Balanced Mixture Design (BMD) and Update on Indirect Tensile Tests for Asphalt Mixture Performance

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From Somewhere in my House

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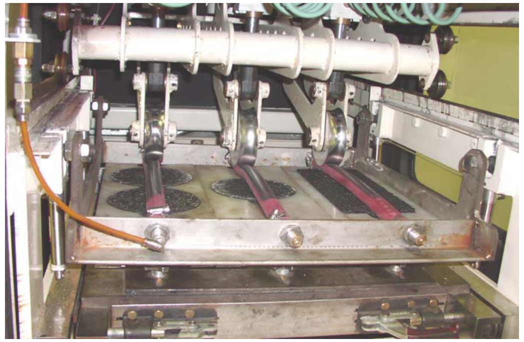
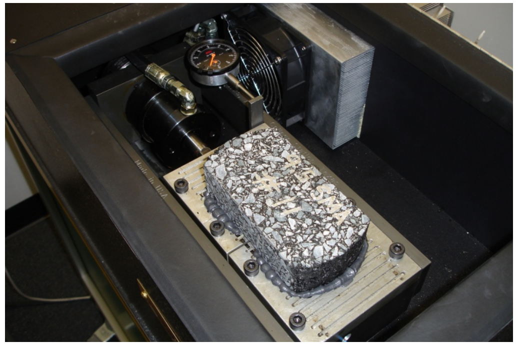
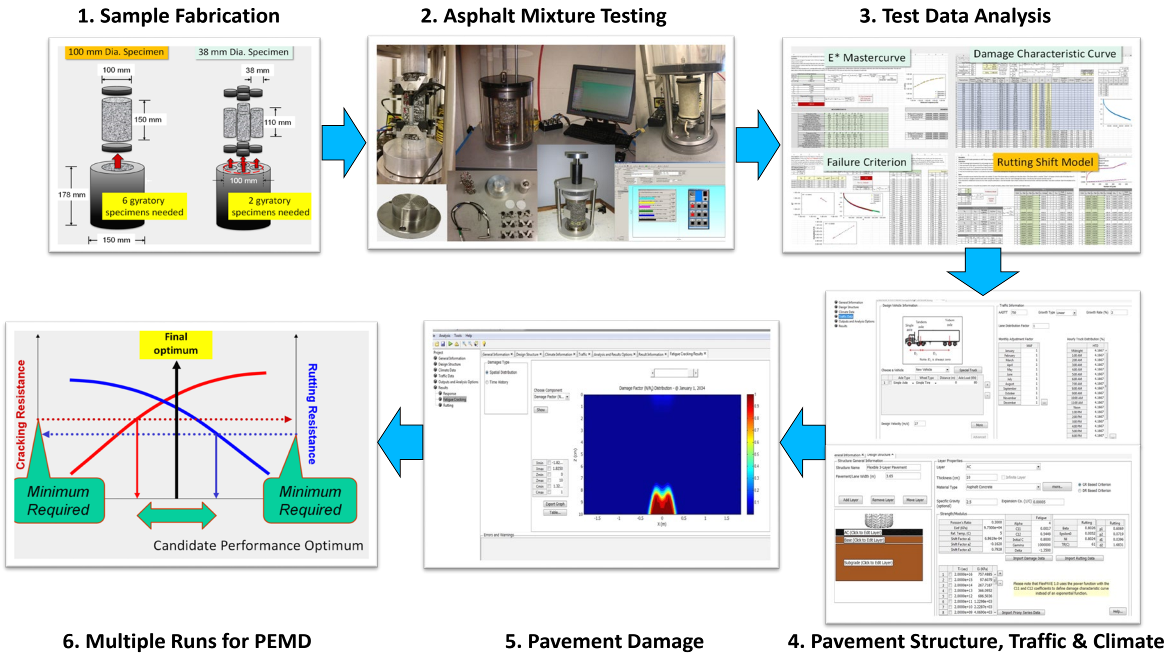
Balanced Mixture Design for HMA

- In simple terms;
  - A method of designing HMA to optimize its overall performance
- It can be as simple or as complicated as you want
  - From performance testing after mixture design
  - To mechanistic evaluations that include traffic, climate, and pavement modeling
- Unfortunately, when Balanced Mixture Design and Performance Testing are mentioned, most agencies and industry do the following…







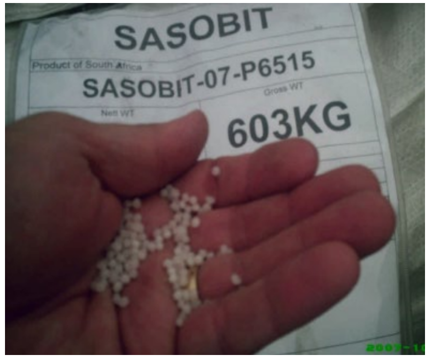
Balanced Mixture Design for HMA

Why the Need for Performance Testing During Mixture Design and Production?

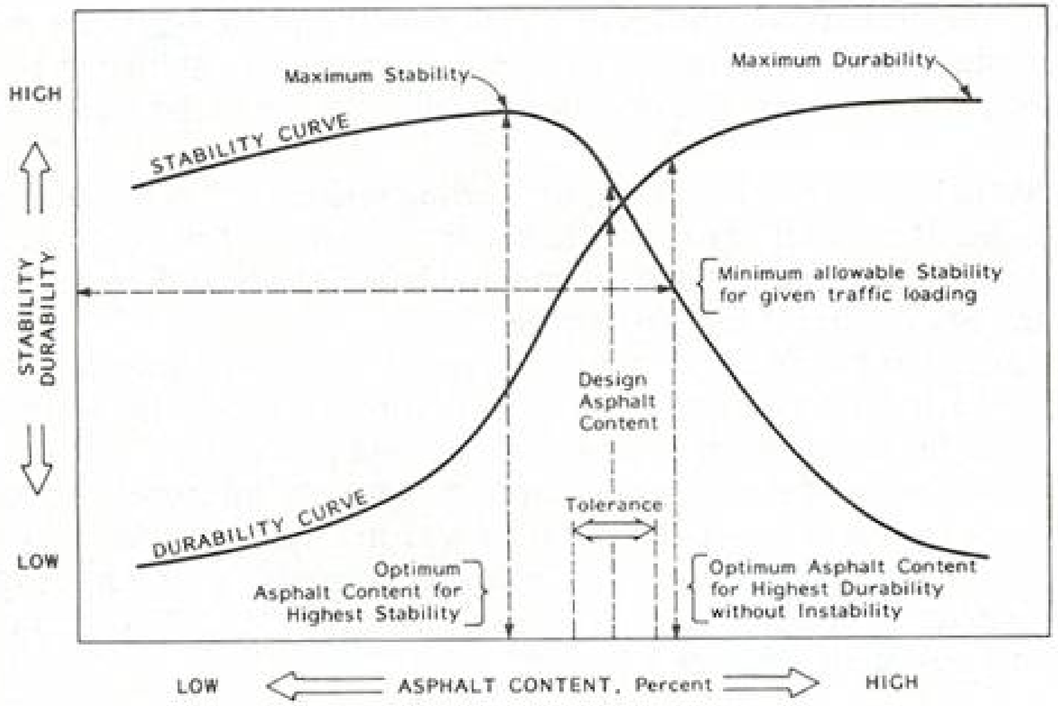
- **Problems:** .
  - Volumetrics alone **can not** adequately evaluate mix variables, such as recycle, warm-mix additives, polymers, rejuvenators, fibers and production factors.
- **Performance Testing Allows Us to:**
  - **Recognize performance issues** related to dry or wet mixes in some areas.
  - **Increase understanding** of the factors which drive mix performance
  - **Design for performance** on critical infrastructure
  - **Evaluate changes** in asphalt mixture performance due to production factors
  - **Innovate! Asphalt is an engineered material!**

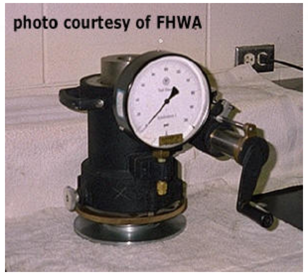


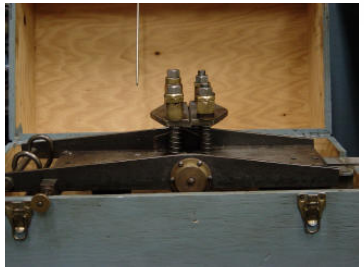




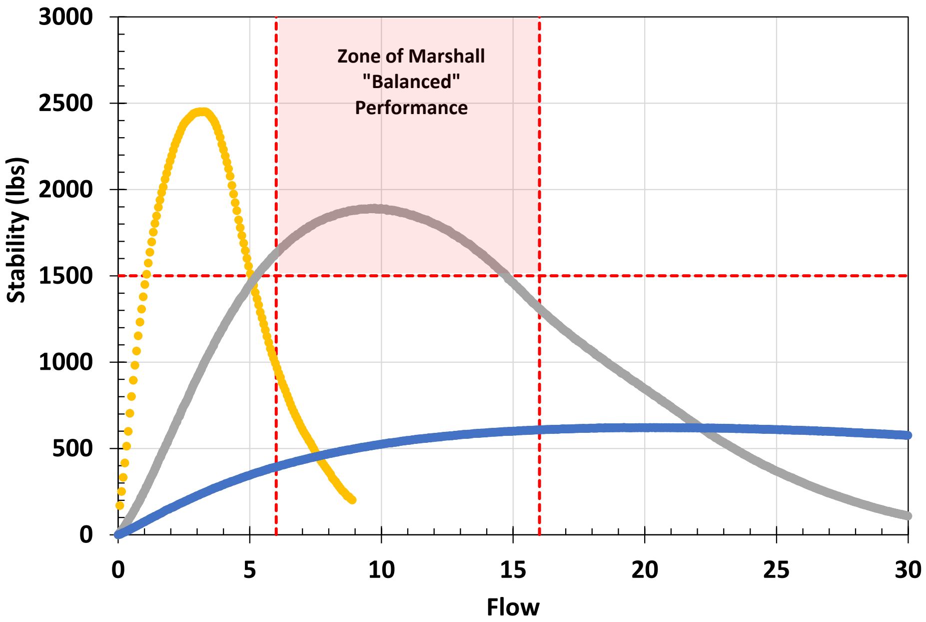
Concept of BMD is not New!





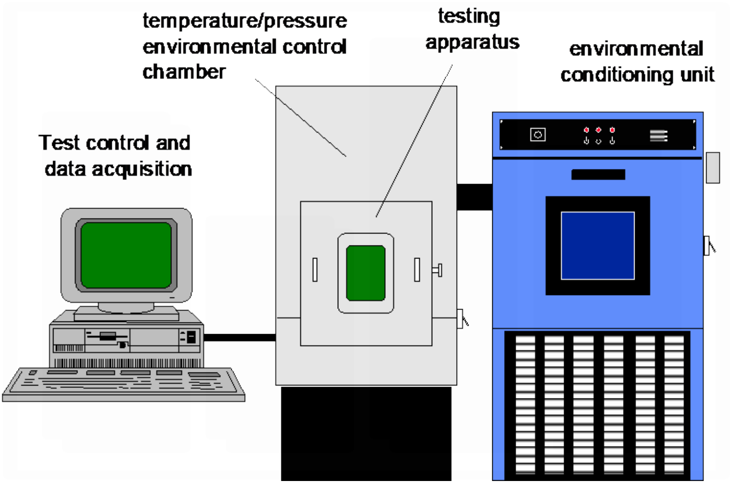


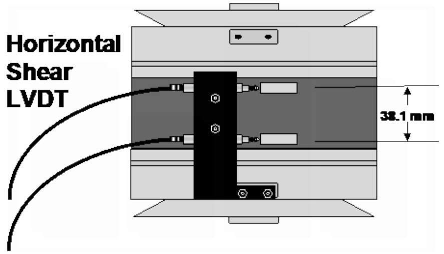
Hveem Design



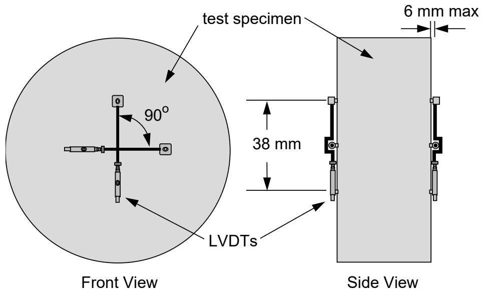
Marshall Design

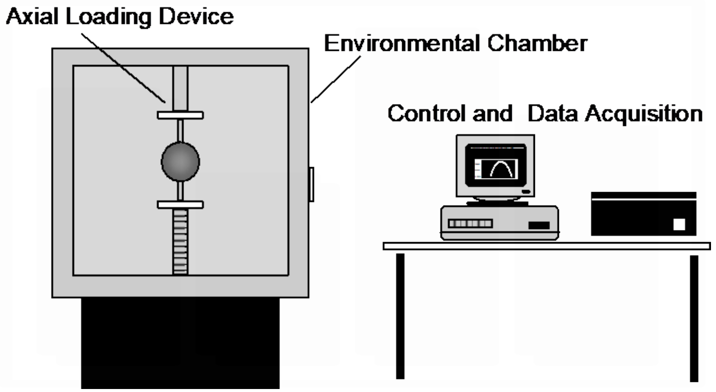
Concept of BMD is not New!



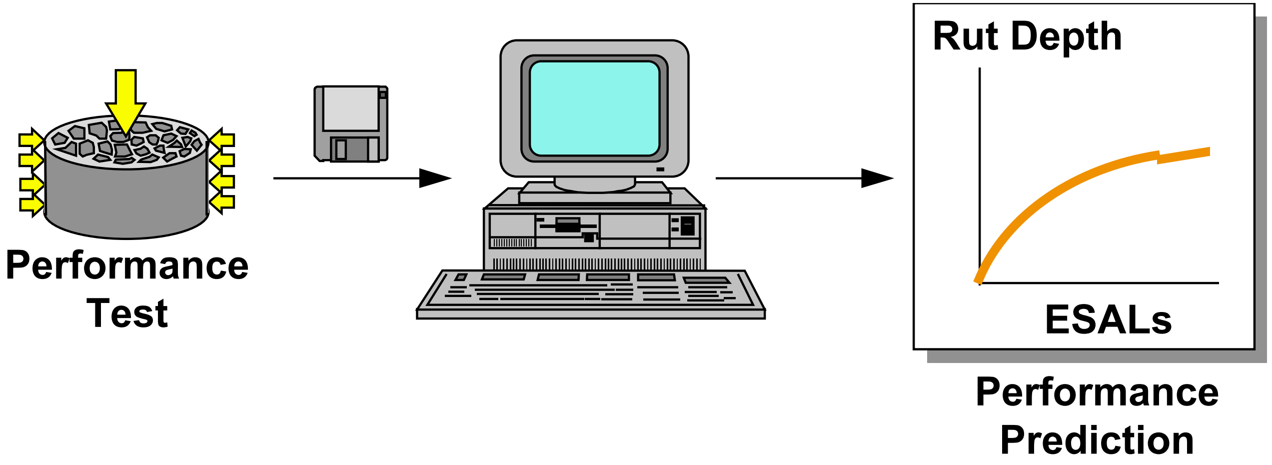


Superpave Rutting & Fatigue Cracking





Superpave Low Temperature Cracking

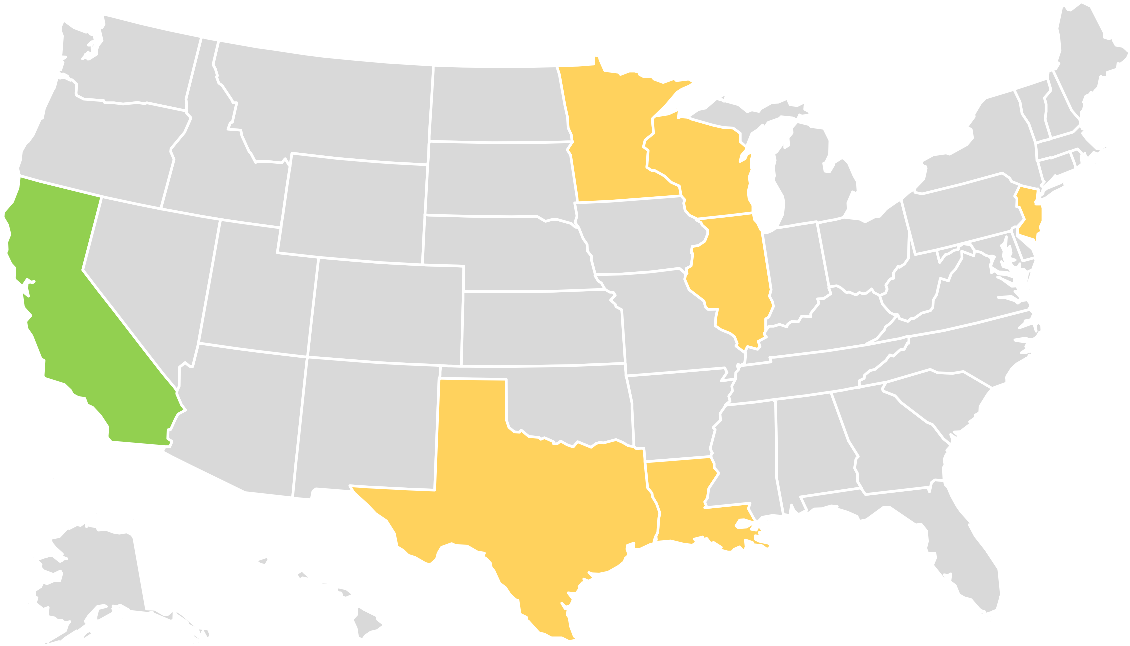


Balanced Mix Design Approaches

1 Volumetric Design with Performance Verification

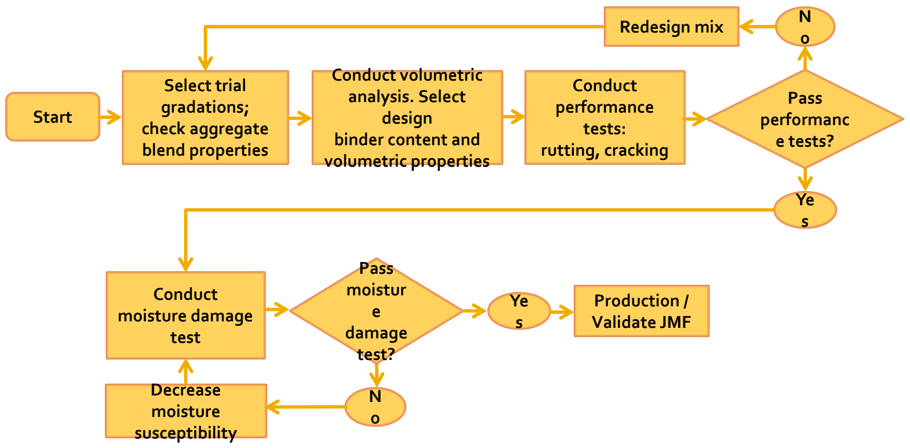
2 Performance-Modified Volumetric Mix Design

3 Performance Design



- Limited states have implemented performance testing in specs
  - Majority using “Approach #1”
- However, a number of states are now evaluating incorporating performance testing and BMD

BMD Approaches



- Approach #1 (NJ, IL, LA, TX, OK)
  - Conduct mix design using volumetrics
  - Check performance – if Fail, Redesign
- Approach #2 (CA)
  - Volumetrics used as starting point
  - Performance testing conducted to “fine tune” optimum AC
  - Ultimately, volumetrics are “relaxed”
- Approach #3
  - Optimum AC solely determined using performance testing
  - True “Balanced Mixture Design”
  - Volumetrics checked but Performance Testing dictates asphalt content

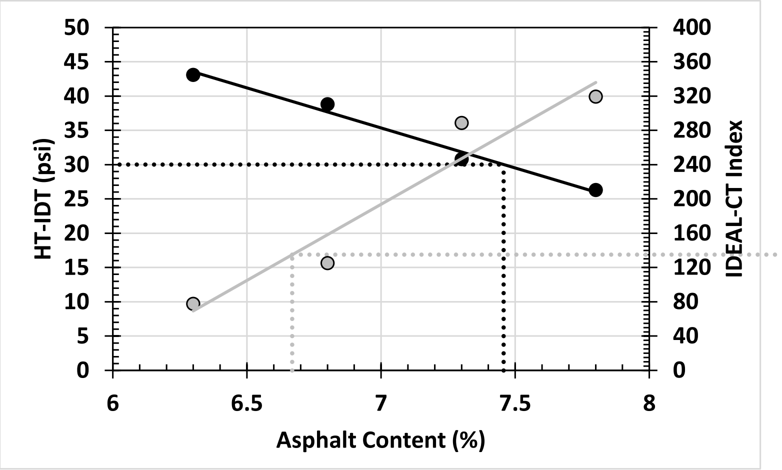
Recent BMD and Performance Specs in the Area

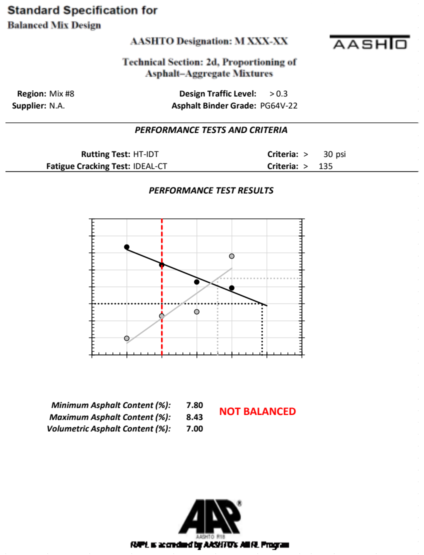
Recent Local BMD Efforts

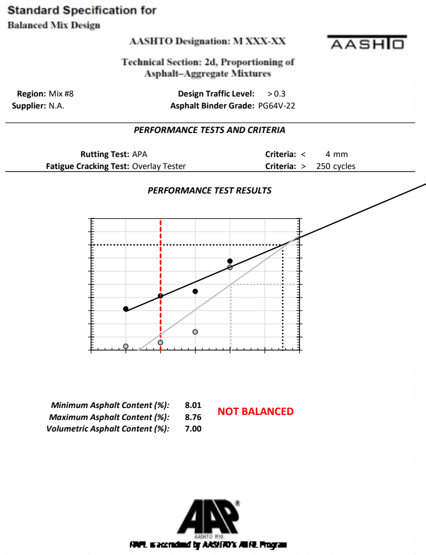
- DelDOT
  - Generating database of mix performance using APA, IDEAL-CT and Overlay Tester
  - Using mix performance to verify High RAP and RAS mixes
- PennDOT
  - Long Life Asphalt Pavements (LLAP)
    - SMA over 19mm
    - Hamburg, SCB FI, Overlay Tester, Low Temp SCB and Disk Shaped Compact Tension (DC(T))
  - 2021 – Projects with Hamburg Wheel Tracking and IDEAL-CT

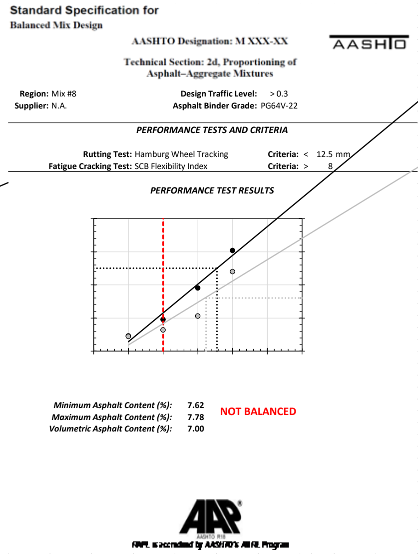
Recent Local BMD Efforts

- NYSDOT
  - Completed study evaluating approved asphalt mixtures utilizing BMD concepts
    - Performance testing at -0.5%, Opt, +0.5%, +1.0%
      - Rutting: APA, Hamburg, High Temperature IDT
      - Cracking: Overlay Tester, SCB FI, IDEAL-CT
    - Determined if volumetric optimum AC% is in the range BMD
  - Half of asphalt mixtures were found to not be balanced (failed for cracking)



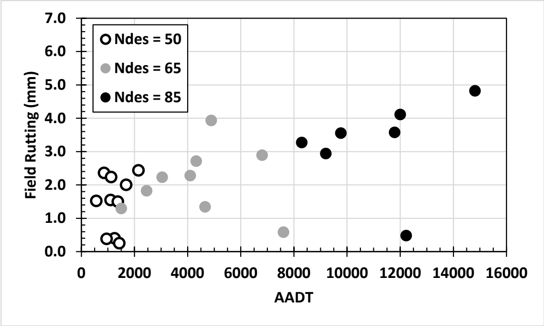


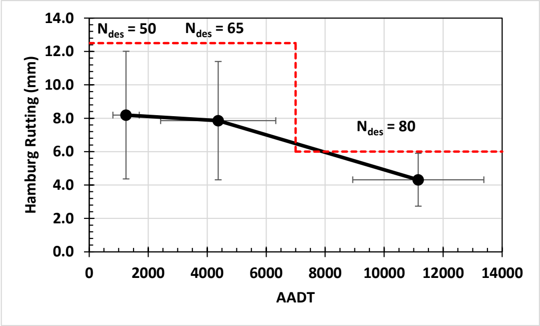


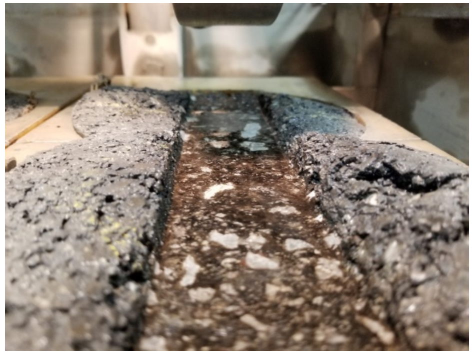


Recent Local BMD Efforts

- NETC (New England Transportation Consortium)
  - Worked with regional state consortium to help develop performance test criteria
    - Surveys on pavement performance and test methods
    - Performance test criteria development
    - Recommendations on implementation and field validation of criteria

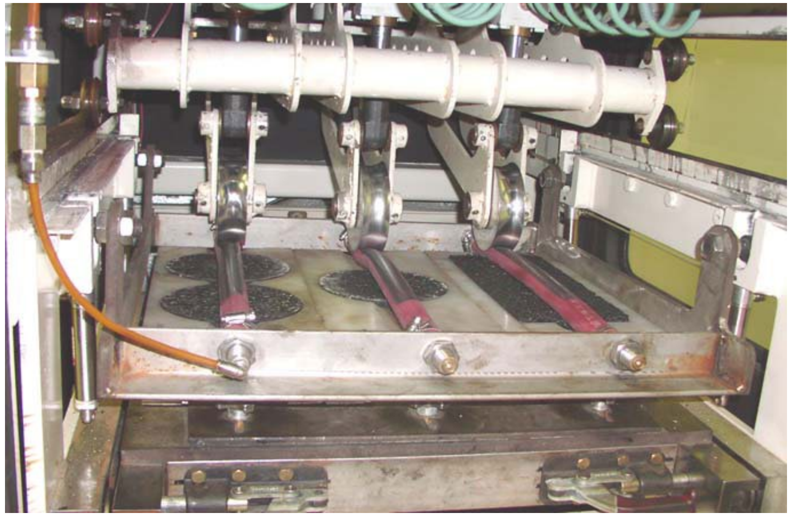


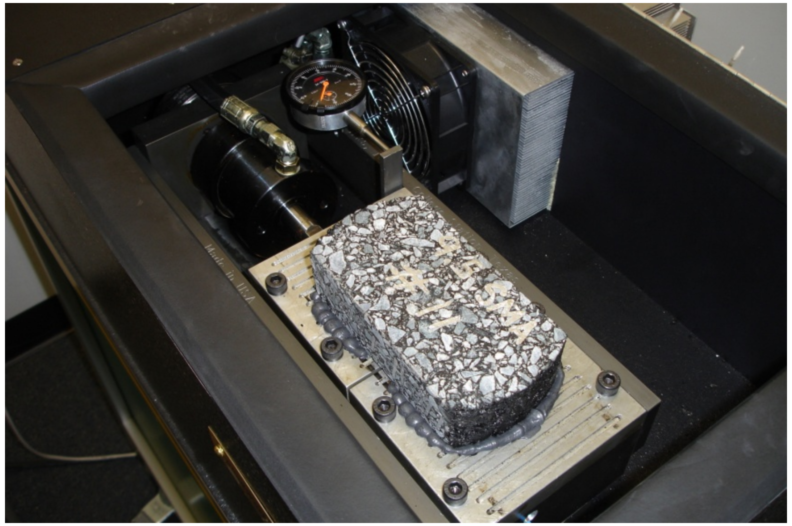




NJDOT Performance Related Specifications (PRS)

- NJDOT developed PRS using the Asphalt Pavement Analyzer (AASHTO T340) and Overlay Tester (NJDOT B-10)
  - Flexural beam fatigue used for BRBC and BDWSC mixes
- Criteria established for different mixes based on research and field performance history





NJDOT – QC Performance

- Although APA and Overlay Tester are great tools for mix design and assurance, not suited for QC testing during plant production
  - APA (Rutting)
    - 4 to 6 gyratories
    - > 6 hours conditioning; 2+ hours testing
    - Larger sized equipment and moderately expensive
  - Overlay Tester (Fatigue Cracking)
    - 5 gyratories
    - Cutting, trimming, gluing and testing ≈ 2 days
    - Larger sized equipment and moderately expensive

Performance Test Method Requirements for QC (NCHRP 9-57)

- Simplicity: no instrumentation, cutting, gluing, drilling and/or notching
- Equipment Cost: as inexpensive as possible
- Practicality: minimum training necessary
- Efficiency: test completed within 1 minute
- Repeatability: Coefficient of Variation (COV) less than 25%
- Sensitivity: sensitive to asphalt content, volumetrics, binder type, aging
- Correlation to Field: a must! (or highly correlated to an accepted & existing procedure)

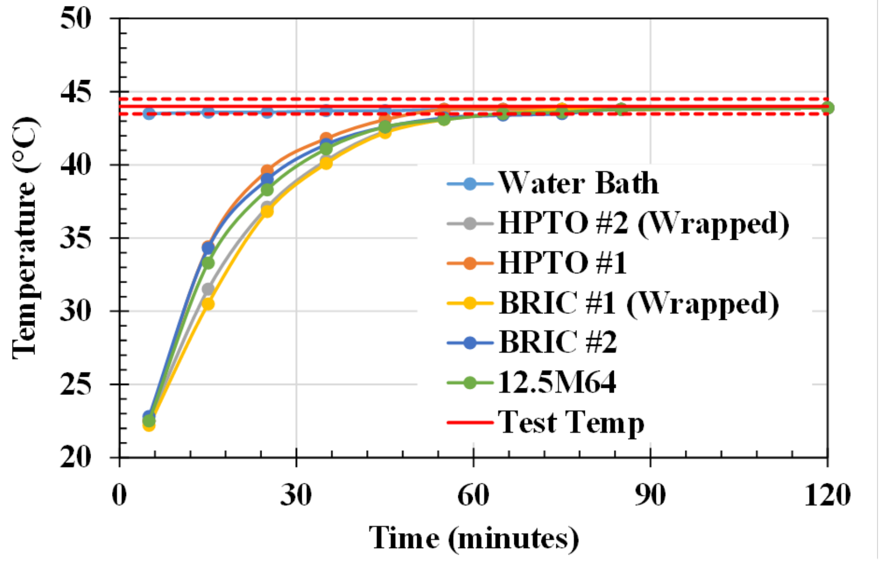
IDT Performance Testing - Procedures

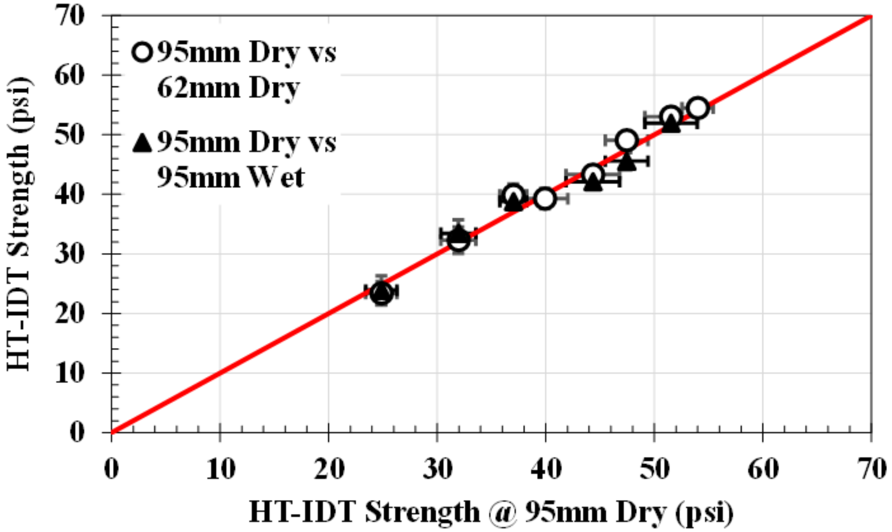
Required IDT Test Procedure Equipment

- 2 Water baths (or environmental or combination of both)
- Loading frame with capacity of 10,000 lbs and loading rate of 2 in/min

IDT Testing – Conditioning

- Conditioning conducted for 2 hours at test temperature in water bath
  - Testing showed specimens could be conditioned wet or dry (sealed)
    - NCHRP 9-57A confirmed for IDEAL-CT
  - Dummy specimen with thermistor helps to speed up time

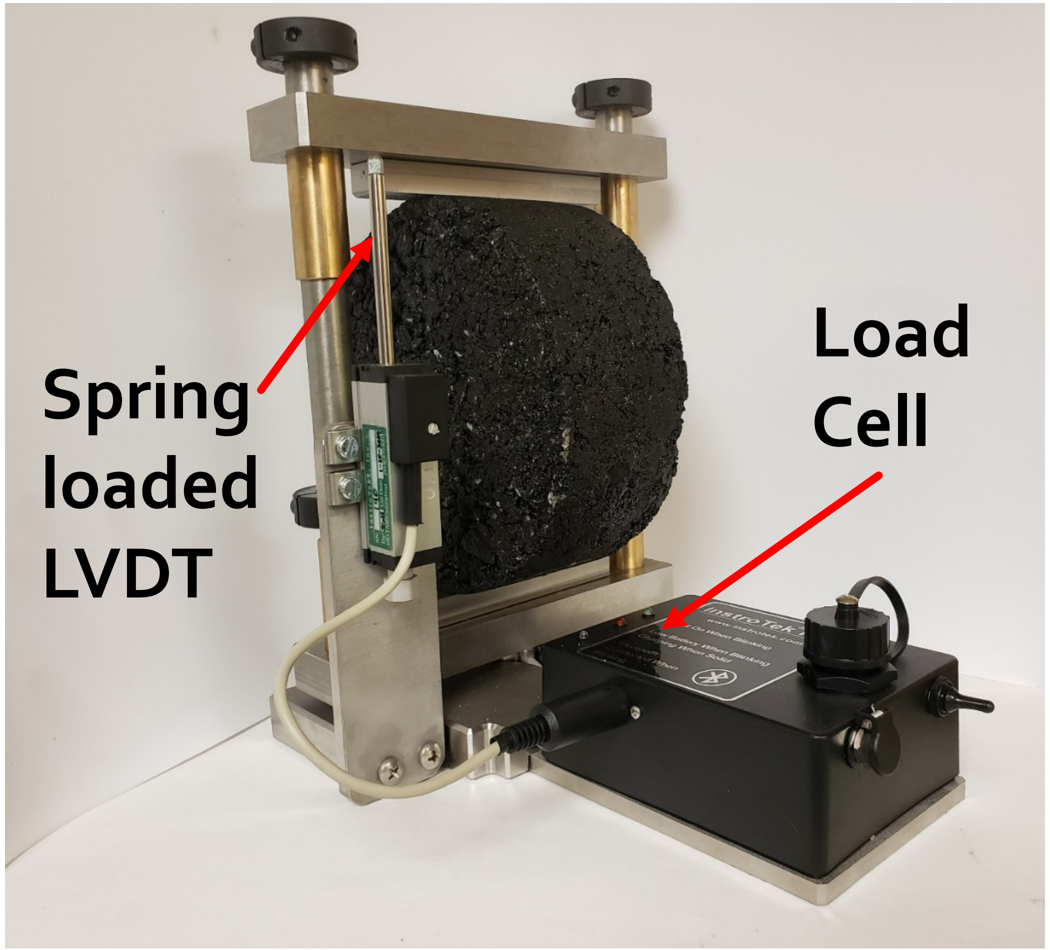


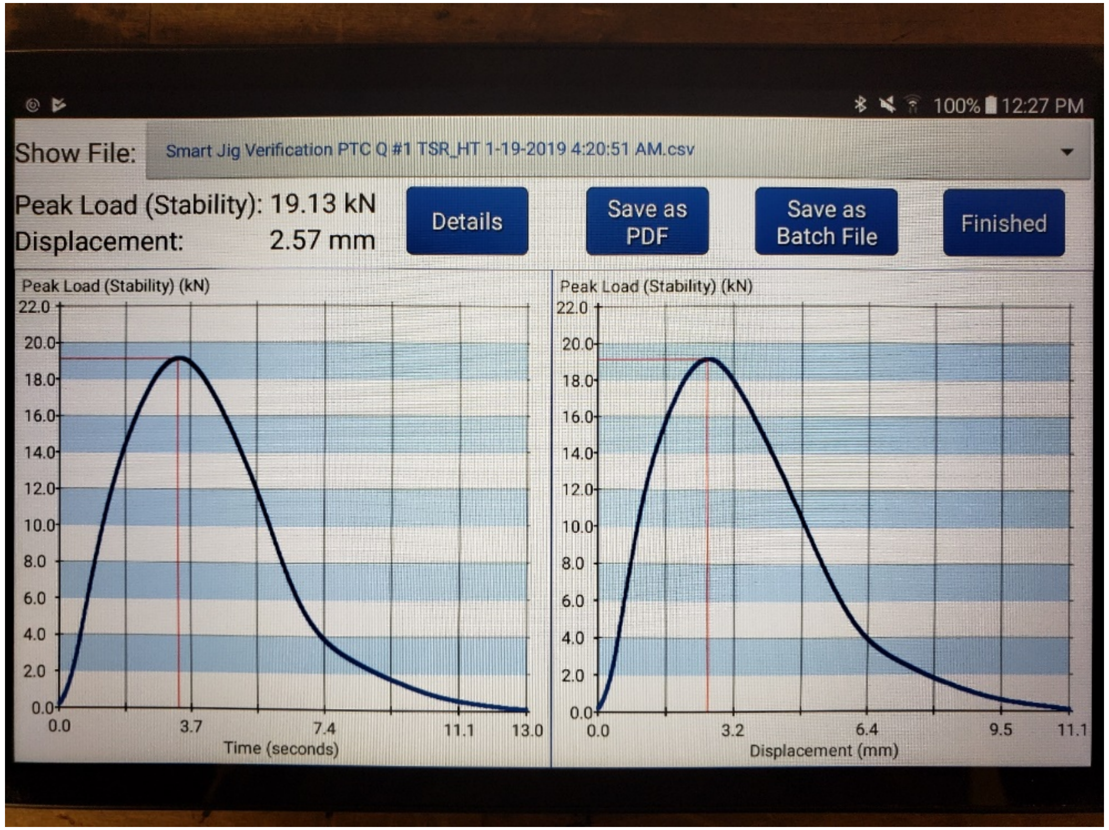


Test Equipment for BMD and QC Performance Testing

- Rutting and cracking performance can be assessed with minor investments using IDT set-up
  - Can use T166 water bath for IDEAL-CT
  - Additional Cost: SMART JIG allows most compression machines at 50 mm/min to be used

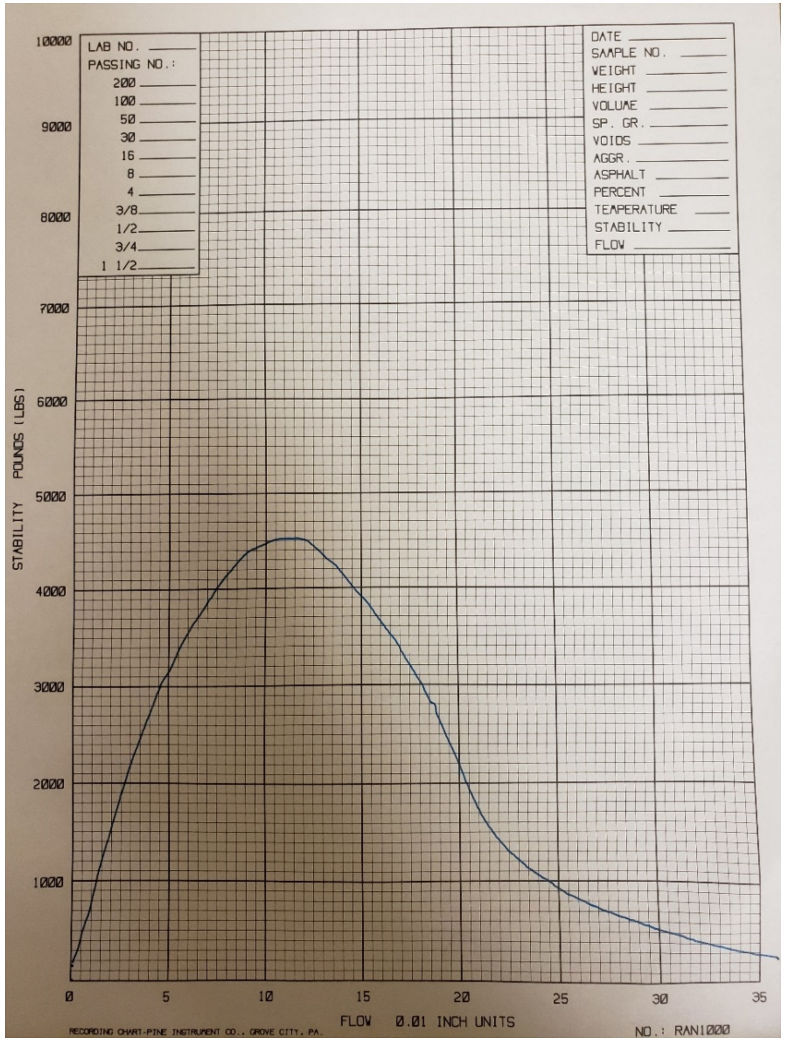
InstroTek's SMART IDT Jig





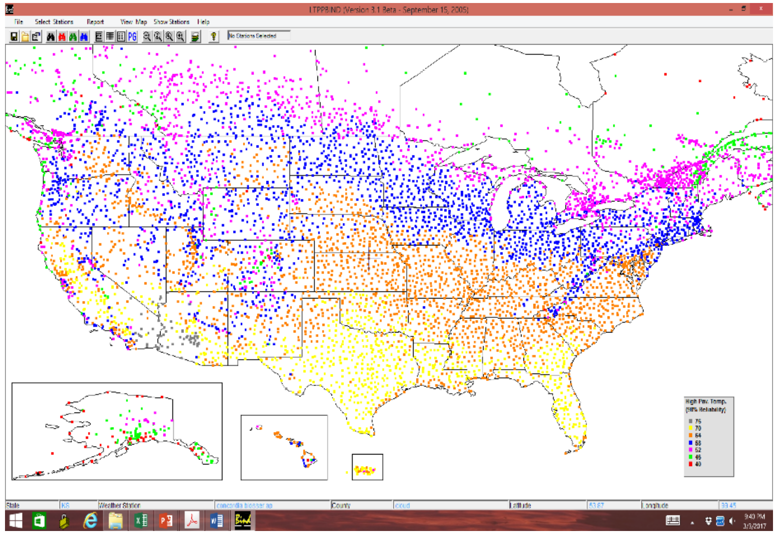
Test Data Output – Pen & Paper

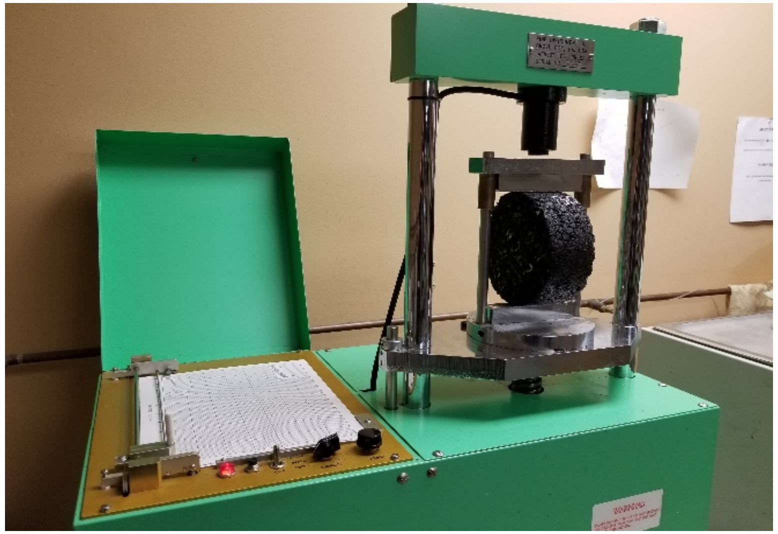
- Can still conduct the test using old pen and paper of Marshall press
  - May have issues with soft mixes running off paper
- Import data to Excel
  - Manual or digitally
- Determine area under curve (integration)
- Follow calculations for slope and final CT_{index}



Rutting – High Temperature IDT, HT-IDT (AAT, 2011)

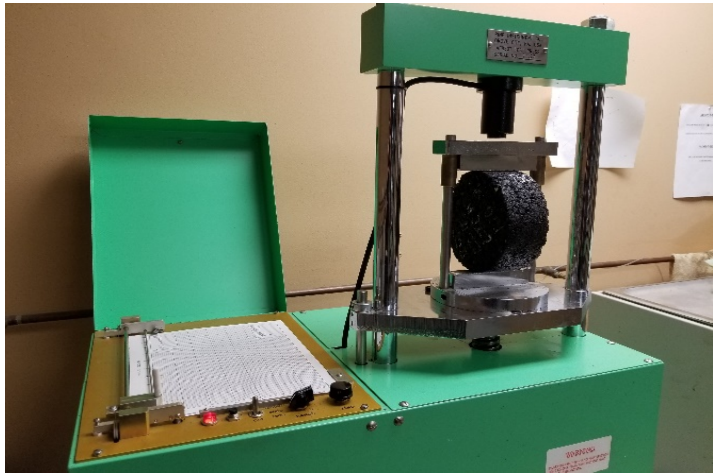
- High temperature IDT (NCHRP 9-33 Recommendations)
  - Uses TSR IDT frame with Lottman head (used for TSR; AASHTO T283)
  - Gyratory compacted samples (set air void level to specified)
  - 50 mm/min (2 inch/min) deformation rate
  - Test temperature is 10°C lower than local climate (LTPPBind 3.1, 98% Reliability, 20 mm below surface, not corrected for traffic or vehicle speed)
    - For NJ = 44°C

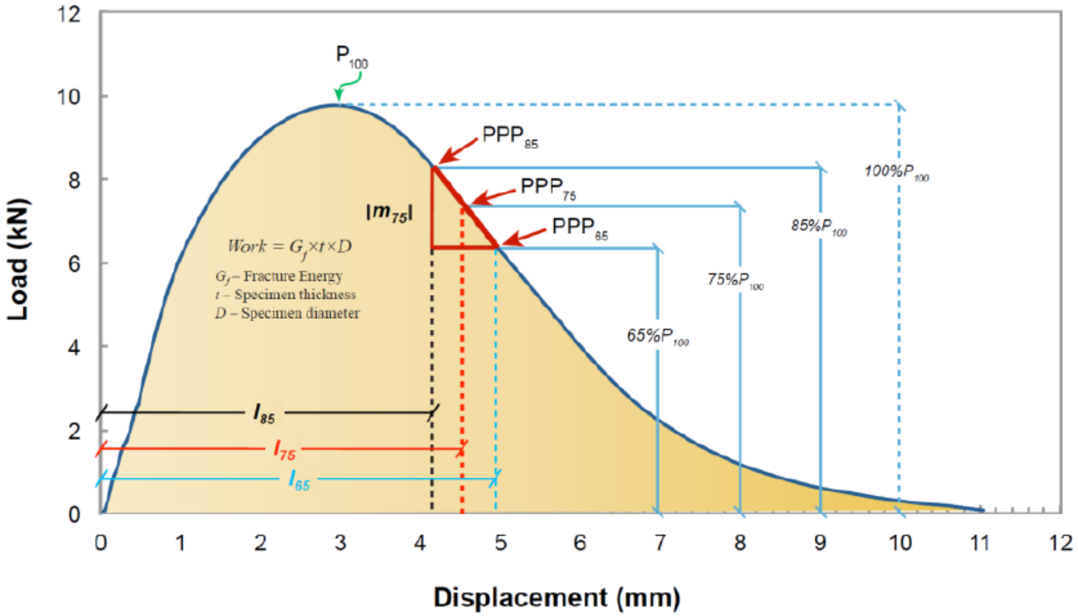




Fatigue Cracking – IDEAL-CT (Zhou et al., AAPT 2017)

- Fatigue Cracking (ASTM D8225)
  - Uses TSR IDT frame with Lottman head (used for TSR; AASHTO T283)
  - Gyratory compacted samples (set air void level to specified)
  - 50 mm/min (2 inch/min) deformation rate
  - Test temperature is 25°C





IDT Performance Testing
- Variability (Round Robin Results)

Variability – NJ Round Robin

- Five different asphalt mixtures designed for different levels of performance
- Specimens compacted to height targeting 6% +/- 0.5% air voids

Asphalt Content	Mixture ID	Binder Grade	HT-IDT (psi)		IDEAL-CT	
			Ave	Std Dev	Ave	Std Dev
5% AC	Mix #1	64-22	38.6	0.9	81.4	6.9
5.5% AC	Mix #2	64-22	32.5	1.2	134.0	4.5
	Mix #3	76-22	60.0	0.6	184.1	41.2
6% AC	Mix #4	64-22	31.7	1.5	169.1	15.7
6.5% AC	Mix #5	76-22	45.0	1.1	456.0	26.8

Variability – NJ Round Robin

- Great care was taken to make sure each specimen was created “identically”
  - Every 4th sample compacted was broken down and tested
    - Gmm
    - Asphalt content
    - Gradation
- After air voids determined, specimens dried, wrapped in plastic and assigned a number
  - Samples designated to labs using random numbers

Sample ID	Gmm (g/cm^3)	Asphalt Content (%)	% Passing		
			3/8"	No. 8	No. 200
B4	2.752	5.01	93.2	39.9	6.8
B8	2.749	5.16	93.8	43.3	7.1
B12	2.743	4.91	90.7	38.3	6.7
B16	2.736	4.94	92.3	40.9	7.0
B20	2.728	5.11	90.8	43.5	8.0
B24	2.724	5.10	91.8	40.3	6.4
B28	2.729	5.01	90.5	40.2	6.8
B32	2.733	5.06	90.7	42.1	6.7
Average	**2.737**	**5.04**	**91.7**	**41.1**	**6.9**
Std Dev	**0.010**	**0.09**	**1.27**	**1.79**	**0.48**
COV%	**0.37**	**1.71**	**1.38**	**4.35**	**6.89**

Sample ID	Gmm (g/cm^3)	Asphalt Content (%)	% Passing		
			3/8"	No. 8	No. 200
C4	2.705	5.59	92.2	41.9	7.5
C8	2.708	5.50	94.1	43.7	7.5
C12	2.706	5.62	91.7	40.7	6.0
C16	2.702	5.59	91.4	39.3	6.1
C20	2.694	5.61	92.5	41.4	7.0
C24	2.696	5.50	90.4	40.7	6.8
C28	2.706	5.55	91.7	39.5	6.4
C32	2.694	5.60	91.8	41.9	5.8
C36	2.690	5.58	89.8	39.1	5.9
Average	**2.701**	**5.57**	**91.7**	**40.9**	**6.6**
Std Dev	**0.006**	**0.04**	**1.23**	**1.50**	**0.67**
COV%	**0.22**	**0.80**	**1.34**	**3.66**	**10.21**

Sample ID	Gmm (g/cm^3)	Asphalt Content (%)	% Passing		
			3/8"	No. 8	No. 200
D4	2.677	5.91	91.2	38.3	6.4
D8	2.684	5.99	92.4	41.1	6.5
D12	2.683	6.11	91.5	42.8	7.2
D16	2.690	6.06	91.1	42.7	6.8
D20	2.690	6.14	91.7	41.4	6.8
D24	2.680	6.00	91.7	40.9	7.2
D28	2.688	5.91	91.4	42.5	7.2
D32	2.664	6.10	89.3	40.1	6.5
Average	**2.682**	**6.03**	**91.3**	**41.2**	**6.8**
Std Dev	**0.009**	**0.09**	**0.90**	**1.52**	**0.34**
COV%	**0.32**	**1.48**	**0.98**	**3.70**	**5.00**

Sample ID	Gmm (g/cm^3)	Asphalt Content (%)	% Passing		
			3/8"	No. 8	No. 200
E4	2.704	5.54	92.9	40.8	6.9
E8	2.703	5.44	91.9	40.9	7.0
E12	2.701	5.51	89.5	40.9	6.7
E16	2.689	5.41	91.6	40.3	6.3
E20	2.690	5.53	91.8	42.3	7.3
E24	2.693	5.39	89.7	38.4	6.5
E28	2.705	5.49	89.2	38.7	6.5
E32	2.702	5.50	92.1	40.4	7.2
E36	2.702	5.48	91.2	40.1	6.2
Average	**2.699**	**5.48**	**91.1**	**40.3**	**6.7**
Std Dev	**0.006**	**0.05**	**1.31**	**1.18**	**0.39**
COV%	**0.24**	**0.96**	**1.44**	**2.93**	**5.80**

Sample ID	Gmm (g/cm^3)	Asphalt Content (%)	% Passing		
			3/8"	No. 8	No. 200
F4	2.655	6.60	91.7	40.7	6.5
F8	2.653	6.54	94.5	42.3	6.9
F12	2.662	6.43	90.4	39.7	6.4
F16	2.655	6.39	88.4	39.2	6.4
F20	2.648	6.41	89.5	39.9	6.8
F24	2.658	6.54	89.8	41.6	7.1
F28	2.653	6.43	90.8	39.1	6.3
F32	2.651	6.57	94.6	42.7	7.3
F36	2.667	6.48	93.2	42.9	7.5
Average	**2.656**	**6.49**	**91.4**	**40.9**	**6.8**
Std Dev	**0.006**	**0.08**	**2.23**	**1.51**	**0.43**
COV%	**0.22**	**1.18**	**2.44**	**3.70**	**6.37**

Variability – NJ Round Robin

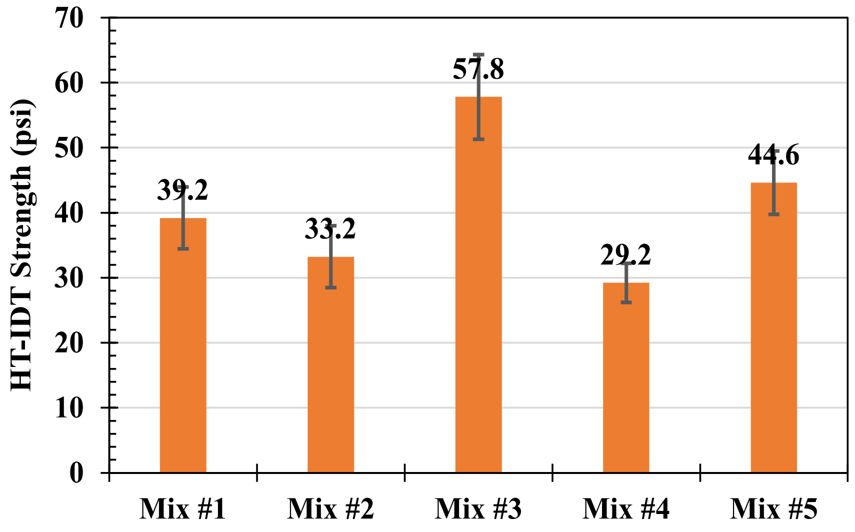
- Nine laboratories tested five different asphalt mixtures for IDEAL-CT Index and HT-IDT
  - 7 asphalt plant QC labs
  - 1 state agency lab
  - 1 university lab

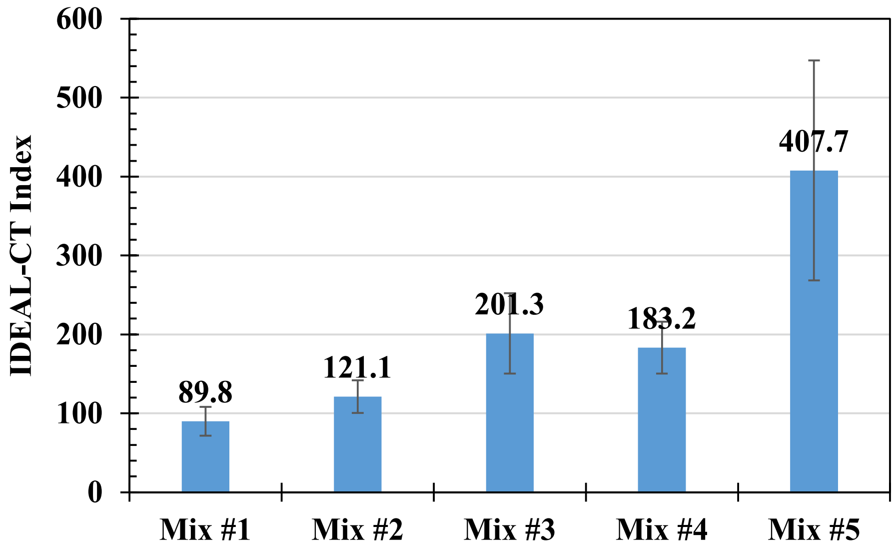
Laboratory	Test Equipment	Conditioning
Lab #1	Smart Jig with Pine Marshall	Rite-Hete Water Bath
Lab #2	Auto SCB Compression	Water Bath
Lab #3	Humboldt Compression	Water Bath
Lab #4	Smart Jig with Pine Marshall	Humboldt Water Bath
Lab #5	Smart Jig with InstroTek Compression	Humboldt Water Bath
Lab #6	Smart Jig with Humboldt Compression	Humboldt Water Bath
Lab #7	Smart Jig with Pine Marshall	Water Bath
Lab #8	Smart Jig with Pine Marshall	Water Bath
Lab #9	Auto SCB Compression	PolyScience Water Bath

Variability – NJ Round Robin

- Test methods found to be repeatable even when using different test and conditioning equipment

Mixture ID	Average Single Operator COV%		Average Multiple Operator COV%	
	HT-IDT	IDEAL-CT	HT-IDT	IDEAL-CT
Mix #1	9.3	16.9	12.1	20.3
Mix #2	12.6	15.7	14.4	17.2
Mix #3	6.8	19.9	11.3	25.3
Mix #4	6.5	8.6	10.3	18.0
Mix #5	5.8	15.0	11.0	34.2
Average	8.2	15.2	11.8	23.0





Variability – NJ IDT Round Robin

- If evaluating variability using AASHTO Re:source methods, no lab scored lower than a "3" for average results
  - RED color shows results lower than average
  - GREEN color shows results higher than average
    - Lab #2 had difficulty testing IDEAL-CT

IDEAL-CT

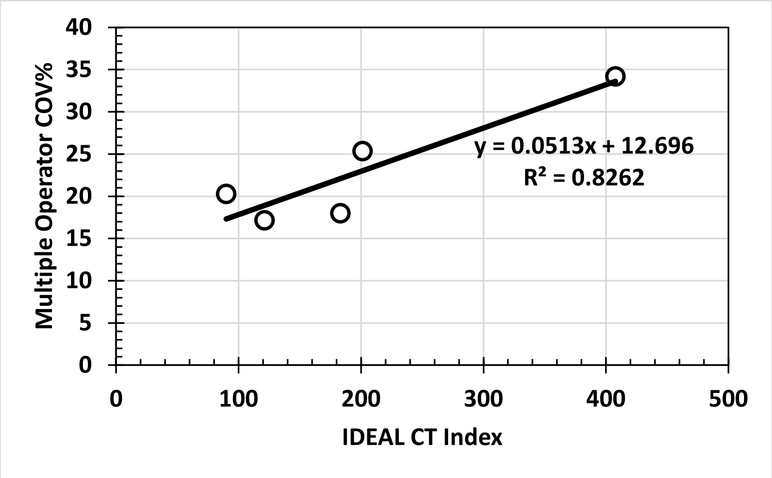
Lab	Sample #	Z-score	Rating	Rating
Lab #1	Sample 1	-0.885	5	5
	Sample 2	0.278	5	
	Sample 3	0.968	5	
Lab #3	Sample 1	0.473	5	5
	Sample 2	-0.804	5	
	Sample 3	0.106	5	
Lab #4	Sample 1	2.696	1	3
	Sample 2	1.457	4	
	Sample 3	0.927	5	
Lab #5	Sample 1	0.728	5	5
	Sample 2	-0.108	5	
	Sample 3	-0.084	5	
Lab #6	Sample 1	0.125	5	5
	Sample 2	-0.411	5	
	Sample 3	-1.160	4	
Lab #7	Sample 1	-1.353	4	5
	Sample 2	-0.559	5	
	Sample 3	-0.369	5	
Lab #8	Sample 1	0.200	5	4
	Sample 2	-1.948	3	
	Sample 3	-0.488	5	
Lab #9	Sample 1	0.496	5	5
	Sample 2	-0.966	5	
	Sample 3	0.678	5	

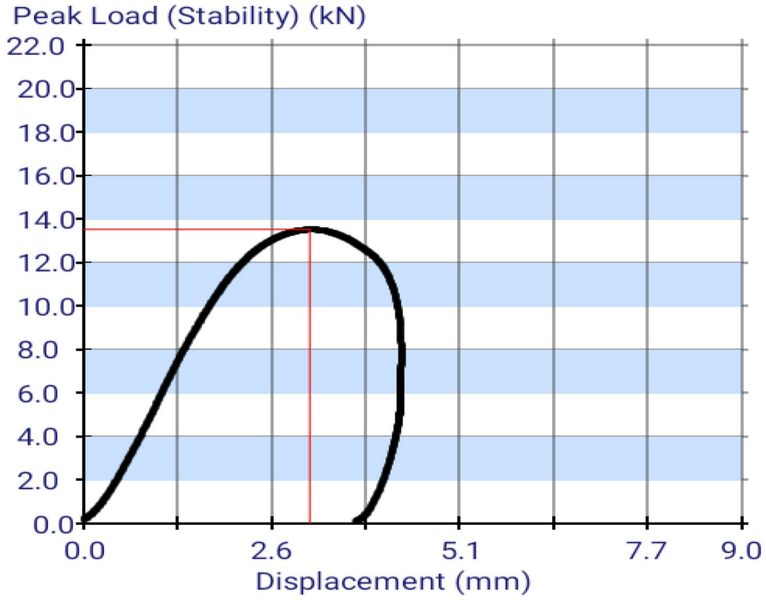
HT-IDT

Lab	Sample #	Z-score	Rating	Rating
Lab #1	Sample 1	-0.110	5	5
	Sample 2	1.170	4	
	Sample 3	0.728	5	
Lab #2	Sample 1	-0.205	5	5
	Sample 2	-0.906	5	
	Sample 3	0.095	5	
Lab #3	Sample 1	-0.716	5	5
	Sample 2	-1.090	4	
	Sample 3	-0.209	5	
Lab #4	Sample 1	-0.783	5	4
	Sample 2	-1.951	3	
	Sample 3	-1.300	4	
Lab #5	Sample 1	1.730	3	3
	Sample 2	2.565	1	
	Sample 3	-0.072	5	
Lab #6	Sample 1	-0.115	5	5
	Sample 2	0.869	5	
	Sample 3	0.489	5	
Lab #7	Sample 1	-0.590	5	5
	Sample 2	0.327	5	
	Sample 3	-0.526	5	
Lab #8	Sample 1	-0.199	5	5
	Sample 2	-1.099	4	
	Sample 3	-0.329	5	
Lab #9	Sample 1	-0.036	5	5
	Sample 2	0.877	5	
	Sample 3	1.386	4	

Variability – NJ IDT Round Robin

- Higher variability associated with IDEAL-CT test than HT-IDT
  - More variability when testing softer mixes
    - Determining slope and area under curve
- When using Marshall press, operator will need to keep holding down "override" switch or specimen will not reach test failure
  - Test conducted on Marshall with SmartJig unit





Equipment Differences (4 Labs)

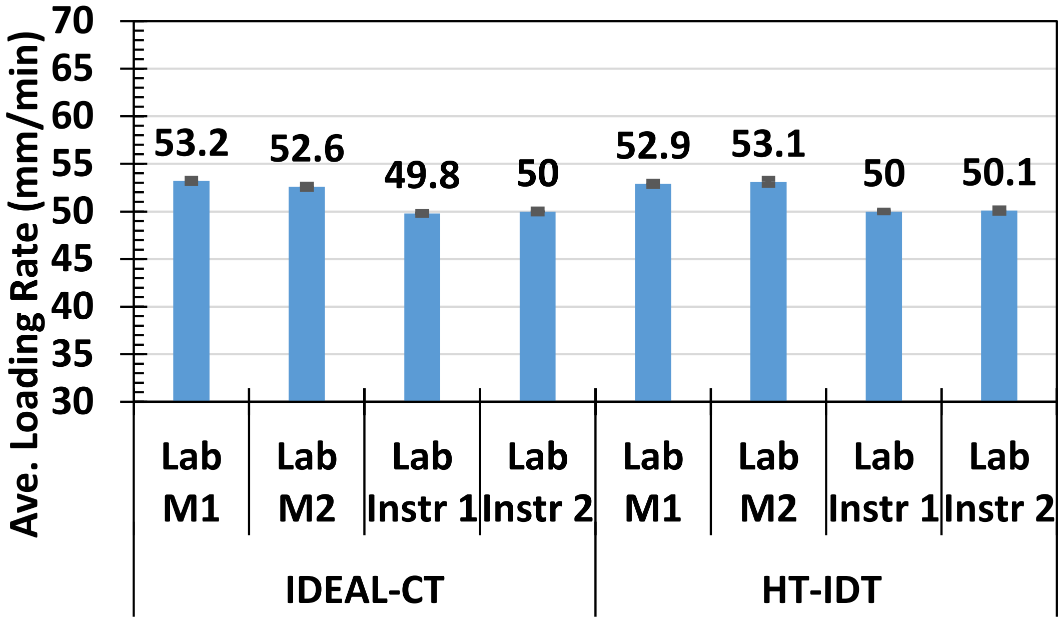
- 60 Lab Comparisons
- 7 Statistical Comparisons "Not Equal"
  - 4 occasions Marshall vs Auto SCB
  - 3 occasions between same equipment
    - 2 Marshall
    - 1 Auto SCB

HT-IDT				
Mix 1	**LAB 1 - M**	**LAB 2 - M**	**LAB 1 - IN**	**LAB 2 - IN**
LAB 1 - M				
LAB 2 - M	EQUAL			
LAB 1 - IN	EQUAL	EQUAL		
LAB 2 - IN	EQUAL	EQUAL	EQUAL	

IDEAL-CT				
Mix 1	**LAB 1 - M**	**LAB 2 - M**	**LAB 1 - IN**	**LAB 2 - IN**
LAB 1 - M				
LAB 2 - M	EQUAL			
LAB 1 - IN	EQUAL	EQUAL		
LAB 2 - IN	EQUAL	EQUAL	UNEQUAL	

Loading Rate Differences

- Evaluated the loading rates for 30 tests for each lab
  - 15 HT-IDT; 15 IDEAL-CT
  - SMART Jig used to collect data
- On average, Marshall devices higher than current spec (48 to 52 mm/min)
  - However, <u>final results found to be statistically equal</u>
  - NCHRP 9-57A Ruggedness Study of IDEAL-CT
    - +/- 2 mm/min not statistically significant



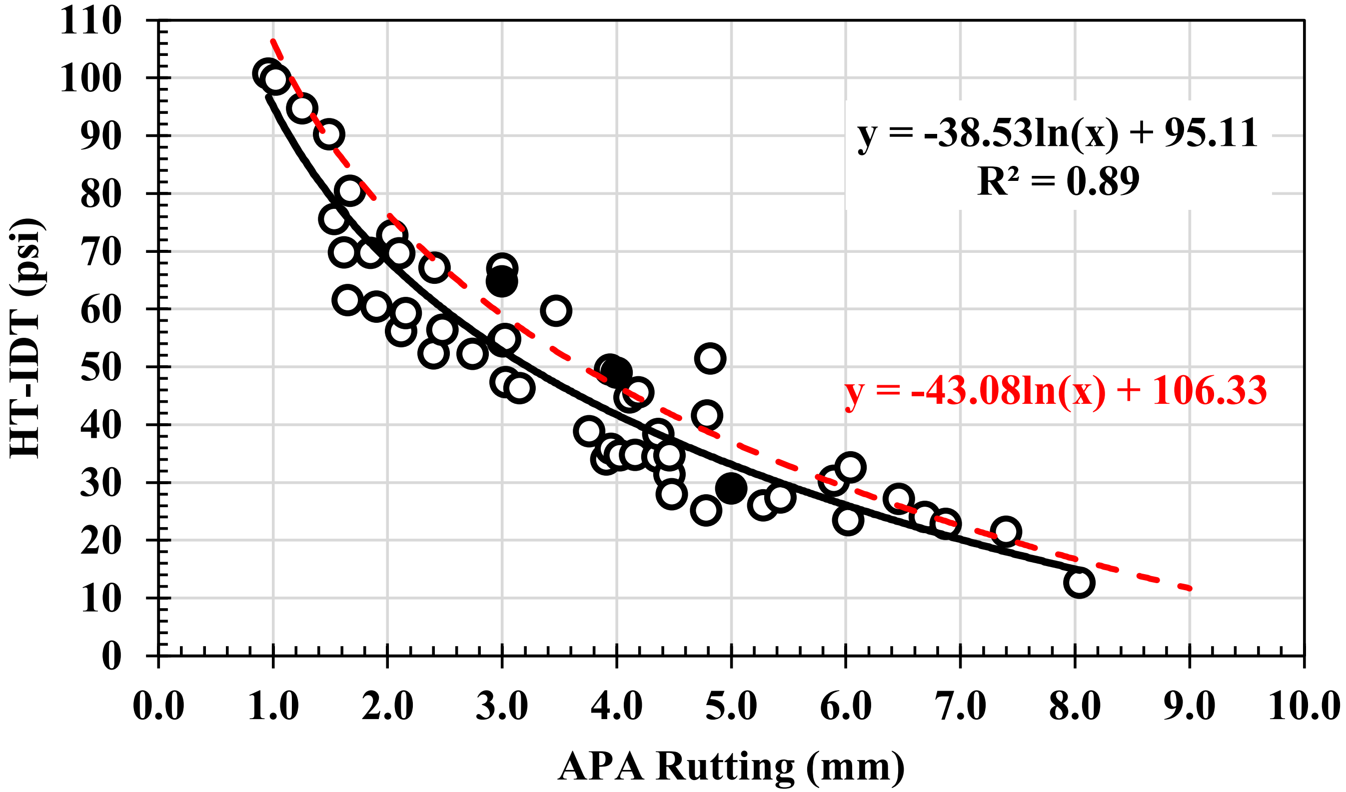
Implementing IDT for QC – Surrogate Testing for NJ

Using IDT Tests as QC Surrogates

- Due to time requirements, APA and Overlay Tester not suitable for QC testing during production
- IDT testing proposed
  - Need to compare IDT results with standard NJ test methods
    - APA ≈ HT-IDT & Overlay Tester ≈ IDEAL-CT
  - Utilized a large database of various laboratory and plant produced asphalt mixtures

HT-IDT vs APA Rutting – Preliminary Guidance Values in NJ

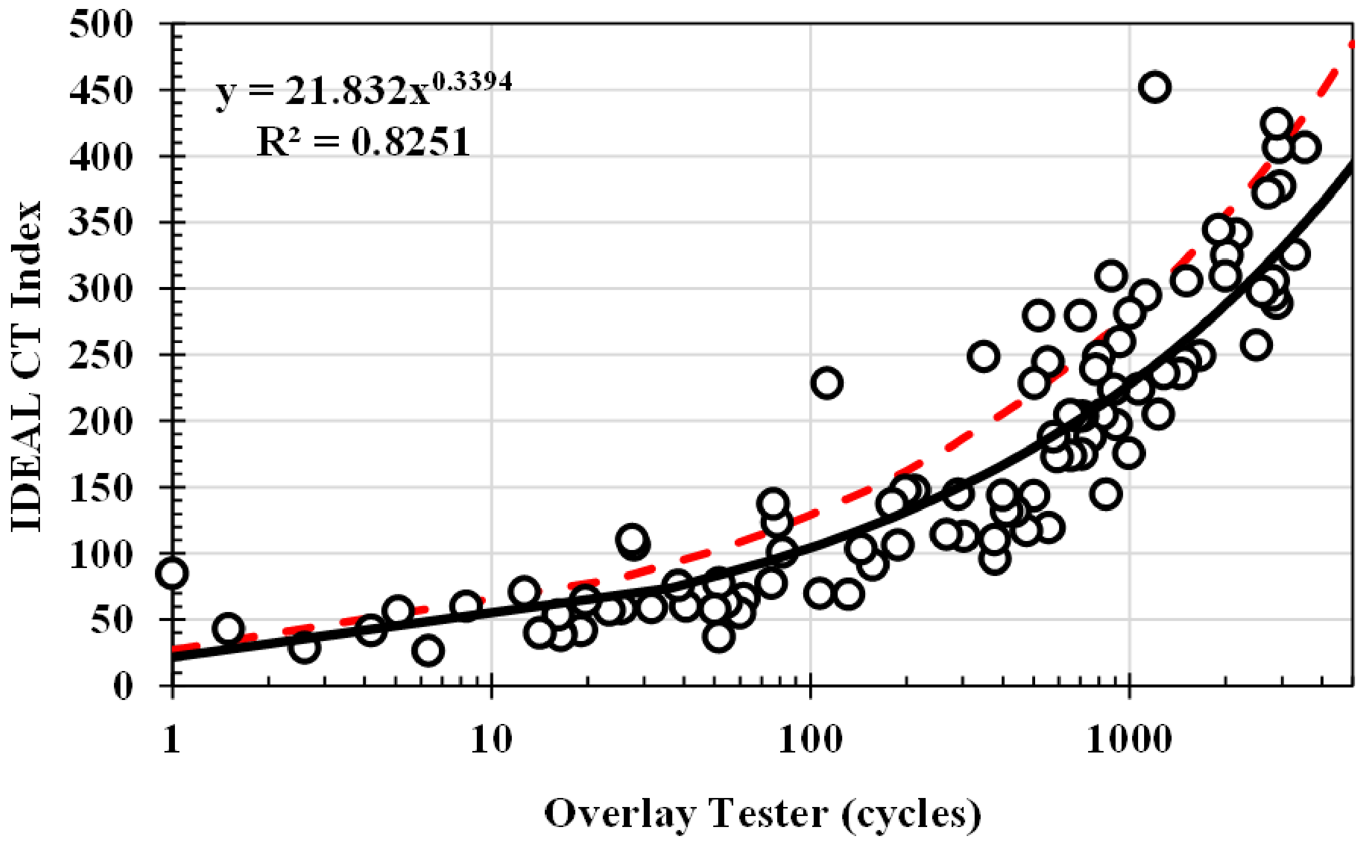
- n = 54; COV% = 11.8%
- APA @ 64C; HT-IDT @ 44C



- Black Symbols from NCHRP 9-33
- Open Symbols Rutgers data
- Black line correlation
- Red dotted line is proposed.
- Pass/Fail criteria that includes HT-IDT Multiple Operator COV% = 11.8%

IDEAL-CT vs Overlay Tester – Preliminary Guidance Values

- n = 101; COV% = 23%



- Open Symbols Rutgers data
- Black line correlation
- Red dotted line is proposed.
- Pass/Fail criteria that includes IDEAL-CT Multiple Operator COV% = 23%

HT-IDT and IDEAL-CT Proposed Criteria for PRS and BMD

Mixture Type			Minimum IDEAL-CT Index	High Temperature IDT Strength (psi)
High RAP (HRAP)	Surface	PG64E-22	190	47
		PG64S-22	170	23
	Intermediate /Base	PG64E-22	150	47
		PG64S-22	130	23
Bituminous Rich Intermediate Course (BRIC)			250	30
High Performance Thin Overlay (HPTO)			240	47

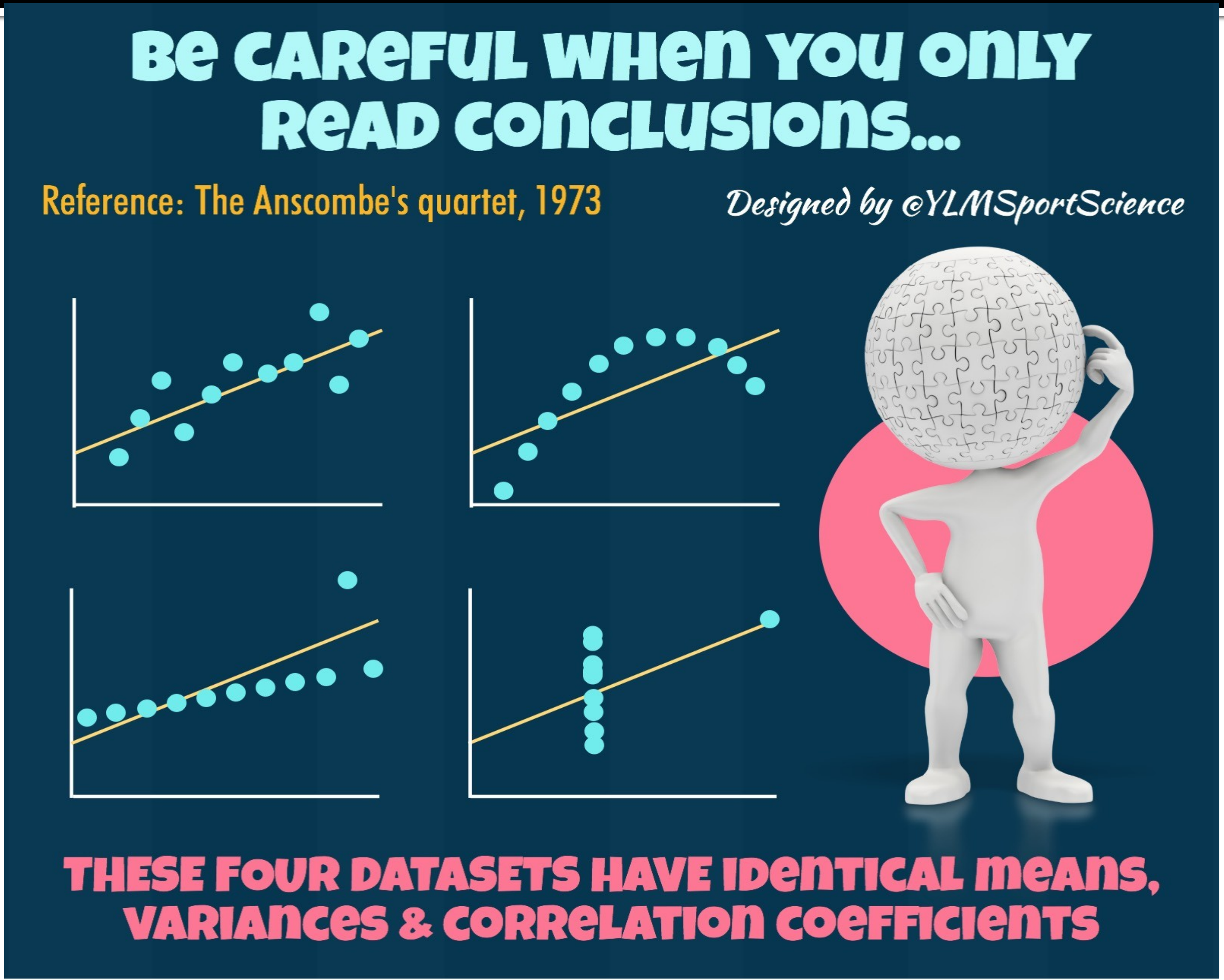
IDT Test Implementation at Other Agencies

- IDEAL-CT test is currently being evaluated by a large number of state agencies across the country
- NYSDOT
- MoDOT
  - Investigating use in Pay Adjustments
- MDSHA
  - Developing database of mixture performance with both IDT test methods
- Alabama DOT
  - Currently evaluating IDT methods for QC
  - Local agencies have already starting adopting

Conclusions

- Inclusion of performance testing in HMA mix design & QC/QA under review and implementation by a number of states
- IDT test procedures
  - Implementable at the QC Lab with quick turnaround time
  - Sensitive to mixture parameters
  - Repeatable
    - Different test devices & levels of experience
  - Correlate well with existing test procedures (Surrogate)
- Give them a try, you may like it!

Thank you for your time!
Questions?



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