MoDOT
TSR QC/QA
TRAINING/CERTIFICATION
COURSE

Missouri University of Science & Technology

Department of Civil, Architectural, and Environmental Engineering

9-21-06
1-29-07, 11-9-07
4-24-08
5-13-09, 5-14-09, 11-18-09
11-11-10
1-17-11
1-23-15, 4-22-15
1-9-17
1-17-18
1-8-19
2-19-19

TSR
CERTIFICATION COURSE
2019-2020

<table>
<tr><th>Time</th><th>Module</th><th>Location</th><th>Topic</th><th>Instructor</th></tr>
<tr><td>8:00-8:15</td><td>Intro</td><td>Lecture</td><td>Intro/welcome</td><td>Richardson</td></tr>
<tr><td>8:15-9:45
9:45-11:15</td><td></td><td>Lecture/
HW</td><td>TSR</td><td>Richardson</td></tr>
<tr><td>11:15-11:35</td><td></td><td>Lab</td><td>Lab demo:
• Shipping Sample
• TSR test
Hands-on practice</td><td>Lusher</td></tr>
<tr><td>11:35-12:05</td><td></td><td></td><td>Lunch on your own</td><td></td></tr>
<tr><td>12:05-1:30</td><td></td><td>Lecture</td><td>Written Exam</td><td>Richardson</td></tr>
<tr><td colspan="5">Once written exam is complete, the attendee can start their proficiency exam. Proficiency exam proctor will be on duty until all attendees have finished their proficiency exam.</td></tr>
<tr><td>?-Until all have finished</td><td></td><td>Lab</td><td>Proficiency Exam</td><td>Lusher</td></tr>
</table>

MoDOT
TSR QC/QA
TRAINING/CERTIFICATION
COURSE

Missouri University of Science & Technology

Department of Civil, Architectural, and Environmental Engineering

9-21-06
1-29-07, 11-9-07
4-24-08
5-13-09, 5-14-09, 11-18-09
11-11-10
1-17-11
1-23-15, 4-22-15
1-9-17
1-17-18
1-8-19
2-19-19

AASHTO T283 Tensile Strength Ratio (TSR)

Resistance of Compacted Asphalt Mixtures to Moisture-Induced Damage

SCOPE

- ***Background***
- TSR Role in QC/QA
- Sampling
- Test procedure
- Field verification

3

Prereqisite Course

- Superpave QC/QA

4

Loss of Strength in a Wet Condition

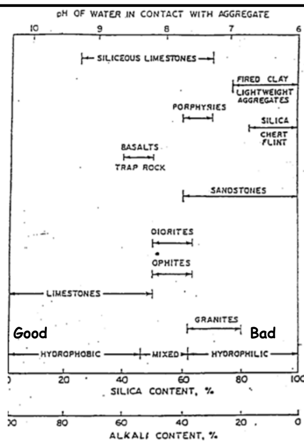
- Synonyms:
  - Moisture sensitivity
  - Moisture susceptibility
  - Stripping
- Main issue is the aggregate
- Loss of bond between aggregate surface and the binder

5

Tests & Specifications to Reduce Stripping

MATERIAL	PROPERTY	TEST/ CALCULATION
Aggregate	Cleanliness	Sand Equivalent; PI; minus#200; deletereous materials
Aggregate	Texture	Fract. Face Count; FA part. Shape
Aggregate	Absorption	Absorption
Aggregate	Affinity for AC	TSR
Mix	permeability	Air voids

6



7

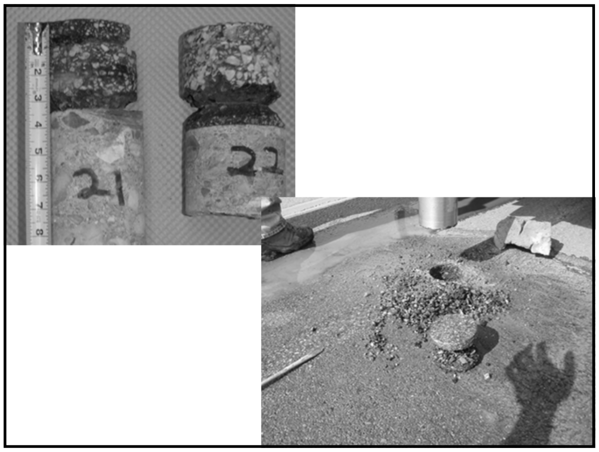
Why are we concerned with Moisture Sensitivity?

- Stripping will result if the bond is broken between the asphalt cement and aggregate.
  - Resulting in pavement:
    - Rutting
    - Shoving
    - Raveling
    - Cracking

8

MOISTURE DAMAGE (STRIPPING)

9



AASHTO TEST METHODS & SPECIFICATIONS

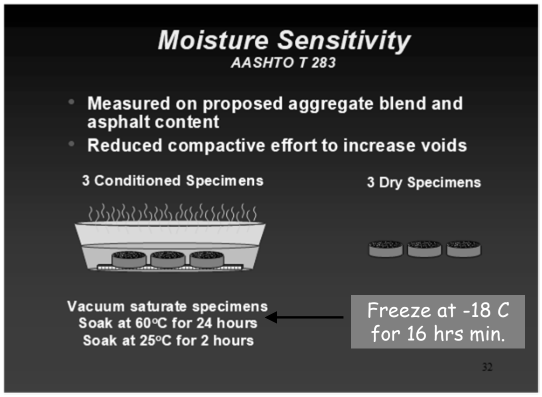
- R35 Volumetric Design Practice
- M323 Volumetric Design Specs
- R30 Mix Conditioning
- T 312 Gyro operation
- T 166 Bulk Sp Gravity of gyro pucks
- T 209 Max Sp Gravity of Voidless Mix (Rice)
- ***T 283 Moisture Sensitivity***
- ***R 47 HMA Sample Splitting***
- ***D 3549 Thickness of Specimens***

11

What is Tensile Strength Ratio?

- Moisture Sensitivity of Asphalt Mixtures
- Affects the structural integrity of a mixture.
- Based on the ratio of the tensile strength of a set of conditioned to a set of unconditioned specimens expressed as a %.

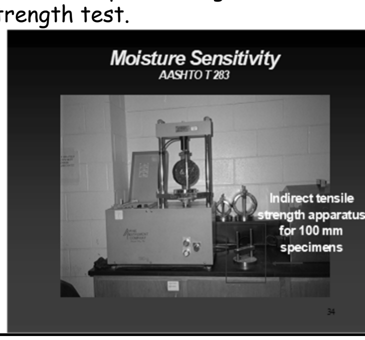
12



13

TSR METHOD

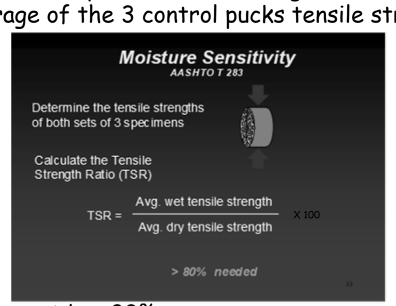
- Test the 3 unconditioned pucks and the 3 conditioned pucks using the indirect tensile strength test.



14

TSR Method

- Calculate the ratio of the average of the 3 conditioned pucks tensile strength to the average of the 3 control pucks tensile strength.



- TSR must be >80%

15

TYPICAL TEST RESULTS

- Range in initial mix design: 40-95+ %

16

MOISTURE SENSITIVITY

- Run T 283, the Tensile Strength Ratio test using the final aggregate structure and at the design binder content.

17

SCOPE

- Background
- ***TSR Role in QC/QA***

18

TSR Role

- ***Mix design/acceptance***
- Field Verification of mix

19

Non-Moisture Sensitive

- The intent is for Superpave and Plant mix be ***non-moisture-sensitive***
  - Superpave- ***must*** be proven through TSR testing
  - Plant mix- ***may*** be required to be proven through TSR testing

20

Section 401: BB and BP Mixes

- 401.2.1 (Standard Spec): During mix design, TSR required when PI exceeds 3 for any individual aggregate fraction with 10% or more passing the #30 sieve
- 401.9 (Standard Spec): During production QA checks PI once per project: if for an individual aggregate fraction the PI > 2 points above mix design value, TSR is required

21

Section 401: BB and BP Mixes, cont'd.

- Engineering Policy Guide 401.2.3: Additional TSR testing is warranted if: in the field, if the PI of the fine aggregate fractions has significantly increased or the overall quality of the aggregate has changed

- If a source has a history of stripping, MoDOT may require TSR testing during design and/or production

22

MIX DESIGN ACCEPTANCE

- TSR ≥ 70% for ***BB and BP*** mixes
- TSR > 80% for ***Superpave*** mixes

23

TSR Role

- Mix design/acceptance
- ***Field Verification of mix***

24

SUPERPAVE TSR PAY ADJUSTMENT

TSR	% of Contract price
≥90	103
75-89	100
70-74	98
65-69	97
<65	Remove

25

SCOPE

- Background
- TSR Role in QC/QA
- ***Sampling***

26

Sampling Field TSR QC/QA

- During production, loose mix samples will be taken and quartered as described in EPG Section 403.1.5
- QC has the option of taking loose mix samples from any point in the production process.
- QA samples should be taken from the same point as the QC, although not at the same time

27

LOOSE MIX: TSR Sample

- QC: 1 per 10,000 tons
- QA: 1 per 50,000 tons or one per mix (combination of projects)

[contract with several projects with same mix, totaling < 50,000 tons]

- Random locations by spec (per EPG: not enforced)

28

SAMPLING: QC

- QC gets their own TSR sample plus a retained sample for QA
- Depth: full depth of the course (if roadway sample)

29

SAMPLING: QA

- QA gets their own "independent" ~250 lb sample, retain 125 lbs

30

LOOSE MIX SAMPLING LOCATION

- *ROADWAY**
- *PLANT DISCHARGE**
- *TRUCK*

** Preferred*

31

TSR Sampling-Roadway

32

CAUTION

- Filling one bucket at a time may render different characteristics bucket-to-bucket---better to place one shovelful per bucket at a time
- Should recombine and quarter

33

TSR SAMPLING
Roadway

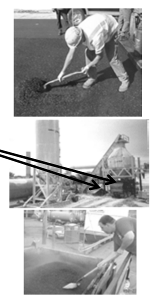
- Profiler issues?
- Big hole to fill

34

LOOSE MIX SAMPLING LOCATION

- ***ROADWAY****
- ***PLANT DISCHARGE****
- ***TRUCK***

**** Preferred***



35

PLANT DISCHARGE

36

PLANT DISCHARGE
(Chop Gate-Diverter Chute)

- Divert entire production stream from drum to a loader bucket


- Sample all across the loader bucket, one shovel per box , all boxes
- Repeat until boxes are full
- Cool (beware of dust)
- Close boxes

37

PLANT DISCHARGE
(Chop Gate-Diverter Chute), cont'd.

- Re-heat material
- Mix all boxes
- Quarter with templates
- Remove quarters to 4 buckets
- Quarter each bucket
- Pull one puck from each quarter

38

TSR SAMPLING
DIVERTER CHUTE

- Contamination issues from diesel used to clean the area

39

LOOSE MIX SAMPLING LOCATION

- ***ROADWAY****
- ***PLANT DISCHARGE****
- ***TRUCK***

**** Preferred***



40

"Mini-stockpile"

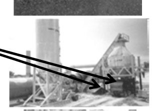
- About 2 tons sampled from silo discharge into a truck
- Dumped
- Back dragged
- Sampled into, say, 4 buckets or boxes
- Back at lab, material is combined, mixed, and quartered , combined into 2 piles
- 4 pucks sampled from each pile


41

LOOSE MIX SAMPLING LOCATION

- ***ROADWAY****
- ***PLANT DISCHARGE****
- ***TRUCK***

**** Preferred***


42

Truck Sampling

43

Truck Sampling

CAUTION

- Possible segregation in truck bed
- Sampling methods (eg. length of arms) limit the position of sampling in the truck bed→ non-representative sample
- Safety issues
- Don't leave sample boxes uncovered at this location—may get contaminated with dust and overspray of release agent

45

QUARTERING THE SAMPLE

46

AASHTO R47

- Quartering templates

- Quartering

- "Quartermaster"

- Riffle splitters

- Incremental (loaf)

47

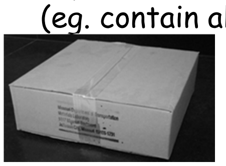
QUARTERMASTER

48

49

QA TSR Sample

- QA inspector will box up 125 lbs loose mix sample and ship to the Central Lab for testing
- Each box should contain as representative a sample as possible (eg. contain all fines, etc)



50

QA TSR Sample, cont'd.

- Central Lab will determine the TSR puck weight to be used from testing one of the boxes
- Central Lab will combine the remaining boxes and go through the splitting procedure
- If boxes are filled one-at-a-time in the field, then the first box may not be the same as the other 3
- So, field tech needs to know how "Central Lab" will handle (combine) the boxes

51

QA TSR Sample

- Field QA should also retain a 125 lb sample ***(Do not send to Central Lab unless asked for. Discard only after issues of favorable comparison between QC and QA have been determined)***

52

TSR BOX INFO

- Site Manager ID number
- Mix number
- G_{mm} from sublot taken (QC or QA)
- Specimen weight QC is using

53

SCOPE

- Background
- TSR Role in QC/QA
- Sampling
- ***Test procedure***

54

TSR FIELD TEST PROCEDURE

- Determine TSR puck weights
- Compact pucks, run specific gravity
- Run Rice specific gravity
- Calculate air voids
- Break dry pucks
- Condition wet pucks
- Break wet pucks
- Calculate TSR
- Inspect conditioned pucks

55

EQUIPMENT

- Gyratory compactor & 150 mm diameter molds (section 403)
- Oven: room temperature up to 176 ±3 °C
- Balance
- Rice specific gravity equipment

56

EQUIPMENT, cont'd.

- Water bath at 25 ± 0.5 °C
- Water bath at 60 ± 1 °C
- Plastic bags
- Cling film

57

EQUIPMENT, cont'd.

- Vacuum dessicator
- Vacuum pump @ up to 26" mercury
- Timer
- Damp towel

58

EQUIPMENT, cont'd.

- 10 ml graduated cylinder
- Freezer @ -18 ± 3 °C
- Load frame (2 in per min movement)
- Indirect tensile strength breaking head

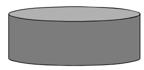
59

ESTIMATING TSR PUCK MASS

60

ESTIMATE TSR PUCK MASS

- Enough to fill a cylinder 150 mm diameter and 95 mm height
- Less 7.0% air voids
- Less side dimples



- The calculation of required mass will be a starting point---experience will fine-tune the actual mass required

61

ESTIMATE TSR PUCK MASS

- V_{solids} = (Mass)/(sp grav)
- $V_{air} = V_{total} - V_{solids}$
- Mix is constantly changing:
  - Bin % changes
  - Exact %'s of each material is changing
  - Each material has a different specific gravity
- So, volumes of each material are changing
- So, puck mix mass must change to keep 7.0% air voids constant

62

ESTIMATE TSR PUCK MASS

- The following slides present one method for determining mass of puck to result in 7.0% air voids & 95 ± 5 mm tall. The method is not mandatory
- There may be equally useful methods

63

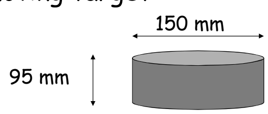
ESTIMATE TSR PUCK MASS

- Do a weight-volume calculation to get initial mass
- Adjust via the most recent puck history (say, using volumetric pucks)
- Fine-tune with experience

64

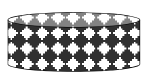
ESTIMATE TSR PUCK MASS

Moving target:



Mass to get 7.0% air voids

But…character of the dimples changes:



So, adjust mass according to how the mix is behaving (info from other compacted pucks)

65

CALCULATION OF MASS REQUIRED FOR 7.0% AIR VOIDS Step # 1

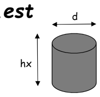
- From historical test data of QC or QA volumetric pucks, average several G_{mb} values appropriate for the TSR sampled mat area: $\boldsymbol{G_{mb,meas}}$
- Average the mass ($\boldsymbol{M_{meas}}$) of each of the G_{mb} pucks
- Average the puck height (from gyro printout) h @ N_{des} ($\boldsymbol{h_x}$) of each of the G_{mb} pucks

h_x in "cm" for historical pucks (usually 11.5±0.5 cm)

66

$G_{mb,est}$
Step #2

- Next, compute the G_{mb} as if there were no side voids (dimples) = $\boldsymbol{G_{mb,est}}$
- $Gmb, estimated = \frac{Avg.Mmeas}{\left(\frac{\pi d^2 (avg\ h_x)}{4}\right)}$



- Thus, for the same mass, the volume will be larger for $\boldsymbol{G_{mb,est}}$, and so $\boldsymbol{G_{mb,est}}$ will be smaller

(Same mass spread over a larger volume)

- So, $\boldsymbol{G_{mb,meas}}$ will be > $\boldsymbol{G_{mb,est}}$

67

CALCULATION of "C" Factor for Historical Pucks-Step#3

- Calculate "***C*** "

Step #1

$$C = \frac{Gmb(measured)}{Gmb(estimated)} + experience$$

Step #2

- $C > 1.0$
- "experience" may be adding ~10g to account for material loss
- Apply "*C*" to TSR pucks

68

CALCULATION OF MASS REQUIRED FOR 7.0% AIR VOIDS Step #4

- Obtain $\boldsymbol{G_{mm}}$ for the sampled roadway mat area
- $V_{air} = \frac{100(G_{mm} - G_{mb})}{G_{mm}}$

69

CAUTION

- The G_{mm} needs to be representative- if not, the computed air voids will be wrong

70

CALCULATION OF MASS REQUIRED FOR 7.0% AIR VOIDS in TSR Puck
Step #4, cont'd.

- Calculate the required puck **_mass_** for 7.0% air voids (mass = Vol x Sp Grav)
- $$\text{Mass} = \frac{[(0.93)(\pi)(d^2/4)(h)](Gmm)}{C}$$

h = 9.5 cm for TSR pucks

71

Alternate Equation
Step #4, cont'd.

- If d=15.0 cm and h= 9.5 cm:
- $Mass = \frac{1561.2\ Gmm}{C}$

72

Example TSR Mass
Using 3 Volumetric Pucks

QCQA\TSRmassEstimate.xls

TSR PUCK MASS ESTIMATION

Job No.		Mix Type	
Route		Formations	
County		Ledges	
Contractor		Binder Type	
Date		Binder Amount, %	

Gyro Puck Information:

Specimen	1	2	3	4	Avg
Mmeas(g)	4601.7	4598	4600.3		4600.0
Gmb,meas	2.321	2.314	2.325		2.320
h, Ndes(mm)	114.3	114.6	114.5		114.5

Step #1

Mmeas,avg	diam,avg(cm)	h,Ndes(cm)	Gmb,est	Gmb,meas.avg	C	Gmm
4600.0	15.0	11.45	2.273	2.320	1.020	2.427

pi 3.141592654

	Mass(g)
Theoretical mass	3713
Additional material	
Other adjustments	
Total mass	3713

Historical volumetric pucks

Step #3:
C = (Gmb,meas.avg) / (Gmb,est)

Step #2:
Gmb,est= (Mmeas,avg) / [(pi)*(d^2)*(h,Ndes) / 4]

TSR puck

Step #4:
Mass = (0.93)*[(pi)*(d^2)*(9.5)] / 4]*(Gmm) / C

73

RUNNING THE TSR TEST

74

DURING MIX DESIGN
In Addition to Field Verification Steps (One extra day for lab mix at front end)

- Mixture prepared in lab
- After mixing, place mixture in a pan (one specimen per pan) and cool at room temperature for 2.0 ± 0.5 hrs
- Place in oven on perforated shelf (or on spacers) at 60±3° C for 16 ± 1 hrs

75

Example TSR Mass
Using 3 Volumetric Pucks

QCQA\TSRmassEstimate.xls — **TSR PUCK MASS ESTIMATION**

Job No.		Mix Type	
Route		Formations	
County		Ledges	
Contractor		Binder Type	
Date		Binder Amount, %	

Gyro Puck Information:

Specimen	**1**	**2**	**3**	**4**	**Avg**
Mmeas(g)	4601.7	4598	4600.3		4600.0
Gmb,meas	2.321	2.314	2.325		2.320
h, Ndes(mm)	114.3	114.6	114.5		114.5

Step #1

Mmeas,avg	**diam,avg(cm)**	**h,Ndes(cm)**	**Gmb,est**	**Gmb,meas.avg**	**C**	**Gmm**
4600.0	15.0	11.45	2.273	2.320	1.020	2.427

pi 3.141592654

	Mass(g)
Theoretical mass	3713
Additional material	
Other adjustments	
Total mass	**3713**

Historical volumetric pucks

Step #3:
C= (Gmb,meas.avg) / (Gmb,est)

Step #2:
Gmb,est= (Mmeas,avg) / [(pi)*(d^2)*(h,Ndes) / 4]

Step #4:
TSR puck Mass= (0.93)*[(pi)*(d^2)*(9.5)] / 4]*(Gmm) / C

PROCEDURE

- The following slides relate to TSR testing of ***field*** samples and to ***lab-mixed*** samples after the first day

76

DAILY PROCEDURE-Outline

- Day 1:
  - Sample, quarter, heat to JMF compaction temperature ± 3°C ***[for lab-mixed, heating time is 2 hr ± 10 min.]***
  - Compact pucks, store at room temperature 24±3hr
  - Run Rice gravity
- Day 2:
  - Determine G_{mb} of pucks
  - Calculate air voids
  - Group into two sets of 3
  - Saturate the Wet set
  - Put Wet set into freezer (16+ hr)
  - Start air drying of Dry set (24±3hr)

77

DAILY PROCEDURE Outline, cont'd.

- Day 3:
  - Test strength of Dry set
  - Start high temperature conditioning of Wet set
- Day 4:
  - Test strength of Wet set
  - Calculate TSR

78

TEST PROCEDURE: Day 1

- Warm the mix to soften it for quartering, then quarter
- Reheat the mix to compaction temperature ± 3 °C (lab mix: 2 hr ± 10 min.)
- Compact: use sufficient mix to achieve 7.0 ± 0.5% air voids in a 95 ± 5 mm tall puck
  - Note: SMA mixes require 6.0±0.5% air voids
- Determine Rice gravity (G_{mm})

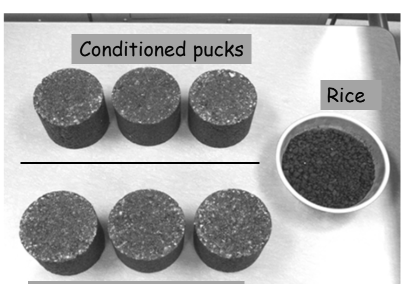
[must be representative of TSR mix]

DAY 1

- Set gyro to "Height control" mode
- Compact 6+ pucks (actually, will make 1 or more trial pucks; may also wish to compact several extra pucks)
- Store at room temperature for 24 ± 3 hrs.

80

TSR



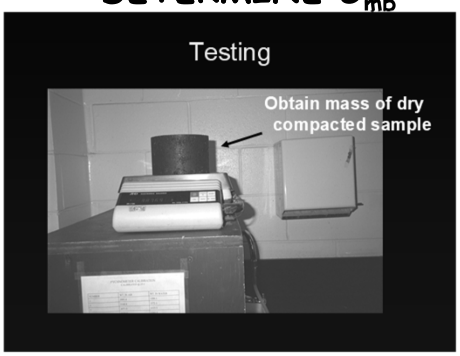
81

DAY 2: Determine Air Voids

- Determine G_{mb} for all 6+ pucks (follow T166—thus, pucks need to be tested at 25±1° C)

82

DETERMINE G_{mb}



83

AASHTO T-283 T-283 Rev3-24-04Example.xls

Mix Number: Example | Gmm = 2.476

Gmb Worksheet		Dry Subset		Wet Subset			
Specimen #	1	2	3	4	5	6	
Weight in air (g) [A]	3725.8	3749.7	3755.1	3822.4	3759.7	3692.3	
SSD Weight (g) [B]	3735.6	3761.0	3765.0	3833.5	3770.7	3707.9	
Weight in water (g) [C]	2114.3	2135.9	2140.2	2180.0	2144.3	2094.9	
Height (0.1 cm) [t]	9.5	9.5	9.5	9.7	9.5	9.5	
Volume (cm^3) [B - C]	1621	1625	1625	1654	1626		[B-C]
Gmb [A / (B - C)]	2.298	2.307	2.311	2.312	2.312		A/[B-C]
% Air Voids [Pa]	7.2	6.8	6.7	6.6	6.6		100[Gmm-Gmb]/Gmm
Dry volume of air (cm^3)[Va]	117	111	108	110	108		Pa[B-C]/100
Average % Air Voids	Dry	6.9		Wet			
Overall							

TSR Worksheet		Dry Subset		Wet Subset			
Specimen #	1	2	3	4	5	6	
Height (0.1 cm) [t]	9.5	9.5	9.5	9.7	9.5	9.5	
Max. Load (lbs) [P]	3852	3601	3761	1564	1517	1197	
Ind. Tens. Str.: ITS (psi)*	111	104	108	44	44		6.4516*2P/3.1415tD
* For 15.0 cm diameter specimen[D]		Vacuum SSD Wt. (g)[B']		3902.9	3846.0	3787.3	
Avg. Wet ITS (psi)[Swet]		Weight in air (g)[A]		3822.4	3759.7		
Avg. Dry ITS (psi)[Sdry]	108	Vol. Absorb H_2O (cm^3)[J']		81	86		B'-A
TSR (%)[100Swet/Sdry]		Dry volume of air (cm^3)[Va]		110	108		
		70% Sat. (Target VSSD)		3899	3835		A+0.7Va
	AVG	80% Sat. (Target VSSD)		3910	3846		A+0.8Va
Air Voids (%)		% Saturation		73	80		100J'/Va
Dry Subset %Air	6.9		in. Hg	22	23	23	
Wet Subset %Air			Time (min)	8	8	8	
Saturation (%)			in. Hg	25	26	24	
			Time (min)	1	1	1	

	Dry Subset		
Time in 25 C waterbath (2 hrs ± 10 min)	1h 50m	1h 55m	2h

NOTE: Shaded cells indicate cells needing input values

	Wet Subset		
Time in Freezer (Minimum 16 hrs)	19h 44m	19h 16m	18h 54m
Time in 60 C waterbath (24 ± 1 hrs)	23h 30m	23h 30m	23h 30m

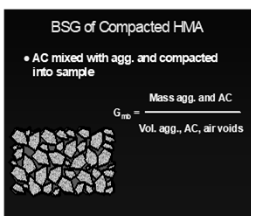
Test Time	12/22/2003 5:25 PM	12/22/2003 5:30 PM	12/22/2003 5:35 PM	12/22/2003 4:20 PM	12/22/2003 4:25 PM	12/22/2003 4:30 PM

85

Puck Bulk Specific Gravity

From Example Spreadsheet Spec #1

$$G_{mb} = \frac{A}{B - C}$$



$$G_{mb} = \frac{3725.8}{3735.6 - 2114.3}$$

G_{mb} = ***2.298***

86

AIR VOIDS

- $P_a = \dfrac{G_{mm} - G_{mb}}{G_{mm}} \times 100$
- P_a = % air voids
- G_{mm}=maximum specific gravity of the voidless mix (Rice sp gravity)
- G_{mb}= sp. gravity of the compacted mix

87

AASHTO T-283 T-283 Rev3-24-04Example.xls

Mix Number	Example					Gmm =	2.476
Gmb Worksheet		Dry Subset		Wet Subset			
Specimen #	1	2	3	4	5	6	
Weight in air (g) [A]	3725.8	3749.7	3755.1	3822.4	3759.7	3692.3	
SSD Weight (g) [B]	3735.6	3761.0	3765.0	3833.5	3770.7	3707.9	
Weight in water (g) [C]	2114.3	2135.9	2140.2	2180.0	2144.3	2094.9	
Height (0.1 cm) [t]	9.5	9.5	9.5	9.7	9.5	9.5	
Volume (cm^3) [B - C]	1621	1625	1625	1654	1626		[B-C]
Gmb [A / (B - C)]	2.298	2.307	2.311	2.312	2.312		A/[B-C]
% Air Voids [Pa]	7.2	6.8	6.7	6.6	6.6		100[Gmm-Gmb]/Gmm
Dry volume of air (cm^3)[Va]	117	111	108	110	108		Pa[B-C]/100
Average % Air Voids	Dry	6.9		Wet			
Overall							

TSR Worksheet	Dry Subset			Wet Subset			
Specimen #	1	2	3	4	5	6	
Height (0.1 cm) [t]	9.5	9.5	9.5	9.7	9.5	9.5	
Max. Load (lbs) [P]	3852	3601	3761	1564	1517	1197	
Ind. Tens. Str.:ITS (psi)*	111	104	108	44	44		6.4516*2P/3.1415tD
* For 15.0 cm diameter specimen[D]		Vacuum SSD Wt. (g)[B']		3902.9	3846.0	3787.3	
Avg. Wet ITS (psi)[Swet]		Weight in air (g)[A]		3822.4	3759.7		
Avg. Dry ITS (psi)[Sdry]	108	Vol. Absorb H_2O (cm^3)[J']		81	86		B'-A
TSR (%)[100Swet/Sdry]		Dry volume of air (cm^3)[Va]		110	108		
		70% Sat. (Target VSSD)		3899	3835		A+0.7Va
	AVG	80% Sat. (Target VSSD)		3910	3846		A+0.8Va
Air Voids (%)		% Saturation		73	80		100J'/Va
Dry Subset %Air	6.9		in. Hg	22	23	23	
Wet Subset %Air			Time (min)	8	8	8	
Saturation (%)			in. Hg	25	26	24	
			Time (min)	1	1	1	

	Dry Subset		
Time in 25 C waterbath (2 hrs ± 10 min)	1h 50m	1h 55m	2h

NOTE: Shaded cells indicate cells needing input values

	Wet Subset		
Time in Freezer (Minimum 16 hrs)	19h 44m	19h 16m	18h 54m
Time in 60 C waterbath (24 ± 1 hrs)	23h 30m	23h 30m	23h 30m

Test Time	12/22/2003 5:25 PM	12/22/2003 5:30 PM	12/22/2003 5:35 PM	12/22/2003 4:20 PM	12/22/2003 4:25 PM	12/22/2003 4:30 PM

DETERMINE %AIR VOIDS

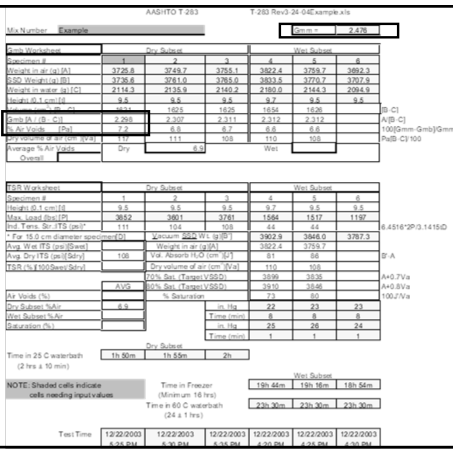
From Example Spreadsheet Spec #1

- Having tested Rice, calculate air voids of each puck:

$$P_a = \frac{G_{mm} - G_{mb}}{G_{mm}} \times 100$$

$$Pa = \frac{2.476 - 2.298}{2.476} \times 100 = \mathbf{7.2\ \%}$$

88



AASHTO T-283 T-283 Rev3-24-04Example.xls

Mix Number: Example Gmm = 2.476

Gmb Worksheet	Dry Subset			Wet Subset			
Specimen #	1	2	3	4	5	6	
Weight in air (g) [A]	3725.8	3749.7	3755.1	3822.4	3759.7	3692.3	
SSD Weight (g) [B]	3735.6	3761.0	3765.0	3833.5	3770.7	3707.9	
Weight in water (g) [C]	2114.3	2135.9	2140.2	2180.0	2144.3	2094.9	
Height (0.1 cm) [t]	9.5	9.5	9.5	9.7	9.5	9.5	
Volume (cm³) [B - C]	1621	1625	1625	1654	1626		[B-C]
Gmb [A / (B - C)]	2.298	2.307	2.311	2.312	2.312		A/[B-C]
% Air Voids [Pa]	7.2	6.8	6.7	6.6	6.6		100[Gmm-Gmb]/Gmm
Dry volume of air (cm³)[Va]	117	111	108	110	108		Pa[B-C]/100
Average % Air Voids	Dry	6.9		Wet			
Overall							

TSR Worksheet	Dry Subset			Wet Subset			
Specimen #	1	2	3	4	5	6	
Height (0.1 cm) [t]	9.5	9.5	9.5	9.7	9.5	9.5	
Max. Load (lbs) [P]	3852	3601	3761	1564	1517	1197	
Ind. Tens. Str.:ITS (psi)*	111	104	108	44	44		6.4516*2P/3.1415tD
* For 15.0 cm diameter specimen[D]		Vacuum SSD Wt. (g)[B']		3902.9	3846.0	3787.3	
Avg. Wet ITS (psi)[Swet]		Weight in air (g)[A]		3822.4	3759.7		
Avg. Dry ITS (psi)[Sdry]	108	Vol. Absorb H_2O (cm³)[J']		81	86		B'-A
TSR (%)[100Swet/Sdry]		Dry volume of air (cm³)[Va]		110	108		
		70% Sat. (Target VSSD)		3899	3835		A+0.7Va
	AVG	80% Sat. (Target VSSD)		3910	3846		A+0.8Va
Air Voids (%)		% Saturation		73	80		100J'/Va
Dry Subset %Air	6.9		in. Hg	22	23	23	
Wet Subset %Air			Time (min)	8	8	8	
Saturation (%)			in. Hg	25	26	24	
			Time (min)	1	1	1	

	Dry Subset		
Time in 25 C waterbath (2 hrs ± 10 min)	1h 50m	1h 55m	2h

NOTE: Shaded cells indicate cells needing input values

	Wet Subset		
Time in Freezer (Minimum 16 hrs)	19h 44m	19h 16m	18h 54m
Time in 60 C waterbath (24 ± 1 hrs)	23h 30m	23h 30m	23h 30m

Test Time	12/22/2003 5:25 PM	12/22/2003 5:30 PM	12/22/2003 5:35 PM	12/22/2003 4:20 PM	12/22/2003 4:25 PM	12/22/2003 4:30 PM

89

AIR VOIDS 2 SIMILAR GROUPS "Wet" and "Dry"

- Group the pucks into 2 groups such that average air voids of each group is about equal
- $P_{a,\,avg} = \frac{P_{a1} + P_{a2} + P_{a3}}{3}$
- Testing pucks at extreme end of allowable voids may lead to poor QC/QA comparison

90

Mix Number: Example

Gmm = 2.476

Gmb Worksheet	Dry Subset			Wet Subset			
Specimen #	1	2	3	4	5	6	
Weight in air (g) [A]	3725.8	3749.7	3755.1	3822.4	3759.7	3692.3	
SSD Weight (g) [B]	3735.6	3761.0	3765.0	3833.5	3770.7	3707.9	
Weight in water (g) [C]	2114.3	2135.9	2140.2	2180.0	2144.3	2094.9	
Height (0.1 cm) [t]	9.5	9.5	9.5	9.7	9.5	9.5	
Volume (cm^3) [B - C]	1621	1625	1625	1654	1626		[B-C]
Gmb [A / (B - C)]	2.298	2.307	2.311	2.312	2.312		A/[B-C]
% Air Voids [Pa]	7.2	6.8	6.7	6.6	6.6		100[Gmm-Gmb]/Gmm
Dry volume of air (cm^3)[Va]	117	111	108	110	108		Pa[B-C]/100
Average % Air Voids	Dry	6.9		Wet			
Overall							

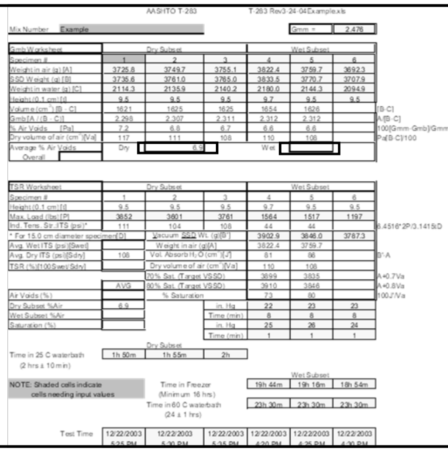
TSR Worksheet	Dry Subset			Wet Subset			
Specimen #	1	2	3	4	5	6	
Height (0.1 cm) [t]	9.5	9.5	9.5	9.7	9.5	9.5	
Max. Load (lbs) [P]	3852	3601	3761	1564	1517	1197	
Ind. Tens. Str.:ITS (psi)*	111	104	108	44	44		6.4516*2P/3.1415tD
* For 15.0 cm diameter specimen[D]		Vacuum SSD Wt. (g)[B']		3902.9	3846.0	3787.3	
Avg. Wet ITS (psi)[Swet]		Weight in air (g)[A]		3822.4	3759.7		
Avg. Dry ITS (psi)[Sdry]	108	Vol. Absorb H_2O (cm^3)[J']		81	86		B'-A
TSR (%)[100Swet/Sdry]		Dry volume of air (cm^3)[Va]		110	108		
		70% Sat. (Target VSSD)		3899	3835		A+0.7Va
	AVG	80% Sat. (Target VSSD)		3910	3846		A+0.8Va
Air Voids (%)		% Saturation		73	80		100J'/Va
Dry Subset %Air	6.9		in. Hg	22	23	23	
Wet Subset %Air			Time (min)	8	8	8	
Saturation (%)			in. Hg	25	26	24	
			Time (min)	1	1	1	

	Dry Subset		
Time in 25 C waterbath (2 hrs ± 10 min)	1h 50m	1h 55m	2h

NOTE: Shaded cells indicate cells needing input values

	Wet Subset		
Time in Freezer (Minimum 16 hrs)	19h 44m	19h 16m	18h 54m
Time in 60 C waterbath (24 ± 1 hrs)	23h 30m	23h 30m	23h 30m

Test Time	12/22/2003 5:25 PM	12/22/2003 5:30 PM	12/22/2003 5:35 PM	12/22/2003 4:20 PM	12/22/2003 4:25 PM	12/22/2003 4:30 PM


AASHTO T-283 T-283 Rev3-24-04Example.xls

Mix Number: Example | Gmm = 2.476

Gmb Worksheet	Dry Subset			Wet Subset			
Specimen #	1	2	3	4	5	6	
Weight in air (g) [A]	3725.8	3749.7	3755.1	3822.4	3759.7	3692.3	
SSD Weight (g) [B]	3735.6	3761.0	3765.0	3833.5	3770.7	3707.9	
Weight in water (g) [C]	2114.3	2135.9	2140.2	2180.0	2144.3	2094.9	
Height (0.1 cm) [t]	9.5	9.5	9.5	9.7	9.5	9.5	
Volume (cm^3) [B - C]	1621	1625	1625	1654	1626		[B-C]
Gmb [A / (B - C)]	2.298	2.307	2.311	2.312	2.312		A/[B-C]
% Air Voids [Pa]	7.2	6.8	6.7	6.6	6.6		100[Gmm-Gmb]/Gmm
Dry volume of air (cm^3)[Va]	117	111	108	110	108		Pa[B-C]/100
Average % Air Voids	Dry	6.9		Wet			
Overall							

TSR Worksheet	Dry Subset			Wet Subset			
Specimen #	1	2	3	4	5	6	
Height (0.1 cm) [t]	9.5	9.5	9.5	9.7	9.5	9.5	
Max. Load (lbs) [P]	3852	3601	3761	1564	1517	1197	
Ind. Tens. Str.: ITS (psi)*	111	104	108	44	44		6.4516*2P/3.1416tD

* For 15.0 cm diameter specimen [D]

Avg. Wet ITS (psi)[Swet]		Vacuum SSD Wt. (g)[B']	3902.9	3846.0	3787.3	
Avg. Dry ITS (psi)[Sdry]	108	Weight in air (g)[A]	3822.4	3759.7		
TSR (%)[100Swet/Sdry]		Vol. Absorb H_2O (cm^3)[J']	81	86		B'-A
		Dry volume of air (cm^3)[Va]	110	108		
		70% Sat. (Target VSSD)	3899	3835		A+0.7Va
	AVG	80% Sat. (Target VSSD)	3910	3846		A+0.8Va
Air Voids (%)		% Saturation	73	80		100J'/Va
Dry Subset %Air	6.9	in. Hg	22	23	23	
Wet Subset %Air		Time (min)	8	8	8	
Saturation (%)		in. Hg	25	26	24	
		Time (min)	1	1	1	

	Dry Subset		
Time in 25 C waterbath (2 hrs ± 10 min)	1h 50m	1h 55m	2h

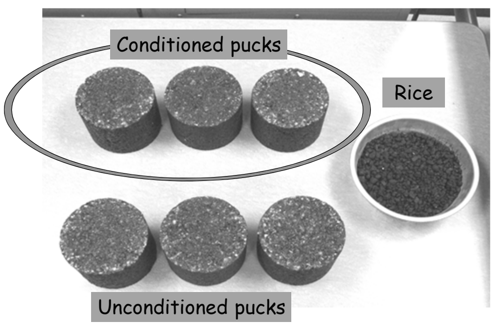
NOTE: Shaded cells indicate cells needing input values

	Wet Subset		
Time in Freezer (Minimum 16 hrs)	19h 44m	19h 16m	18h 54m
Time in 60 C waterbath (24 ± 1 hrs)	23h 30m	23h 30m	23h 30m

Test Time	12/22/2003 5:25 PM	12/22/2003 5:30 PM	12/22/2003 5:35 PM	12/22/2003 4:20 PM	12/22/2003 4:25 PM	12/22/2003 4:30 PM

91

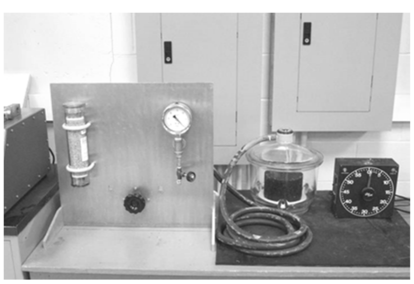
TSR-Conditioned (Wet)



92

Day 2, Cont'd. Wet Pucks

- Overview: Vacuum saturate the 3 other pucks that are to be "conditioned"



93

Mix Number: Example

Gmm = 2.476

Gmb Worksheet	Dry Subset			Wet Subset			
Specimen #	1	2	3	4	5	6	
Weight in air (g) [A]	3725.8	3749.7	3755.1	3822.4	3759.7	3692.3	
SSD Weight (g) [B]	3735.6	3761.0	3765.0	3833.5	3770.7	3707.9	
Weight in water (g) [C]	2114.3	2135.9	2140.2	2180.0	2144.3	2094.9	
Height (0.1 cm) [t]	9.5	9.5	9.5	9.7	9.5	9.5	
Volume (cm^3) [B - C]	1621	1625	1625	1654	1626		[B-C]
Gmb [A / (B - C)]	2.298	2.307	2.311	2.312	2.312		A/[B-C]
% Air Voids [Pa]	7.2	6.8	6.7	6.6	6.6		100[Gmm-Gmb]/Gmm
Dry volume of air (cm^3)[Va]	117	111	108	110	108		Pa[B-C]/100
Average % Air Voids	Dry	6.9		Wet			
Overall							

TSR Worksheet	Dry Subset			Wet Subset			
Specimen #	1	2	3	4	5	6	
Height (0.1 cm) [t]	9.5	9.5	9.5	9.7	9.5	9.5	
Max. Load (lbs) [P]	3852	3601	3761	1564	1517	1197	
Ind. Tens. Str.:ITS (psi)*	111	104	108	44	44		6.4516*2P/3.1415tD

* For 15.0 cm diameter specimen[D]		Vacuum SSD Wt. (g)[B']	3902.9	3846.0	3787.3	
Avg. Wet ITS (psi)[Swet]		Weight in air (g)[A]	3822.4	3759.7		
Avg. Dry ITS (psi)[Sdry]	108	Vol. Absorb H_2O (cm^3)[J']	81	86		B'-A
TSR (%)[100Swet/Sdry]		Dry volume of air (cm^3)[Va]	110	108		
		70% Sat. (Target VSSD)	3899	3835		A+0.7Va
	AVG	80% Sat. (Target VSSD)	3910	3846		A+0.8Va
Air Voids (%)		% Saturation	73	80		100J'/Va
Dry Subset %Air	6.9	in. Hg	22	23	23	
Wet Subset %Air		Time (min)	8	8	8	
Saturation (%)		in. Hg	25	26	24	
		Time (min)	1	1	1	

	Dry Subset		
Time in 25 C waterbath (2 hrs ± 10 min)	1h 50m	1h 55m	2h

NOTE: Shaded cells indicate cells needing input values

	Wet Subset		
Time in Freezer (Minimum 16 hrs)	19h 44m	19h 16m	18h 54m
Time in 60 C waterbath (24 ± 1 hrs)	23h 30m	23h 30m	23h 30m

Test Time						
	12/22/2003 5:25 PM	12/22/2003 5:30 PM	12/22/2003 5:35 PM	12/22/2003 4:20 PM	12/22/2003 4:25 PM	12/22/2003 4:30 PM

VACUUM SATURATION
Wet Pucks

- Permissible range: 70-80%
- Pre-calculate partially saturated puck weights at 70 and 80%
- By iteration, progressively vacuum & weigh at intervals until puck weight is in the permissible weight range

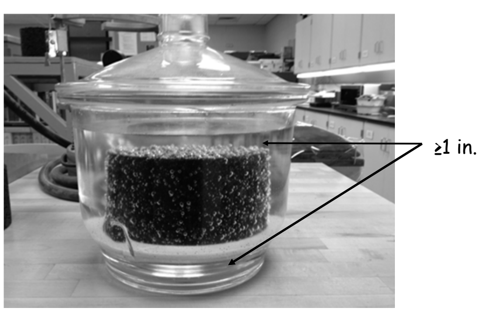
94

Day 2: Wet Pucks

- Determine the surface dry weight.

95

Apply Vacuum



96

VACUUM SATURATION, cont'd.

- Place puck in vacuum chamber and submerge in water (≥ 1" cover and ≥ 1" above chamber bottom)
- Apply 10-26" (suggested 23") mercury vacuum for 5-10 (suggested 8) minutes (it's more important to achieve vacuum than stay within time limits).
- This step is pulling air out of the puck and creating a vacuum inside the puck
- If use high/fast vacuum, may get uneven saturation—poor QC/QA comparison
- Slowly remove vacuum

97

VACUUM SATURATION, cont'd.

- Let puck set in water for 5-10 minutes. During this time, the puck is pulling water in. Don't shortcut this step.
- Remove puck, quickly surface dry with a damp towel

98

Day 2, Cont'd. Wet Pucks

- Determine the saturated surface dry weight (T 166).

If in the 70 -80% saturation weight range, wrap in cling film, place in plastic bag, add 10 ± 0.5 ml water, seal.

- Calculate % saturation

99

Day 2
Calculation of % Saturation
From Example Spreadsheet Spec. #4

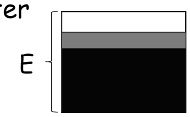
E (puck volume) = B - C

B = puck SSD weight

C = puck weight in water

["B" & "C" from G_{mb} testing]:

E = 3833.5 – 2180.0 = ***1654 cm³***



100

DETERMINE %AIR VOIDS
Specimen #4

- Calculate air voids of each puck:

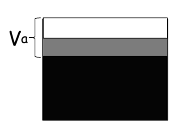
$$P_a = \frac{G_{mm} - G_{mb}}{G_{mm}} \times 100$$

$$Pa = \frac{2.476 - 2.312}{2.476} \times 100 = \mathbf{6.6\ \%}$$

101

Open Voids
Specimen #4

$$Va(volume\ of\ air\ voids) = \frac{(Pa)\ E}{100}$$



- $V_a = \dfrac{(6.6)\ (1654\ cm^3)}{100}$

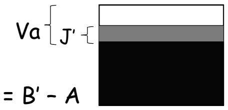
V_a = ***110 cm³***

102

% Saturation

Specimen #4

$$\%Saturation = \frac{100\,J'}{Va}$$



J' (volume of absorbed water) = B' – A

B' = SSD weight after saturation
A = puck dry weight in air ["A" from G_{mb} testing]

J' = 3902.9 – 3822.4 = ***81 cm³***

% Saturation = 100 (81) / 110 = ***73%***

103

AASHTO T-283 T-283 Rev3-24-04Example.xls

Mix Number: Example Gmm = 2.476

Gmb Worksheet	Dry Subset			Wet Subset			
Specimen #	1	2	3	4	5	6	
Weight in air (g) [A]	3725.8	3749.7	3755.1	3822.4	3759.7	3692.3	
SSD Weight (g) [B]	3735.6	3761.0	3765.0	3833.5	3770.7	3707.9	
Weight in water (g) [C]	2114.3	2135.9	2140.2	2180.0	2144.3	2094.9	
Height (0.1 cm) [t]	9.5	9.5	9.5	9.7	9.5	9.5	
Volume (cm³) [B - C]	1621	1625	1625	1654	1626		[B-C]
Gmb [A / (B - C)]	2.298	2.307	2.311	2.312	2.312		A/[B-C]
% Air Voids [Pa]	7.2	6.8	6.7	6.6	6.6		100[Gmm-Gmb]/Gmm
Dry volume of air (cm³)[Va]	117	111	108	110	108		Pa[B-C]/100
Average % Air Voids	Dry	6.9		Wet			
Overall							

TSR Worksheet	Dry Subset			Wet Subset			
Specimen #	1	2	3	4	5	6	
Height (0.1 cm) [t]	9.5	9.5	9.5	9.7	9.5	9.5	
Max. Load (lbs)[P]	3852	3601	3761	1564	1517	1197	
Ind. Tens. Str.: ITS (psi)*	111	104	108	44	44		6.4516*2P/3.1415tD

* For 15.0 cm diameter specimen[D]	
Avg. Wet ITS (psi)[Swet]	
Avg. Dry ITS (psi)[Sdry]	108
TSR (%)[100Swet/Sdry]	
	AVG
Air Voids (%)	
Dry Subset %Air	6.9
Wet Subset %Air	
Saturation (%)	

		4	5	6	
Vacuum SSD Wt. (g)[B']		3902.9	3846.0	3787.3	
Weight in air (g)[A]		3822.4	3759.7		
Vol. Absorb H_2O (cm³)[J']		81	86		B'-A
Dry volume of air (cm³)[Va]		110	108		
70% Sat. (Target VSSD)		3899	3835		A+0.7Va
80% Sat. (Target VSSD)		3910	3846		A+0.8Va
% Saturation		73	80		100J'/Va
	in. Hg	22	23	23	
	Time (min)	8	8	8	
	in. Hg	25	26	24	
	Time (min)	1	1	1	

	Dry Subset		
Time in 25 C waterbath (2 hrs ± 10 min)	1h 50m	1h 55m	2h

NOTE: Shaded cells indicate cells needing input values

	Wet Subset		
Time in Freezer (Minimum 16 hrs)	19h 44m	19h 16m	18h 54m
Time in 60 C waterbath (24 ± 1 hrs)	23h 30m	23h 30m	23h 30m

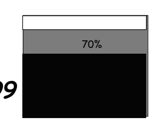
Test Time	12/22/2003 5:25 PM	12/22/2003 5:30 PM	12/22/2003 5:35 PM	12/22/2003 4:20 PM	12/22/2003 4:25 PM	12/22/2003 4:30 PM

104

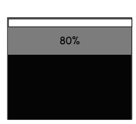
Pre-Determined Weights

Specimen #4

- Note: for water, M ≈ V
- At 70% saturation:
  - $M_{70} = A + 0.7\,(V_a)$
  - M_{70} = 3822.4 + 0.7 (110) = ***3899***



- At 80% saturation:
  - $M_{80} = A + 0.8\,(V_a)$
  - M_{80} = 3822.4 + 0.8 (110) = ***3910** g*



105

AASHTO T-283 T-283 Rev3-24-04Example.xls

Mix Number	Example	Gmm =	2.476

Gmb Worksheet	Dry Subset			Wet Subset			
Specimen #	1	2	3	4	5	6	
Weight in air (g) [A]	3725.8	3749.7	3755.1	3822.4	3759.7	3692.3	
SSD Weight (g) [B]	3735.6	3761.0	3765.0	3833.5	3770.7	3707.9	
Weight in water (g) [C]	2114.3	2135.9	2140.2	2180.0	2144.3	2094.9	
Height (0.1 cm) [t]	9.5	9.5	9.5	9.7	9.5	9.5	
Volume (cm^3) [B - C]	1621	1625	1625	1654	1626		[B-C]
Gmb [A / (B - C)]	2.298	2.307	2.311	2.312	2.312		A/[B-C]
% Air Voids [Pa]	7.2	6.8	6.7	6.6	6.6		100[Gmm-Gmb]/Gmm
Dry volume of air (cm^3)[Va]	117	111	108	110	108		Pa[B-C]/100
Average % Air Voids	Dry	6.9		Wet			
Overall							

TSR Worksheet	Dry Subset			Wet Subset			
Specimen #	1	2	3	4	5	6	
Height (0.1 cm) [t]	9.5	9.5	9.5	9.7	9.5	9.5	
Max. Load (lbs) [P]	3852	3601	3761	1564	1517	1197	
Ind. Tens. Str.:ITS (psi)*	111	104	108	44	44		6.4516*2P/3.1415tD

* For 15.0 cm diameter specimen[D]

Avg. Wet ITS (psi)[Swet]	
Avg. Dry ITS (psi)[Sdry]	108
TSR (%)[100Swet/Sdry]	
	AVG
Air Voids (%)	
Dry Subset %Air	6.9
Wet Subset %Air	
Saturation (%)	

	4	5	6	
Vacuum SSD Wt. (g)[B']	3902.9	3846.0	3787.3	
Weight in air (g)[A]	3822.4	3759.7		
Vol. Absorb H_2O (cm^3)[J']	81	86		B'-A
Dry volume of air (cm^3)[Va]	110	108		
70% Sat. (Target VSSD)	3899	3835		A+0.7Va
80% Sat. (Target VSSD)	3910	3846		A+0.8Va
% Saturation	73	80		100J'/Va
in. Hg	22	23	23	
Time (min)	8	8	8	
in. Hg	25	26	24	
Time (min)	1	1	1	

	Dry Subset		
Time in 25 C waterbath (2 hrs ± 10 min)	1h 50m	1h 55m	2h

NOTE: Shaded cells indicate cells needing input values

	Wet Subset		
Time in Freezer (Minimum 16 hrs)	19h 44m	19h 16m	18h 54m
Time in 60 C waterbath (24 ± 1 hrs)	23h 30m	23h 30m	23h 30m

Test Time	1	2	3	4	5	6
	12/22/2003 5:25 PM	12/22/2003 5:30 PM	12/22/2003 5:35 PM	12/22/2003 4:20 PM	12/22/2003 4:25 PM	12/22/2003 4:30 PM

% SATURATION, Cont.

- If the saturation is less than 70%, re-vacuum at 26" mercury vacuum for 1 minute. Slowly remove vacuum. Let puck set in water for 5-10 minutes (if this is omitted, QA & QC may not compare)
- Check saturation
- Repeat as necessary

- If the saturation is greater than 80%, puck is considered destroyed and must be discarded.

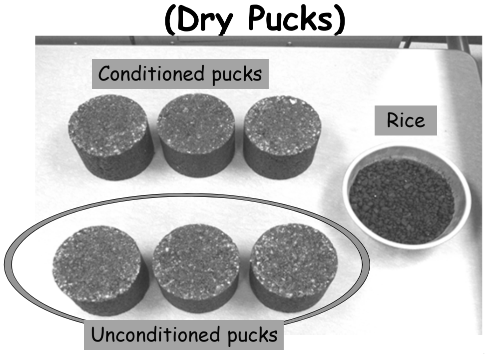
106

DAY 2, Cont'd. Wet Pucks

- When saturation is 70-80%, wrap the pucks in cling film, place in bag with 10cc water, seal, and place in freezer at -18 ± 3 °C for at least 16 hrs. Verify temperature throughout the freezer.
- Do not allow specimens to drain after saturation but prior to freezing

107

TSR-Unconditioned (Dry Pucks)



108

DAY 2
Dry Pucks

- Let the 3 unconditioned pucks air dry at room temperature for 24 ± 3 hrs until Day 3
- CAUTION: If tested damp, this may change indirect tensile strength (and TSR)

109

DAY 3
Dry Pucks

- Bag the 3 unconditioned pucks, place in water bath at 25 ± 0.5 C for 2 hrs ± 10 min. Indirect tensile strength is very sensitive to temperature

110

BAGGING/STANDARD TEMPERATURE PROCEDURE

- Place each "dry" puck into a heavy-duty leak-proof plastic bag
- Submerge in the water bath; pucks covered by at least 1 in. of water. Creation of an air bath with a concrete cylinder mold within the water bath may not give equivalent results
- Remove pucks from water, determine puck thickness (t)

111

DETERMINE THICKNESS (t)

ASTM D3549

- Use a calipers: *dry or wet pucks*
  - average of 4 points around the perimeter
  - Caliper method is more accurate than printout method if puck swells

Or

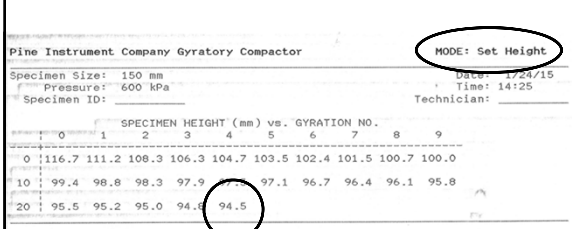
- Use puck height from gyro printout
- *(dry pucks only)*

112

From Gyro Printout

113

From Gyro Printout



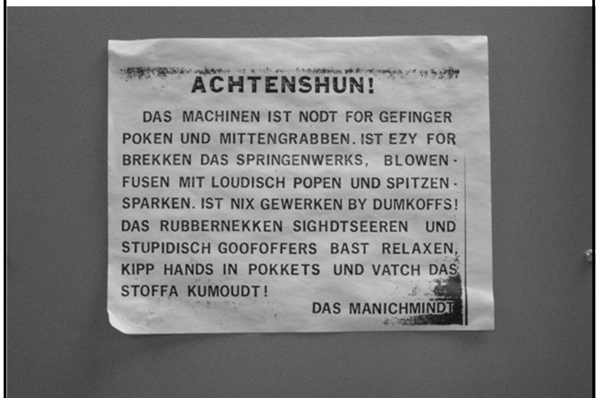
Pine Instrument Company Gyratory Compactor MODE: Set Height

Specimen Size: 150 mm Date: 1/24/15
Pressure: 600 kPa Time: 14:25
Specimen ID: ________ Technician: ________

SPECIMEN HEIGHT (mm) vs. GYRATION NO.

	0	1	2	3	4	5	6	7	8	9
0	116.7	111.2	108.3	106.3	104.7	103.5	102.4	101.5	100.7	100.0
10	99.4	98.8	98.3	97.9	97.5	97.1	96.7	96.4	96.1	95.8
20	95.5	95.2	95.0	94.8	94.5					

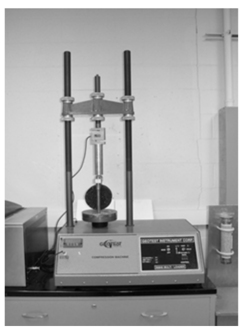
114



115

DAY 3, Cont'd. Dry Pucks

- Test for indirect tensile strength (S_1):
- Apply load at 2" travel per minute.
- Record maximum load.



116

CALCULATIONS: DRY TENSILE STRENGTH

- Calculate dry indirect tensile strength, S_1 (psi):

$$S_1 = \frac{2P}{\pi t D}$$

P= load (lbs)

t=dry puck thickness (in.)

D= puck diameter (6 in.)

117

OR
Using metric puck measurements:

Indirect Tensile Strength "Dry" ,S_1 (psi)

$$S_1 = \frac{2P}{\pi t D} \times 6.4516$$

P = load (lbs)
t = puck thickness (cm)
D = puck diameter (15.0 cm)

118

Specimen #1

- S = 2(3852 lbs)(6.4516)
- π(9.5 cm)(15.0 cm)

- S = 111 psi

119

AASHTO T-283 T-283 Rev3-24-04Example.xls

Mix Number: Example Gmm = 2.476

Gmb Worksheet	Dry Subset			Wet Subset			
Specimen #	1	2	3	4	5	6	
Weight in air (g) [A]	3725.8	3749.7	3755.1	3822.4	3759.7	3692.3	
SSD Weight (g) [B]	3735.6	3761.0	3765.0	3833.5	3770.7	3707.9	
Weight in water (g) [C]	2114.3	2135.9	2140.2	2180.0	2144.3	2094.9	
Height (0.1 cm) [t]	9.5	9.5	9.5	9.7	9.5	9.5	
Volume (cm³) [B - C]	1621	1625	1625	1654	1626		[B-C]
Gmb [A / (B - C)]	2.298	2.307	2.311	2.312	2.312		A/[B-C]
% Air Voids [Pa]	7.2	6.8	6.7	6.6	6.6		100[Gmm-Gmb]/Gmm
Dry volume of air (cm³)[Va]	117	111	108	110	108		Pa[B-C]/100
Average % Air Voids	Dry	6.9		Wet			
Overall							

TSR Worksheet	Dry Subset			Wet Subset			
Specimen #	1	2	3	4	5	6	
Height (0.1 cm) [t]	9.5	9.5	9.5	9.7	9.5	9.5	
Max. Load (lbs) [P]	3852	3601	3761	1564	1517	1197	
Ind. Tens. Str.: ITS (psi)*	111	104	108	44	44		6.4516*2P/3.1415tD

* For 15.0 cm diameter specimen[D]		Vacuum SSD Wt. (g)[B']	3902.9	3846.0	3787.3	
Avg. Wet ITS (psi)[Swet]		Weight in air (g)[A]	3822.4	3759.7		
Avg. Dry ITS (psi)[Sdry]	108	Vol. Absorb H_2O (cm³)[J']	81	86		B'-A
TSR (%)[100Swet/Sdry]		Dry volume of air (cm³)[Va]	110	108		
		70% Sat. (Target VSSD)	3899	3835		A+0.7Va
	AVG	80% Sat. (Target VSSD)	3910	3846		A+0.8Va
Air Voids (%)		% Saturation	73	80		100J'/Va
Dry Subset %Air	6.9	in. Hg	22	23	23	
Wet Subset %Air		Time (min)	8	8	8	
Saturation (%)		in. Hg	25	26	24	
		Time (min)	1	1	1	

	Dry Subset		
Time in 25 C waterbath (2 hrs ± 10 min)	1h 50m	1h 55m	2h

NOTE: Shaded cells indicate cells needing input values

	Wet Subset		
Time in Freezer (Minimum 16 hrs)	19h 44m	19h 16m	18h 54m
Time in 60 C waterbath (24 ± 1 hrs)	23h 30m	23h 30m	23h 30m

Test Time	12/22/2003 5:25 PM	12/22/2003 5:30 PM	12/22/2003 5:35 PM	12/22/2003 4:20 PM	12/22/2003 4:25 PM	12/22/2003 4:30 PM

120

AASHTO T-283 T-283 Rev3-24-04Example.xls

Mix Number	Example	Gmm =	2.476

Gmb Worksheet	Dry Subset			Wet Subset			
Specimen #	1	2	3	4	5	6	
Weight in air (g) [A]	3725.8	3749.7	3755.1	3822.4	3759.7	3692.3	
SSD Weight (g) [B]	3735.6	3761.0	3765.0	3833.5	3770.7	3707.9	
Weight in water (g) [C]	2114.3	2135.9	2140.2	2180.0	2144.3	2094.9	
Height (0.1 cm) [t]	9.5	9.5	9.5	9.7	9.5	9.5	
Volume (cm^3) [B - C]	1621	1625	1625	1654	1626		[B-C]
Gmb [A / (B - C)]	2.298	2.307	2.311	2.312	2.312		A/[B-C]
% Air Voids [Pa]	7.2	6.8	6.7	6.6	6.6		100[Gmm-Gmb]/Gmm
Dry volume of air (cm^3)[Va]	117	111	108	110	108		Pa[B-C]/100
Average % Air Voids	Dry	6.9		Wet			
Overall							

TSR Worksheet	Dry Subset			Wet Subset			
Specimen #	1	2	3	4	5	6	
Height (0.1 cm) [t]	9.5	9.5	9.5	9.7	9.5	9.5	
Max. Load (lbs) [P]	3852	3601	3761	1564	1517	1197	
Ind. Tens. Str.:ITS (psi)*	111	104	108	44	44		6.4516*2P/3.1415tD

* For 15.0 cm diameter specimen[D]		Vacuum SSD Wt. (g)[B']	3902.9	3846.0	3787.3	
Avg. Wet ITS (psi)[Swet]		Weight in air (g)[A]	3822.4	3759.7		
Avg. Dry ITS (psi)[Sdry]	108	Vol. Absorb H_2O (cm^3)[J']	81	86		B'-A
TSR (%)[100Swet/Sdry]		Dry volume of air (cm^3)[Va]	110	108		
		70% Sat. (Target VSSD)	3899	3835		A+0.7Va
	AVG	80% Sat. (Target VSSD)	3910	3846		A+0.8Va
Air Voids (%)		% Saturation	73	80		100J'/Va
Dry Subset %Air	6.9	in. Hg	22	23	23	
Wet Subset %Air		Time (min)	8	8	8	
Saturation (%)		in. Hg	25	26	24	
		Time (min)	1	1	1	

	Dry Subset		
Time in 25 C waterbath (2 hrs ± 10 min)	1h 50m	1h 55m	2h

NOTE: Shaded cells indicate cells needing input values

	Wet Subset		
Time in Freezer (Minimum 16 hrs)	19h 44m	19h 16m	18h 54m
Time in 60 C waterbath (24 ± 1 hrs)	23h 30m	23h 30m	23h 30m

Test Time						
	12/22/2003 5:25 PM	12/22/2003 5:30 PM	12/22/2003 5:35 PM	12/22/2003 4:20 PM	12/22/2003 4:25 PM	12/22/2003 4:30 PM

DAY 3, cont.(Wet Pucks)

- Remove the pucks from freezer, remove from bag, and thaw pucks in a water bath at 60 ± 1 C for 24 ± 1 hr. Minimum 1 in. water cover above specimens.
- Unwrap cling film as soon as the film thaws.

121

DAY 4: Wet Pucks

Place pucks in water bath at 25 ± 0.5° C for 2 hrs ± 10 min. Minimum 1 in. water cover above specimens. Bath must be at 25°C no later than 15 min. after placing hot pucks. Use ice to help achieve this.

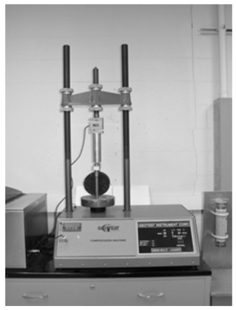
122

Wet Pucks

123

DAY 4, Cont'd. (Wet Pucks)

- Measure puck thickness (t')- *after soaking, with calipers*
- Test for indirect tensile strength (S_2)



124

Indirect Tensile Testing

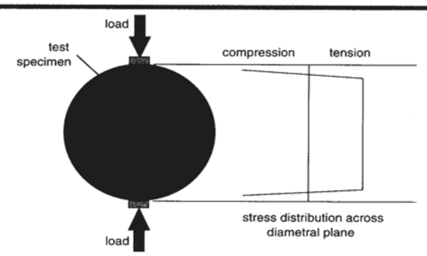


Figure 7.4 Indirect Tensile Test

125

CALCULATIONS WET TENSILE STRENGTH

- Calculate wet indirect tensile strength, S_2 (psi):

$$S_2 = \frac{2P}{\Pi t' D}$$

P= load (lbs)

t'=wet puck thickness (in.)

D= puck diameter (6 in.)

126

OR
Using metric puck measurements:

- Wet indirect tensile strength, S_2 (psi)

$$S_2 = \frac{2P}{\pi t' D} \times 6.4516$$

P = load (lbs)
t' = puck thickness (cm)
D = puck diameter (15.0 cm)

127

Specimen #4

- S = 2(1564 lbs)(6.4516)
-        π(9.7 cm)(15.0 cm)

- S = 44 psi

128

AASHTO T-283   T-283 Rev3-24-04Example.xls

Mix Number: Example   Gmm = 2.476

Gmb Worksheet	Dry Subset			Wet Subset			
Specimen #	1	2	3	4	5	6	
Weight in air (g) [A]	3725.8	3749.7	3755.1	3822.4	3759.7	3692.3	
SSD Weight (g) [B]	3735.6	3761.0	3765.0	3833.5	3770.7	3707.9	
Weight in water (g) [C]	2114.3	2135.9	2140.2	2180.0	2144.3	2094.9	
Height (0.1 cm) [t]	9.5	9.5	9.5	9.7	9.5	9.5	
Volume (cm^3) [B - C]	1621	1625	1625	1654	1626		[B-C]
Gmb [A / (B - C)]	2.298	2.307	2.311	2.312	2.312		A/[B-C]
% Air Voids [Pa]	7.2	6.8	6.7	6.6	6.6		100[Gmm-Gmb]/Gmm
Dry volume of air (cm^3)[Va]	117	111	108	110	108		Pa[B-C]/100
Average % Air Voids	Dry	6.9		Wet			
Overall							

TSR Worksheet	Dry Subset			Wet Subset			
Specimen #	1	2	3	4	5	6	
Height (0.1 cm) [t]	9.5	9.5	9.5	9.7	9.5	9.5	
Max. Load (lbs) [P]	3852	3601	3761	1564	1517	1197	
Ind. Tens. Str.: ITS (psi)*	111	104	108	44	44		6.4516*2P/3.1415tD

* For 15.0 cm diameter specimen[D]						
		Vacuum SSD Wt. (g)[B']	3902.9	3846.0	3787.3	
Avg. Wet ITS (psi)[Swet]		Weight in air (g)[A]	3822.4	3759.7		
Avg. Dry ITS (psi)[Sdry]	108	Vol. Absorb H_2O (cm^3)[J']	81	86		B'-A
TSR (%)[100Swet/Sdry]		Dry volume of air (cm^3)[Va]	110	108		
		70% Sat. (Target VSSD)	3899	3835		A+0.7Va
	AVG	80% Sat. (Target VSSD)	3910	3846		A+0.8Va
Air Voids (%)		% Saturation	73	80		100J'/Va
Dry Subset %Air	6.9	in. Hg	22	23	23	
Wet Subset %Air		Time (min)	8	8	8	
Saturation (%)		in. Hg	25	26	24	
		Time (min)	1	1	1	

	Dry Subset		
Time in 25 C waterbath (2 hrs ± 10 min)	1h 50m	1h 55m	2h

NOTE: Shaded cells indicate cells needing input values

	Wet Subset		
Time in Freezer (Minimum 16 hrs)	19h 44m	19h 16m	18h 54m
Time in 60 C waterbath (24 ± 1 hrs)	23h 30m	23h 30m	23h 30m

Test Time	12/22/2003 5:25 PM	12/22/2003 5:30 PM	12/22/2003 5:35 PM	12/22/2003 4:20 PM	12/22/2003 4:25 PM	12/22/2003 4:30 PM

129

Mix Number	Example	Gmm =	2.476

Gmb Worksheet	Dry Subset			Wet Subset			
Specimen #	1	2	3	4	5	6	
Weight in air (g) [A]	3725.8	3749.7	3755.1	3822.4	3759.7	3692.3	
SSD Weight (g) [B]	3735.6	3761.0	3765.0	3833.5	3770.7	3707.9	
Weight in water (g) [C]	2114.3	2135.9	2140.2	2180.0	2144.3	2094.9	
Height (0.1 cm) [t]	9.5	9.5	9.5	9.7	9.5	9.5	
Volume (cm^3) [B - C]	1621	1625	1625	1654	1626		[B-C]
Gmb [A / (B - C)]	2.298	2.307	2.311	2.312	2.312		A/[B-C]
% Air Voids [Pa]	7.2	6.8	6.7	6.6	6.6		100[Gmm-Gmb]/Gmm
Dry volume of air (cm^3)[Va]	117	111	108	110	108		Pa[B-C]/100
Average % Air Voids	Dry	6.9		Wet			
Overall							

TSR Worksheet	Dry Subset			Wet Subset			
Specimen #	1	2	3	4	5	6	
Height (0.1 cm) [t]	9.5	9.5	9.5	9.7	9.5	9.5	
Max. Load (lbs) [P]	3852	3601	3761	1564	1517	1197	
Ind. Tens. Str.:ITS (psi)*	111	104	108	44	44		6.4516*2P/3.1415tD

* For 15.0 cm diameter specimen[D]		Vacuum SSD Wt. (g)[B']	3902.9	3846.0	3787.3	
Avg. Wet ITS (psi)[Swet]		Weight in air (g)[A]	3822.4	3759.7		
Avg. Dry ITS (psi)[Sdry]	108	Vol. Absorb H_2O (cm^3)[J']	81	86		B'-A
TSR (%)[100Swet/Sdry]		Dry volume of air (cm^3)[Va]	110	108		
		70% Sat. (Target VSSD)	3899	3835		A+0.7Va
	AVG	80% Sat. (Target VSSD)	3910	3846		A+0.8Va
Air Voids (%)		% Saturation	73	80		100J'/Va
Dry Subset %Air	6.9	in. Hg	22	23	23	
Wet Subset %Air		Time (min)	8	8	8	
Saturation (%)		in. Hg	25	26	24	
		Time (min)	1	1	1	

	Dry Subset		
Time in 25 C waterbath (2 hrs ± 10 min)	1h 50m	1h 55m	2h

NOTE: Shaded cells indicate cells needing input values

	Wet Subset		
Time in Freezer (Minimum 16 hrs)	19h 44m	19h 16m	18h 54m
Time in 60 C waterbath (24 ± 1 hrs)	23h 30m	23h 30m	23h 30m

Test Time						
	12/22/2003 5:25 PM	12/22/2003 5:30 PM	12/22/2003 5:35 PM	12/22/2003 4:20 PM	12/22/2003 4:25 PM	12/22/2003 4:30 PM

CALCULATIONS: TSR

- Calculate TSR:
- $$TSR = \frac{S_2}{S_1} \times 100$$

S_2=average of conditioned (wet) pucks tensile strength

S_1=average of unconditioned (dry) pucks tensile strength

130

CALCULATIONS: TSR

- Specimen #6 ITS is 35 psi, so the average (#4, #5, #6) wet S_2 = 41 psi
- $$TSR = \frac{41}{108} \times 100$$

TSR = 38

131

AASHTO T-283 T-283 Rev3-24-04Example.xls

Mix Number: Example Gmm = 2.476

Gmb Worksheet	Dry Subset			Wet Subset			
Specimen #	1	2	3	4	5	6	
Weight in air (g) [A]	3725.8	3749.7	3755.1	3822.4	3759.7	3692.3	
SSD Weight (g) [B]	3735.6	3761.0	3765.0	3833.5	3770.7	3707.9	
Weight in water (g) [C]	2114.3	2135.9	2140.2	2180.0	2144.3	2094.9	
Height (0.1 cm) [t]	9.5	9.5	9.5	9.7	9.5	9.5	
Volume (cm^3) [B - C]	1621	1625	1625	1654	1626		[B-C]
Gmb [A / (B - C)]	2.298	2.307	2.311	2.312	2.312		A/[B-C]
% Air Voids [Pa]	7.2	6.8	6.7	6.6	6.6		100[Gmm-Gmb]/Gmm
Dry volume of air (cm^3)[Va]	117	111	108	110	108		Pa[B-C]/100
Average % Air Voids	Dry	6.9		Wet			
Overall							

TSR Worksheet	Dry Subset			Wet Subset			
Specimen #	1	2	3	4	5	6	
Height (0.1 cm) [t]	9.5	9.5	9.5	9.7	9.5	9.5	
Max. Load (lbs) [P]	3852	3601	3761	1564	1517	1197	
Ind. Tens. Str.:ITS (psi)*	111	104	108	44	44		6.4516*2P/3.1415tD

* For 15.0 cm diameter specimen[D]	
Avg. Wet ITS (psi)[Swet]	
Avg. Dry ITS (psi)[Sdry]	108
TSR (%)[100Swet/Sdry]	
	AVG
Air Voids (%)	
Dry Subset %Air	6.9
Wet Subset %Air	
Saturation (%)	

	4	5	6	
Vacuum SSD Wt. (g)[B']	3902.9	3846.0	3787.3	
Weight in air (g)[A]	3822.4	3759.7		
Vol. Absorb H_2O (cm^3)[J']	81	86		B'-A
Dry volume of air (cm^3)[Va]	110	108		
70% Sat. (Target VSSD)	3899	3835		A+0.7Va
80% Sat. (Target VSSD)	3910	3846		A+0.8Va
% Saturation	73	80		100J'/Va
in. Hg	22	23	23	
Time (min)	8	8	8	
in. Hg	25	26	24	
Time (min)	1	1	1	

	Dry Subset		
Time in 25 C waterbath (2 hrs ± 10 min)	1h 50m	1h 55m	2h

NOTE: Shaded cells indicate cells needing input values

	Wet Subset		
Time in Freezer (Minimum 16 hrs)	19h 44m	19h 16m	18h 54m
Time in 60 C waterbath (24 ± 1 hrs)	23h 30m	23h 30m	23h 30m

	1	2	3	4	5	6
Test Time	12/22/2003 5:25 PM	12/22/2003 5:30 PM	12/22/2003 5:35 PM	12/22/2003 4:20 PM	12/22/2003 4:25 PM	12/22/2003 4:30 PM

132

AASHTO T-283 T-283 Rev3-24-04Example.xls

Mix Number	Example	Gmm =	2.476

Gmb Worksheet	Dry Subset			Wet Subset			
Specimen #	1	2	3	4	5	6	
Weight in air (g) [A]	3725.8	3749.7	3755.1	3822.4	3759.7	3692.3	
SSD Weight (g) [B]	3735.6	3761.0	3765.0	3833.5	3770.7	3707.9	
Weight in water (g) [C]	2114.3	2135.9	2140.2	2180.0	2144.3	2094.9	
Height (0.1 cm) [t]	9.5	9.5	9.5	9.7	9.5	9.5	
Volume (cm^3) [B - C]	1621	1625	1625	1654	1626		[B-C]
Gmb [A / (B - C)]	2.298	2.307	2.311	2.312	2.312		A/[B-C]
% Air Voids [Pa]	7.2	6.8	6.7	6.6	6.6		100[Gmm-Gmb]/Gmm
Dry volume of air (cm^3)[Va]	117	111	108	110	108		Pa[B-C]/100
Average % Air Voids	Dry	6.9		Wet			
Overall							

TSR Worksheet	Dry Subset			Wet Subset			
Specimen #	1	2	3	4	5	6	
Height (0.1 cm) [t]	9.5	9.5	9.5	9.7	9.5	9.5	
Max. Load (lbs) [P]	3852	3601	3761	1564	1517	1197	
Ind. Tens. Str.:ITS (psi)*	111	104	108	44	44		6.4516*2P/3.1415tD
* For 15.0 cm diameter specimen[D]		Vacuum SSD Wt. (g)[B']		3902.9	3846.0	3787.3	
Avg. Wet ITS (psi)[Swet]		Weight in air (g)[A]		3822.4	3759.7		
Avg. Dry ITS (psi)[Sdry]	108	Vol. Absorb H_2O (cm^3)[J']		81	86		B'-A
TSR (%)[100Swet/Sdry]		Dry volume of air (cm^3)[Va]		110	108		
		70% Sat. (Target VSSD)		3899	3835		A+0.7Va
	AVG	80% Sat. (Target VSSD)		3910	3846		A+0.8Va
Air Voids (%)		% Saturation		73	80		100J'/Va
Dry Subset %Air	6.9		in. Hg	22	23	23	
Wet Subset %Air			Time (min)	8	8	8	
Saturation (%)			in. Hg	25	26	24	
			Time (min)	1	1	1	

	Dry Subset		
Time in 25 C waterbath (2 hrs ± 10 min)	1h 50m	1h 55m	2h

	Wet Subset		
Time in Freezer (Minimum 16 hrs)	19h 44m	19h 16m	18h 54m
Time in 60 C waterbath (24 ± 1 hrs)	23h 30m	23h 30m	23h 30m

NOTE: Shaded cells indicate cells needing input values

Test Time	12/22/2003 5:25 PM	12/22/2003 5:30 PM	12/22/2003 5:35 PM	12/22/2003 4:20 PM	12/22/2003 4:25 PM	12/22/2003 4:30 PM

SUSPECTED STRENGTH OUTLIER

- If attributable to an air void content different from other 2 pucks, leave in the set
- If a mystery, calculate if statistically is an outlier (ASTM E178)-if so, pitch and do one of the following:
  - Substitute another puck if compacted extra pucks
  - Test a new set of 3
  - Go with 2 pucks in the set
  - Prepare and test a substitute puck---must be assured that the material is the same as what was used for the other pucks

133

OUTLIER EVALUATION
ASTME 178
Applies to test values: TSR

1. If the largest test value (x_{max}) in the set is suspected to be an outlier, calculate the t-statistic:

$$t = \frac{(x_{max} - x_{avg})}{S}$$

Where X_{avg}=average
S = standard deviation

2. If the smallest test value (x_{min}) in the set is suspected to be an outlier, calculate the t-statistic:

$$t = \frac{(x_{avg} - x_{min})}{S}$$

3. Compare the largest *calculated t-statistic* to the *critical t-statistic*. The *critical t-statistic* depends on the desired significance level and the number of test results in the set. MoDOT has set the significance level at 5%. If the evaluation is of an outlier either being too high, or too low, the following is a table of t-critical values. Typically, there are 3 TSR replicate specimens:

No. of tests	t @ 5% in tail
3	1.153
4	1.463
5	1.672
6	1.822
7	2.938
8	2.032
9	2.110
10	2.176

If the *calculated t-statistic* is greater than $t_{critical\ (\alpha=5\%)}$, consider the test result to be an outlier.

134

Example

- Triplicate dry set: 111, 108, 104 psi
- Average = 107.7 psi
- Standard deviation = 3.51 psi
- $t_{max} = (x_{max} - x_{avg})/S$
- $= (111 - 107.7)/3.51 = 0.940$
- $t_{min} = (x_{avg} - x_{min})/S$
- $= (107.7 - 104)/3.51 = 1.054$
- From table: $t_{critical} = 1.153$
- Is 111 an outlier? (Is 0.940 > 1.153?) No
- Is 104 an outlier? (Is 1.054 > 1.153?) No

135

OUTLIER EVALUATION
ASTM E 178
Applies to test values: TSR

1. **If the largest test value (x_{max}) in the set is suspected to be an outlier, calculate the t-statistic:**

$$t = \frac{(x_{max} - x_{avg})}{S}$$

Where X_{avg}=average
S = standard deviation

2. **If the smallest test value (x_{min}) in the set is suspected to be an outlier, calculate the t-statistic:**

$$t = \frac{(x_{avg} - x_{min})}{S}$$

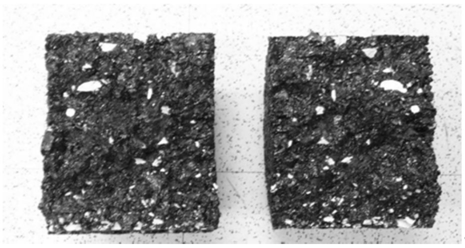
3. **Compare the largest *calculated t-statistic* to the *critical t-statistic*. The *critical t-statistic* depends on the desired significance level and the number of test results in the set. MoDOT has set the significance level at 5%. If the evaluation is of an outlier either being too high, or too low, the following is a table of t-critical values. Typically, there are 3 TSR replicate specimens:**

No. of tests	t @ 5% in tail
3	1.153
4	1.463
5	1.672
6	1.822
7	2.938
8	2.032
9	2.110
10	2.176

If the *calculated t-statistic* is greater than $t_{critical\ (\alpha=5\%)}$, consider the test result to be an outlier.

INSPECT

- Rate the degree of moisture damage on a scale of 0 to 5, with 5 being the greatest amount of stripping



136

SCOPE

- Background
- TSR Role in QC/QA
- Sampling
- Test procedure
- ***Field verification***

137

REPORTING

- Report TSR to the nearest whole %

138

COMPARISON: QC TO QA

TSR -favorable comparison is when QA and QC results are within 10% of each other.

If the difference is 5 to 10%, TSR's are evaluated by MoDOT field office.

If difference is >10%, initiate dispute resolution

QC and QA retained samples may have to be kept for extended periods

139

COMMON ERRORS/ Unfavorable Comparison

- Shaking saturated puck to "adjust" saturated mass
- Using pucks out of the acceptable air void range (7.0±0.5 or 6.0±0.5%)
- Proper water tank temperature not maintained (25 and 60° C)
- Using puck that has been over or under saturated instead of discarding or applying additional vacuum

140

COMMON ERRORS / Unfavorable Comparison

- Using incorrect maximum specific gravity to calculate voids and % saturation.
- Specimen in water bath for the incorrect amount of time.
- Not cleaning breaking apparatus when dirty.
- Not annually verifying breaking machine.

141

COMMON ERRORS / Unfavorable Comparison

- Not molding specimens at correct temperature (if cool, may break aggregate)
- Not aging lab specimens the correct time & temperature (lab-mixed only)
- Not adding 10 ml of water prior to freezing
- Allowing specimens to drain after saturation but prior to freezing.

142

COMMON ERRORS / Unfavorable Comparison

- Using vacuum out of allowable range (10-26 in. Hg)
- Not allowing specimen to "rest" 5-10 minutes after vacuum period.
- Exceeding time of vacuum
- Not air-drying bulked unconditioned pucks for 24 hrs prior to breaking
- Sample contaminated with dust, release agent overspray, etc.

143

COMMON ERRORS / Unfavorable Comparison

- Improper filling of sample into boxes
- Improper mixing and splitting procedures
- One or more mixture re-warmings
- Testing pucks at extreme ends of allowable range of voids [6.5, 7.5] may result in poor QC/QA comparison
- QC and QA not sampling at the same location-type (roadway vs plant) TSR and Rice gravity

144

APPENDIX

Splitting

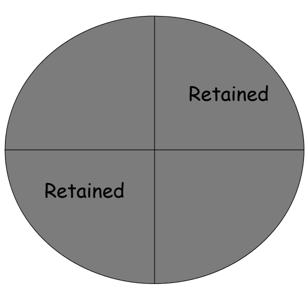
145

TSR Sample Quartering

- ***Sample for TSR is quartered per AASHTO R 47***
- ***Opposing 2 quarters are removed and combined for the retained split.***
- Combine remaining 2 quarters
- Quarter again
- Combine opposite quarters, producing 2 piles
- Quarter each pile. Now have 8 splits.
- Pull 6 pucks.
- Pull Rice if necessary.

146

Opposing 2 quarters are removed and combined for the retained split.



147

- Note-you will need about 175 lbs if you do this step—if not, 75 lbs will work

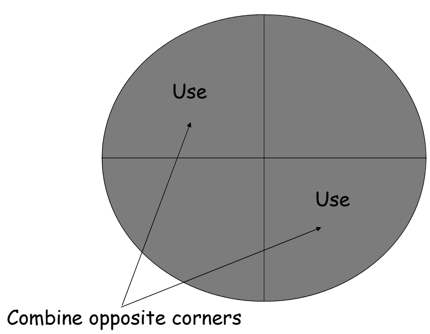
148

TSR Sample Quartering

- Sample for TSR is quartered per AASHTO R 47
- Opposing 2 quarters are removed and combined for the retained split.
- ***Combine remaining 2 quarters***
- Quarter again
- Combine opposite quarters, producing 2 piles
- Quarter each pile. Now have 8 splits.
- Pull 6 pucks.
- Pull Rice if necessary.

149

Combine remaining 2 quarters



150

SAMPLE SIZE

- Need ~ 175 lbs to follow this whole procedure
- Need ~ 75 lbs if you skip the first 3 steps

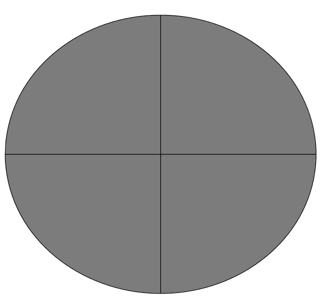
151

TSR Sample Quartering

- Sample for TSR is quartered per AASHTO R 47
- Opposing 2 quarters are removed and combined for the retained split.
- Combine remaining 2 quarters
- ***Quarter again***
- Combine opposite quarters, producing 2 piles
- Quarter each pile. Now have 8 splits.
- Pull 6+ pucks.
- Pull Rice if necessary.

152

Quarter Again



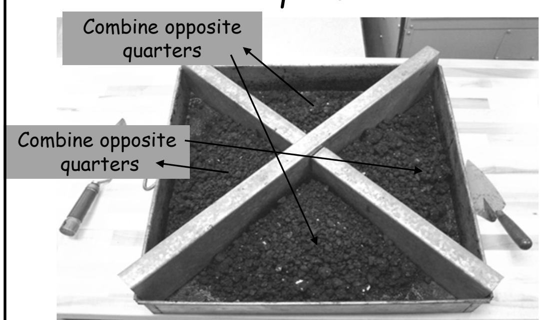
153

TSR Sample Quartering

- Sample for TSR is quartered per AASHTO R 47
- Opposing 2 quarters are removed and combined for the retained split.
- Combine remaining 2 quarters
- Quarter again
- ***Combine opposite quarters, producing 2 piles***
- Quarter each pile. Now have 8 splits.
- Pull 6 pucks.
- Pull Rice if necessary.

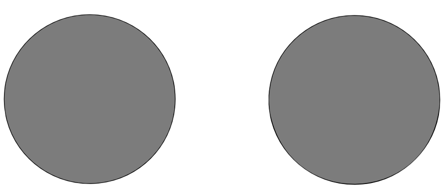
154

Combine opposite quarters, producing 2 piles



155

2 Piles



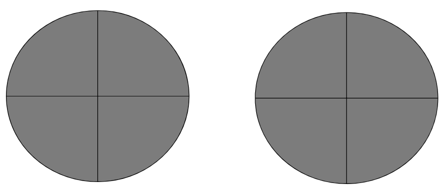
156

TSR Sample Quartering

- Sample for TSR is quartered per AASHTO R 47
- Opposing 2 quarters are removed and combined for the retained split.
- Combine remaining 2 quarters
- Quarter again
- Combine opposite quarters, producing 2 piles
- ***Quarter each pile. Now have 8 splits.***
- Pull 6 pucks.
- Pull Rice if necessary.

157

Quarter each pile. Now have 8 splits.



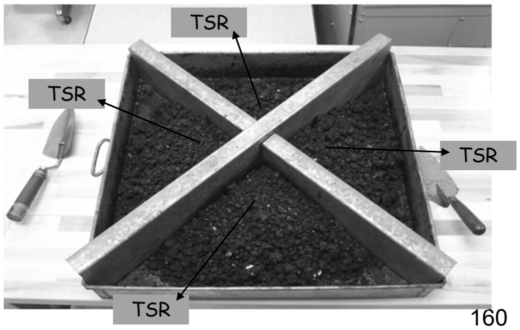
158

TSR Sample Quartering

- Sample for TSR is quartered per AASHTO R 47
- Opposing 2 quarters are removed and combined for the retained split.
- Combine remaining 2 quarters
- Quarter again
- Combine opposite quarters, producing 2 piles
- Quarter each half again. Now have 8 splits.
- ***Pull 6 pucks.***
- ***Pull Rice if necessary.***

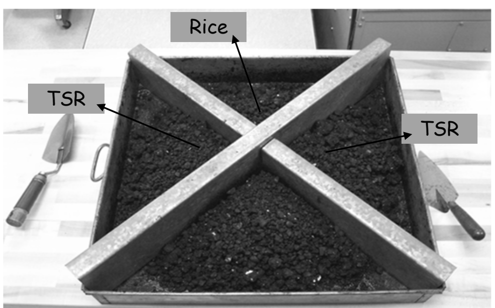
159

Obtain four TSR puck amounts

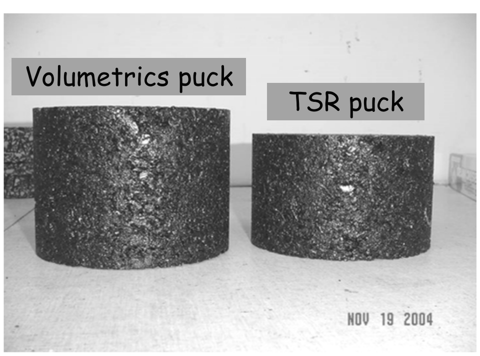


160

Obtain two TSR puck amounts and a Rice



161



162

Resistance of Compacted Asphalt Mixtures to Moisture-Induced Damage: Tensile Strength Ratio (TSR): Field-Mixed, Laboratory-Compacted Specimens AASHTO T 283-14 (2018)

1. Per specified sampling frequency, obtain a loose mix field sample to produce a Rice specific gravity test sample (AASHTO T 209) and at least 6 TSR pucks that will be 150 mm (6″) in diameter and 95 ± 5 mm thick after compaction. QC should obtain enough mix to retain a sample (e.g. ~75 lbs for the field sample and an additional 100 lbs retained for QA testing). For QA, a 125 lb sample should be sent to MoDOT Central Lab, and an additional 125 lb sample should be retained.
2. Reduce the field sample (AASHTO R 47) into previously determined test sample sizes based on the specific mix.
3. Place each TSR loose mix sample in an oven until it reaches the required compaction temperature ± 3°C (± 5°F).
4. Compact the TSR specimens to 7.0 ± 0.5 % air voids (6.0 ± 0.5% for SMA).
5. Store at room temperature for 24 ± 3 hours.
6. For each puck, obtain the thickness, t, (ASTM D 3549 or from gyro printout) and G_{mb} (AASHTO T 166).

$$G_{mb} = \frac{A}{B - C}$$

A = Dry mass of specimen in air (g)
B = Saturated, surface-dry (SSD) mass of specimen (g)
C = Mass of specimen in water (g)

7. Having obtained G_{mm} for the associated Rice specific gravity test sample, calculate the percent air voids, P_a, for each puck.

$$P_a = \frac{G_{mm} - G_{mb}}{G_{mm}} \times 100$$

8. Group the 6 pucks into 2 groups of 3 pucks each such that the average P_a of each group is approximately equal. Designate one group as “dry” or non-conditioned and the other group as “wet” or conditioned.

9. “DRY” GROUP TSR TESTING:

   9.1. After determining G_{mb}, store the pucks (at room temp) for 24 ± 3 hours.
   9.2. Place each designated dry (non-conditioned) puck in a heavy-duty, leak-proof plastic bag. Place each bagged puck in a water bath set at 25 ± 0.5°C (77 ± 1°F) for 2 hours ± 10 minutes, being sure that the pucks are covered by at least 1″ of water.

9.3. Remove the puck(s) from the 25 $\pm$ 0.5°C bath, determine thickness, t, and immediately test for indirect tensile strength. [See item #11 below].

10. "WET" GROUP TSR TESTING:

10.1. Place each designated wet (conditioned) puck in a vacuum container (e.g. dessicator) supported at least 1″ from the bottom by a perforated plate. Using potable water, fill the container until the puck is covered by at least 1″ of water.

10.2. Apply a vacuum of 10″ – 26″ (suggested 23″) of mercury (Hg) partial (gauge) pressure for approximately 5 – 10 (suggested 8) minutes.

10.3. During this vacuuming period, prepare for saturation determination by placing a sheet of cling film on a balance and then zeroing the balance.

10.4. At the end of the 5 – 10 minute vacuum period, gradually remove the vacuum and let the puck set submerged in the water for approximately 5 – 10 minutes. NOTE: The time required for some specimens to achieve the correct degree of saturation may be less than 5 minutes. Additionally, some specimens may require more than 26″ of mercury partial pressure or less than 10″ of mercury partial pressure.

10.5. Remove the puck from the vacuum container, quickly surface-dry with a damp cloth, and place the puck on the cling film. Record the saturated, surface-dry (SSD) weight of the puck and calculate the degree of saturation based on the volume of absorbed water as a percentage of the volume of air voids.

$$E = B - C$$

E = Volume of specimen (cm^3)
[Note: B & C are obtained during G_{mb} determination]

$$V_a = \frac{P_a E}{100}$$

V_a = Volume of air voids (cm^3)
P_a = Percent air voids (%)

$$J' = B' - A$$

J′ = Volume of absorbed water (cm^3)
B′ = SSD mass of specimen after vacuum saturation (g)
[Note: A is obtained during G_{mb} determination]

$$\%Sat = \frac{100\, J'}{V_a}$$

10.6. If the degree of saturation is 70-80%, wrap the puck in the cling film (preserving any moisture that had drained from the puck) and place it in a plastic bag containing 10 ± 0.5 ml of water, and seal the bag. If the saturation level is less than 70%, return the puck to the vacuum container, increase the vacuum to 26″ Hg partial pressure and run at 1-minute intervals (always letting the puck set in the water 5-10 minutes after removal of vacuum) until the saturation requirement is satisfied.
NOTE: When returning the puck to the vacuum chamber, inversion of the puck from the original orientation may facilitate additional air removal and is not disallowed by T 283.

If saturation is greater than 80%, the test is invalid and the puck must be discarded.

10.7. As soon as possible, place the plastic bag containing the puck in a freezer at -18 ± 3°C (0 ± 5°F) for a minimum of 16 hours.

10.8. Upon removing the pucks from the freezer, immediately place them in a water bath set at 60 ± 1°C (140 ± 2°F) for 24 ± 1 hour. As soon as possible, remove the cling film from around the puck. There should always be at least 1″ of water over the pucks.

10.9. Remove the pucks from the 60 ± 1°C bath and place in a 25 ± 0.5°C for 2 hours ± 10 minutes, again assuring at least 1″ of water over the pucks. It may be necessary to use ice to moderate the bath water temperature. No more than 15 minutes should be required to bring the bath water temperature to 25 ± 0.5°C.

10.10. Upon removal of each puck, determine thickness, t′, and immediately test for indirect tensile strength. [See item #11 below].

11. INDIRECT TENSILE TESTING:

11.1. Place the puck between the steel loading strips of the breaking head taking care that the loading strips are diametrically opposed to one another; i.e. the load is applied along the diameter of the puck.

11.2. Place the breaking head into the testing machine.

11.3. Apply the load to the breaking head such that a constant rate of movement equal to 50 mm (2″) per minute is achieved. This is the same load rate as in Marshall testing.

11.4. Record the maximum load and continue loading until a crack is formed along the diameter of the puck.

11.5. Pull the puck apart and visually inspect the interior surface. Check for cracked or broken aggregate and rate the general degree of moisture damage on a scale from 0 to 5, with 5 being the greatest amount of stripping. Record your observations.

12. CALCULATIONS:

12.1. Calculate the tensile strength as follows:

$$S = \frac{2P}{\pi t D}$$

S = Tensile strength (psi)
P = Maximum load (lbs)
t = Puck thickness for “dry” specimen (in.)
t′ = Puck thickness for “wet” specimen (in.)
D = Puck diameter (in.)

12.2. Calculate the tensile strength ratio, TSR, to 2 decimal places as follows:

$$TSR = \frac{S_{(conditioned)}}{S_{(dry)}}$$

$S_{(conditioned)}$ = Average tensile strength of conditioned subset
$S_{(dry)}$ = Average tensile strength of dry subset
Because MoDOT specs are in terms of percent, express TSR as a percentage to the nearest whole number