About the Presenter

- **Mark Snyder** is the President of Pavement Engineering and Research Consultants (PERC), LLC and a Special Consultant to the American Concrete Pavement Association (ACPA).
- He holds BS, MS and PhD degrees in Civil Engineering from the University of Illinois (Urbana-Champaign) and is a registered professional engineer in Illinois, Minnesota, Pennsylvania and Hawaii.
- Mark has more than 40 years of experience in pavement engineering and research, including 13 years as a professor, 10 years of concrete paving association work, and many more years of engineering consulting.
- He is currently about 90 percent retired and is trying for 100.

Load Transfer Test Results and Proposed Dowel Specification Changes

Presented by:

Mark B. Snyder, Ph.D., P.E.

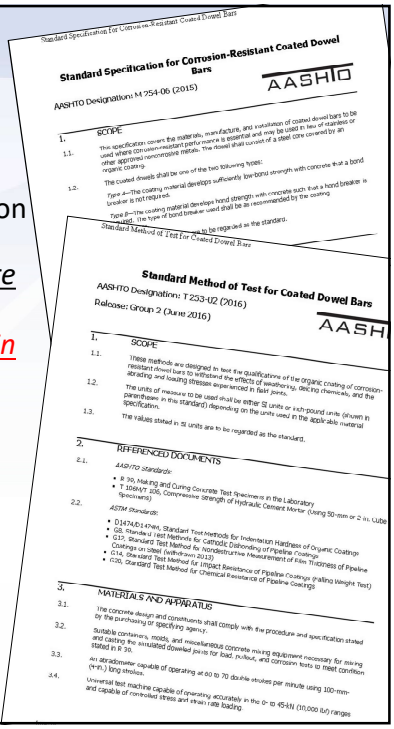
Pavement Engineering and Research Consultants, LLC

Special Consultant to ACPA National

National Concrete Consortium (NCC)
Spring 2021 Virtual Meeting
April 15, 2021

Current AASHTO Dowel Specs

- M 254 – Standard Specification for Corrosion-Resistant Coated Dowel Bars (last revised 2006, reapproved 2019)
  - "… specification covers the materials, manufacture and installation of coated dowel bars to be used where corrosion-resistant performance is essential … [t]he *dowel shall consist of a steel core covered by an organic coating*." (Emphasis added)
  - For "organically coated" (epoxy- or plastic-coated) dowels, *1.25-in diameter*, 20-30 mils coating (Type A, low bond strength) or 5-9 mils (Type B, bond breaker required).
  - *Dowels qualified as individual products*, not as part of a system.
- T 253 – Standard Method of Test for Coated Dowel Bars (last revised 2002, reapproved 2020)
  - "..methods to test the qualifications of the organic coating of corrosion-resistant dowel bars to withstand the effects of weathering, de-icing chemicals, and the abrading and loading stresses experienced in field joints."


Standard Specification for Corrosion-Resistant Coated Dowel Bars

Standard Specification for Corrosion-Resistant Coated Dowel Bars

AASHTO Designation: M 254-06 (2015)

AASHTO

1. SCOPE

Standard Method of Test for Coated Dowel Bars

AASHTO Designation: T 253-02 (2016)

Release: Group 2 (June 2016)

AASH

1. SCOPE

2. REFERENCED DOCUMENTS

3. MATERIALS AND APPARATUS

Current AASHTO Dowel Spec Details

- Originally approved in 1975
  - Predominant corrosion-resistant dowel was epoxy-coated solid steel
  - Directly applicable to 1.25-inch cylindrical dowels
- Structural Testing
  - Load-Deflection (Static Load, Single Dowel)
  - Pullout
- Durability Testing
  - Abrasion
  - Corrosion
  - Chemical Resistance
  - Cathodic Disbonding
  - Coating Hardness
  - Coating Impact Resistance

Limitations of Current AASHTO Dowel Specs

- Not directly applicable to many dowel products being used and developed today
  - Can't evaluate different dowel materials
    - Different tests needed for different materials, different coatings
  - Can't evaluate behavior of groups of dowels
  - No ability to evaluate potential structural performance potential (differential deflection) of nonstandard dowel spacing

Difficult for manufacturers to innovate.
Difficult for agencies to adopt new products.

What is needed:

A specification and associated suite of structural and corrosion tests that can:

- Provide *manufacturers* with targets and evaluation criteria for *innovative improvements*,

and

- Provide *agencies* with *objective measures of* the relative *potential performance* of competing products.

Brief History

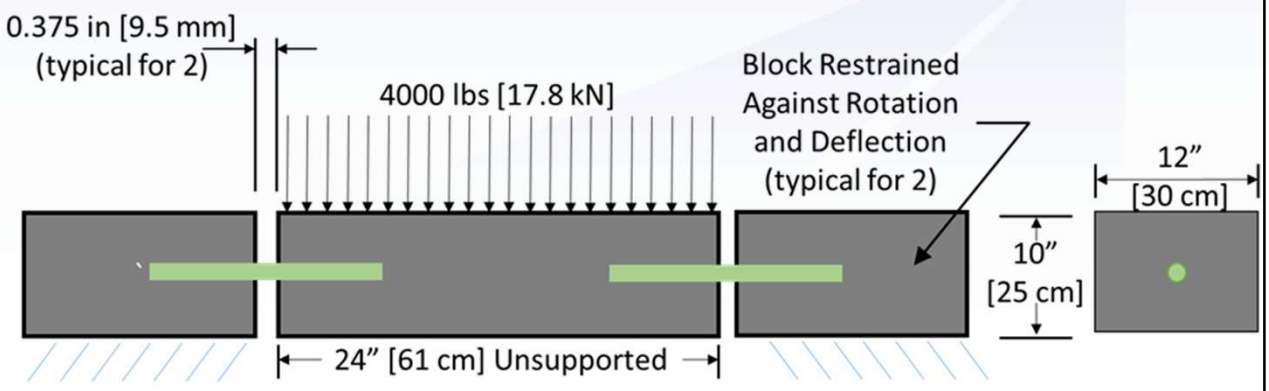
- Effort initiated by NCC around 2014
- Much discussion and energy at first
  - Various drafts and concepts presented and discussed
  - Early 2016 version (Burnham and Snyder) gained general support/consensus of NCC agency members, but interest in concept was insufficient to drive to completion.
- In Mid-2016, ACPA's Jointing Task Force resolved to pick up where NCC left off
  - "Universal" Dowel Spec subcommittee established to include manufacturers and suppliers of dowel products, ACPA Chapter/State staff, and ACPA National staff (with interested NCC state DOT reps as subcommittee "friends")

Objectives

- Establish specifications and tests that can be used by agencies for evaluation of *all* dowel systems
- Provide indications of performance potential
  - Structural adequacy
  - Durability (Corrosion resistance, etc.)
- Use existing T 253/M 254 as basis of development

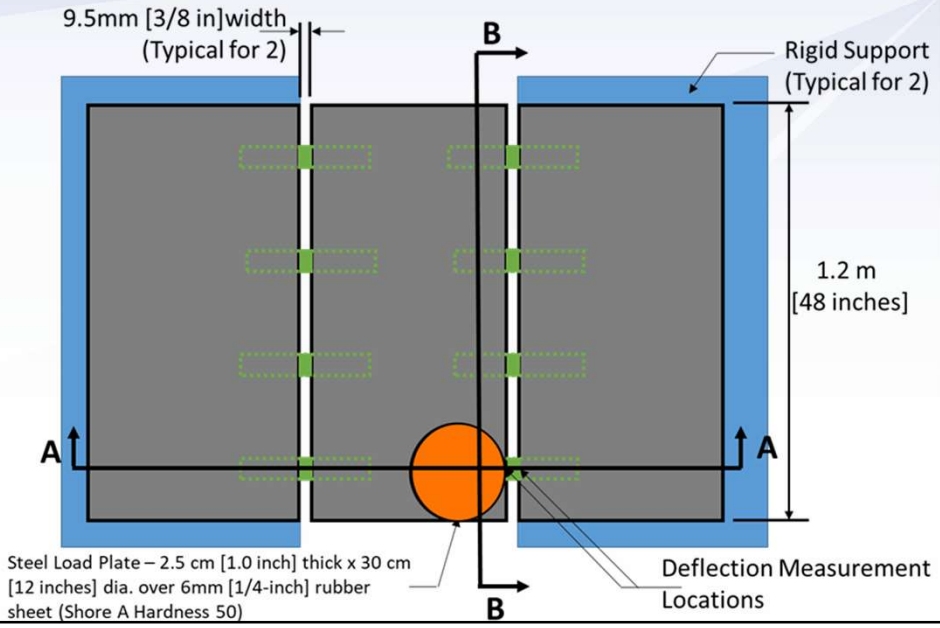
Structural Testing of Dowel *Systems*

Current AASHTO T253 Load-Deflection Test Schematic

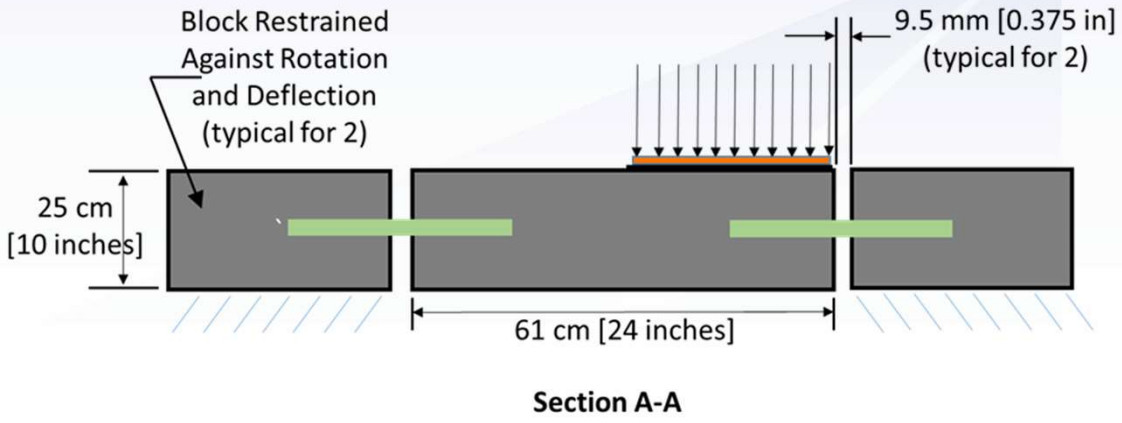


Performance criterion: Limit relative deflection across joints to 10 mils (0.01 inches).

ACPA T253 Load-Deflection Test Schematic



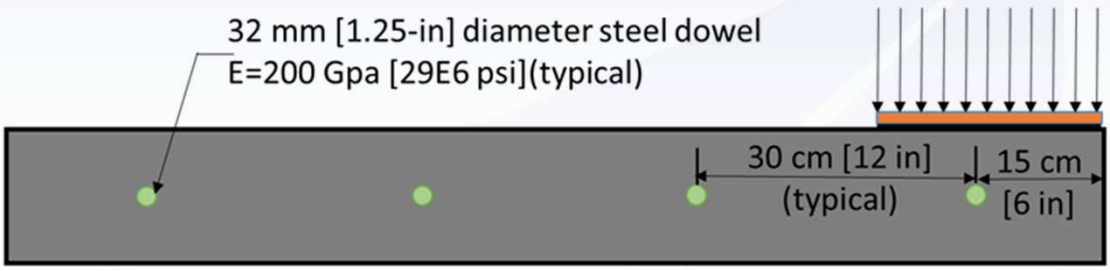
ACPA T253 Load-Deflection Test Schematic



Section A-A

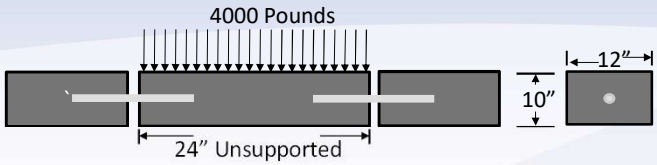
Performance criterion: Limit relative deflection across joints to … ???

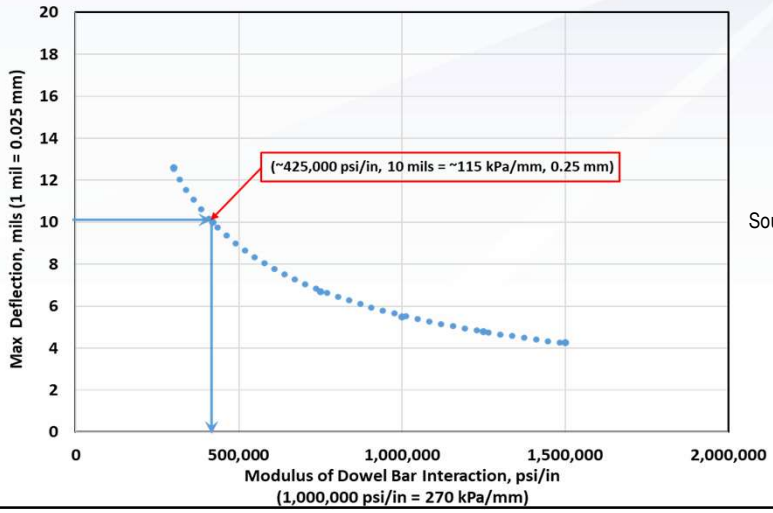
ACPA T253 Load-Deflection Test Schematic



Section B-B
(Typical for Common Steel Dowel Layout)

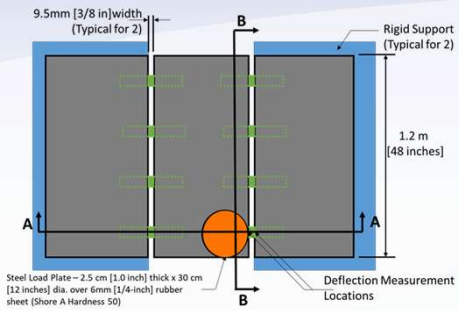
AASHTO T253 Load-Deflection Test Sensitivity to K *(Theoretical)*





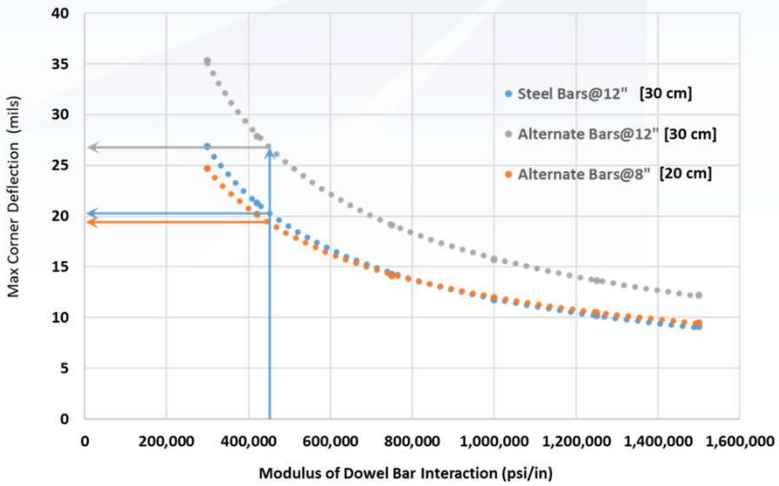
Source: K. Alland, Univ. of Pittsburgh

ACPA T253 Load-Deflection Test Sensitivity to K *(Theoretical)*



FE analysis indicates AASHTO standard T253 test with 10-mil relative deflection should produce 20 mils relative deflection in ACPA T253 procedure. *Validation testing required.*

Source: K. Alland, Univ. of Pittsburgh



Validation of New Structural Test Protocol

Goal:

- Validate multi-dowel structural model behavior (load-deflection) and acceptance threshold (~20 mils)

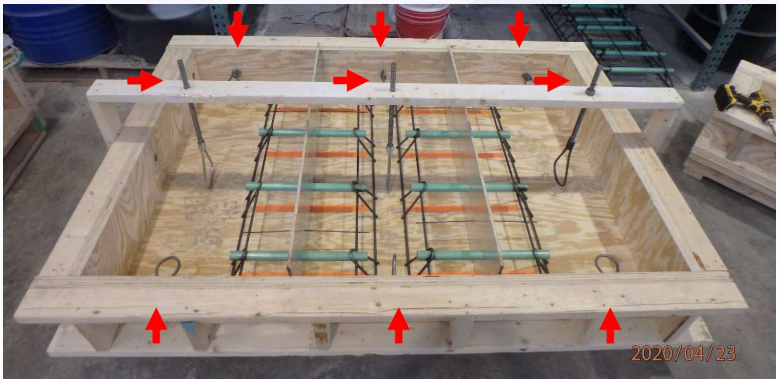
Testing:

- 4 replicates AASHTO T253 load-deflection testing
  - 1.25-inch diameter epoxy-coated steel dowels
  - Yields 8 measurements of relative deflection
- 2 replicates of the proposed modified version of this test
  - Four 1.25-inch diameter epoxy-coated steel dowels per joint
  - *Four test locations per specimen* (one in each of the four corners of the unsupported slab)
  - Yields 8 measurements of relative deflection
- Test protocol modification:
  - Hold load for 10 mins at specified peak (4000 lbs or 9000 lbs), measure RD at start and end of hold
  - Increase load to 150% of specified peak
  - Hold load for 10 mins at new peak (6000 lbs or 13,500 lbs), measure RD at start and end of hold
  - Release load; measure RD at release and 1 minute after release.
- Companion compressive strength/elastic modulus test cylinders

Funding and Execution of Validation Testing

- Request for Testing Proposals solicited by ACPA from 3 labs.
  - Construction Technology Laboratories (Skokie, IL) selected
- Testing funded by National Concrete Consortium through the CPTech Center at Iowa State University
- Some staff time donated by ACPA
- Standard epoxy-coated dowels donated by TyE Bar, LLC
- Testing performed May 20-21, 2020

CTL Specimen Moulds with Dowels and Lift Anchors

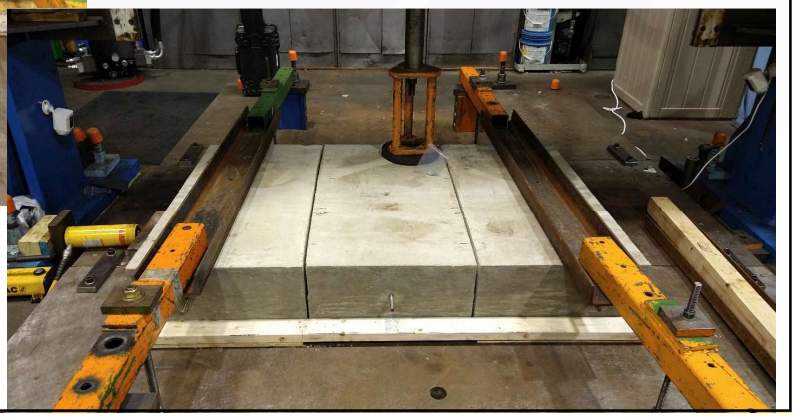


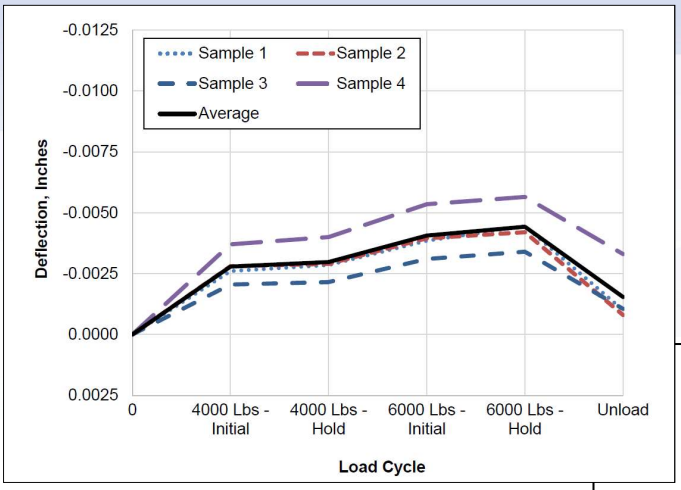
Joint Forming Detail

Test Stand Setup

AASHTO T253

ACPA T253





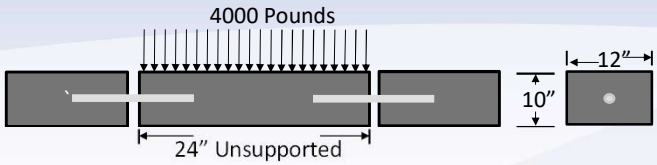
Test Results – AASHTO T253 Load-Deflection (with added load and holds)

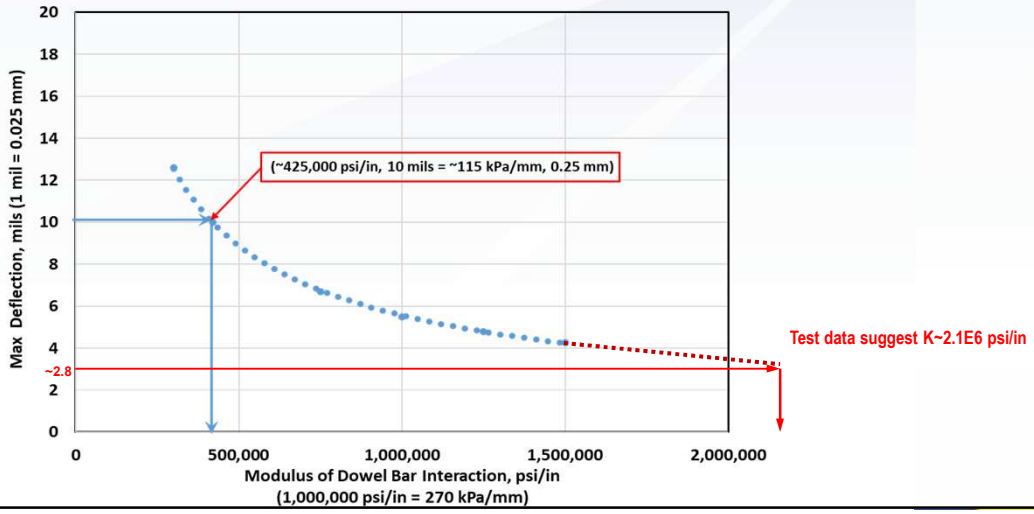
	First load application (4000 lbs)		*Second Load (6000 lbs)*		*Unloaded*
	Average Initial Deflection, Inches	Average Deflection After Hold Period of 10 minutes, Inches	Average Initial Deflection, Inches	Average Deflection After Hold Period of 10 minutes, Inches	Average Deflection 1 Minute After Unloading
Sample 1	-0.0026	-0.0029	-0.0039	-0.0045	-0.0010
Sample 2	-0.0028	-0.0029	-0.0040	-0.0042	-0.0008
Sample 3	-0.0021	-0.0022	-0.0031	-0.0034	-0.0011
Sample 4	-0.0037	-0.0040	-0.0054	-0.0057	-0.0033
Average	**-0.0028**	**-0.0030**	**-0.0041**	**-0.0044**	**-0.0015**

Concrete Strength (all specimens):

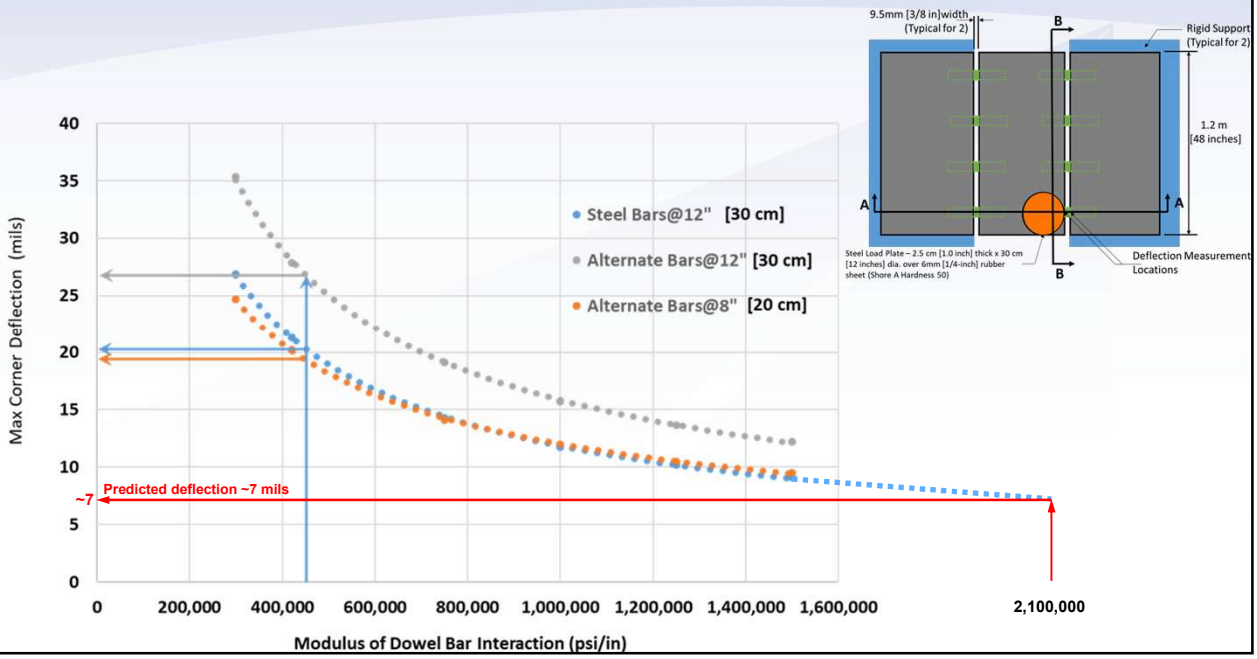
- 14-day compressive: 5590 psi
- 28-day compressive: 6360 psi
- 28-day elastic modulus: 4700 ksi

AASHTO T253 Load-Deflection Test Sensitivity to K *(Theoretical)*

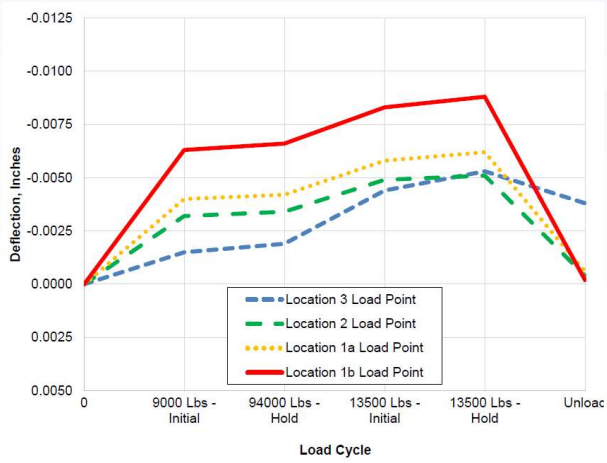




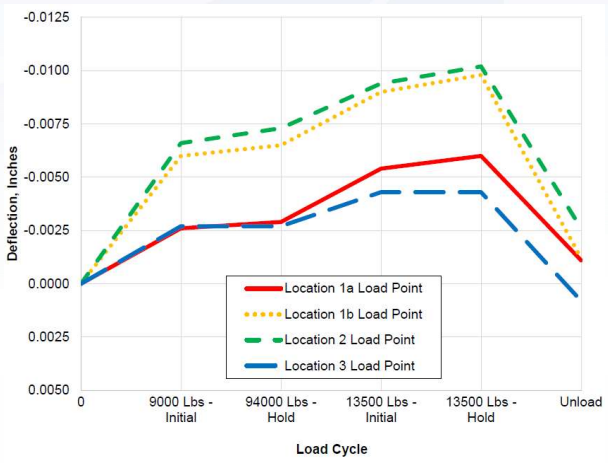
ACPA T253 Load-Deflection Test Sensitivity to K *(Theoretical)*



Test Results – ACPA T253 Load-Deflection (with added load and holds)



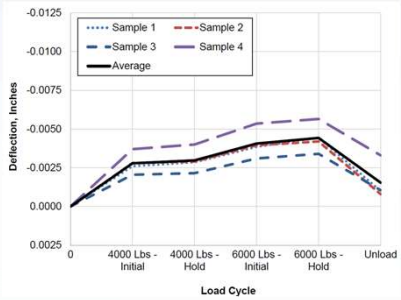
Specimen 1



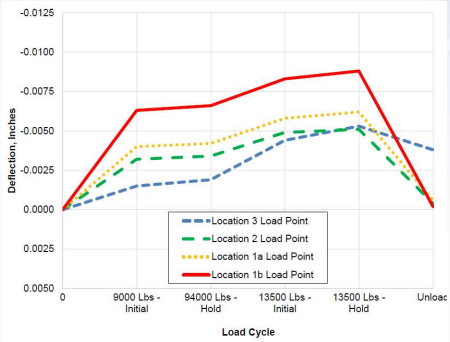
Specimen 2

Comparing Test Results – AASHTO T253 vs ACPA T253 Load-Deflection

AASHTO T253 (Average of all tests)



ACPA T253 Specimen 1



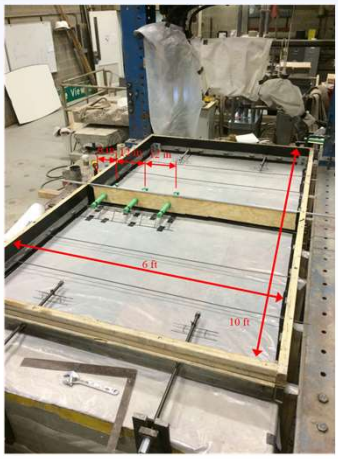
- New test procedure has higher absolute variability (but comparable relative variability)
  - For tested materials, highest *AASHTO standard test result* is about 3.75 mils or 37 percent of 10-mil limit
  - For tested materials, highest *ACPA standard test result* is about 7 mils or 37 percent of 20-mil limit
- Load-deflection response fairly linear (50% increase in load results in approximately 50 percent increase in relative deflection)
- Very little load-hold drift observed at standard load; slight drift at increased load

Recommendation for Implementation in Specifications

- Consider 20-mil limit for new test to be comparable to 10-mil limit for old test for standard loading
  - 4000 lbs in AASHTO T253
  - 9000 lbs in ACPA T253
- Evaluate using higher load (13500 lbs) for high-volume, heavy load routes
- Evaluation threshold to be set by specifying agency in context of design reliability
  - Higher thresholds for low-volume roads, parkways, etc.; lower for heavy traffic, long service life, etc.
  - Lower thresholds for soft, unbound foundations; higher thresholds for strong, stabilized foundations, etc.
- Limit drift for heavy load pavements?

Alternate Structural Evaluation Techniques (Agency Option)

- Dynamic load testing (e.g., Pitt ALF)

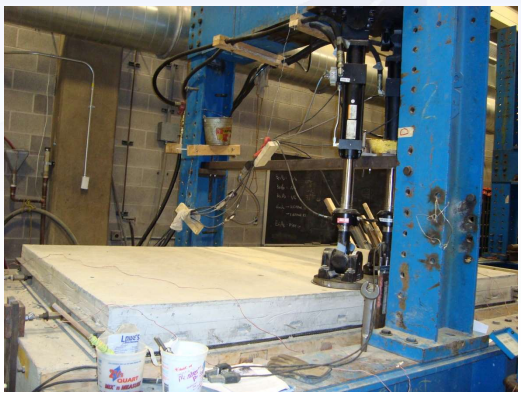


Used as part of dowel acceptance standard by several DOTs

- **PennDOT PTM 642**
- **MnDOT HP Dowel Approval Procedure**

Test:

- **10M Load Cycles**
- **Simulate 9000 lb wheel load**
- **Simulate 45mph vehicle speed**
- **Costly and time-consuming**



- Analytical evaluation
  - Compute or model shear, bending and bearing stresses

ACPA Specification Development

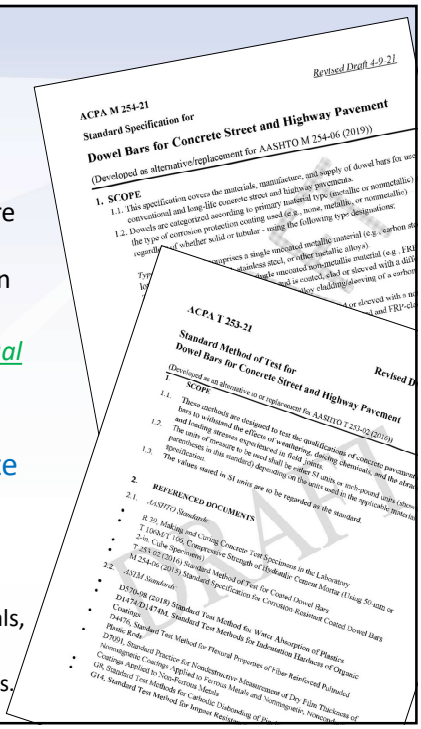
- AASHTO T253 and M254 used as basis for development
  - Primary goal: Incorporate new load-deflection test
  - Development approach: Keep general AASHTO spec format and content to extent possible
- Specification Development Committee

- Agency Staff
  - MnDOT - Maria Masten, Rob Golish
  - PennDOT - Neal Fannin
  - MoDOT - Brett Trautman
- ACPA
  - National - Jerry Voigt, Eric Ferrebee
  - WCPA – Kevin McMullen

- Dowel Manufacturers/Distributors
  - O-Dowel - Chris Schenk
  - Artazn - Mike Mather
  - CMC – Bassam "Ben" Sadawi
  - MasterDowel – Brad Zaun
  - PNA – Feng Mu
  - AHT/Simplex – Glenn Eder, Mark Kaler
  - CRT – Jim Olson
  - Owens Corning – Doug Gremel, Bryan Barragan

New ACPA "Universal" Dowel Specifications

- M 254 – Standard Specification for Dowel Bars for Concrete Pavement
  - Specification developed to address the requirements for manufacture and installation of all types of dowel bars (coated or not, corrosion-resistant or not, cylindrical or not, metallic or not) intended for use in concrete pavements.
  - *Dowels qualified as engineered load transfer systems, not as individual products.*
- T 253 – Standard Method of Test for Dowel Bars for Concrete Pavement
  - Methods to test:
    - Structural behavior or dowel load transfer systems
    - Ability of dowels to withstand the effects of weathering, de-icing chemicals, UV exposure, abrasion and other measures of dowel durability.
      - Suite of applicable durability tests varies with dowel materials and coatings.



Dowel Types (determines applicable test suite)

- ***Type A*** **- Single metallic material**
  - ***AASHTO M255 or M334, ASTM A276, A312, A955 or A1035 (CS, CM and CL)***
  - *Grade as specified by purchaser*.
- ***Type B*** **- Single nonmetallic material**
  - ***ASTM D7957**** or as specified by the purchasing agency.
- ***Type C*** **– Metallic core with metallic corrosion protection**
  - Steel core : ***AASHTO M 255 or M334, ASTM A513 or A615***
  - *Metallic* corrosion protection: ***ASTM A249, A276 or A312 for stainless steel coatings, ASTM A513, ASTM A1035 (CS, CM and CL) for low-carbon chromium coatings, ASTM B69 for rolled zinc coating, or ASTM A1094 for hot-dip galvanizing***.
- ***Type D*** **– Metallic core with nonmetallic corrosion protection**
  - Core material: ***AASHTO M255 or M334, ASTM A276, A312, A513, A615, or A1035 (CS, CM and CL)***; grade specified by the purchasing agency.
  - Type D1: mechanically bonded nonmetallic cladding material (ASTM D7957* or as specified by purchaser), e.g., GFRP
  - Type D2: meet requirements of ASTM A1078 one or more thin layers of epoxy, plastic or similar materials of primarily organic composition … epoxy coating systems to meet material requirements of ASTM A775, A934 and/or CSA-Z245.20.

Physical Test Requirements

- Load Deflection Testing (all dowel types)
- Pullout (measure surface shear instead of total force; all dowel types)
- UV Exposure (Types B and D only)
- Abrasion (all dowel types)
- Corrosion (all dowels with metallic components – Types A, C and D)
  - Primary consideration to lateral surfaces, not ends
- Chemical Resistance (Type D2 only)
- Cathodic Disbonding (Type D2 only)
- Coating Impact Resistance (Type D2 only)

Acceptance/Rejection Thresholds for Tests

- Specifications generally define which tests to perform, how to perform them and how to measure/obtain results
  - Different types of tests apply to different dowel material/coating combinations
- Acceptance/rejection criteria are often not provided
  - Agencies determine limit values and how they are categorized for service life and/or climate
  - Concept is similar to specs for determining PCC compressive strength and other material properties
  - Guidance is provided (notes to specifiers) to aid agencies in setting/modifying acceptance/rejection thresholds

Comparing AASHTO and ACPA M254 Specs – Dowel Types

1.2 The coated dowels shall be one of the two following types:

Type A – Coating material develops low bond strength with concrete – no bond breaker required.

Type B – Coating material develops bond strength with concrete – bond breaker is required.

1.2 Dowels are categorized according to primary material type (metallic or nonmetallic) and the type of corrosion protection coating used (e.g., none, metallic, or nonmetallic) – regardless of [dowel shape] – using the following type designations:

- *Type A* – The dowel comprises a single uncoated metallic material (e.g., carbon steel, low-carbon chromium steel, stainless steel, or other metallic alloys).
- *Type B* – The dowel comprises a single uncoated non-metallic material (e.g., FRP).
- *Type C* - The dowel has a metallic core and is coated, clad or sleeved with a different metallic material (e.g., stainless steel or zinc alloy cladding/sleeving of a carbon steel core).
- *Type D* - The dowel has a metallic core and is coated, clad or sleeved with a non-metallic material (e.g., epoxy-coated, plastic/polyethylene-coated and FRP-clad carbon steel dowels).

Comparing AASHTO and ACPA M254 Specs – Dimensions

5.1 Core metal shall be 1.25-in diameter or as specified.

5.2 Nonabraded thickness of coatings:

Type A: 25 ± 5 mils.

Type B: 7 + 2 mils

5.3 Coating thickness determined using ASTM G12 or by stripping coating from bar.

5.4 Supply dowels in lengths and assemblies or baskets as specified.

5.1 Dowel bar dimensions as specified. Dimensions measured before application of coating or cladding materials except for D1 (CRT dowel – measured before cladding and overall diameter after cladding).

5.1.1 Solid cylindrical dowels – specify min length and min diameter. For D1, specify min core diameter and min overall diameter.
5.1.2 Solid elliptical dowels – specify min length and min required lengths of ellipse section axes.
5.1.3 Tube and pipe dowels – specify min length, wall thickness, and overall diameter.
5.1.4 Plate dowel systems – min required and max allowable plate thickness and all other dimensions to accurately define plate shape
5.1.5 Other dowel shapes – agency calls out structural or behavioral equivalency (e.g., EI or deflection results) of solid steel cylindrical dowel (e.g., 1.25-inch diameter round steel equivalent).

5.2 For Type C and D systems - non-abraded minimum thickness of coated systems shall be sufficient to resist corrosion and impact damage when tested in accordance with ACPA T253-20. Determine coating thickness according to ASTM D7091 or by measuring with high-precision calipers after cutting the bar across its section or stripping the coating from the bar.

Comparing AASHTO and ACPA M254 Specs – Physical Requirements

Load Deflection:
- Test 3 specimens; No relative deflection > 10 mils

Pullout:
- 2-part test with freeze-thaw in salt solution
- Max pullout = 3000 lb
- No corrosion, tears, or perforation

Abrasion:
- Wear depth < 70% of original coating thickness

Corrosion:
- None visible under 5x magnification

Chemical Resistance:
- No blistering, softening, disbondment, holidays or undercutting at drilled holes

Cathodic Disbondment:
- No film failure during first hour of test.
- No undercutting during rest of test at drilled holes.

Coating Hardness:
- Exceeds Knoop Hardness Number of 16

Coating Impact Resistance:
- No shattering of disbanding of coating outside of impact area.

Load Deflection:
- Test 1 specimen, 4 locations; Agency specifies limits
- Alternative test or analytical procedure

Pullout:
- Similar except freeze-thaw portion is agency option

UV Exposure:
- Agency-established limits on flex strength and modulus changes for B and D1 dowels; conditioning step for D2 dowels.

Abrasion:
- Agency-specified limits – consider corrosion protection and loss of load transfer.

Corrosion:
- No visible steel corrosion. Limit corrosion-induced expansion.

Chemical Resistance:
- Similar

Cathodic Disbondment:
- Similar, with 4mm disbondment radius limit.

Coating Hardness:
- Deleted

Coating Impact Resistance:
- Similar.

Comparing AASHTO and ACPA T253 Specs – Materials

3.1 The concrete design and constituents shall be specified by the agency.

3.1 The concrete mix design and constituents shall comply with the following:

- 3.1.1 Type I, Type II or Type I/II cement conforming to ASTM C150/C150M.
- 3.1.2 Coarse and fine aggregate conforming with ASTM C33, with coarse aggregate meeting Grading 67 and conforming to Class 4S (ASTM C33, Table 4).
- 3.1.3 Air-entrained concrete proportioned using ACI 211.1 procedures using 307 $\pm$ 3 kg cement/m^3 of concrete (517 $\pm$ 5 lb/yd^3) produce concrete with 90 $\pm$ 15mm (3½ $\pm$ ½ in.) slump and 6.0 $\pm$ 1.0 percent air content.

Comparing AASHTO and ACPA T253 Specs – Pullout Test

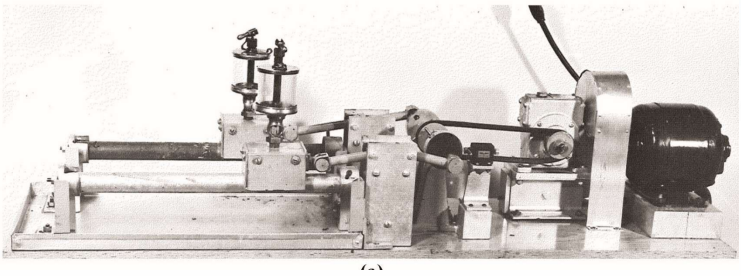
- AASHTO requires initial ½-inch pullout after 48 hours, 12 days added curing, 50 cycles of freeze-thaw while half-submerged in deicing chemicals (1 cycle per day), then additional ½-inch pullout.
  - Approximately 54 days

Photo courtesy of American Engineering Testing

- ACPA requires only initial test (2-3 days); freeze-thaw and added pullout is agency option. Also specifies minimum concrete mould-dowel cover.

Comparing AASHTO and ACPA T253 Specs – Corrosion-Abrasion

- Required for all dowels.
- Abrading block fits over about 1/3 dowel perimeter



- Type A (Uncoated metal) – Corrosion test only.
- Type B (Solid FRP) – Abrasion test only.
- Types C and D (coated and clad metal) – Both abrasion and corrosion tests.
- Includes UV preconditioning for epoxy or FRP surfaced dowels.
- Abrading block covers standard area, regardless of dowel size/shape

Comparing AASHTO and ACPA T253 Specs – Corrosion-Abrasion

- After abrasion, determine loss of coating thickness.
- Partially submerge abraded dowels in 10% NaCl for 50 cycles of freeze-thaw.
- Examine for corrosion under 5x magnification.

- After abrasion, determine loss of coating thickness (Types C and D) *or change in diameter (Type B only).*
- Partially submerge Type A and abraded Types C and D dowels in 10% NaCl for 50 cycles of freeze-thaw.
- Examine for corrosion under 5x magnification.
- Determine percentage of expansion due to corrosion.

Comparing AASHTO and ACPA T253 Specs – Chemical Resistance Test (Epoxy-coated only)

Three dowel bars tested using ASTM G20 procedures

- Immerse 45 days in
  - Distilled water
  - 3M $CaCl_2$
  - 3M NaOH
  - Saturated $Ca(OH)_2$ solution

… except ASTM G20 has very different requirements!

Modified to be consistent with perceived intent of AASHTO T253

- Provide 3 replicate specimens in each reagent, with and without holidays (as req'd by ASTM G20).

- Total of 24 specimens

Comparing AASHTO and ACPA T253 Specs – Cathodic Disbonding Test (Epoxy-coated dowels only)

Two dowel bars tested using a modified version of ASTM G8:

- Cathode and anode are both dowels
- 7% mass NaCl solution
- 2-volt potential
- ¼-inch holiday at mid-depth of both cathode and anode
- Test for 30 days

AASHTO T253, ASTM A775 and ASTM A934 tests are all different. ACPA T253 was modified to be consistent with ASTM A775 Annex.

- Use three 10-inch dowel sections (cathode) and thin platinum electrode (anode)
- 3% mass NaCl solution
- 1.5-volt potential
- 1/8-inch holiday
- Test for 168 hrs (7 days)
- Limit disbondment radius to 4mm

Comparing AASHTO and ACPA T253 Specs – Coating Hardness Test (Epoxy-coated dowels only)

Coating hardness test procedure in AASHTO T253 has been deleted from ACPA T253.

- This test is not a part of either ASTM A775 or A934, and the related ASTM standard (D1474).
- It is a method for determining "indentation hardness of organic materials such as dried paint, varnish and lacquer coatings applied to an acceptable plane, rigid surface, for example metal or glass."
- *Committee determined this is test is not directly applicable to epoxy-coated pavement dowel systems and unlikely to provide information not provided by other tests in the specification (e.g., the coating impact resistance test.*

Comparing AASHTO and ACPA T253 Specs – Coating Impact Resistance Test (Type D dowels only)

Test three dowels using an impact force of 80 in-lb with a 4-lb "tup" according to ASTM G14.

ASTM G14 process includes different tup weights, different drop heights, and is an iterative process – very different from AASHTO T253 description.

ACPA T253 references instead ASTM A775 Annex A1.3.9, which is essentially the same as AASHTO T253 except for allowing three tests at different locations on a single dowel.

Next Steps

- ACPA publishing (website) current standards as ACPA Guide Specifications
- Agency "champions" promote new specifications to AASHTO for adoption
- Engage NTPEP for use of new specifications and tests for single-source testing of dowel products
- Consider Supplemental Test Program

Thank You For Your Attention!

Mark B. Snyder, Ph.D., P.E. – President and Manager
Pavement Engineering and Research Consultants (PERC), LLC
Special Consultant to American Concrete Pavement Association
mbsnyder2@gmail.com