1. Establish the limits of portion(s) of the lot to be removed by use of cores. Determine the limits of removal for each core test site location that is less than the minimum allowable percent compaction.
- 8.2. Measure roadway density with cores at fifty foot (50') intervals in each direction from the original test site(s) in the lot until at least two (2) density tests in each direction equal or exceed the minimum allowable compaction. Do not enter into an adjacent lot. The density sites are to be located using the random chart in a transverse direction. If all of the density tests for any of the investigation sites (4 total - two in each direction) exceed the compaction criteria for removal, replace the original compaction result with the average of the four new core tests, calculate the pay quantities and do not remove any pavement represented by that site.

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- 8.3. The area of removal is defined as the full lane width between the first of the two consecutive readings in each direction from the test that equaled or exceeded the minimum compaction requirement. Based on the procedure in Subsection 8.2 above, the minimum possible area of removal will be 150' long by the full lane width.

Example:

The average core compaction results for Lot 1 was 89.8 percent which requires that the mixture be removed and replaced at no additional cost to the project. To determine the limit of the removal, evaluate the percent compaction for each test site. The results show that the percent compaction at test site 1 was 90.2 and 89.4 at test site 2. Because the results at site 1 exceed the compaction criteria for removal, only evaluate site 2 using the above procedures.

9. Procedure For Re-Evaluating Corrected Lot

When removal is required and the limits for removal have been determined as outlined in Section 8 above, the replacement shall be made in accordance with the specifications. After the replacement is completed, the replacement area and the non-removal part of the lot requiring replacement will be divided into two separate lots and evaluated for percent compaction. For the replacement lot, take two randomly located nuclear gauge readings and calculate compaction according to the above procedures. For the non-replacement lot, use the average of the original test results from the lot for the test site(s) that were not removed and the two core density tests results (one on either side of the removal area) for each removal area in the lot to calculate payment. **NOTE:** If the original lot had one removal area, then the non-removal area would be evaluated based on the average of the remaining original core density test site(s) and the two core density test results (one on either side of the removal area). If the original lot had two or more removal areas, then the non-removal area would be evaluated using the average of the core density tests taken outside the removal areas (one on each side of each removal area) and the core results for any of the original core sites that were not removed.