Separating Load from Moisture Effects in Wet Hamburg Wheel-Track Test

Quan (Mike) Lv, Ph.D.
Hussain Bahia, Ph.D.
March 6, 2019 Fort Worth, Texas

THE UNIVERSITY of WISCONSIN MADISON

MARC MODIFIED ASPHALT RESEARCH CENTER

AAPT Association of Asphalt Paving Technologists

School of Transportation Engineering
Tongji University

Acknowledgments

- The financial supports:
  - WisDOT: Wisconsin Highway Research Program 17-06.
- Project Collaborator:
  - Dr. Preeda Chaturabong

Outline

- Background
- Materials & Testing Methods
- Identification of Confounding Effect
- Proposal of a Novel Analysis Method
- Validation of the Proposed Method
- Findings & Conclusions

Part 01

Background

Background

- The wet HWTD test is widely used to identify asphalt mixes that are prone to rutting and moisture damage (Aschenbrener et al., 1993).

  - Confounding effects of loading and moisture (Lu, 2005; Mohammad et al. 2015, NCHRP-W219; Tsai et al., 2016; Swiertz et al., 2017).

  - Limited specifics are provided in AASHTO T324-17 for the analysis of results (Mohammad et al., 2017).

Background

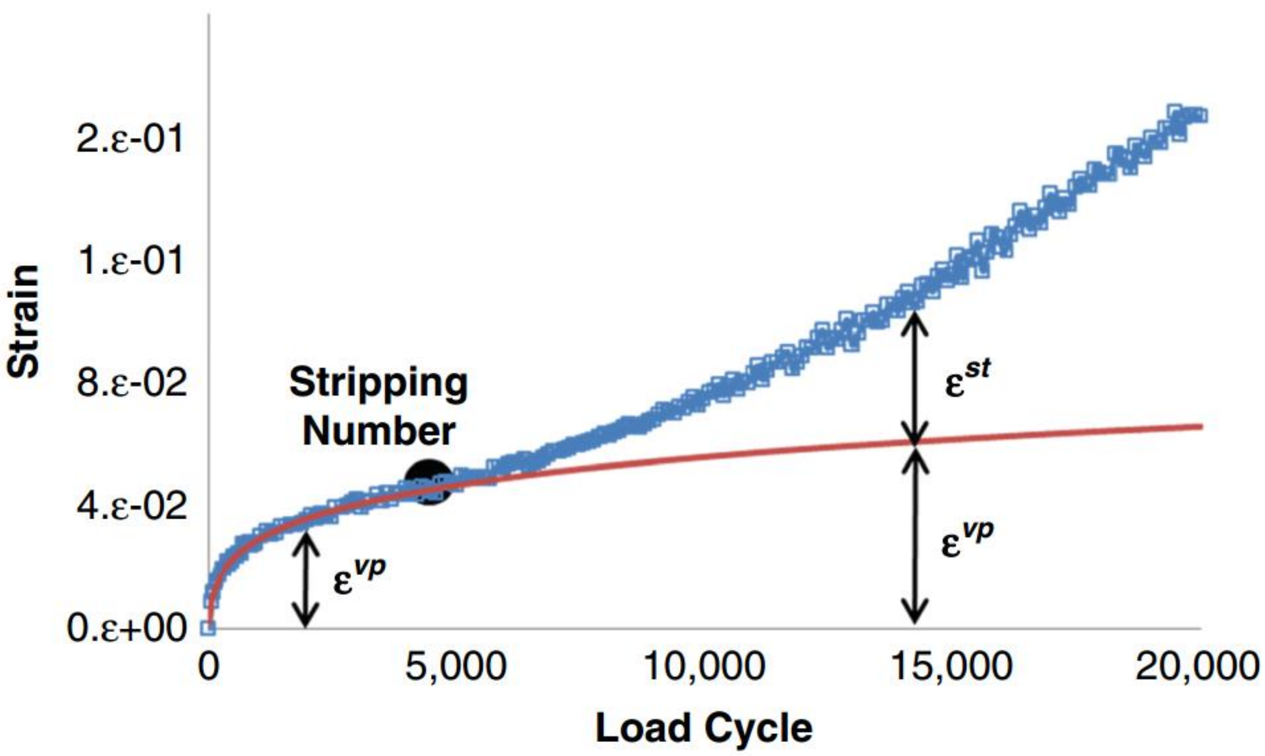
- There is a need to separate Loading effects from Moisture effects
- Option 1: Conducting the HWTD test under **both dry and wet**.

  “The moisture sensitivity related performance can be determined by subtracting the rutting response curve of a dry HWTD test from that of a wet HWTD test. ”

  Lu, Q. Investigation of conditions for moisture damage in asphalt concrete and appropriate laboratory test methods. University of California Transportation Center, 2005.

Option 2

- Separating Load from Moisture Effects in Wet HWT test. *(Yin et al., NCHRP Project 9-49, 2014)*



$$\varepsilon^{vp} = \varepsilon_{\infty}^{vp} \exp\left[-\left(\frac{\alpha}{LC}\right)^{\lambda}\right]$$

$$\varepsilon^{st} = \frac{RD_{LC}}{T} - \varepsilon_{\infty}^{vp} \exp\left[-\left(\frac{\alpha}{LC}\right)^{\lambda}\right]$$

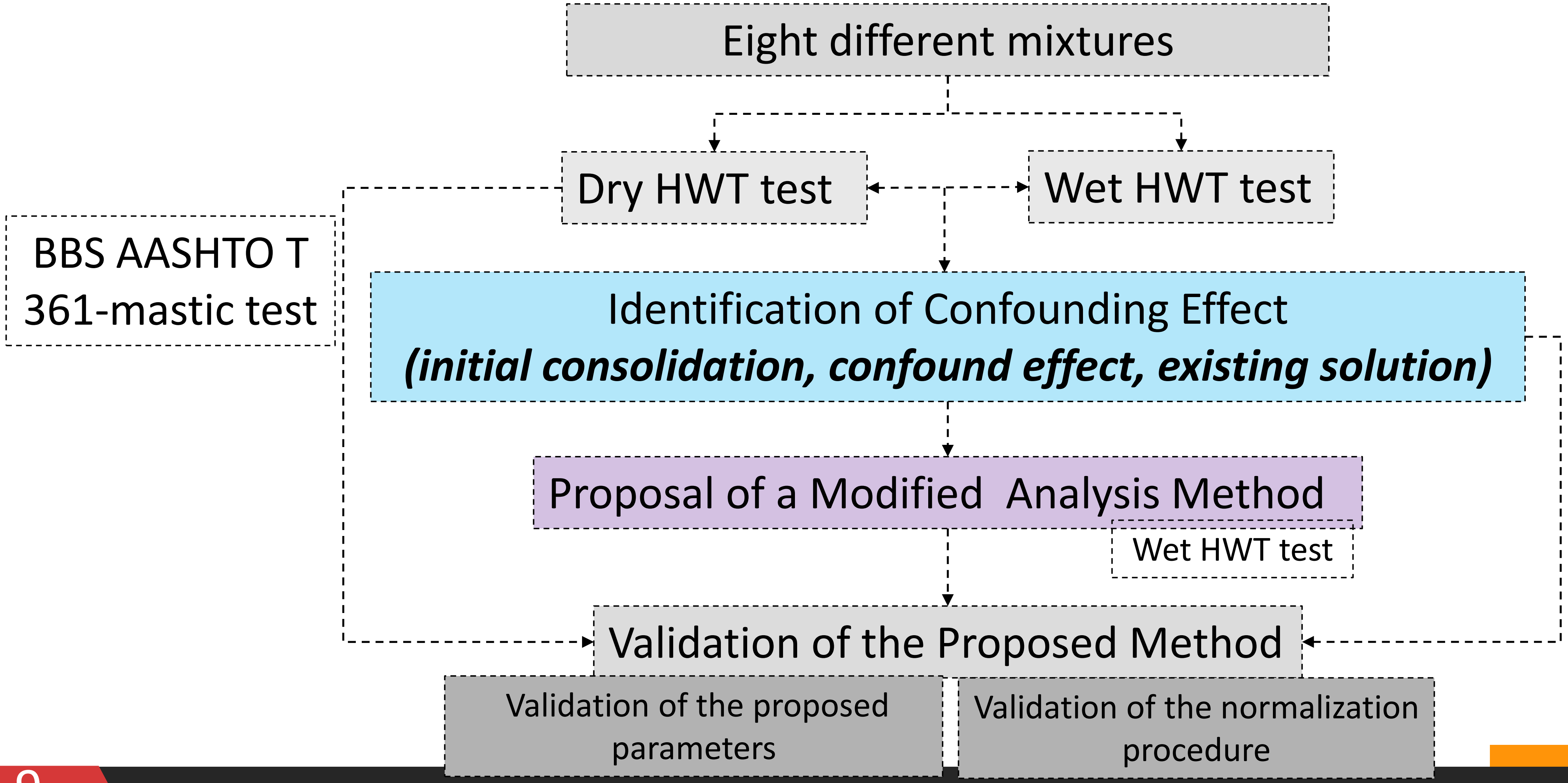
Part 02

Materials & Testing Methods




Materials & Testing Methods

Experimental Plan



Materials

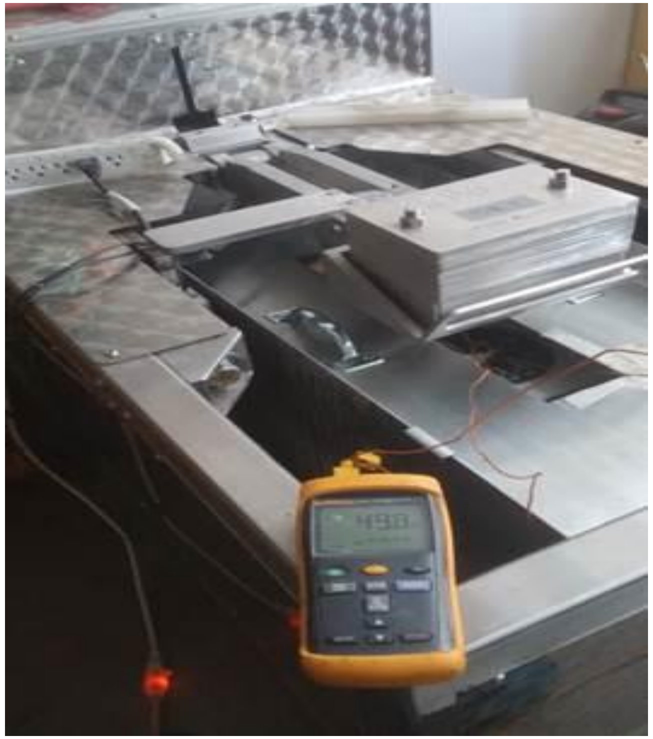
- **Eight mixture types: 2 aggregate types, 2 traffic levels and 2 binders**

Mixture ID	Aggregate Type	Traffic Mix Level	Binder Type PG 58
C-MT-S28	Cisler (Granite)	MT	S-28
C-MT-V28		MT	V-28
C-HT-S28		HT	S-28
C-HT-V28		HT	V-28
W-MT-S28	Waukesha (Limestone)	MT	S-28
W-MT-V28		MT	V-28
W-HT-S28		HT	S-28
W-HT-V28		HT	V-28

◆ HWT test:

- AASHTO T324-17, 50 ± 1 °C

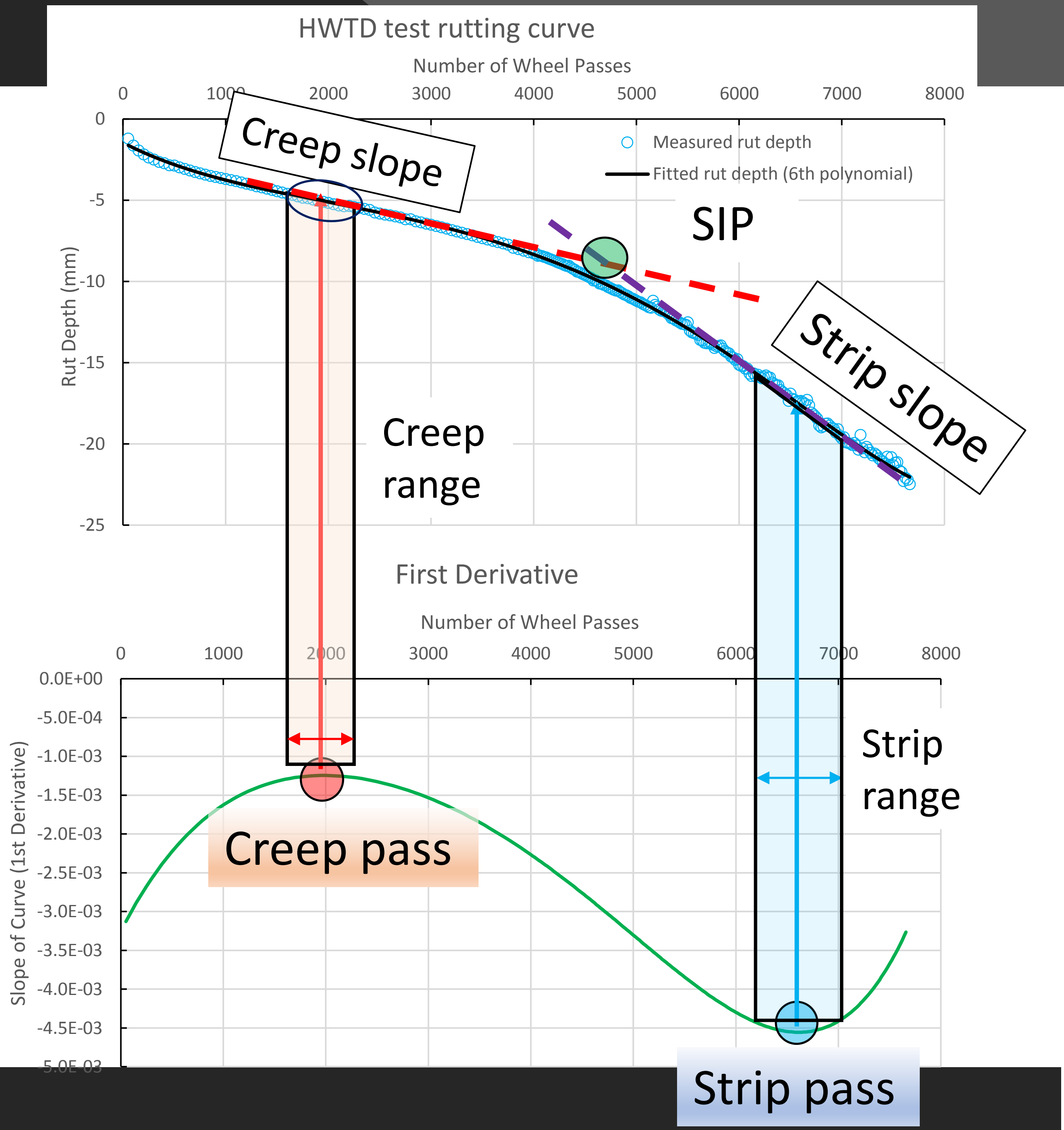
(a) PMW Hamburg Single Wheel Tracker



(b) Set up for the dry condition test.

Testing Methods

- **HWT test:**
  - Iowa DOT analysis method
    - Creep Slope: CS
    - Stripping Inflection Point: SIP
    - Strip Slope: SS



Binder Bonding Strength (BBS) test:

- Based on AASHTO T361

$$\text{Loss of POTS} = \frac{POTS_{dry} - POTS_{wet}}{POTS_{dry}} \times 100$$

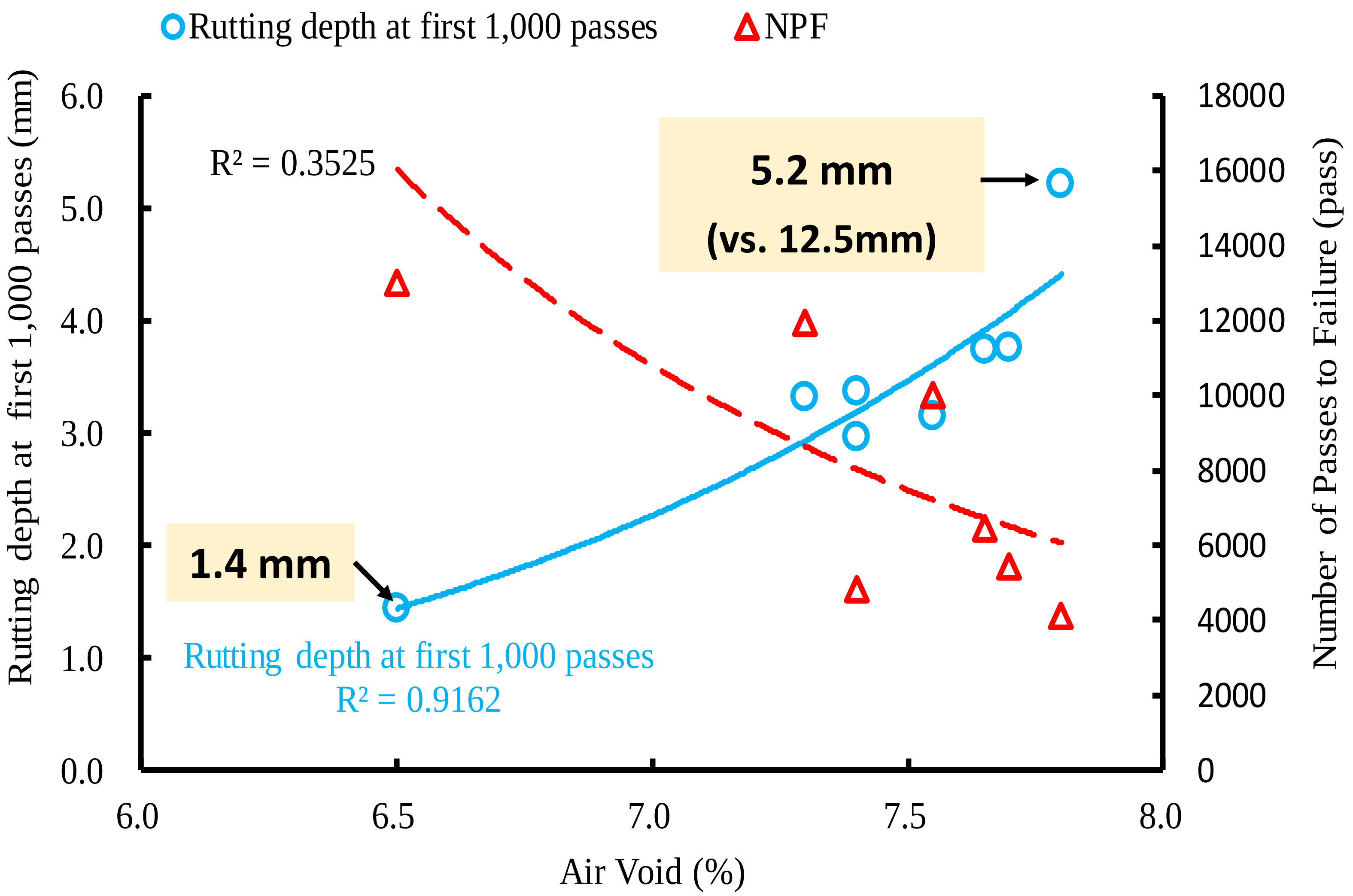
(a) BBS test device (b) the equipment to control the temperature.

Part 03

Identification of Confounding Effect

Identification of Confounding Effect

Confounding effect of initial consolidation (First 1000 Cycles)

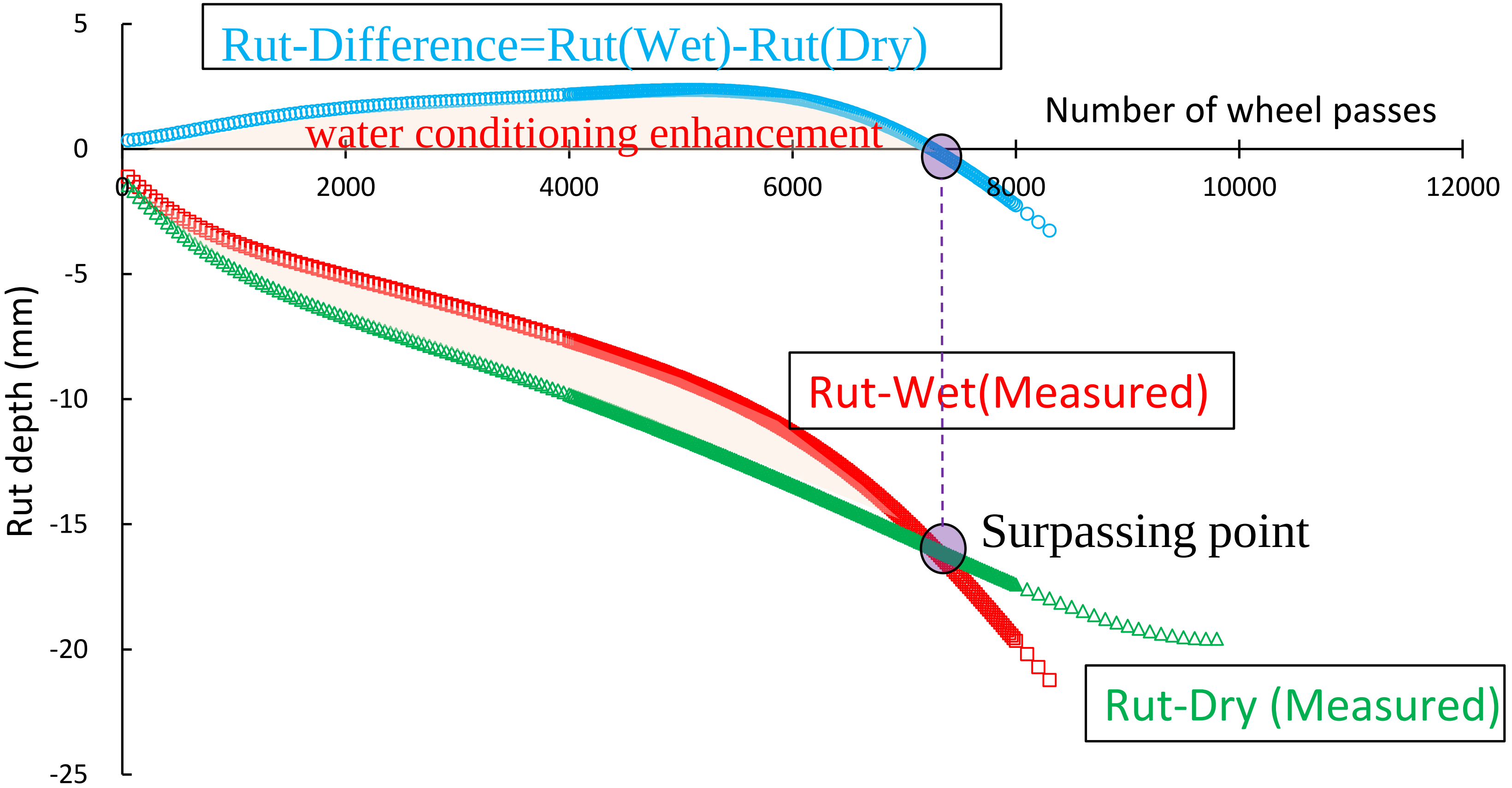


Rutting depths after first 1000 wheel passes are highly correlated to the AV contents.

There are strong confounding effects of specimen air void and post-compaction consolidation

Identification of Confounding Effect

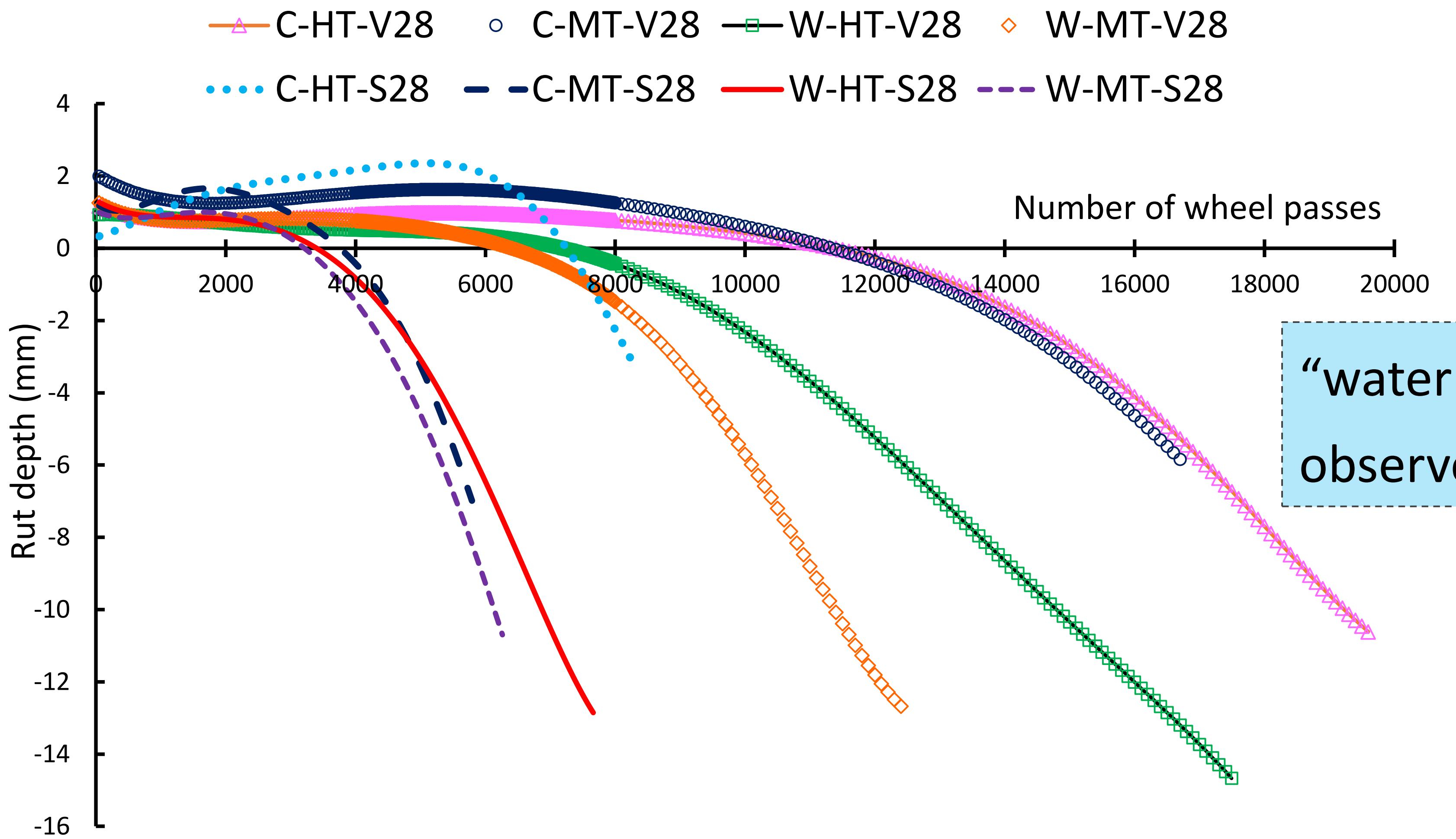
Effects of water conditioning on the creep stage



"water conditioning enhancement" will affect the CS, SS, SIP.

Identification of Confounding Effect

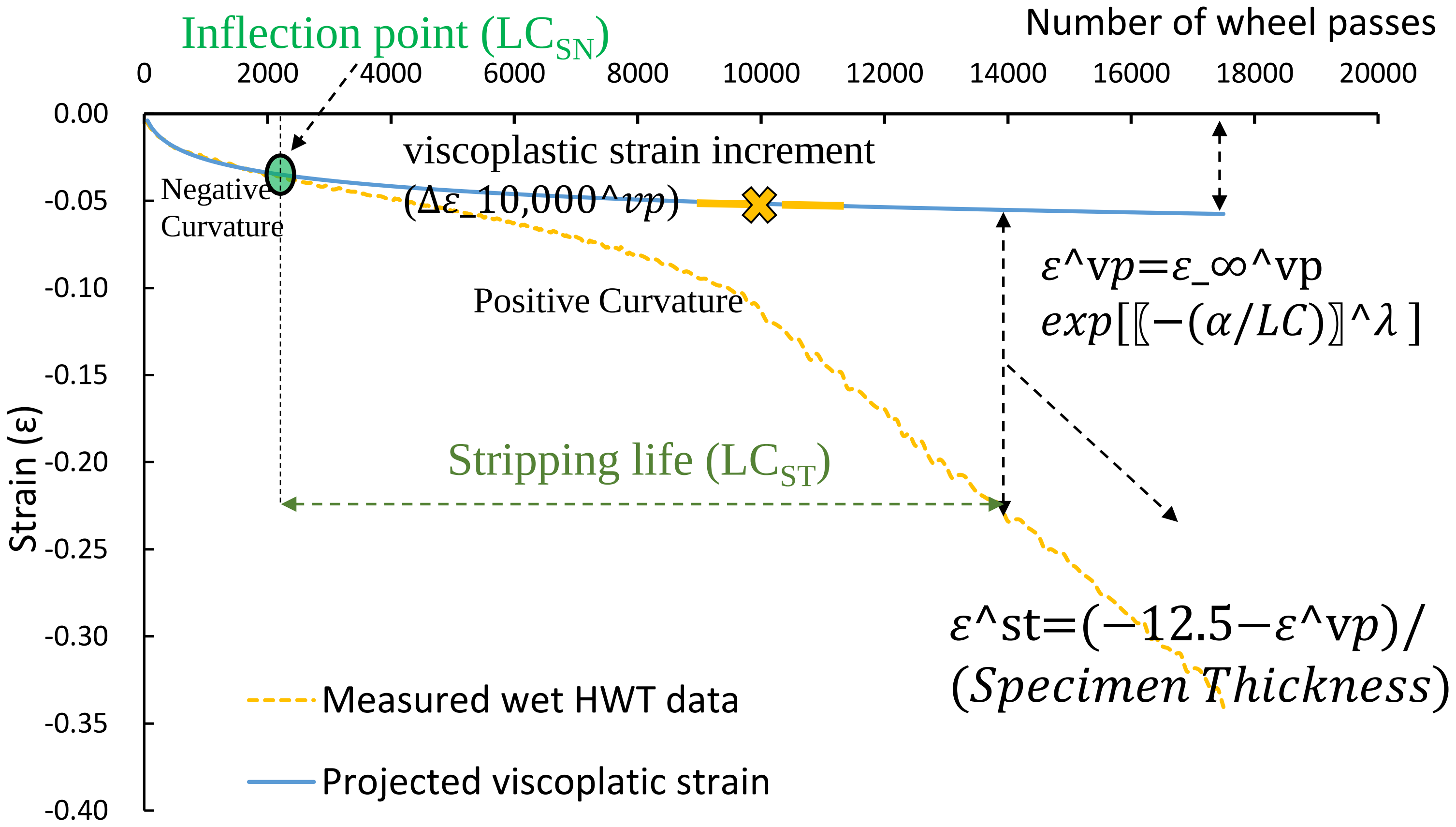
Effects of water conditioning on the creep stage



"water conditioning enhancement" is observed in all eight mixtures.

Identification of Confounding Effect

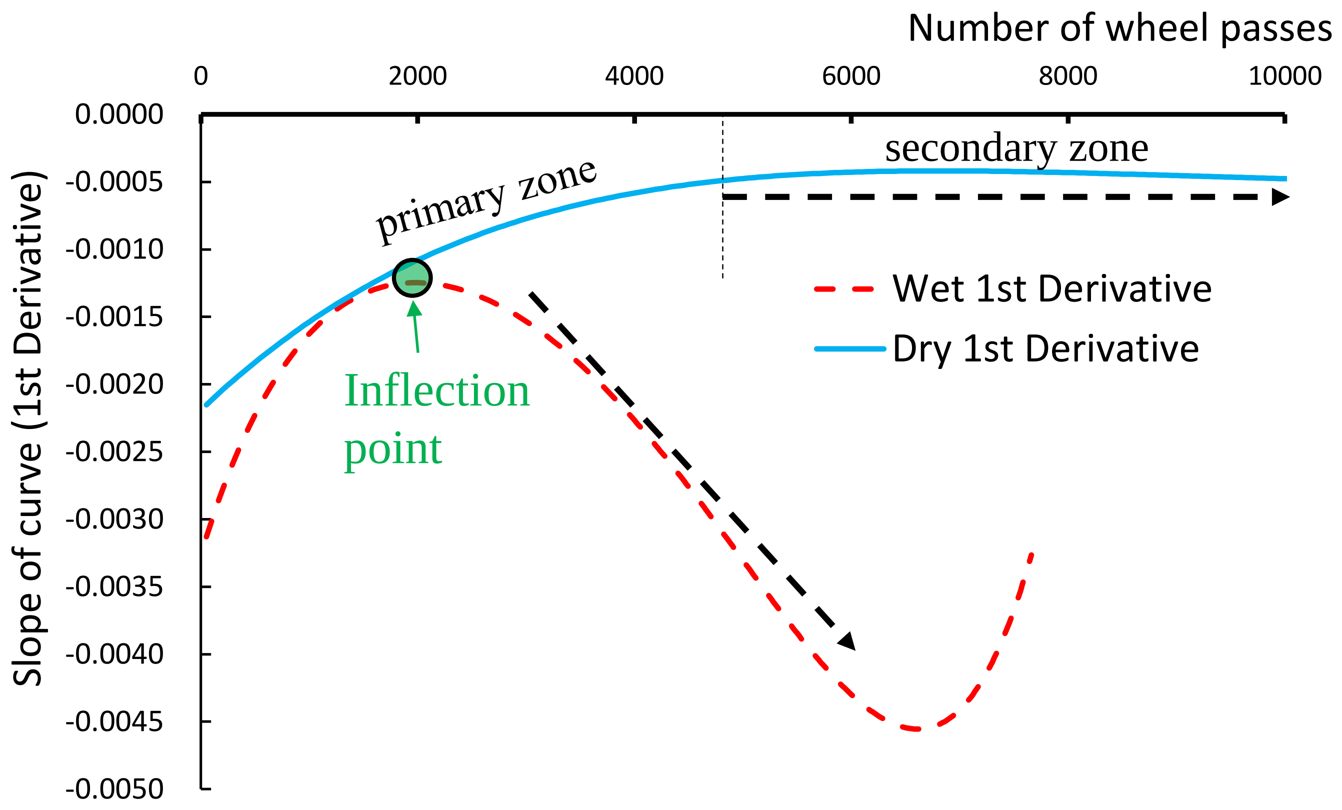
- **Existing method to solve the confounding effect (Texas method, NCHRP Project 9-49)**



Assumption: the inflection point of the curve is an indicator of the onset of the stripping.

Identification of Confounding Effect

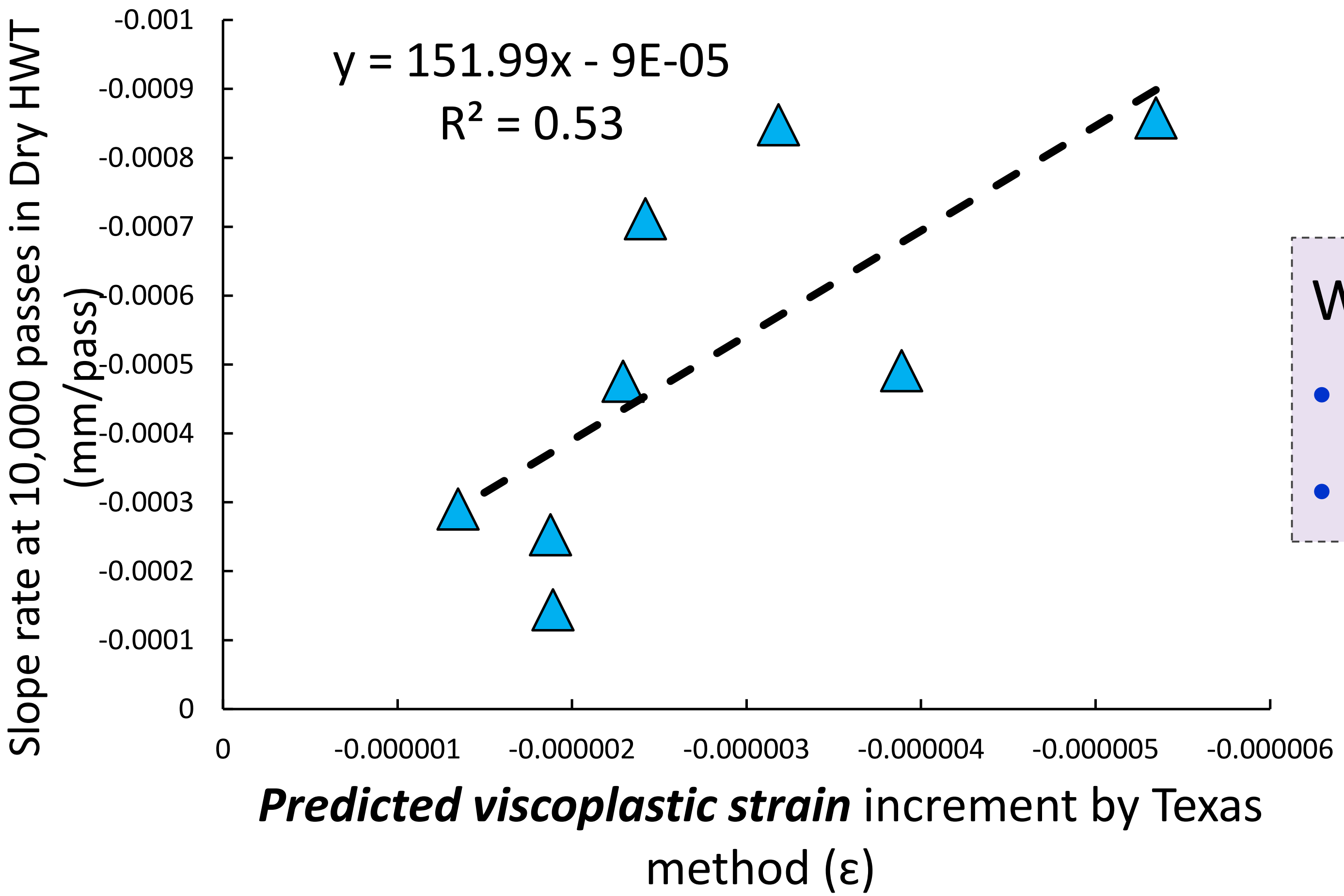
- **Existing method to solve the confounding effect (Texas method, NCHRP Project 9-49)**



Two models to fit 2 parts of the trend; before and after inflection point

Identification of Confounding Effect

- **Using the proposed method to solve the confounding effect (Texas method, NCHRP Project 9-49) applied to our data.**



Wet HWT (Texas method) vs. Dry HWT

- Correlation - R^2 is not high enough.
- Need discount the post-compaction.

Part 04

Proposal of a Novel Analysis Method

Proposal of a novel analysis method for wet HWT

Assumptions

- The total rutting depth = the contribution from visco-plastic deformation + the moisture-induced damage.

- But we need to discount the contribution from the post-compaction phase.

- The inflection point of the curve (when the curvature changes from negative to positive.) is where the water starts to affect.

- Need an easier model and fit method.

Proposal of a novel a

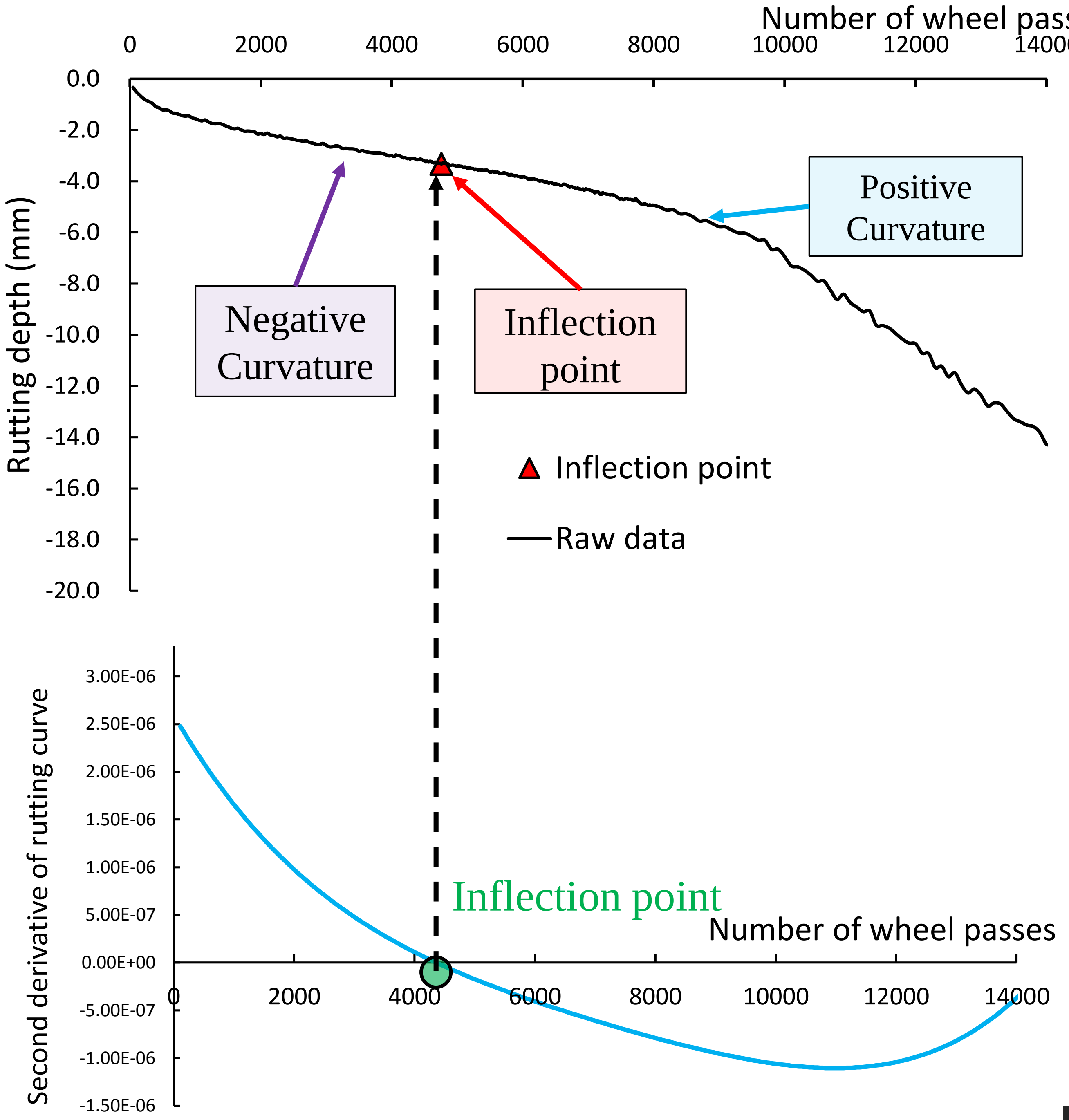
Step 1:Fitting of the raw data

Fit curve with a sixth-degree polynomial function. (Eq.1)

The inflection point where the second derivative of the polynomial first reaches zero after first 1,000 passes. (Eq.2)

$$\textbf{Eq. 1}: \mathrm{RD}(N) = P_1 \times N^6 + P_2 \times N^5 + P_3 \times N^4 + P_4 \times N^3 + P_5 \times N^2 + P_6 \times N + P_7$$

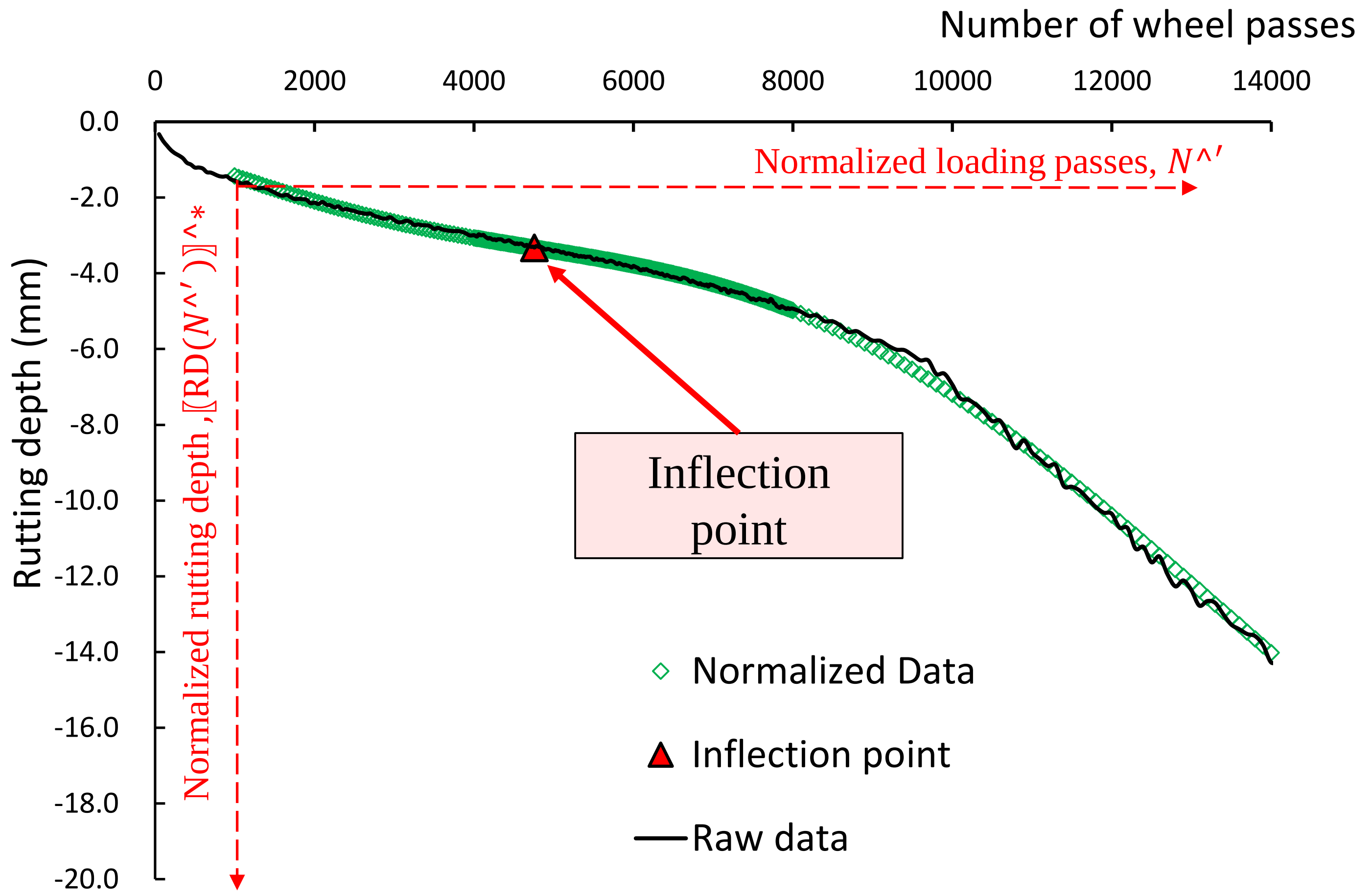
$$\textbf{Eq.2}: \frac{\partial^2 \mathrm{RD}(N)}{\partial N^2} = 30 \times P_1 \times N^4 + 20 \times P_2 \times N^3 + 12 \times P_3 \times N^2 + 6 \times P_4 \times N + 2 \times P_5 = 0$$



Step 2: Normalization of the fitted data

The fitted rutting depth at first 1000 passes should be subtracted from the fitted rutting curve to normalize the data. (Eq.3)

Eq. 3: $\mathrm{RD}(N')^{*}$
$= \mathrm{RD}(N' + 1000) - \mathrm{RD}(1000)$



$\mathrm{RD}(N')^{*}$ is the normalized rutting depth, N' is the normalized number of loading passes, $\mathrm{RD}(1000)$ is the fitted rutting depth at 1,000 passes.

Proposal of a novel analysis method for wet HWT

Step 3: Calculation of the performance-related parameters

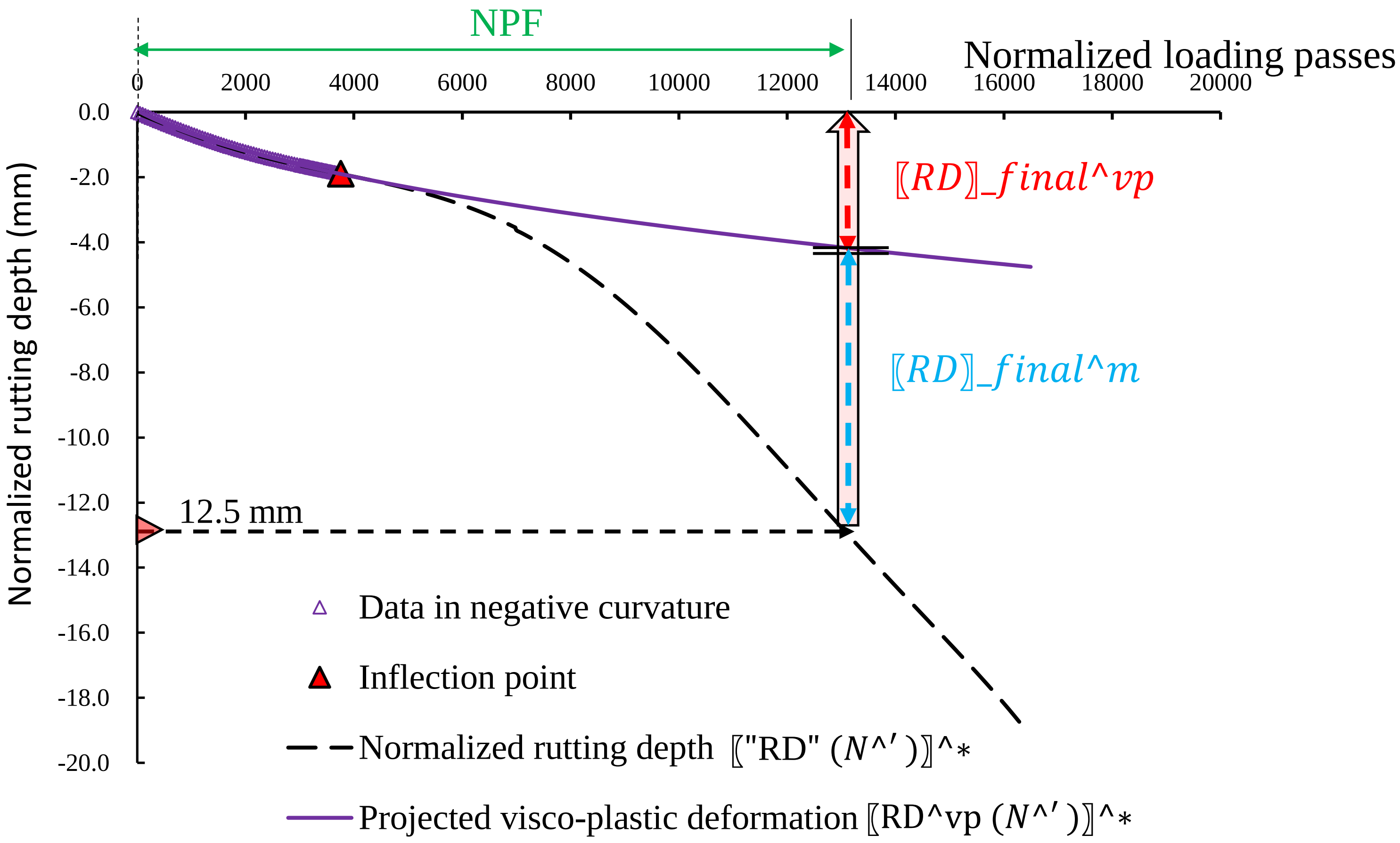
- Overall performance evaluation: Number of Passes to Failure (12.5mm, NPF) or maximum Rutting Depth (Rut_{max}).

- Rutting resistance evaluation: Visco-plastic Ratio (VR)

$$\mathrm{RD^{vp}}(N')^{*} = a \times (N')^{VR}$$

- Moisture resistance evaluation: Moisture Ratio (MR)

$$\mathrm{MR} = \frac{\mathrm{RD_{final}^{m}}}{\mathrm{RD_{final}^{m}} + \mathrm{RD_{final}^{vp}}} \times 100$$

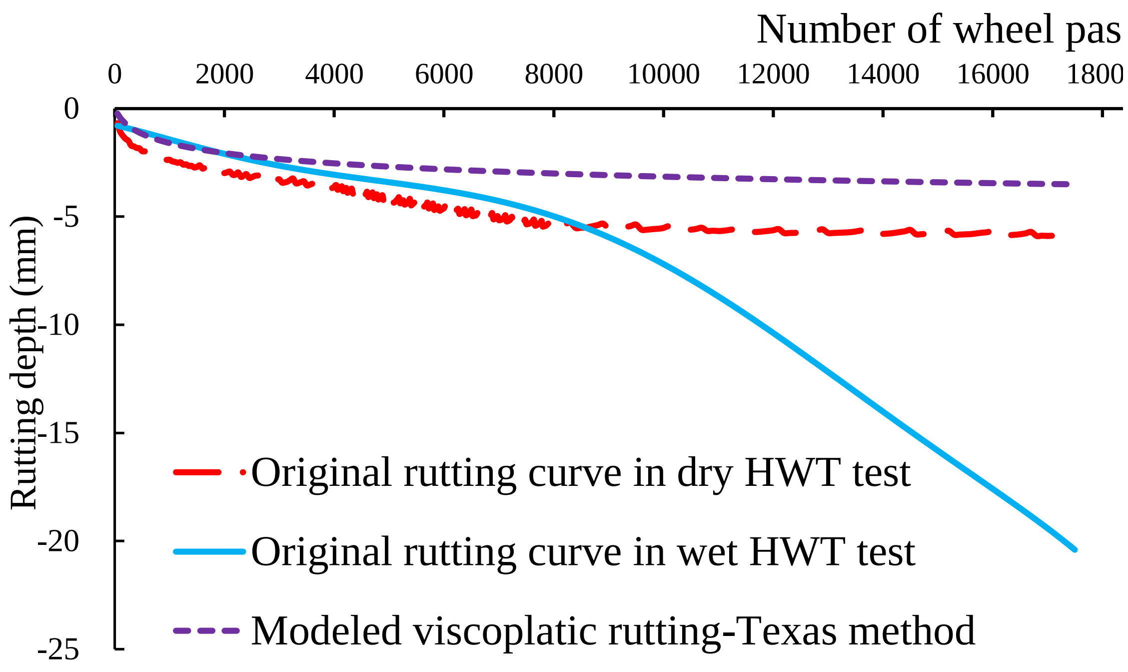


Part 05

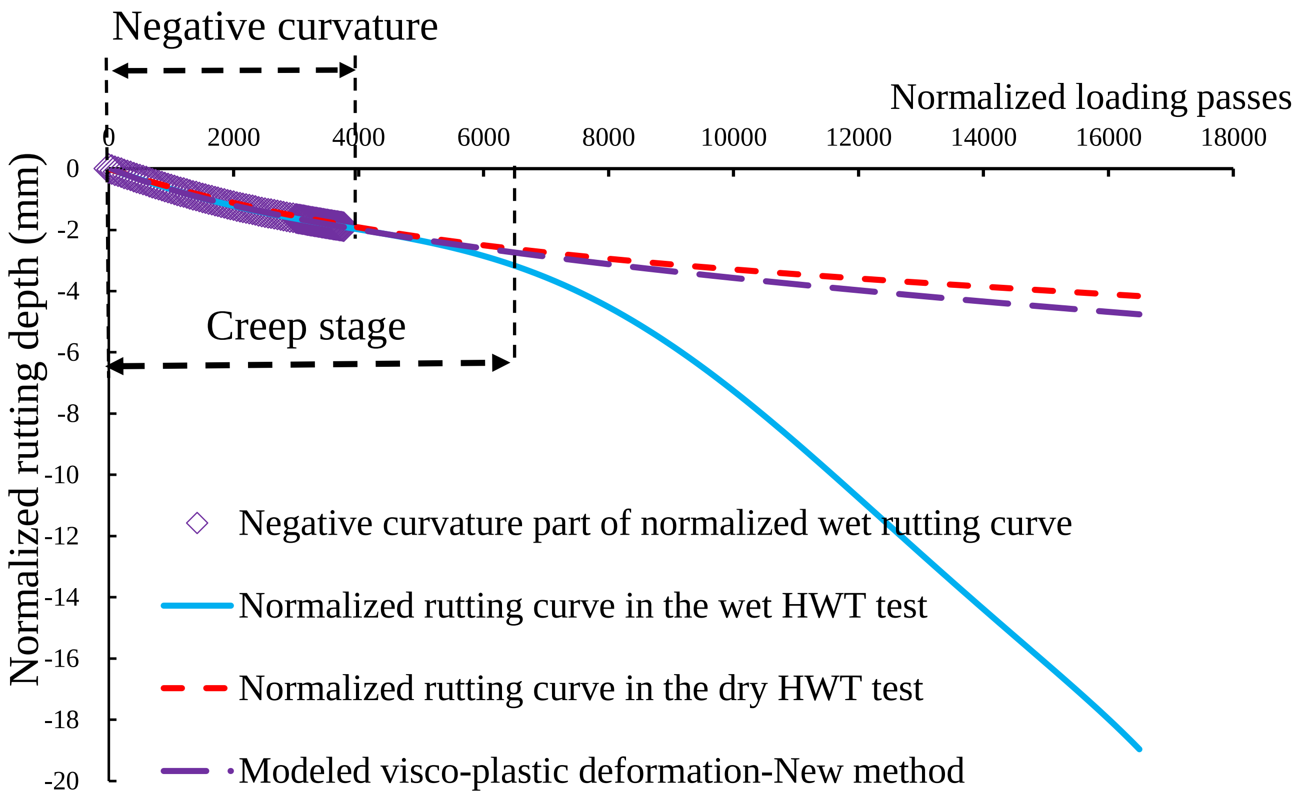
Validation of the Proposed Method

Validation of the Proposed Method

Validation of the normalization procedure



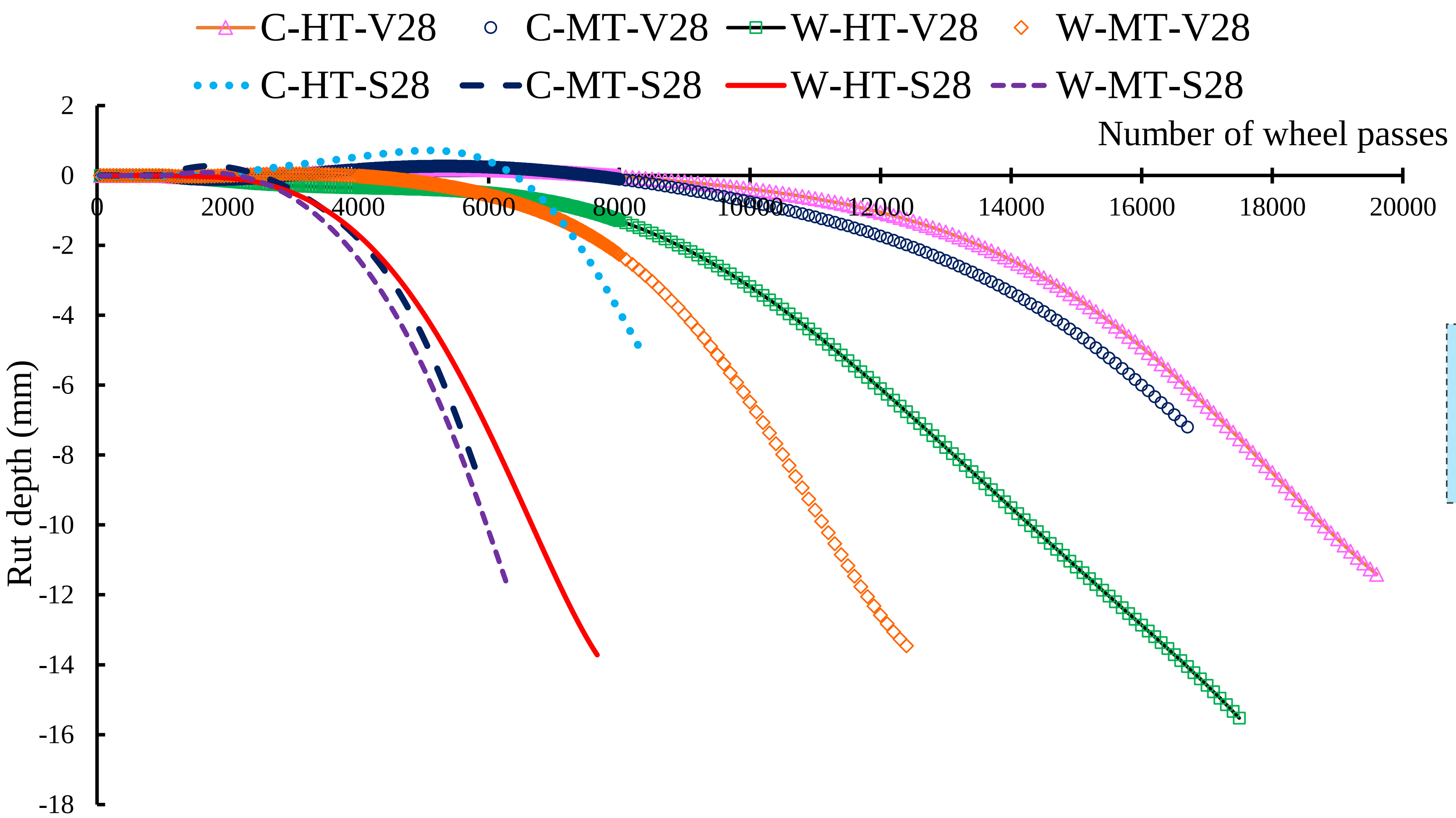
(a) Current method no normalization



(b) New method after normalization

Validation of the Proposed Method

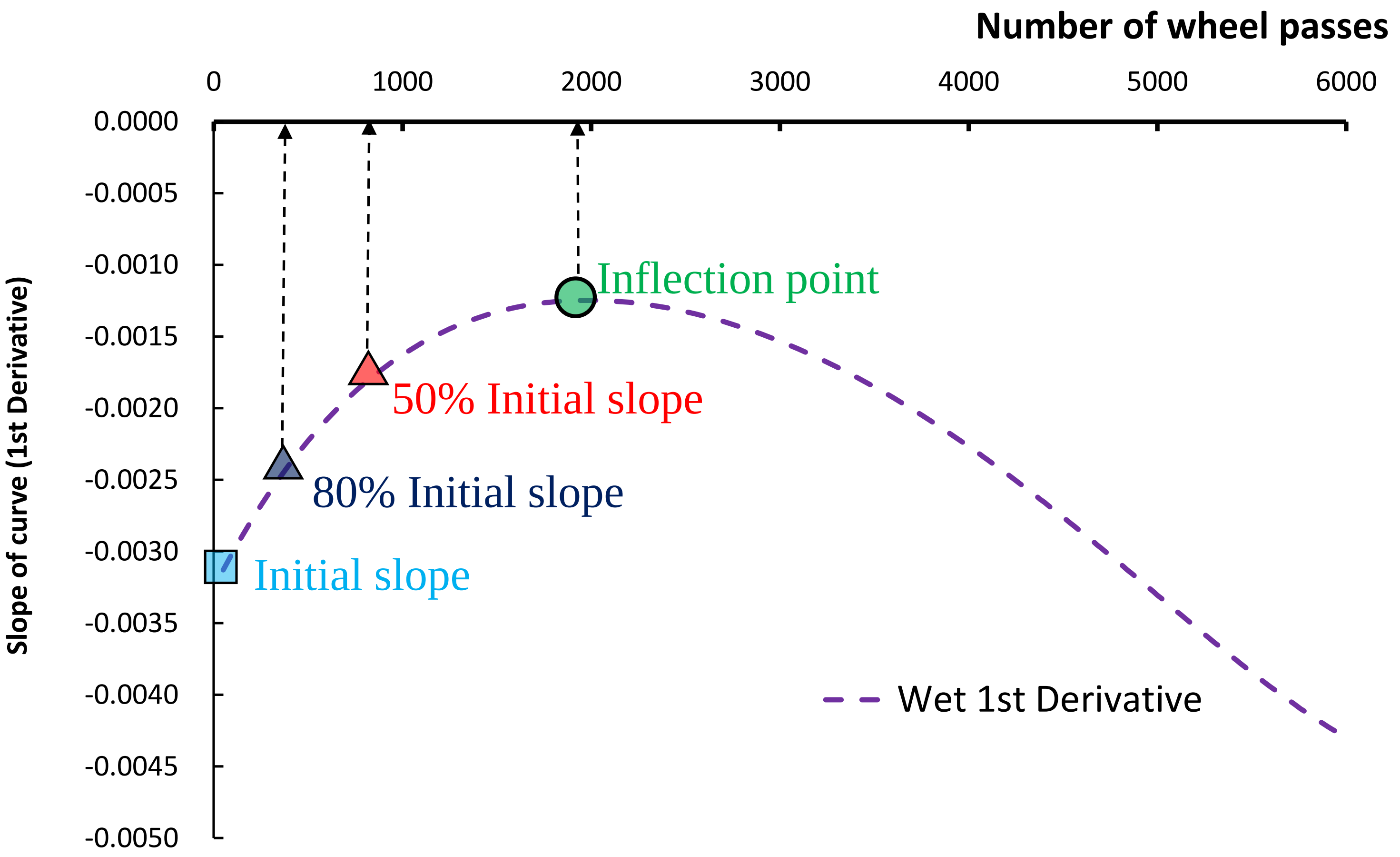
Validation of the normalization procedure



"water conditioning enhancement" is reduced.

Validation of the Proposed Method

Evaluating the Post Compaction Phase Limits



Assumption: the post-compaction phase is the first 1,000 passes in the wet HWT test .

The point at where the slope is decreased to 80% or 50% of its initial value.

Validation of the Proposed Method

Evaluating the Post Compaction Phase Limits

Mixture type	Inflection point (pass)	passes to 80% initial slope (pass)	passes to 50% initial slope (pass)
C-HT-S28	2,100	250	700
C-MT-S28	1,850	200	600
C-HT-V28	4,300	450	1350
C-MT-V28	4,300	450	1450
W-HT-S28	2,000	300	1050
W-HT-V28	4,760	3,000	Not reached
W-MT-S28	1,800	250	850
W-MT-V28	2,600	300	850
Average	2,964	650	**979**

- Reasonable to define the post-compaction range as the first 1,000 passes.
- There are enough data between 1,000 passes to the inflection point that can be used to build the visco-plastic rutting model.

Validation of the Proposed Method

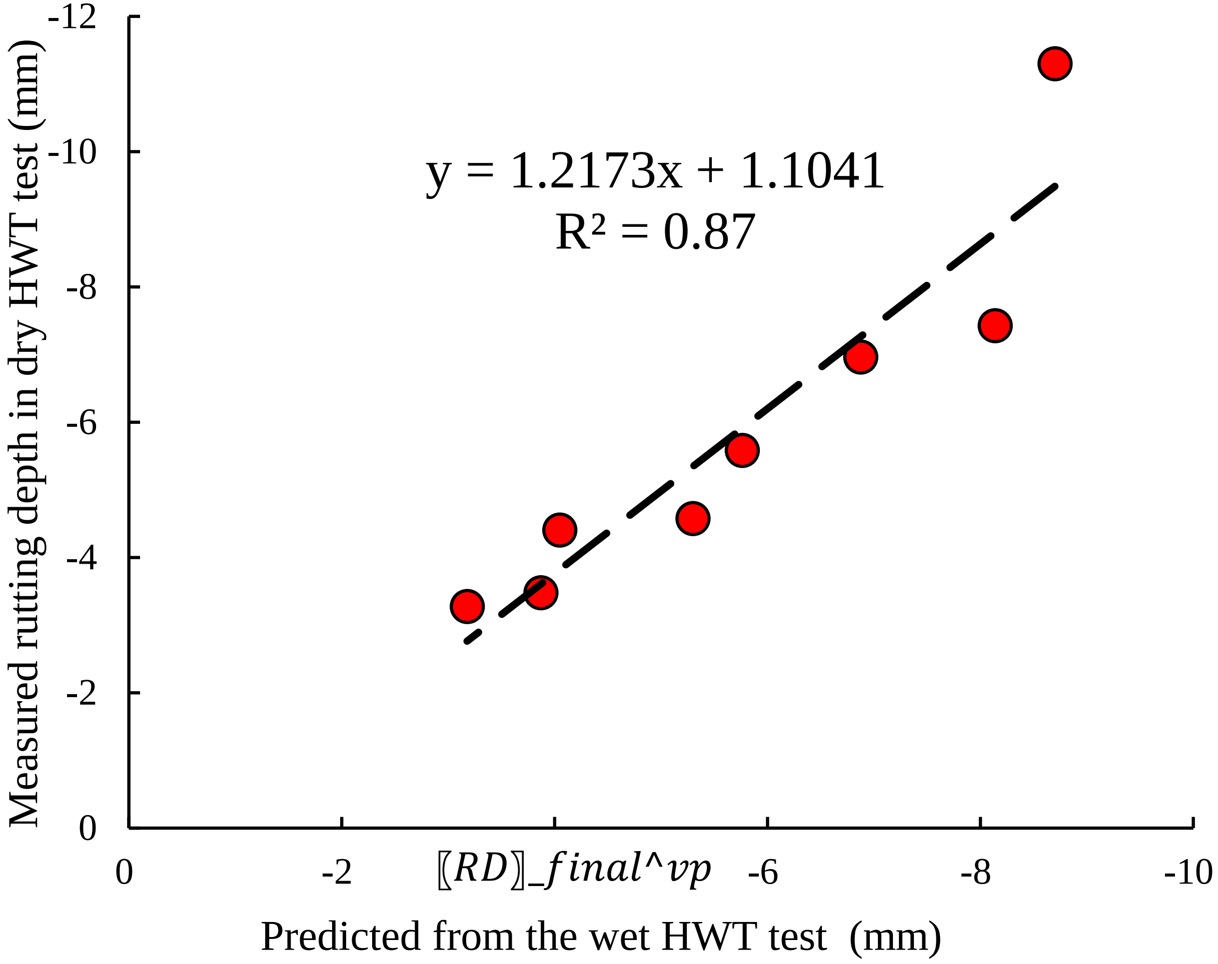
Validation of the proposed parameters

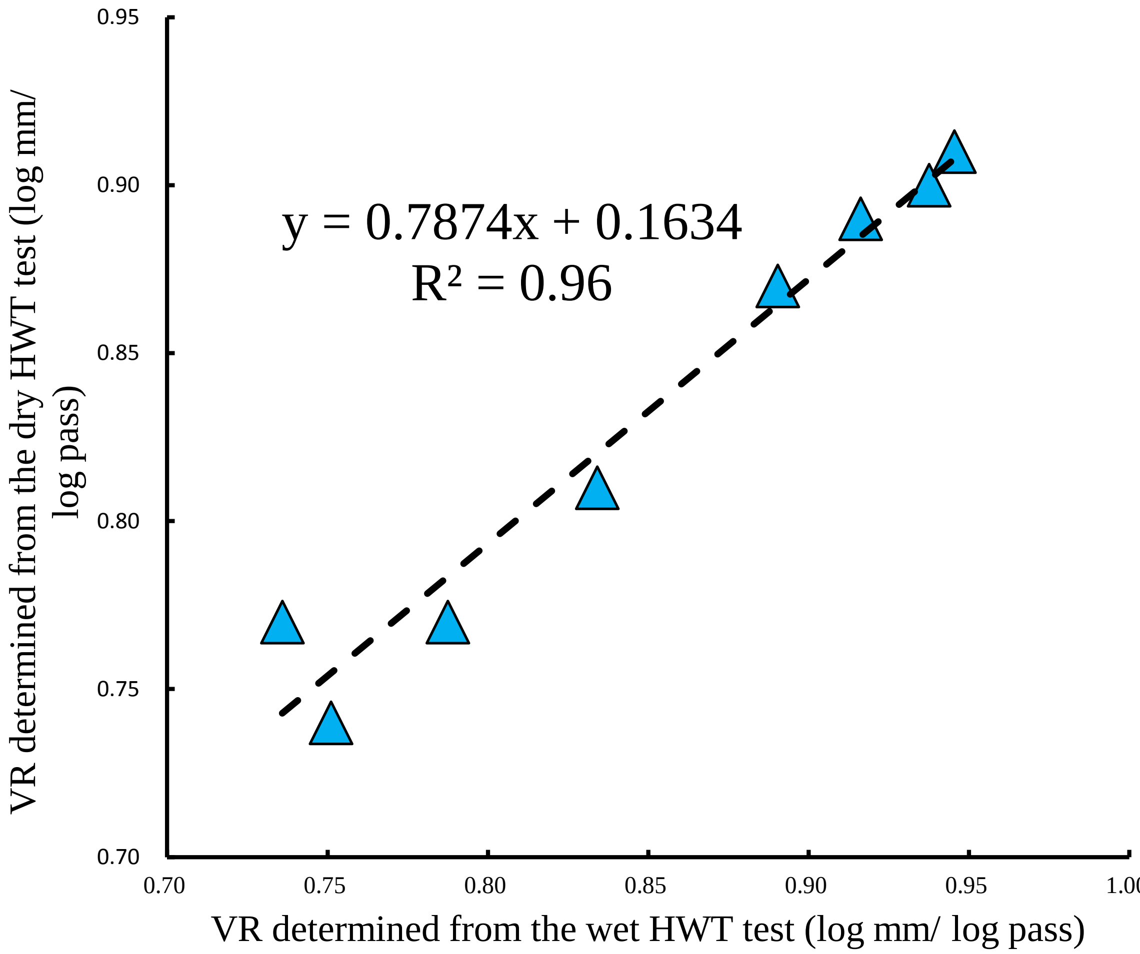
Mixtures	NPF-new (pass)	RD_{final}^{vp} (mm)	RD_{final}^{m} (mm)	VR (log mm/ log pass)	MR (%)	NPF-Iowa (pass)
C-HT-S28	6320	-8.7	-3.8	0.89	30.4 (rutting sensitive)	6377
C-MT-S28	4300	-8.1	-4.4	0.95	34.9	4073
C-MT-V28	**13400**	-6.9	-5.6	0.75	45.0	**11892**
C-HT-V28	16300	-4.0	-8.5	0.74	67.6	16143
W-HT-S28	5300	-5.3	-7.2	0.92	57.6	5395
W-HT-V28	**13000**	-3.9	-8.6	0.79	69.0	**13172**
W-MT-S28	4560	-5.8	-6.7	0.94	53.9	4774
W-MT-V28	9700	-3.2	-9.3	0.83	74.6 (moisture sensitive)	10093

- This different ranking confirms that the initial consolidation affects the calculated parameters in the current analysis method and thus should be discounted.
- MR parameter can be used to evaluate the sensitivity of mixtures.

Validation of the Proposed Method

Validation of the proposed parameters





Validation of the Proposed Method

- **Validation of the new parameters: Moisture Effects are related to Adhesion**

Groups	Current parameters						BBS test	
	SS (mm/pass)		SIP (pass)		SS/CS		Loss of Adhesion POTS (%)	
	Value	Rank	Value	Rank	Value	Rank	Value	Rank
C-HT-S28	-0.0052	B	6189	A	4.33	C	16.85	**A**
C-MT-S28	-0.0059	C	4549	C	2.68	A	30.09	**B**
W-HT-S28	-0.0045	A	4685	B	3.46	B	33.73	**C**

Groups	Texas method				New method	
	LC_{SN} (pass)		LC_{ST} (pass)		MR (%)	
	Value	Rank	Value	Rank	Value	Rank
C-HT-S28	1800	A	6300	A	30.4	**A**
C-MT-S28	1400	B	4700	C	34.9	**B**
W-HT-S28	1400	B	5500	B	57.6	**C**

Loss of Adhesion Can Explain The MR

Part 06

Findings & Conclusions

Findings and Conclusions

- The rutting depths at the first 1,000 wheel passes are very sensitive to the AV contents of the specimen.
  - This initial consolidation should be discounted if the interest is in shear deformation rutting.
- After eliminating the post-compaction stage, fitting of a simple power-law model allows effective procedure for separating the visco-plastic response due to loading from the moisture effects.
  - **Visco-plastic Ratio (VR),** the power factor in the rutting modeling, is proposed to **characterize the mixture's rutting resistance under dry conditions;**
  - **Moisture Ratio (MR)**, the percentage of the moisture-induced deformation in the final rutting depth, is recommended as a moisture resistance parameter and can be used to indicate the damage sensitivity of the mixture.

- More work is needed to verify this method, especially the comparison with the field performance.

Question or Comments?

Hussain Bahia, Ph.D.
bahia@engr.wisc.edu
March 3-6, 2019 Fort Worth, Texas