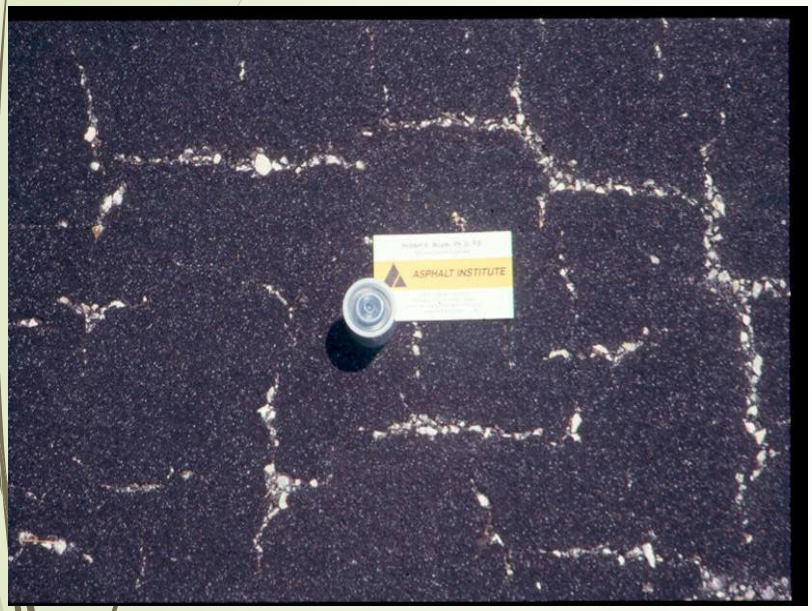
Development and Performance History of the FAA P-404 Fuel-Resistant Asphalt Mix Specification

2023 Airfield Asphalt User Producer Meeting
January 10, 2023

Ron Corun
Consultant for Associated Asphalt Partners LLC

RON CORUN CONSULTING LLC
Asphalt is Our Business

Fuel-Resistant Pavement Sealers



- Coal tar sealers are most commonly used to protect Hot Mix Asphalt pavements from fuel damage
- Different coefficient of expansion for coal tar causes substantial alligator cracking within 2-3 years
- Cracking allows fuel penetration - short service life
- Coal tar sealers are carcinogenic
  - SDS – "Unusual Chronic Toxicity: May cause cancer of the skin, lungs, kidney and bladder."
  - Adding carcinogenic material to pavement that may be recycled – future exposure

Development of Fuel-Resistant PMA

- CITGO Asphalt (currently Associated Asphalt) recognized dangers of coal tar sealers and formulated a safe, environmentally-friendly alternative using a highly polymer-modified asphalt binder
  - PG 76-22 typically contains 3% polymer
  - Fuel-resistant asphalt binder contains 7.5% polymers
- Objective – make the asphalt pavement surface course fuel-resistant and eliminate the need for sealers

Development of Fuel-Resistant PMA

- Developed test to measure fuel resistance
- Weigh 4 Marshall or Gyratory samples after compaction
- Immerse in jet fuel for 24 hours
- Remove samples from fuel bath, dry and weigh
- Average weight loss of 4 Marshall specimens must be less than 1.5%

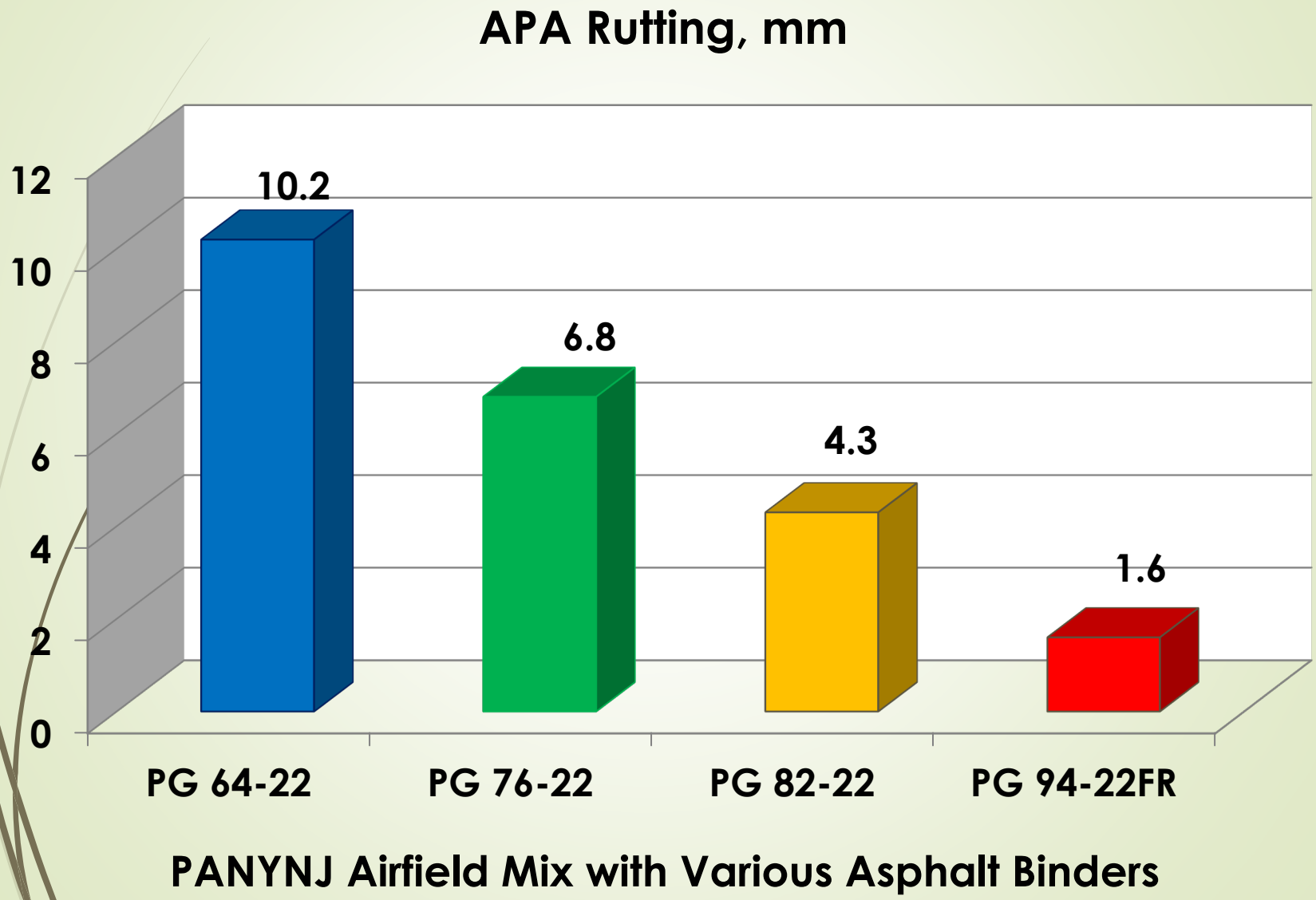
Development of Fuel-Resistant PMA

- Standard Unmodified Asphalt (PG 64-22) mix loses 10% weight from 24 hour soak in jet fuel
- Standard Polymer Modified Asphalt (PG 76-22) mix loses 5-6% weight after 24 soak in jet fuel
- Fuel-Resistant PMA – less than 1.0% weight loss

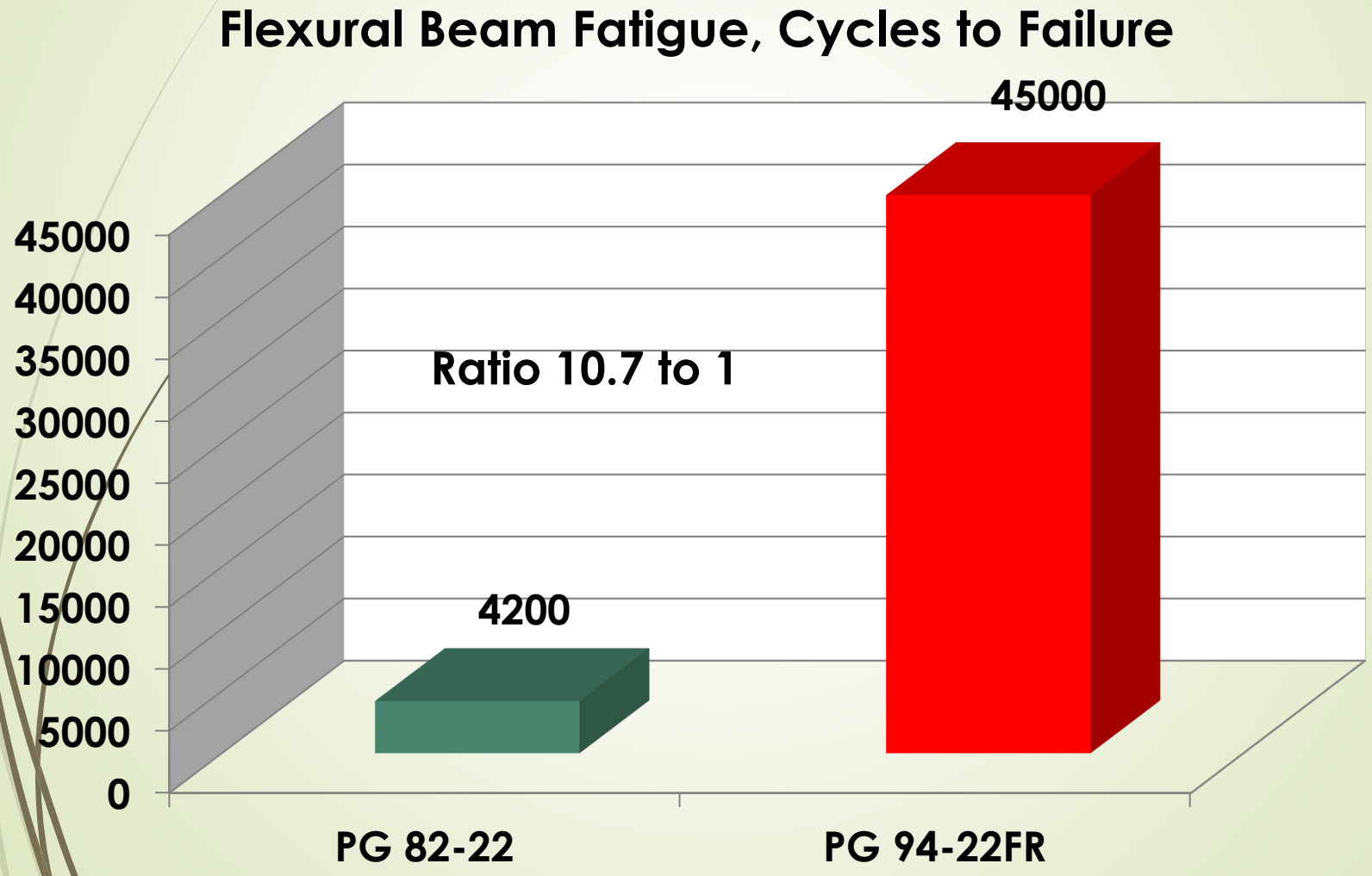
First Fuel-Resistant Mix Usage

- First Fuel-Resistant mix construction project at La Guardia Airport in 2002
  - Test section on Taxiway GG – 450 tons
- Before first use of FR mix, the Port Authority of New York and New Jersey wanted some mix performance testing to justify the usage
  - Rut testing
  - Crack testing

Fuel-Resistant Mix – Rut Resistance



Fuel-Resistant Mix– Crack Resistance



Fuel-Resistant Mix Usage – La Guardia Airport

- Placed Fuel-Resistant Mix on Taxiway GG at La Guardia Airport August 2002
- FR Binder Graded as PG 94-22
- Pumped into plant at 330°F
- Produced mix at 340°F
- Placed in silo for 4 hours

Fuel-Resistant Mix Usage – La Guardia Airport

- Paved at 330°F
- No problems with placement
- Handwork and longitudinal joints look good
- Density achieved
- Paving crew could not see a difference in Fuel-Resistant Mix from standard P-401 mix containing PG 76-22

La Guardia Airport 2012

Ten Years After Paving

Fuel-Resistant PMA Usage – La Guardia Airport

- 2018 – Taxiway GG was still performing well, a pavement condition survey found Taxiway GG the only pavement at LaGuardia not rutted
- Rutting in pavements surrounding Taxiway GG in 2018 shown in picture

Fuel-Resistant Binder Specification

- Worked with engineers at Massachusetts Port Authority (Logan Airport) to develop a generic specification for Fuel-Resistant HMA
  - FR binder is a PG 94-22 liquid asphalt, but ASTM D6373 specification had a table with PG 82-22 the highest grade listed
  - Minimum PG 82-22 polymer modified asphalt
    - Minimum 85% Elastic Recovery
    - Separation test
    - Pass fuel resistance test
  - Standard test method for fuel resistance

Fuel-Resistant Mix Specification

- Goal – use the properties of a PG 94-22 asphalt to produce a longer-lasting more durable airfield pavement
- Use the existing P-401 mix 9.5 mm gradation
- How do you make an asphalt pavement last longer during the mix design?
- Increase the asphalt content
  - Design at lower air voids – 2.5% instead of 3.5%
  - Reduce lab compaction – specify 50 Marshall blows or 50 gyrations for all pavement areas and aircraft weights

Fuel-Resistant Mix Specification

- How do you make an asphalt pavement last longer when paving?
  - Achieve better density when compacting the pavement
  - Many studies link higher densities with longer pavement life – 1% increase in density equals 10% increase in pavement life
  - Lower in-place air voids reduce penetration of air, water and jet fuel into the pavement
  - Designing the mix at lower air voids with higher asphalt contents make the mix easier to compact - liquid asphalt is a lubricant until it cools
  - P-401 density lower limit is 92.8% (7.2% air voids)
  - P-404 lower density limit is 96.0% (4.0% air voids)

Fuel-Resistant Mix – Logan Airport

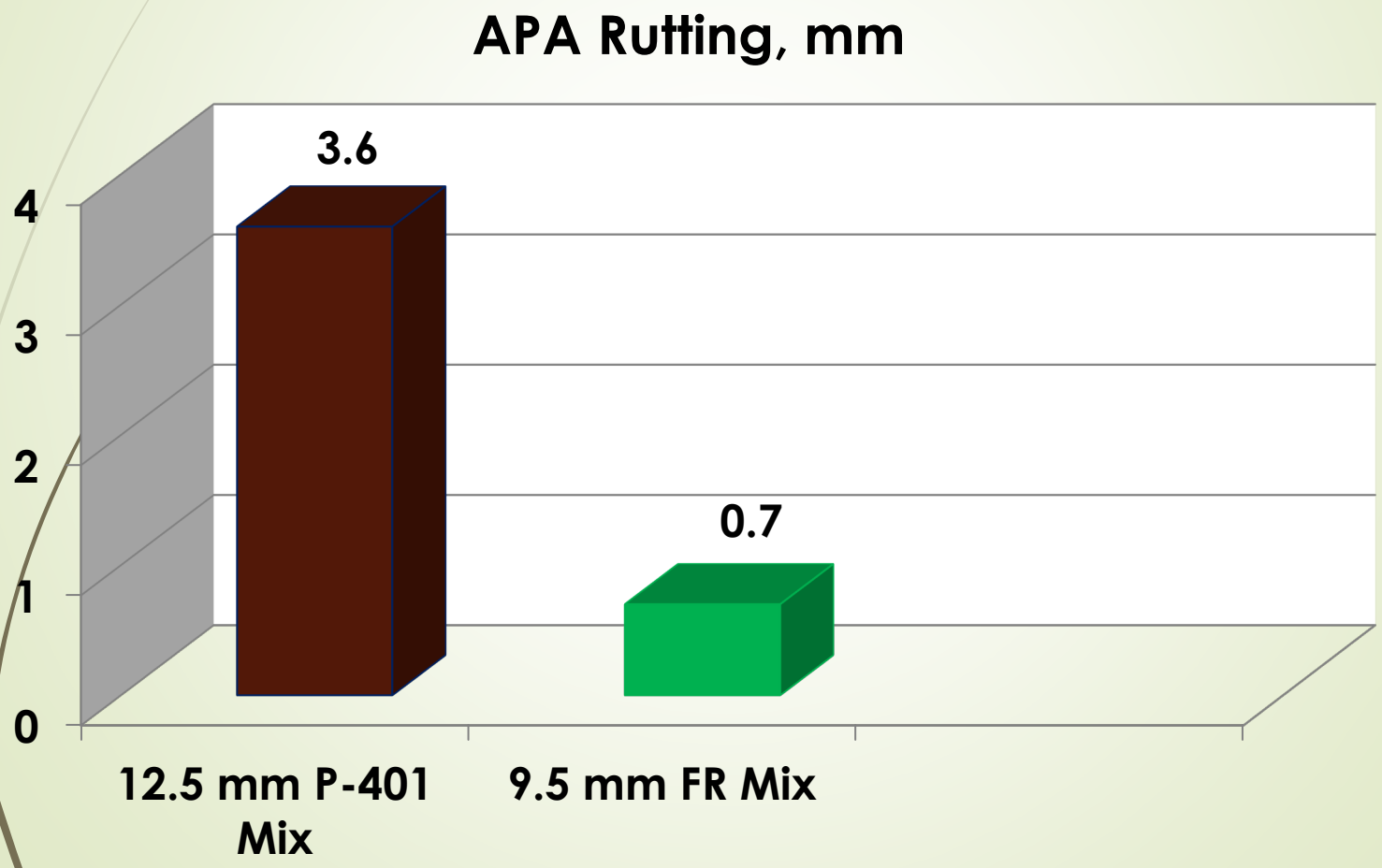
- First use of modified P-401 mix with FR binder at Boston Logan Airport
- Placed 1300 tons of Fuel-Resistant (FR) mix on Taxiway N and Runway 4L-22R at Logan Airport in June 2004

Fuel-Resistant Mix – Logan Airport

Fuel-Resistant Mix – Logan Airport

- FR Asphalt graded as PG 94-22
- 9.5 mm P-401 mix designed at 2.5% air voids with 50 Marshall blows
- 7% asphalt content design target
- MassPort engineers concerned about rutting
- APA testing at Worcester Polytechnic Institute

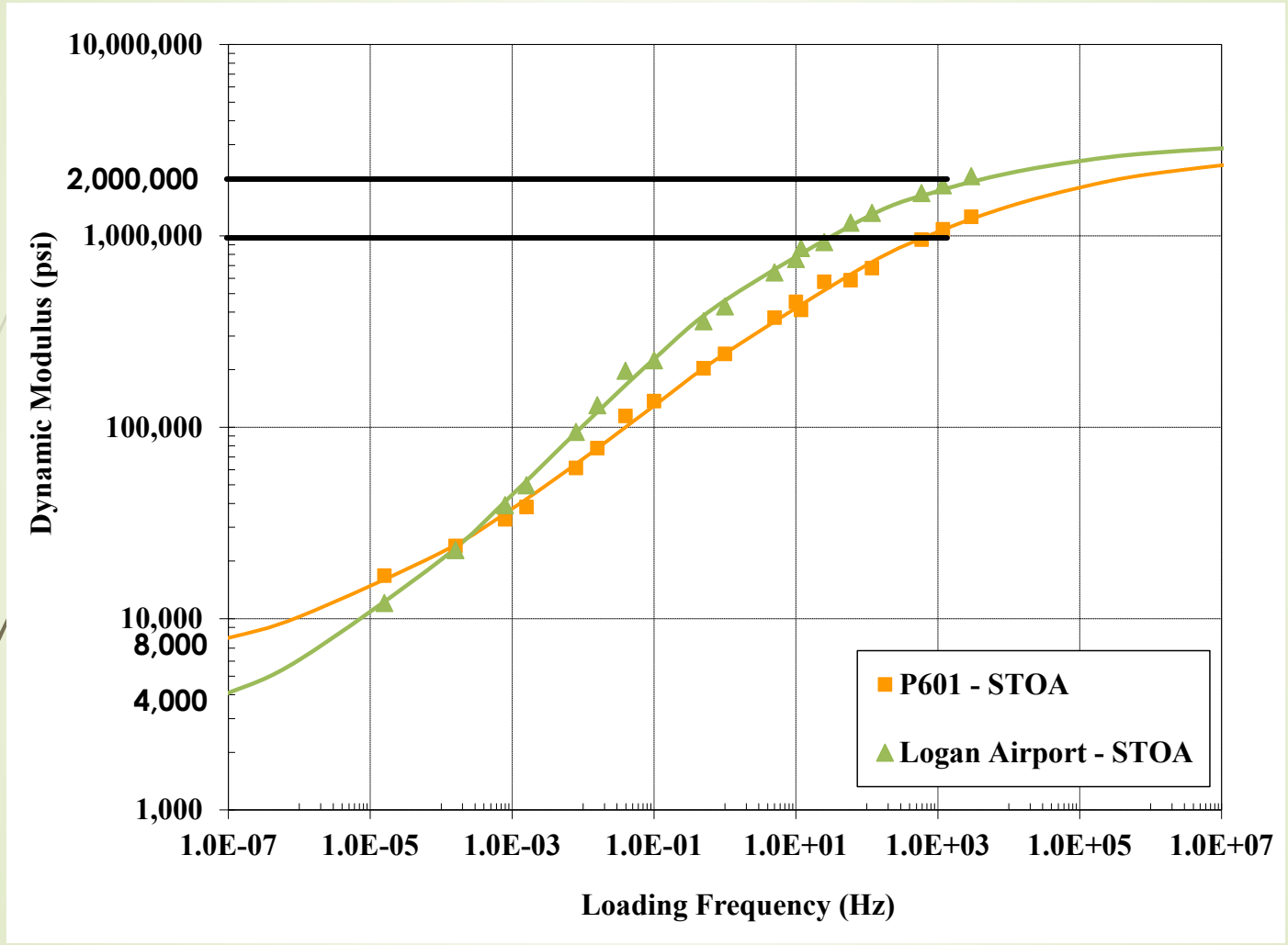
Worcester Polytechnic Institute – APA Rut Testing



Logan P-401 vs FR Mix

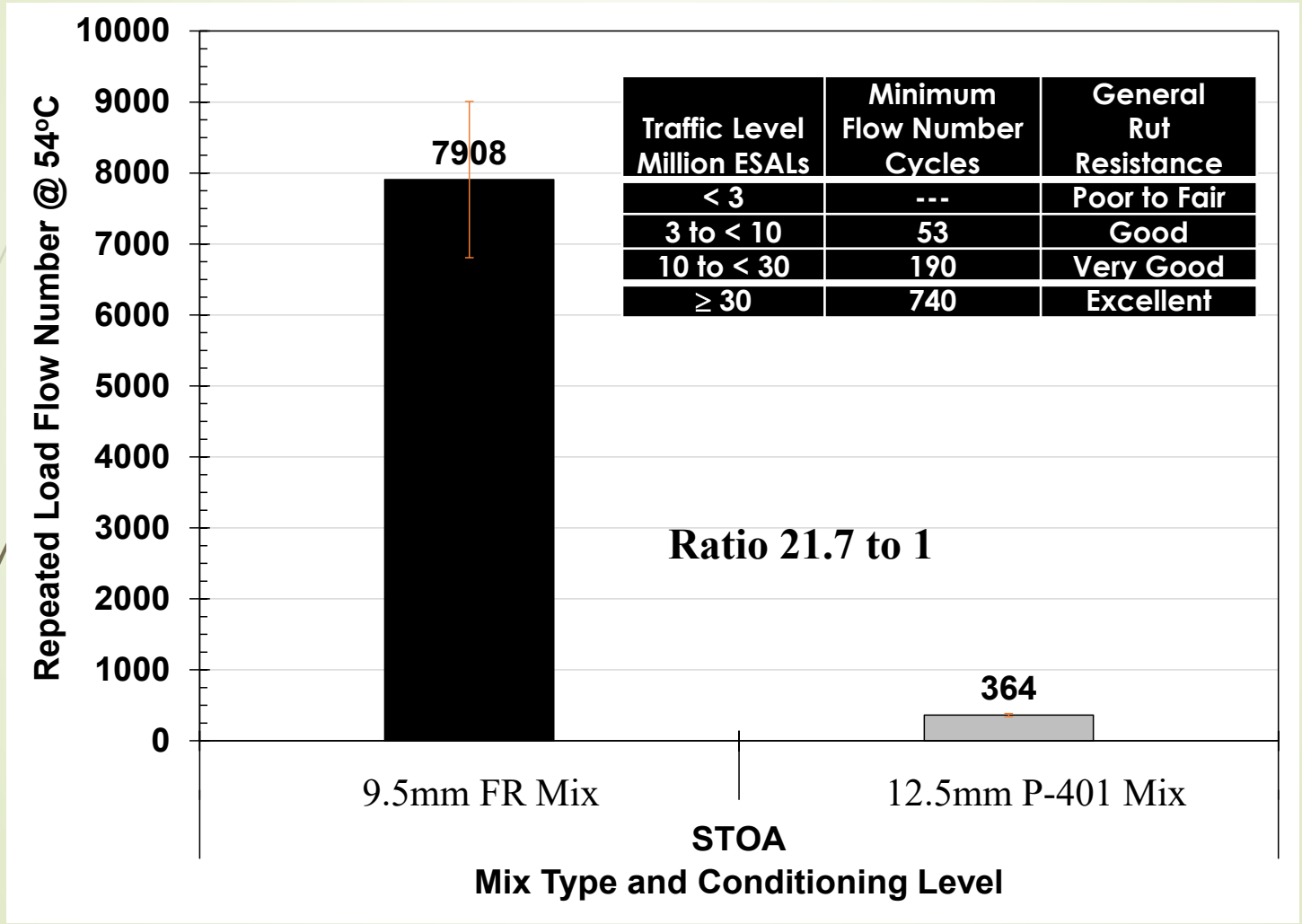
Asphalt Mix Performance Tester (AMPT)

Logan P-401 Mix vs FR Mix



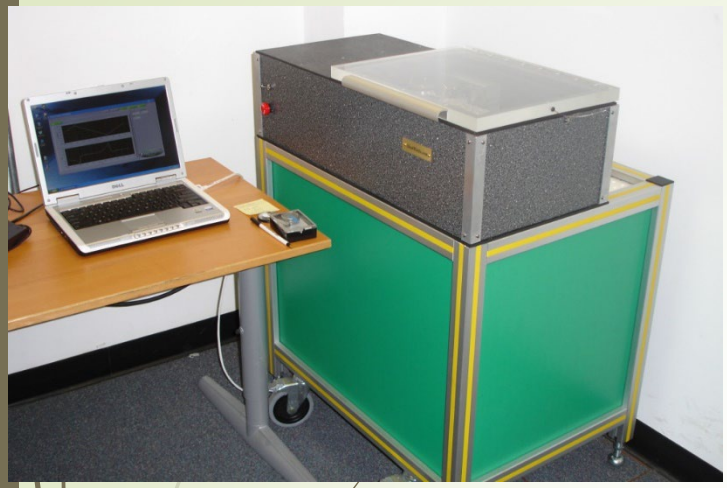
AMPT Dynamic Modulus

Logan P-401 Mix vs FR Mix



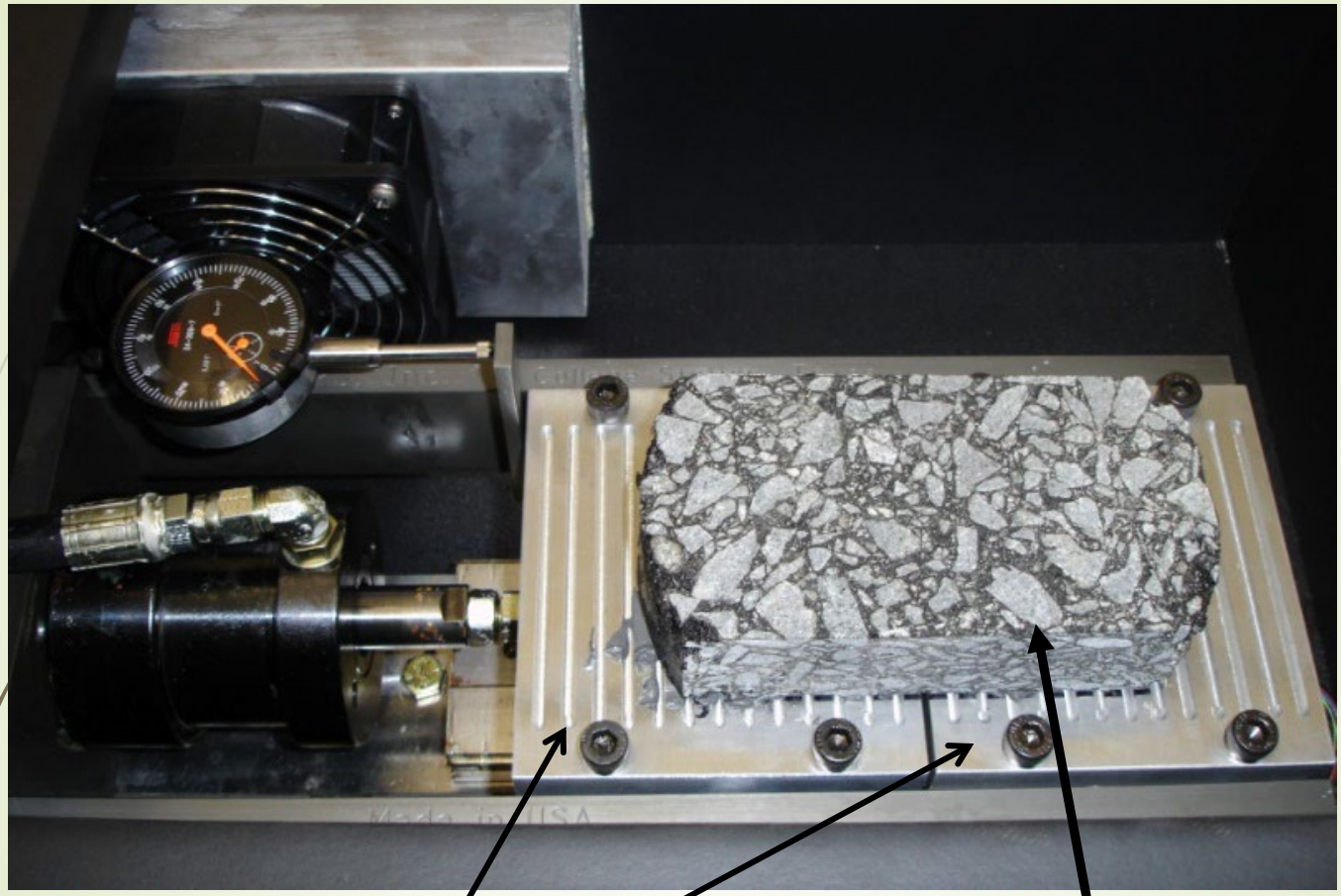
Traffic Level Million ESALs	Minimum Flow Number Cycles	General Rut Resistance
< 3	---	Poor to Fair
3 to < 10	53	Good
10 to < 30	190	Very Good
≥ 30	740	Excellent

Texas Overlay Tester



- Test developed at Texas A&M University for Texas DOT
- Simulates horizontal movement at a concrete joint
- Very severe test – brittle samples do very poorly
- Measures number of cycles to failure
- Texas DOT specification requires > 300 cycles for mixes that have been Short Term Oven Aged (STOA)

Texas Overlay Tester



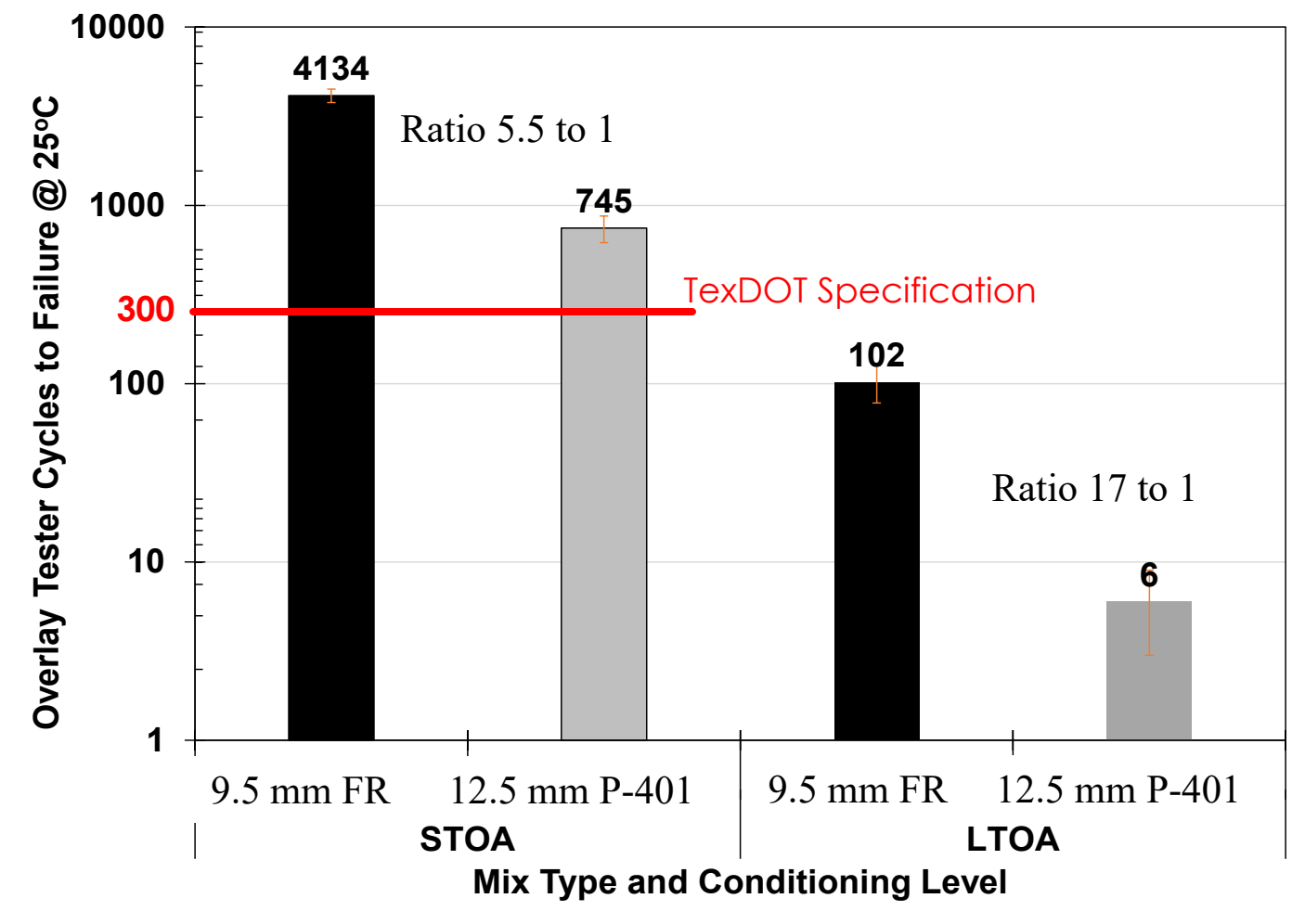
Movable plate

Fixed plate

Saw cut gyratory specimen and glue onto both plates

Logan P-401 Mix vs FR Mix

Texas Overlay Tester

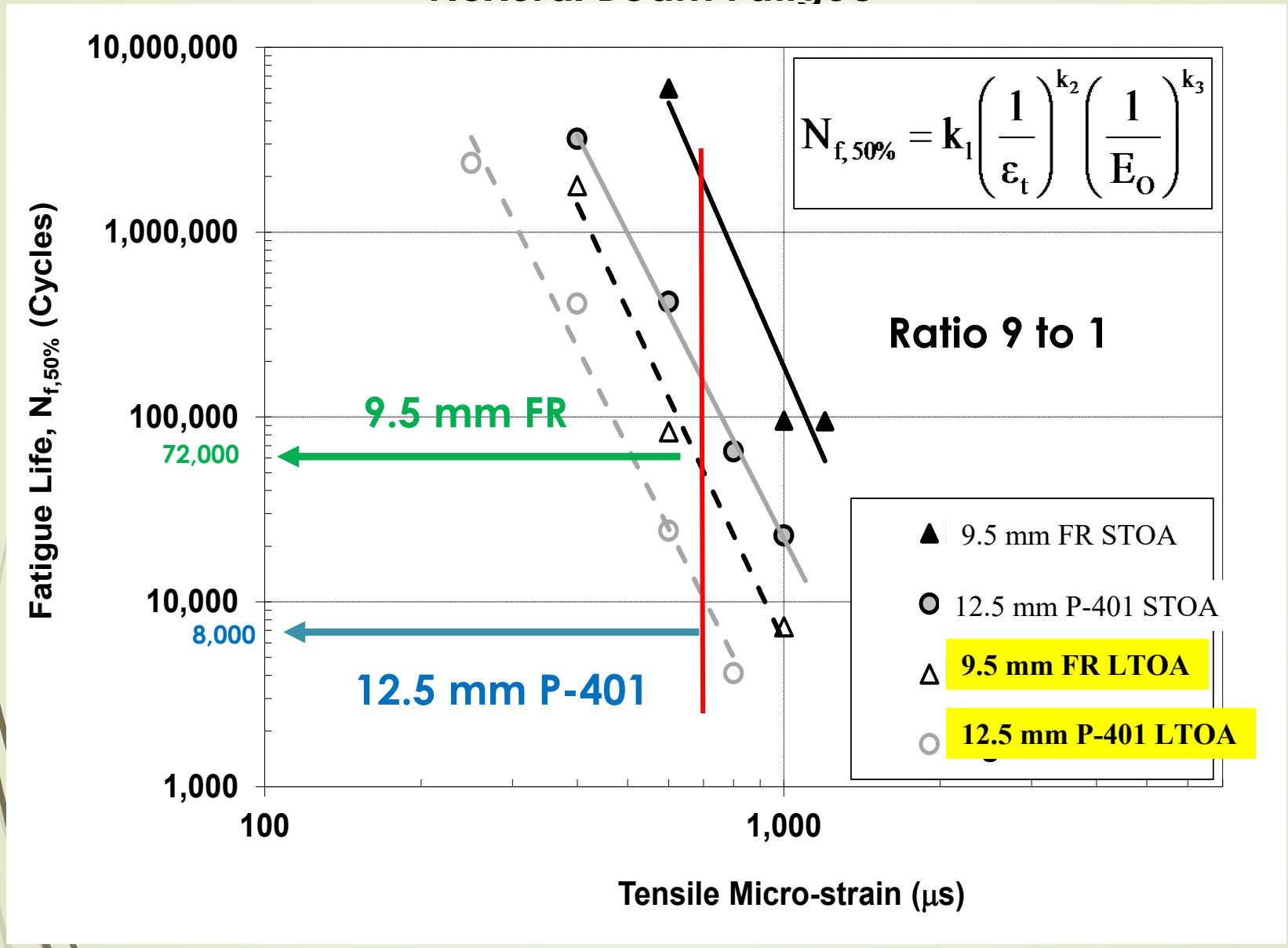


STOA – Short Term Oven Aged
1 year old pavement

LTOA – Long Term Oven Aged
10 year old pavement

Logan P-401 Mix vs FR Mix

Flexural Beam Fatigue



Fuel-Resistant Mix – Logan Airport

- Mix produced in drum plant at 340˚F
- Placed at 325˚F without difficulty
- Met density specification
- Excellent surface appearance

Fuel-Resistant Mix – Logan Airport

Fuel-Resistant Mix – New Projects

- Boston, MA - Logan Airport
  - Alleyway Projects – 2005, 2006, 2007
- Charlotte, NC - Douglas International Airport
  - Runway Project – 2006
- Florida DOT
  - Truck Inspection Station – 2006
- Portland, ME - Portland Jetport Apron, 2015
- Fryeburg, ME – Eastern Slopes Airport Apron, 2016
- BWI Marshall Airport – Freight Apron, 2016
- Burbank, CA - Bob Hope Airport Apron, 2019
- Numerous GA airports in SE US
- Hurlburt Field – First DOD project. Apron, 2018
- Toronto International Airport – Apron, 2020

Fuel-Resistant Mix – Logan Airport

Fuel-Resistant Mix – Logan Airport

FR Mix at Logan Airport - 2014

10 year old FR Pavement

FR Mix at Logan Airport - 2014

10 year old FR Pavement

FR Mix at Logan Airport – Why did the Joints Open Up?

FR Mix at Logan Airport - 2014

10 year old FR Pavement

FR Mix at Logan Airport - 2014

10 Year Old P-401 Pavement with PG 76-28

FR Mix at Logan Airport - 2014

10 year old FR

10 year old P-401

FR Mix at Logan Airport - 2014

9 year old FR Alleyway Pavement

FR Mix at Logan Airport

- De-icing at Logan Airport is done at the gates
- Alleyway FR pavement in picture has been exposed to de-icing chemicals for 15 winters – no visible damage to date
- 2020 - “It does not need replacing anytime soon”

FAA P-601 Specification

- FAA was looking for alternative to coal tar sealers – projecting it would be outlawed in near future
  - Evaluated performance of Logan Airport StellarFlex FR mixes
  - Adopted Logan Airport FR specification as P-601 “Fuel-Resistant Hot Mix Asphalt Pavement” specification in July 2014

FAA P-601 Specification

- FAA issued Advisory Circular # 150/5370-10G , dated 07/21/2014
- Contained new specification item P-601 Fuel-Resistant Hot Mix Asphalt Pavement

FAA P-601 Specification

- Asphalt Binder Specification
  - ASTM D6373 - Minimum grade of PG 82-22
  - ASTM D6084 Elastic Recovery Test Method A – test at 25°C, Elastic Recovery ≥ 85%
  - ASTM D7173 Separation Test - Maximum temperature difference of 4°C when using ASTM D36 Ring and Ball apparatus

FAA P-601 Specification

- Mix Specification
  - **P-401 Mix #3 (9.5 mm mix)**
  - Target air voids = 2.5%
  - **50 blow or 50 gyration mix compaction regardless of aircraft type**
  - Maximum Weight loss by fuel immersion 2.5% as measured by test procedure in FAA P-601 Specification Section 601-3.3

P-601 Mix at Bob Hope Airport Burbank, CA - 2019

1” P-601 Surface Course

P-601 Mix at Bob Hope Airport Burbank, CA - 2019

1” P-601 Surface Course

P-601 Mix at Bob Hope Airport Burbank, CA - 2019

1” P-601 Surface Course

FAA P-404 Specification

- FAA issued Advisory Circular # 150/5370-10H on December 21, 2018
- Renumbers specification item P-601 Fuel-Resistant Hot Mix Asphalt Pavement to P-404 Fuel-Resistant Asphalt Mix Pavement

FAA P-404 Specification

- Asphalt Binder Specification
  - ASTM D6373 - PG 88-22FR or PG 82-28FR as dictated by project location climate
  - ASTM D6084 Elastic Recovery Test Method A – test at 25°C, Elastic Recovery ≥ 85%
  - ASTM D7173 Separation Test - Maximum temperature difference of 4°C when using ASTM D36 Ring and Ball apparatus

FAA P-404 Specification

- Mix Specification
  - Mix design criteria
    - P-401 Mix #3 gradation (9.5 mm mix) and/or Mix #2 gradation (12.5 mm mix)
    - 2.5% target air voids
    - 50 Marshall blows or 50 gyrations compaction
  - **Adds Asphalt Pavement Analyzer (APA) rutting requirement**
    - **APA Rut Depth <10mm @ 4000 passes, hose pressure 240 psi OR**
    - **APA Rut Depth <5mm @ 8000 passes, hose pressure 100 psi OR**
    - Hamburg Wheel Tracking < 10mm @ 20,000 passes
  - Allowable lift thickness: 1½" – 3"
  - **Maximum Weight Loss Fuel Soak Test = 1.5%**
  - In place density – Maximum 4% air voids compared to P-401 7.2% maximum air voids

First Military Fuel-Resistant Mix Project – Hurlburt Field AFB, Florida

- Repaved apron area in July 2018 using FAA P-601 specification
- Excellent performance to date – project is monitored by US Army Corps of Engineers
- DOD has adopted a fuel-resistant specification almost identical to FAA P-404
- Draft Unified Facilities Guide Specification – UFGS 32 12 17 .19

V-22 Osprey Pavement Effects

- V-22 Ospreys land at Lynchburg Regional Airport on a regular basis
- Apron area was repaved with P-404 mix in Fall 2020
- V-22 sits stationary for approximately 30 minutes with engines running during “hot refueling”

V-22 Osprey Pavement Effects

- Note slight discoloration beneath engine exhaust
- I believe it is small amount of unburned fuel
- Walked out to area immediately after takeoff – darkened area was too hot to touch with your hand
- No damage to P-404 pavement to date

12.5 mm FR Mix Development

- Despite demonstrated performance over the past eighteen years, some engineers are uncomfortable with a 9.5 mm mix (FAA Mix #3) that is currently in the P-404 specification
- They believe a 12.5 mm FAA Mix #2 gradation is needed to withstand aircraft loadings on taxiways and runways
- Associated Asphalt sponsored a research project at Rutgers University to see if a 12.5 mm P-401 Mix #2 could be designed using P-404 criteria
  - Designed at 2.5% air voids
  - Designed with 50 Marshall blows

12.5 mm FR Mix Development

- Compared 12.5 mm P-404 FR Mix #2 version to standard P-401 Mix #2
- Compared to P-401 Mix #2 with best asphalt binder available – PG 82-22
- AC 150 5370-10H recommends three grade bumps for heavily loaded pavements – yields a PG 82-22 in PG 64-22 climate regions
- Compared mix performance using multiple laboratory rutting and cracking tests

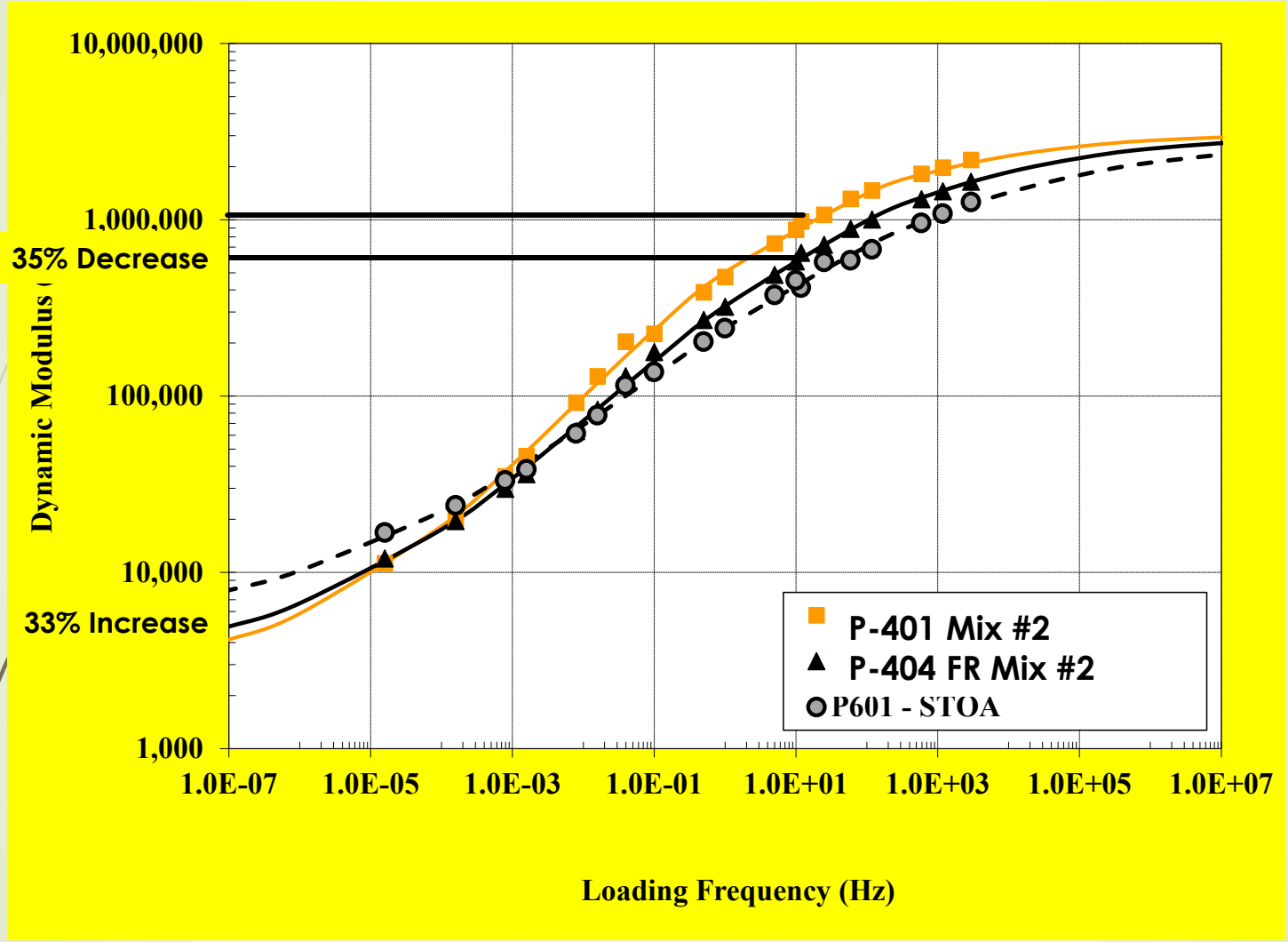
12.5 mm Fuel-Resistant Mix

- Asphalt Binders (true grade)
  - PG 82-22: PG 83.1-25.3
  - PG 88-22FR: PG 95.1-25.9

12.5 mm Fuel-Resistant Mix

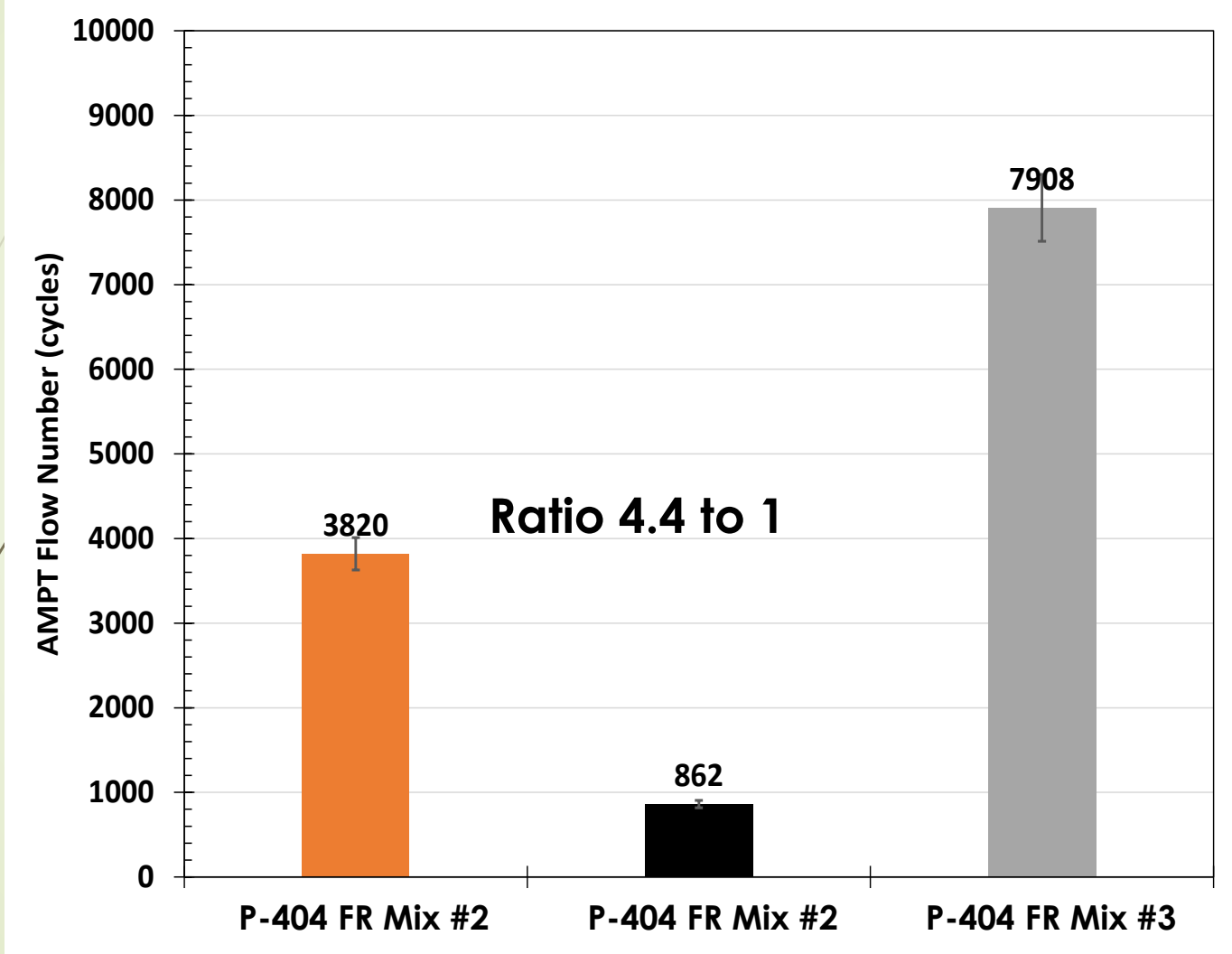
- Mix Design Results
  - Air Voids
    - P-404 FR Mix #2 = 2.5%
    - P401 Mix #2 = 3.5%
  - Optimum Asphalt Content
    - P-404 FR Mix #2 = 6.7%
    - P401 Mix #2 = 5.8%
  - Fuel Resistance Mass Loss
    - P-404 FR Mix #2 = 0.31%
    - P401 Mix #2 = 5.07%

¾” Fuel-Resistant Mix



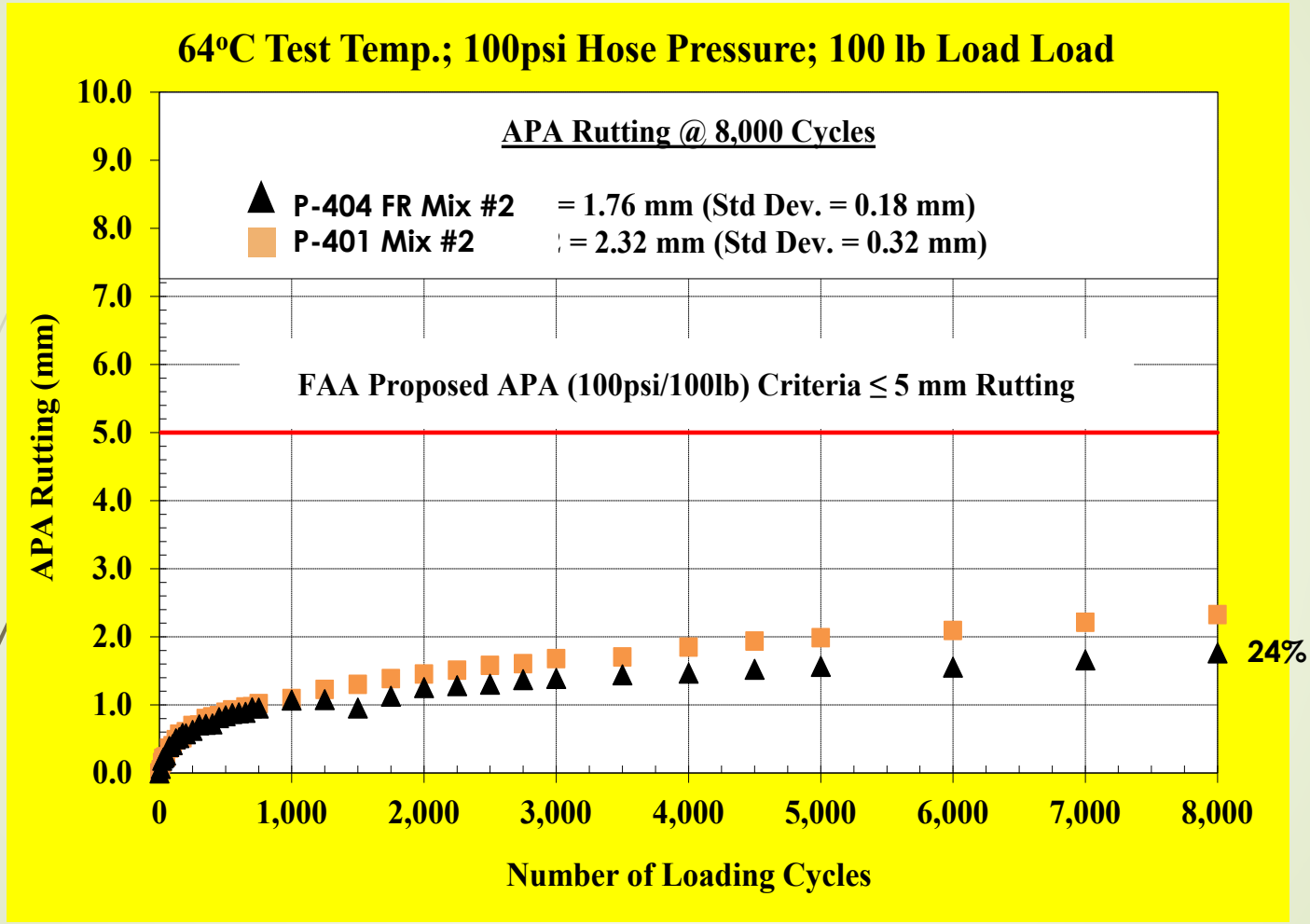
Dynamic Modulus Master Stiffness Curve for Short-Term Oven Aged (STOA) Asphalt Mixtures

¾” Fuel-Resistant Mix



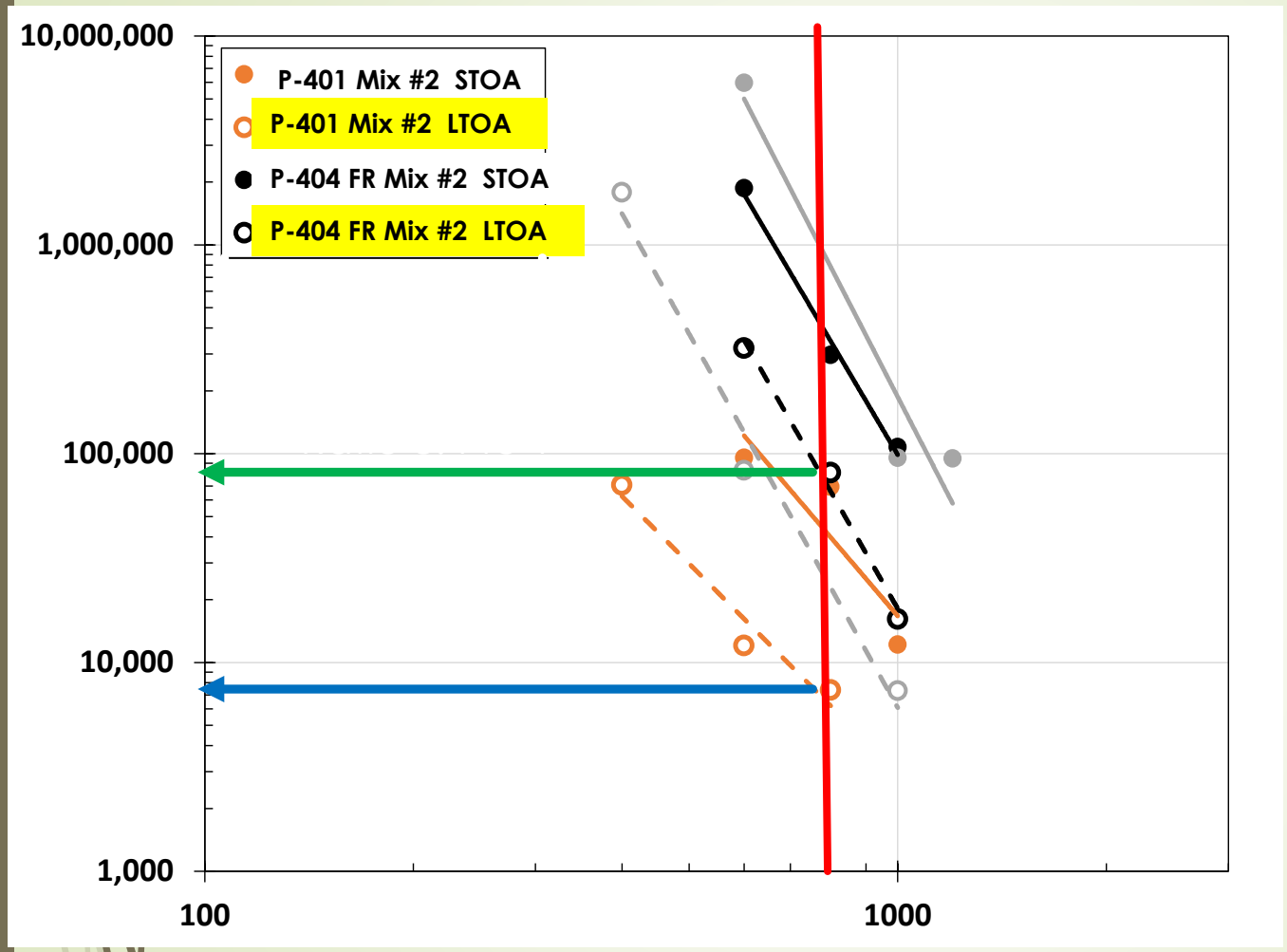
AMPT Repeated Load Flow Number Results

¾” Fuel-Resistant Mix



Asphalt Pavement Analyzer (APA) Rutting Performance

¾” Fuel-Resistant Mix



Beam Fatigue Cycles to Failure @ 800 microstrain

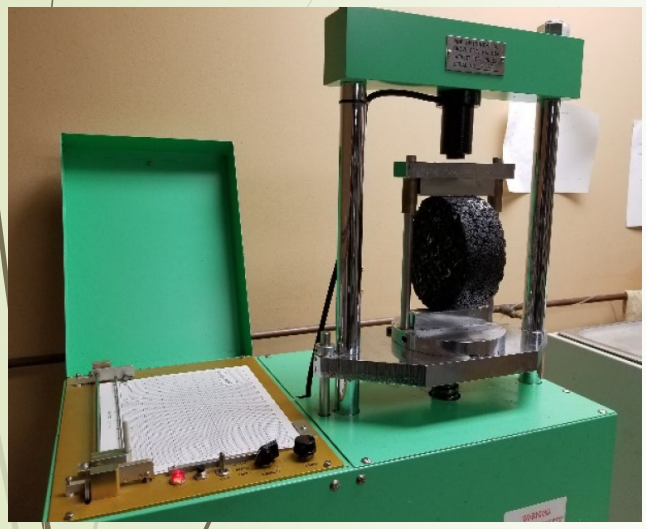
P-404 Mix #2 – 80,000 cycles

P-401 Mix #2 – 8,000 cycles

Ratio 10 to 1

Flexural Fatigue Life for P-404 FR Mix #2 and P-401 Mix #2 Asphalt Mixtures

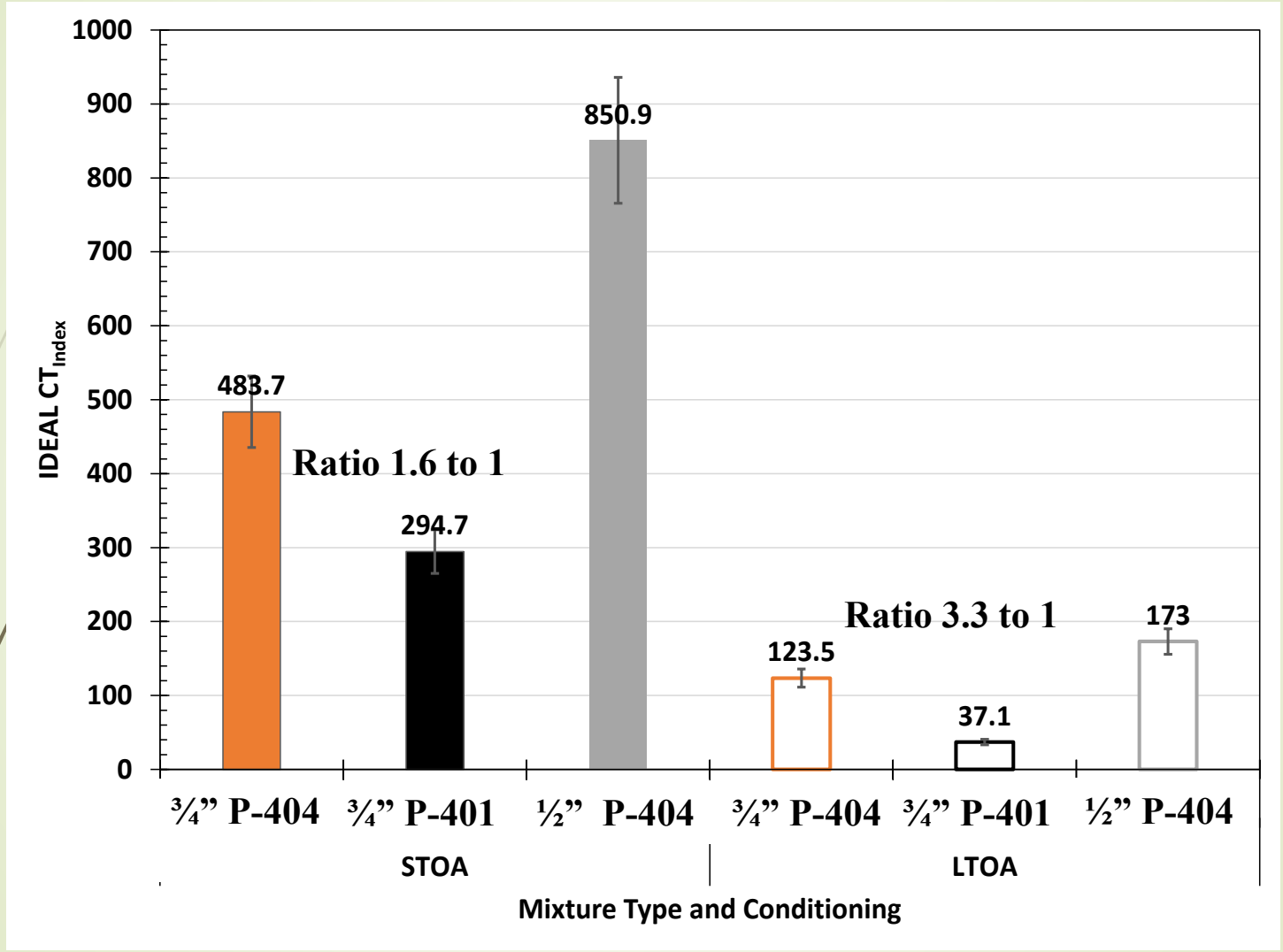
Intermediate Temperature Cracking Resistance Test (IDEAL-CT Test)



IDEAL-CT

- Test performed at 25°C
- Gyratory-sized (150 mm diameter) test specimens
- Thickness range of 38 to 75 mm
- No need for cutting or notching
- Vertically loaded at a rate of 50 mm/min – can be run on Marshall test apparatus

¾” Fuel-Resistant Mix



IDEAL CT_{Index} Test Results

P-404 Mix Apron Project at Toronto International Airport - 2020

FAA P-401 Mix #2 Gradation (12.5 mm mix)
with PG 82-28 FR Binder

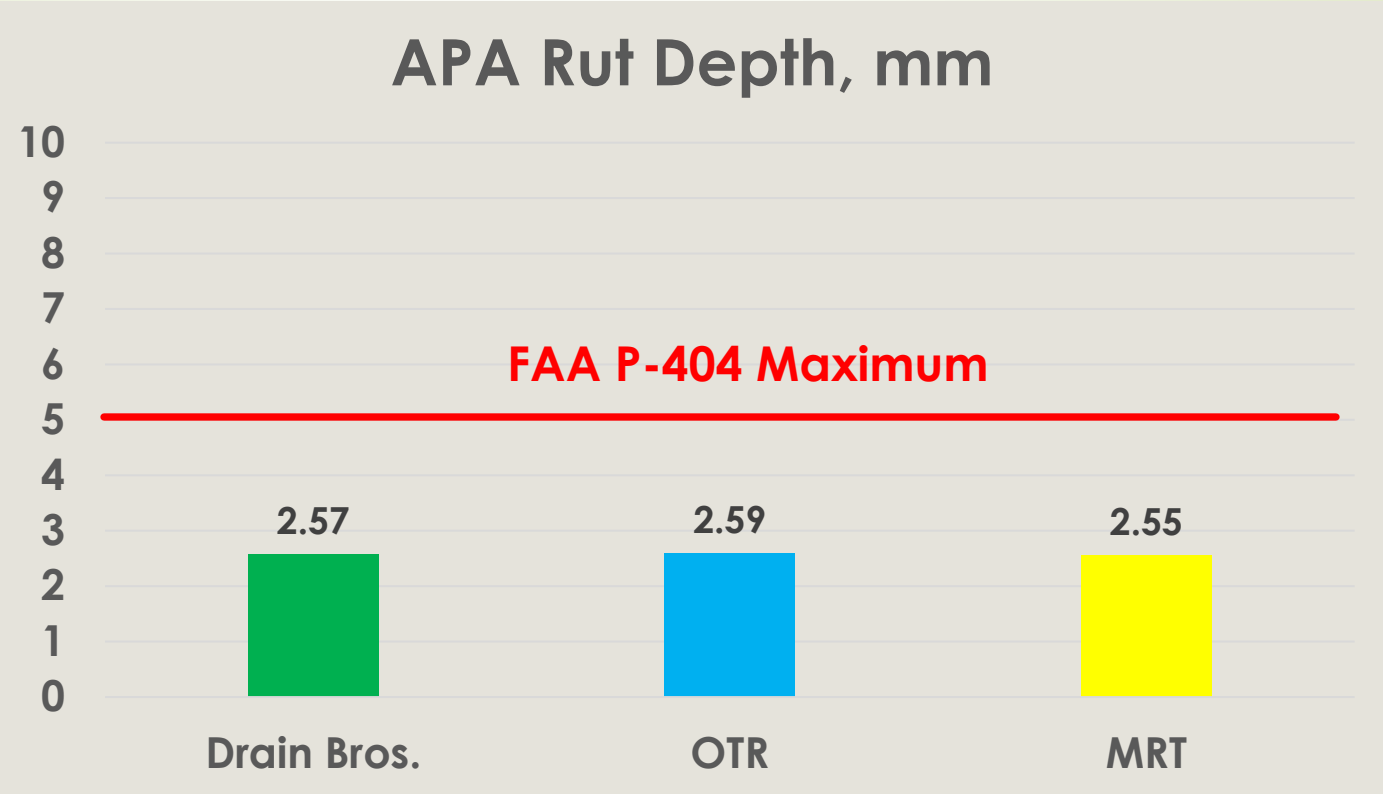
P-404 Mix Apron Project at Toronto International Airport

- Prior to using 12.5 mm P-404 mix, Greater Toronto Airport Authority (GTAA) commissioned SNC-Lavalin to perform performance testing
- SNC-Lavalin produced three 12.5 mm P-404 mixes in the laboratory using three aggregate types available in the Toronto area

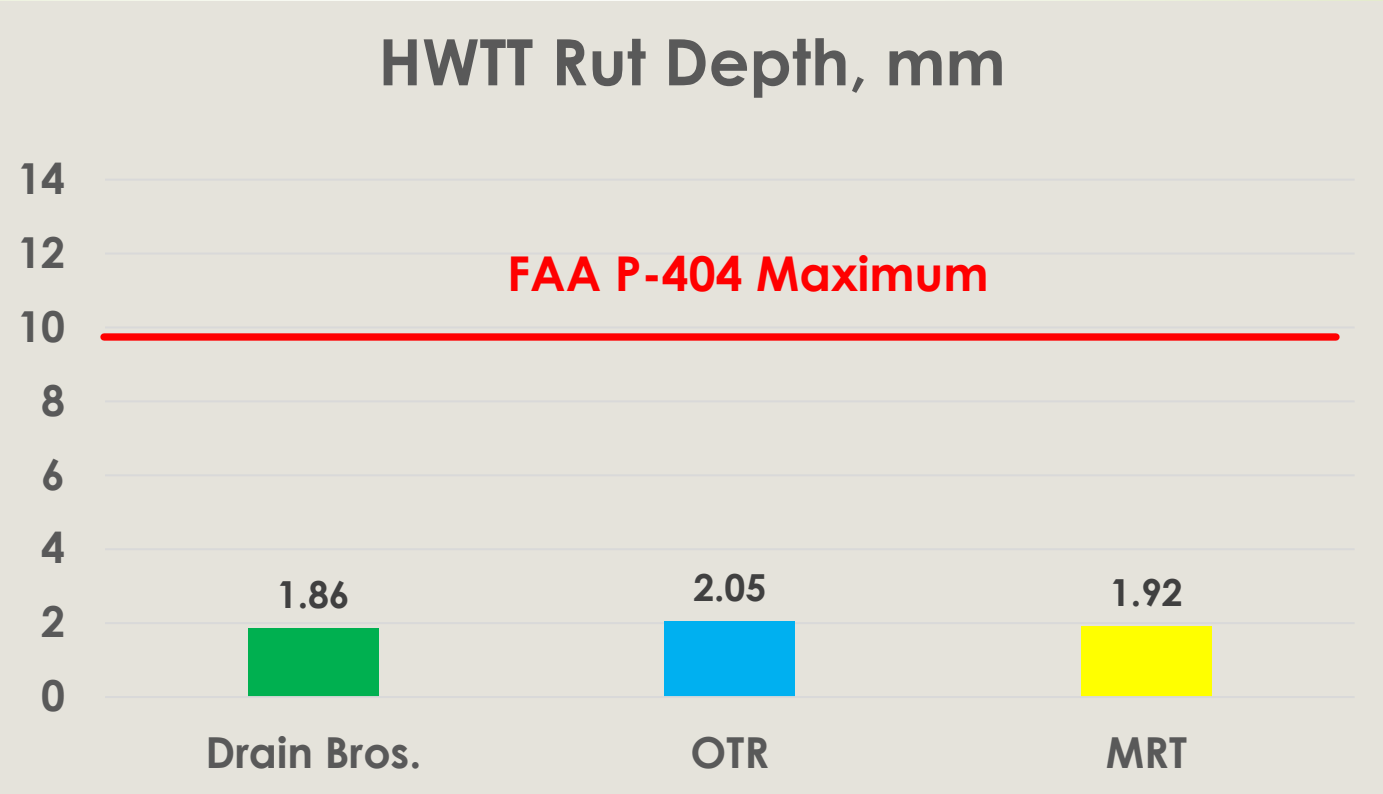
SNC-Lavalin P-404 Research Results

- Asphalt Binder Grade = PG 88-28 FR
- Optimum Asphalt Content
  - Havelock Quarry (Drain Bros.) = 6.9%
  - Bruce Mines Quarry (OTR) = 6.9%
  - Methuen Quarry (MRT) = 6.5%
- Fuel Resistance Mass Loss
  - Drain Bros. = 0.14%
  - OTR = 0.11%
  - MRT = 0.12%

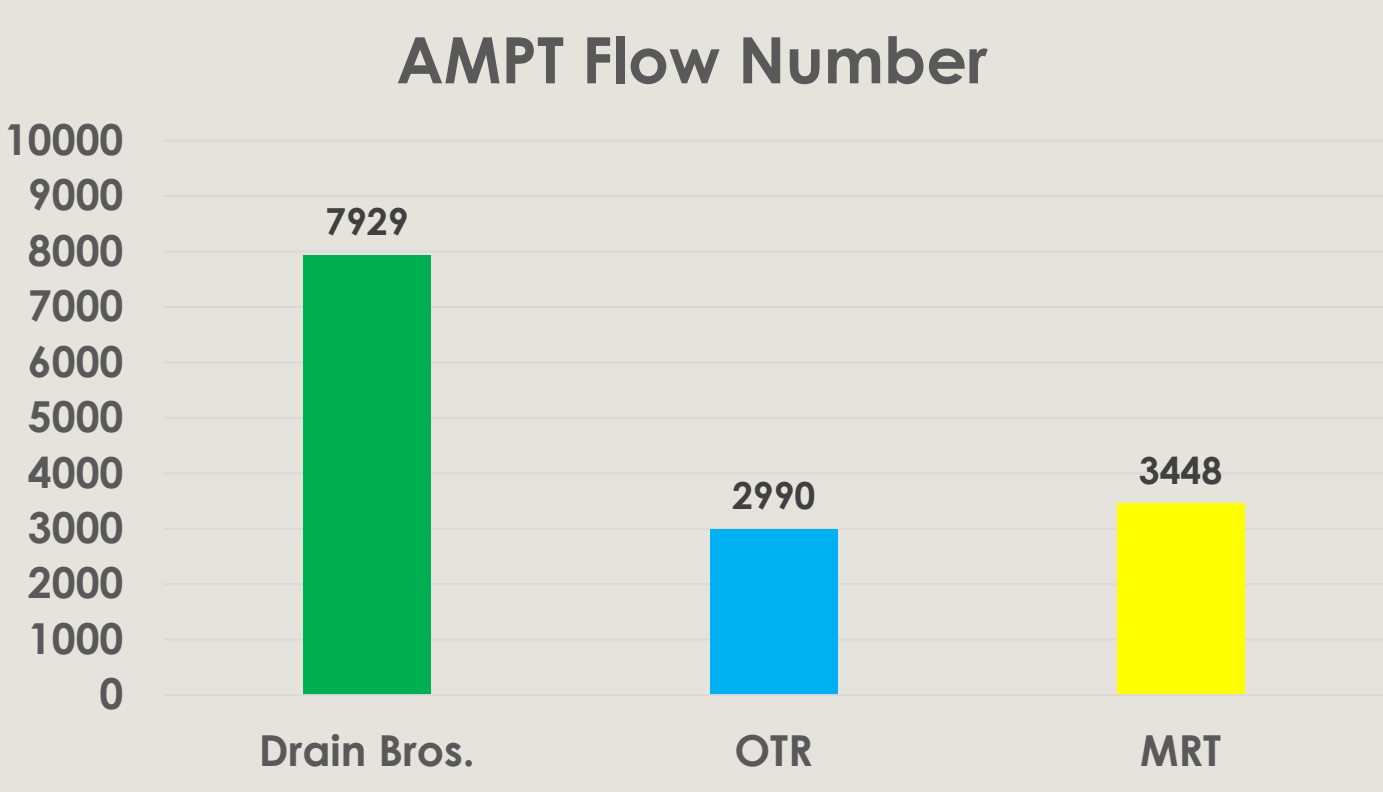
SNC-Lavalin Asphalt Pavement Analyzer (APA) Rutting Results



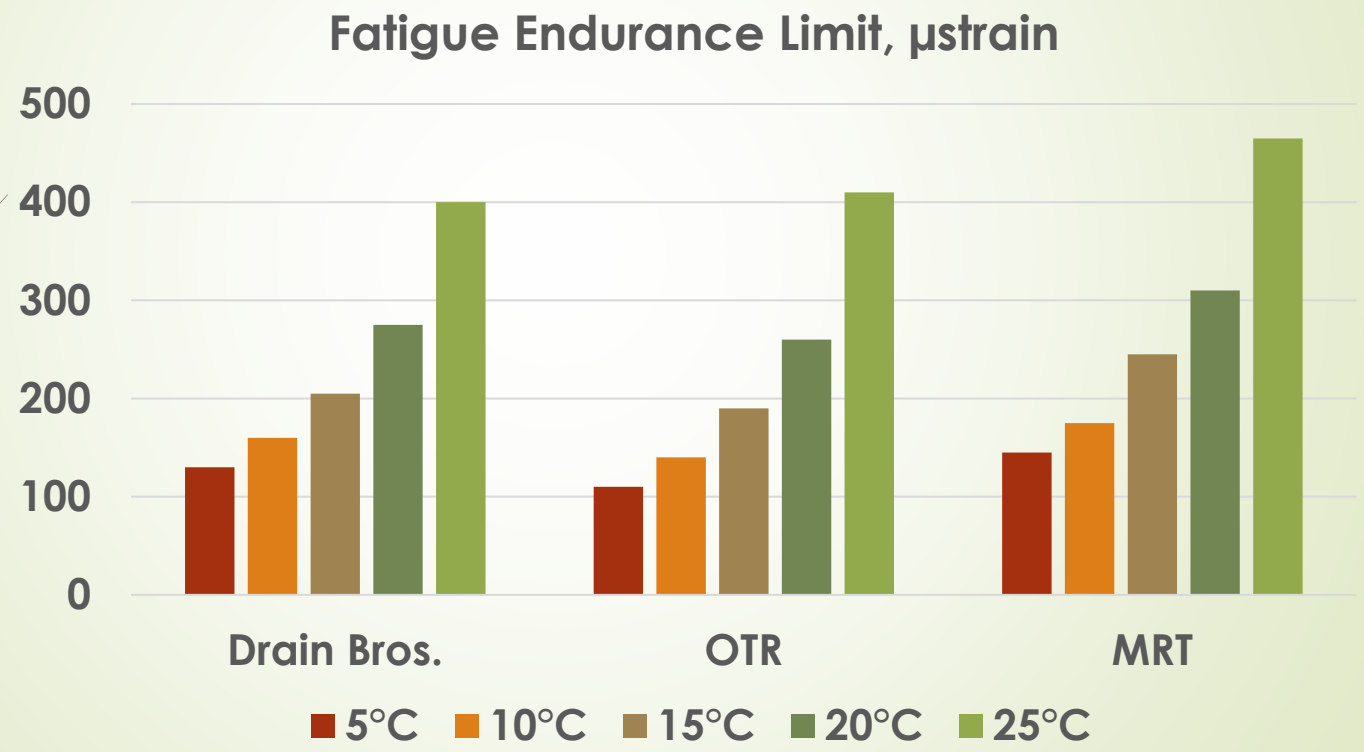
SNC-Lavalin Hamburg Wheel Tracker Test (HWTT) Rutting Results



SNC-Lavalin AMPT Flow Number Rutting Results



SNC-Lavalin Fatigue Endurance Limit Cracking Results



SNC-Lavalin GTAA Study Conclusions

- “Based on the HMA Fuel Resistant Mix Design laboratory study, it can be concluded that the GTAA P-404 mixes with StellarFlex FR asphalt cement showed high fatigue and rutting performance. As such, it is recommended that, through a field study, a trial section of the runways / taxiways be paved using GTAA P-404 Marshall mixes and compare the performance against a control section paved using GTAA conventional mixes.”

P-404 Cost

- P-404 mix costs approximately 20-25% more than P-401 mix
- Two factors contribute to increase
  - Two to three times more polymer in the liquid asphalt
  - ≈1.0% more liquid asphalt in the mix

P-404 Cost

- P-404 mix cost increase affects only one item in the project cost – the surface layer
- Unaffected items typically found on airfield paving projects
  - Milling
  - Patching
  - Base and intermediate pavement layers
  - Striping
  - Electrical work
- Cost increase to total project cost (depending on scope of work) is typically 5-7%

Benefits of FAA P-404 Mix

- FR highly polymer-modified asphalt provides:
  - Outstanding rut resistance
  - Improved fatigue resistance
  - Resistance to fuel and oil damage – eliminates need for coal tar sealers
  - Excellent workability
  - Longer life
- P-404 mix design has increased asphalt content, which provides:
  - Improved fatigue (cracking) resistance
  - Increased pavement life (durability)
- Combination provides resistance to all potential airfield pavement damages – results in longer pavement life and lower life cycle cost

Contact Information

Ron Corun

roncorun@roncorunconsulting.com

(410) 952-4020

Questions?