Using Accelerated Pavement Testing to Evaluate Permeable Interlocking Concrete Pavement Performance

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Outline

- **Overview of APT Program at UCPRC**
- **Introduction**
- **Design Method**
- **Section Design**
- **Section Construction**
- **APT Testing**
- **Test Results**
- **Findings**

Program Overview – Major Milestones

- **1993: CAL/APT program established**
- **1995: two HVS Mk3s delivered**
- **2009: new UCPRC facility opened at Davis, CA**
- **2011: new HVS Mk6 delivered**
- **2012: 3 HVSs operating**
- **2013: HVS-1 retired**
- **2014: First test with extension**

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Program Overview – Google Earth View

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Program Overview – Past Tests

- **Since program start:**
  - 22 projects
    - Asphalt concrete
    - Portland cement concrete
    - Interlocking concrete pavements
    - Bridge deck
  - 160 test sections
  - 8 different test locations
  - >85 million load repetitions
  - >4.3 billion ESALs

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Program Overview - Current Testing 1/2

- **Phase 2 FDR test (soaked base)**
  - 12/2014~6/2015
  - Soak section with a dam for one week
  - Dripping water to the FDR layer through holes during tests
  - Temperature controlled at 30C
  - Looking at rutting performance and fatigue cracking

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...t Testing 2/2

Program Overview - Upcoming Projects

- **FDR-PC crack mitigation**
- **Ultra-thin white-topping**
- **High RAP (binder replacement)**

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Introduction – Permeable Interlocking Concrete Pavement (PICP)

- **Background**
  - Want to use PICP with heavy traffic
  - Funded by industry
- **Objectives**
  - Compare performance of permeable pavement under dry and wet subgrade conditions
  - Validate mechanistic designs
  - Develop mechanistic based catalogue

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Design Method

- **Distress**
  - Unbound layer rutting
- **Methodology**
  - Shear Stress Ratio (SSR)
  - $SSR < 0.3$, low risk of rutting;
  - $0.3 \le SSR \le 0.7$, medium risk of rutting;
  - $SSR > 0.7$, high risk of rutting.
- **Needed Inputs**
  - Unbound layer stiffness and strength

Section Design – Standard Structure Profile

- **Surface (interlocking concrete paver, 80 mm thick)**
- **Bedding layer (ASTM #8 aggregate, 50 mm thick)**
- **Base layer (ASTM #57 aggregate, 100 mm thick)**
- **Subbase layer (ASTM #2 aggregate, with varying thickness)**
- **Subgrade soil (compacted as the client requested)**

Section Design – Getting Stiffness

- **Find existing PICP**
- **Conduct surface deflection testing using RSD**
- **Back-calculate subbase stiffness**

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Section Design – Deflection Testing Setup

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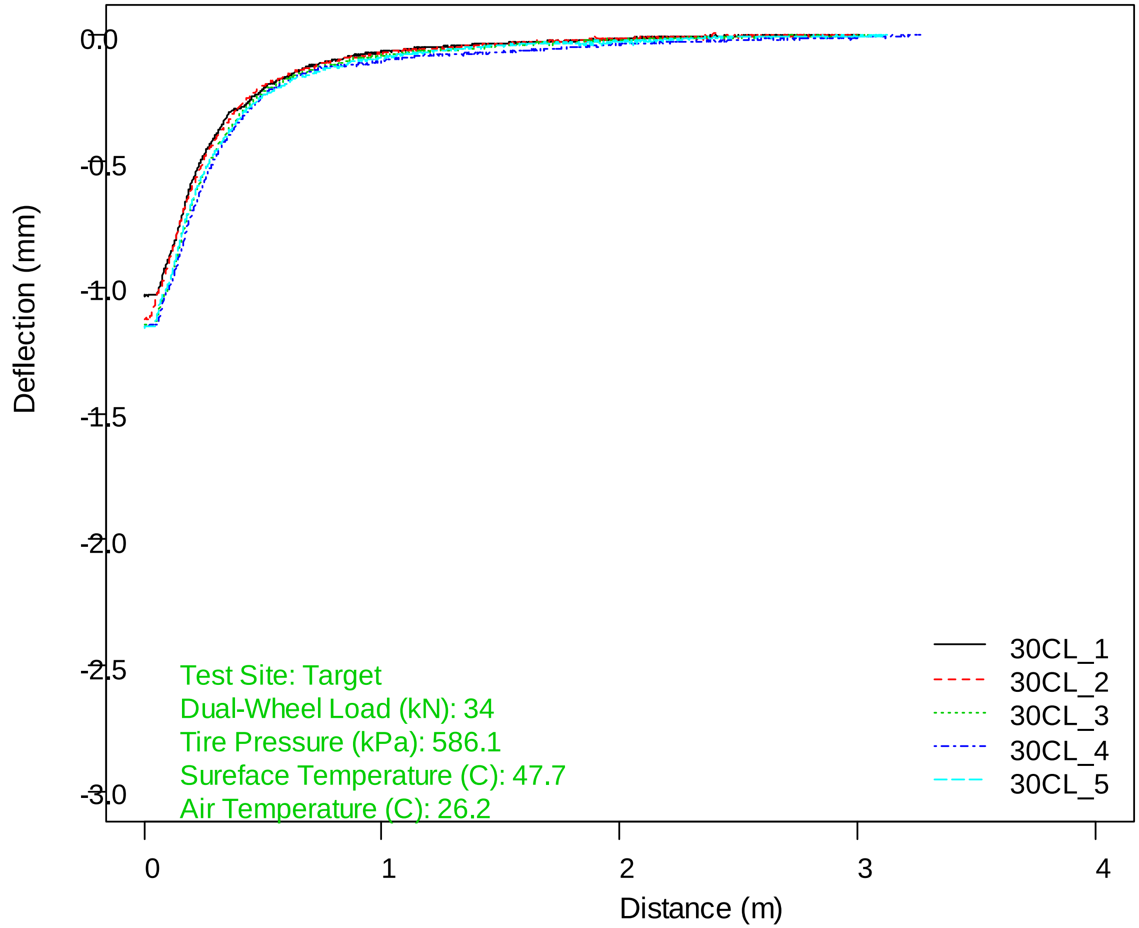
Section Design – Deflection Testing Results



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Section Design – Back-Calculated Stiffness

Measurement Location		Layer Stiffness at Different Wheel Load Levels (MPa)					
		Paver + Bedding		Aggregate Base/Subbase		Subgrade	
Site	Location	Low	High	Low	High	Low	High
Matsui Park	Centerline	23	41	89	100	94	93
	Wheelpath	18	35	50	56	71	75
Target	Centerline	240	227	38	35	47	40
	Wheelpath	136	205	33	23	30	26
Yolo Credit Union	Centerline	514	618	40	36	43	45
	Wheelpath	264	220	25	26	37	36
Average		238	265	45	43	51	49

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Section Design – Stiffness Used

Layer	Layer No. in Design	Design Layer Stiffness (MPa)
Surface		
Bedding Layer	1	500
Base Layer		
Subbase Layer	2	40
Subgrade	3	40

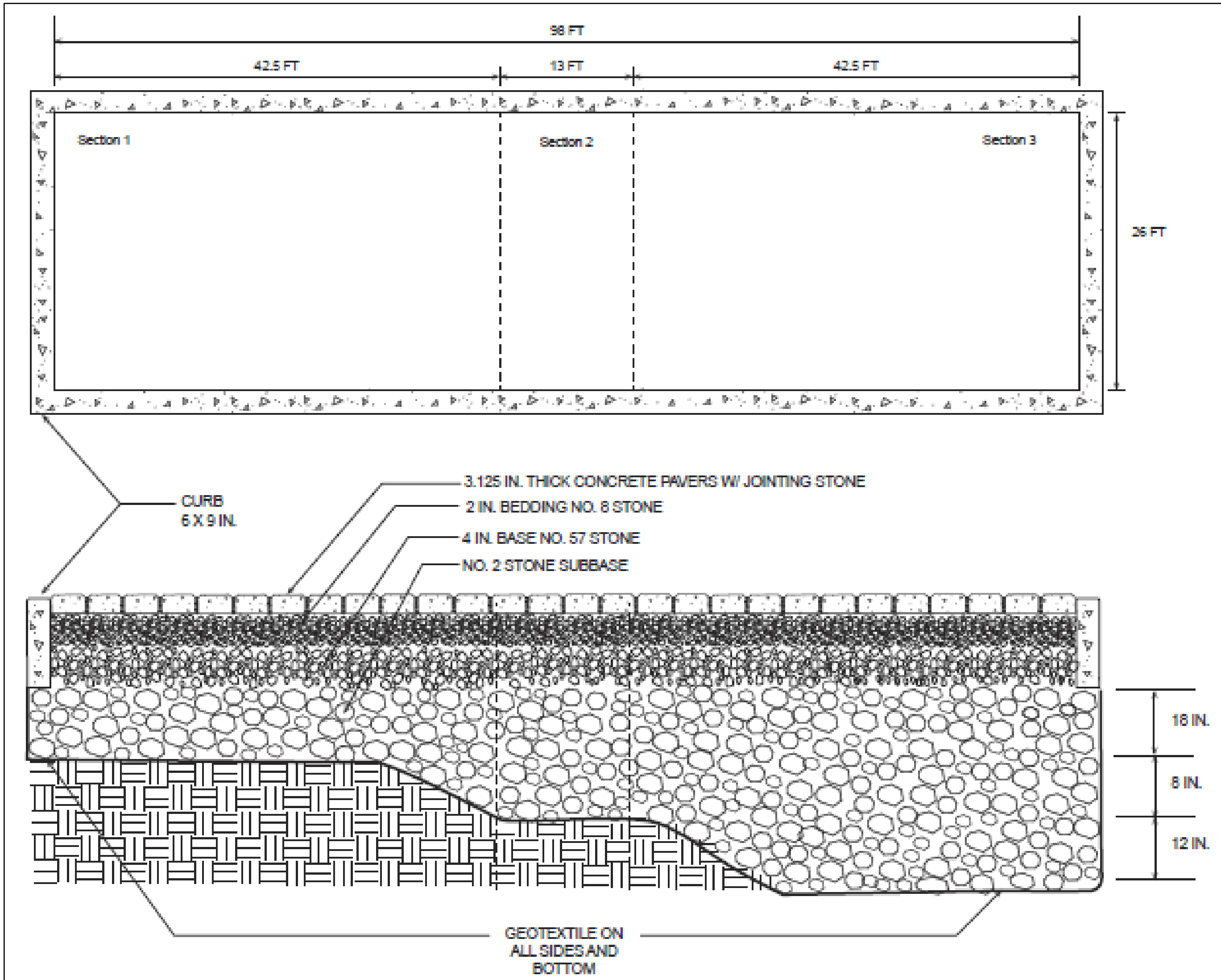
Section Design – Strength Inputs

- **Subbase layer**
  - $c = 0$, $\phi = 45°$ based on literature review
- **Subgrade**
  - Silty clay
  - Cohesion of 15 kPa, with a friction angle of 25° for dry condition and 0° for wet condition based on literature review

Section Design – The subbase thickness

Subbase Thickness Type	Shear Stress Ratio (SSR)	Calculated		As-Built
		Dry	Wet	
Shallow	0.8	450	650	460
Medium	0.5	800	950	660
Deep	0.2	1,350	1,450	960

Section Design – The Structure



Section Construction – 1/2

Section Construction – 2/2

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Section Construction – Cool Video

- **<Good luck>**

Section Construction – Instrumentation 1/2

- **Aggregate size limited options**
- **Pressure cell**
  - Top of subgrade
  - Top of base
- **Deformation indicators**
  - Top of subgrade
  - Top of base
- **Profile**
- **Road surface deflectometer**
- **Water level**
  - Manual readings; and
  - Automatic readings

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Section Construction – Instrumentation 2/2

- **Permanent Deformation Holes**
  - Base set on top of SG and #2 subbase
  - Record base distance to surface regularly

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APT Testing – Loading Programs

Stage	Starting Repetition	Ending Repetition	HVS Wheel Load (kN)
1	1	100,000	25
2	100,001	200,000	40
3	200,001	340,000	60
4	340,001	till completion	80

APT Testing – Factorials

- **Three conditions**
  - Dry
  - Wet: water table maintained at the top of the #2 rock subbase
  - Drained
    - Conducted right after the wet test
    - No standing water, all drained
- **Three subbase thicknesses**
  - 460, 660 and 960 mm
  - Tested at the same time
  - With the extender, HVS-3 covers 13m
- **Failure criteria**
  - 25 mm of surface rut

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APT Testing – Wet Testing

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APT Test Results – Visual Assessment

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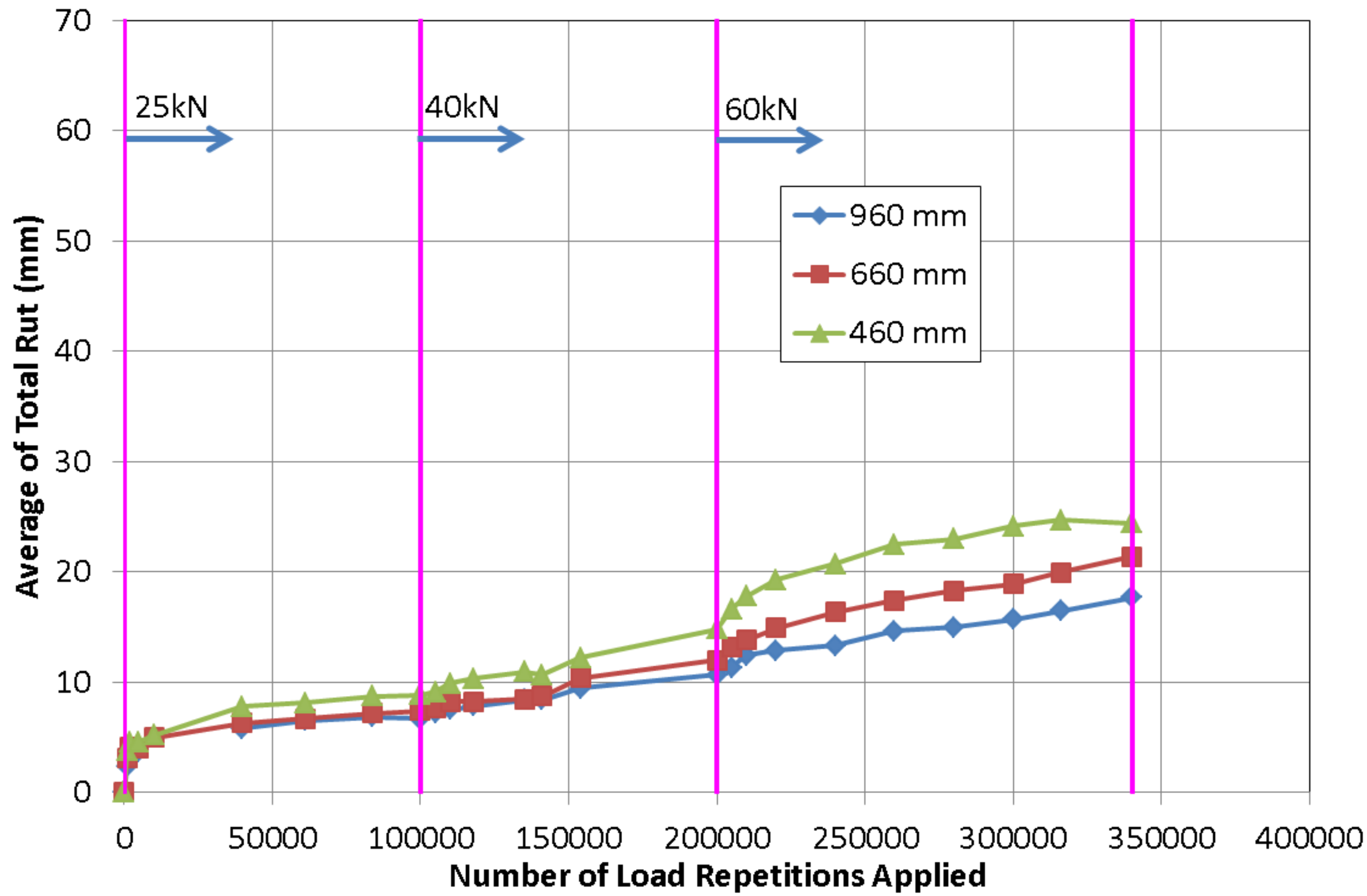
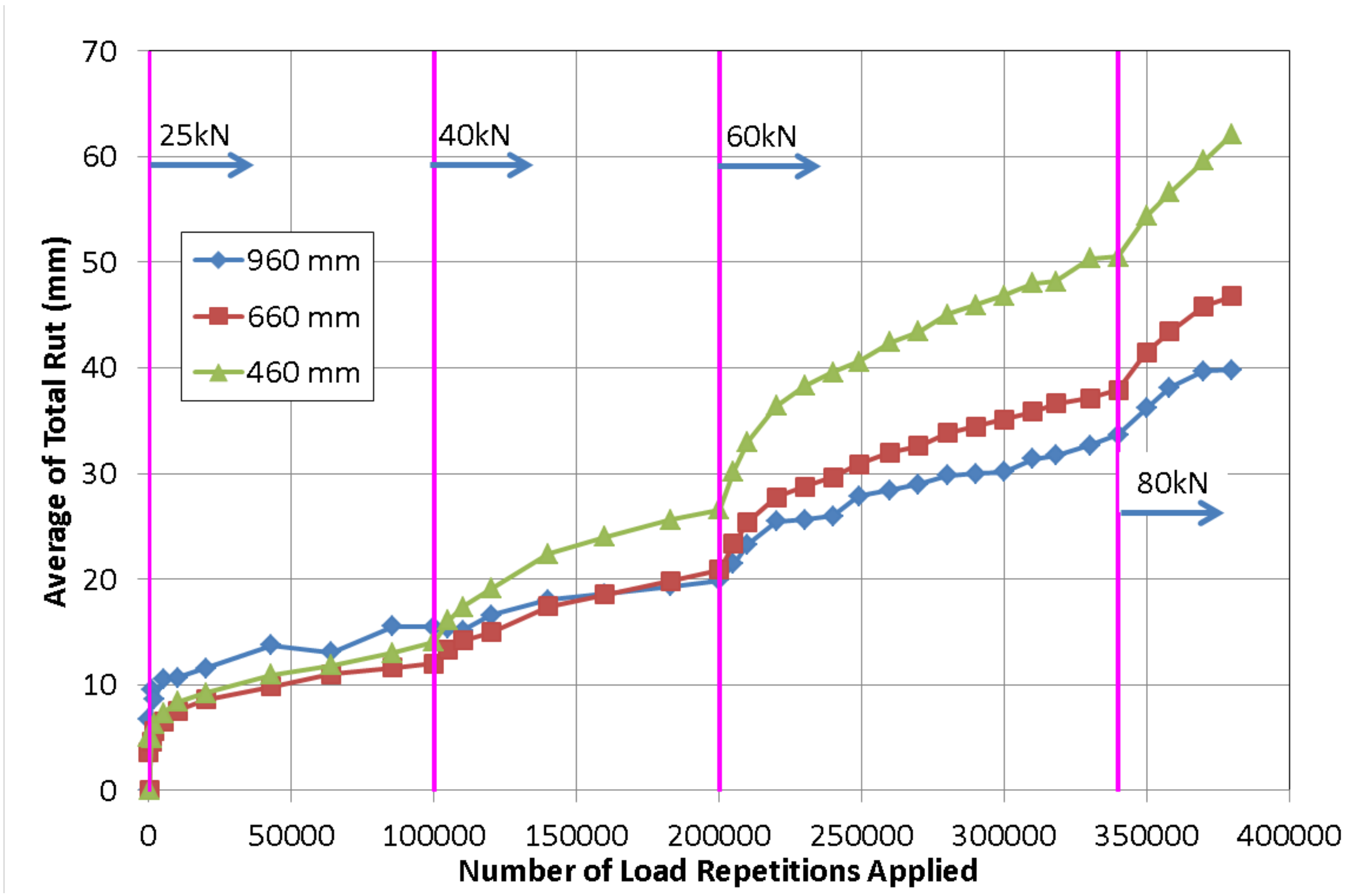
APT Test Results – Total Surface Rut: Dry



APT Test Results – Total Surface Rut: Wet



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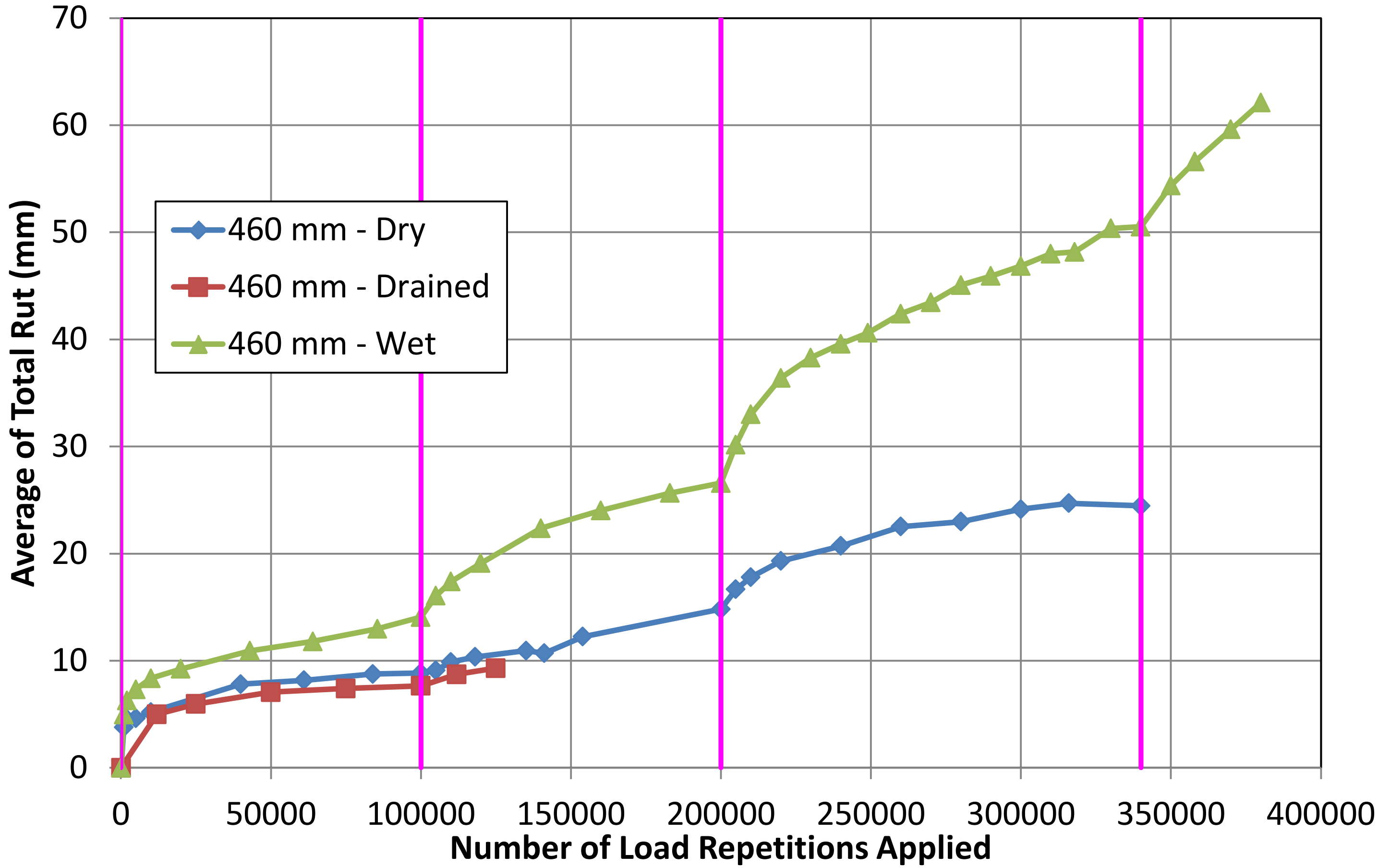
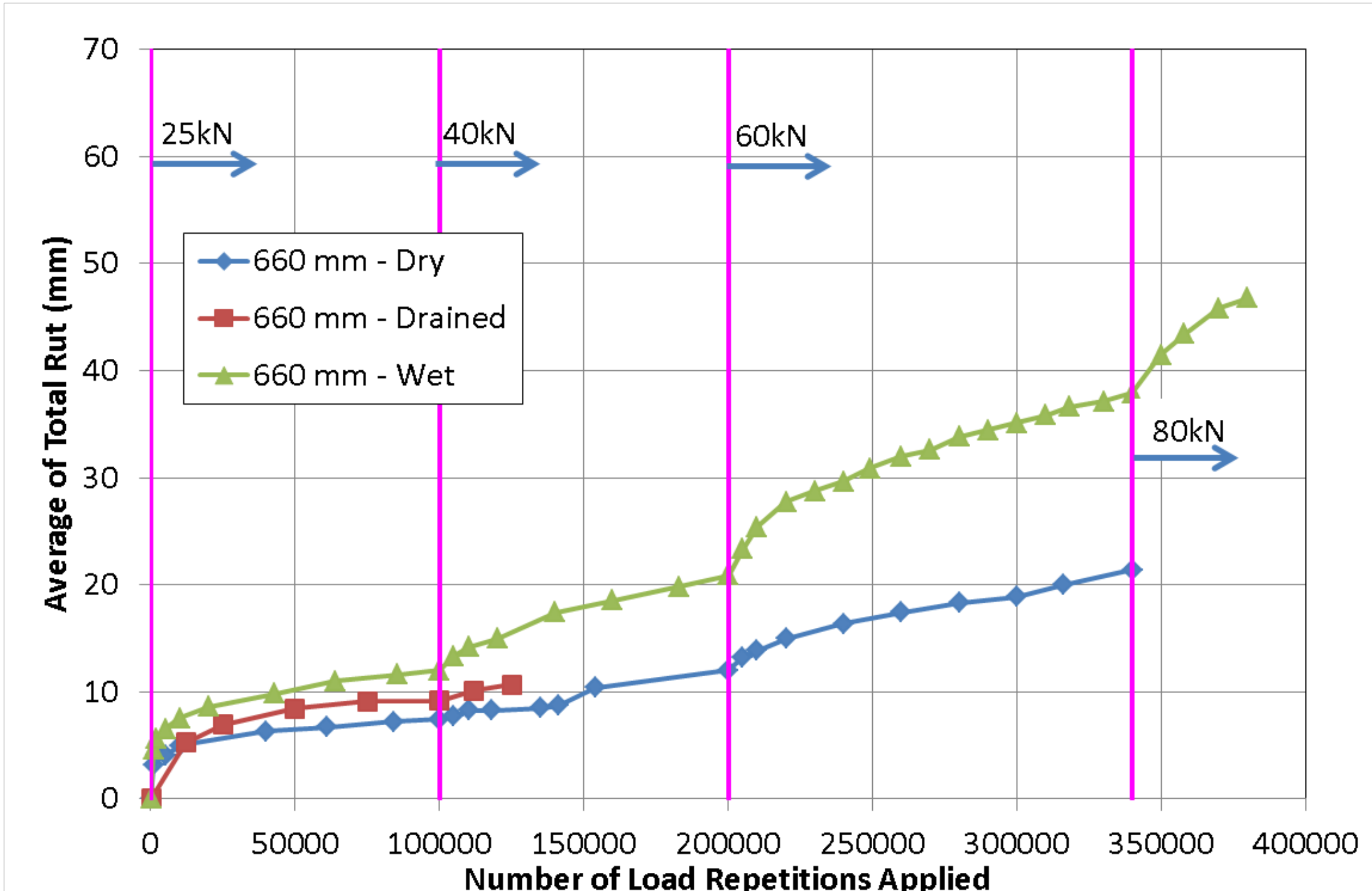
APT Test Results – Total Surface Rut: 460mm



APT Test Results – Total Surface Rut: 660mm



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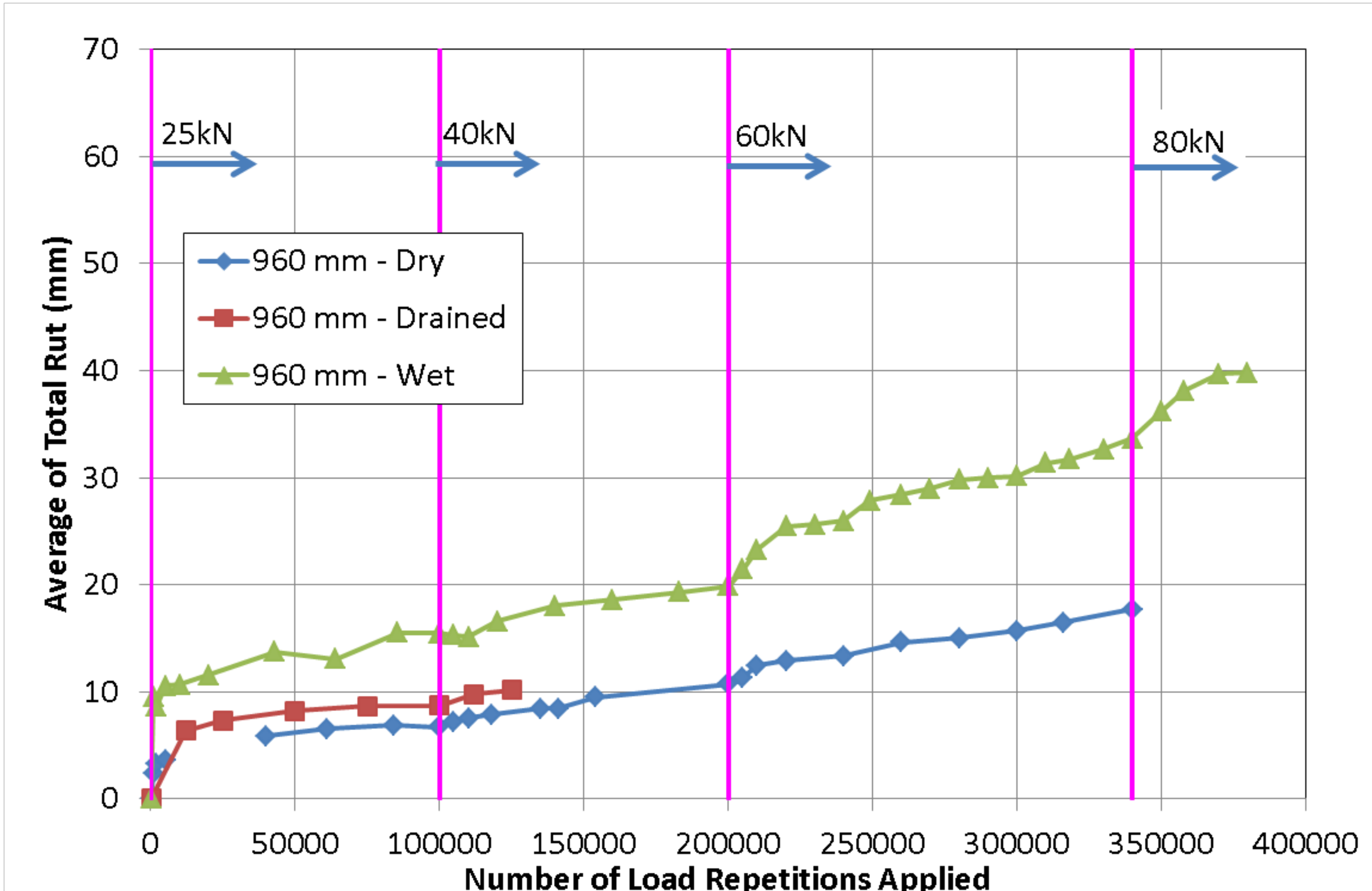
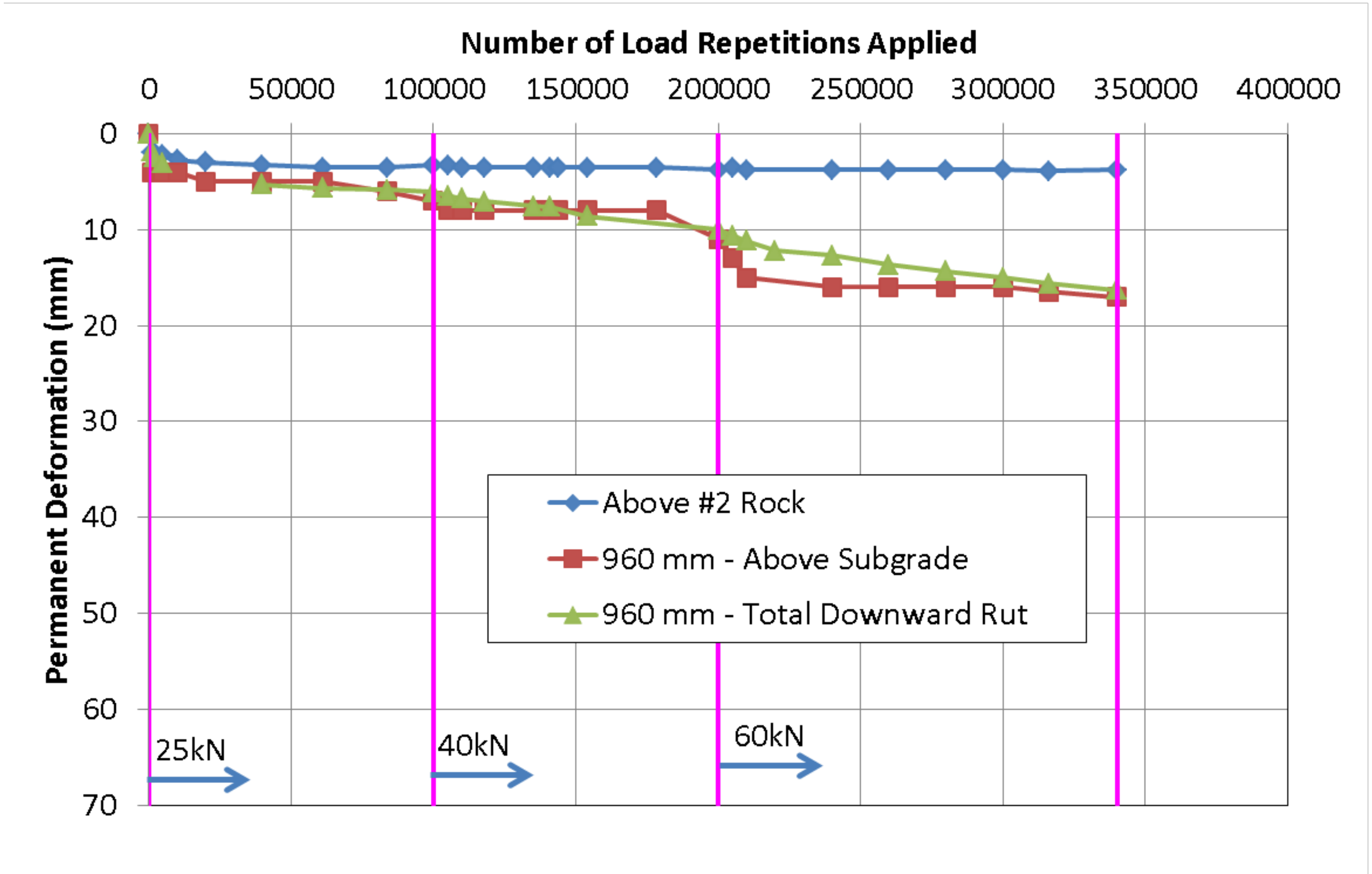
APT Test Results – Total Surface Rut: 960mm



APT Test Results – Downward Rut: Dry@ 960mm



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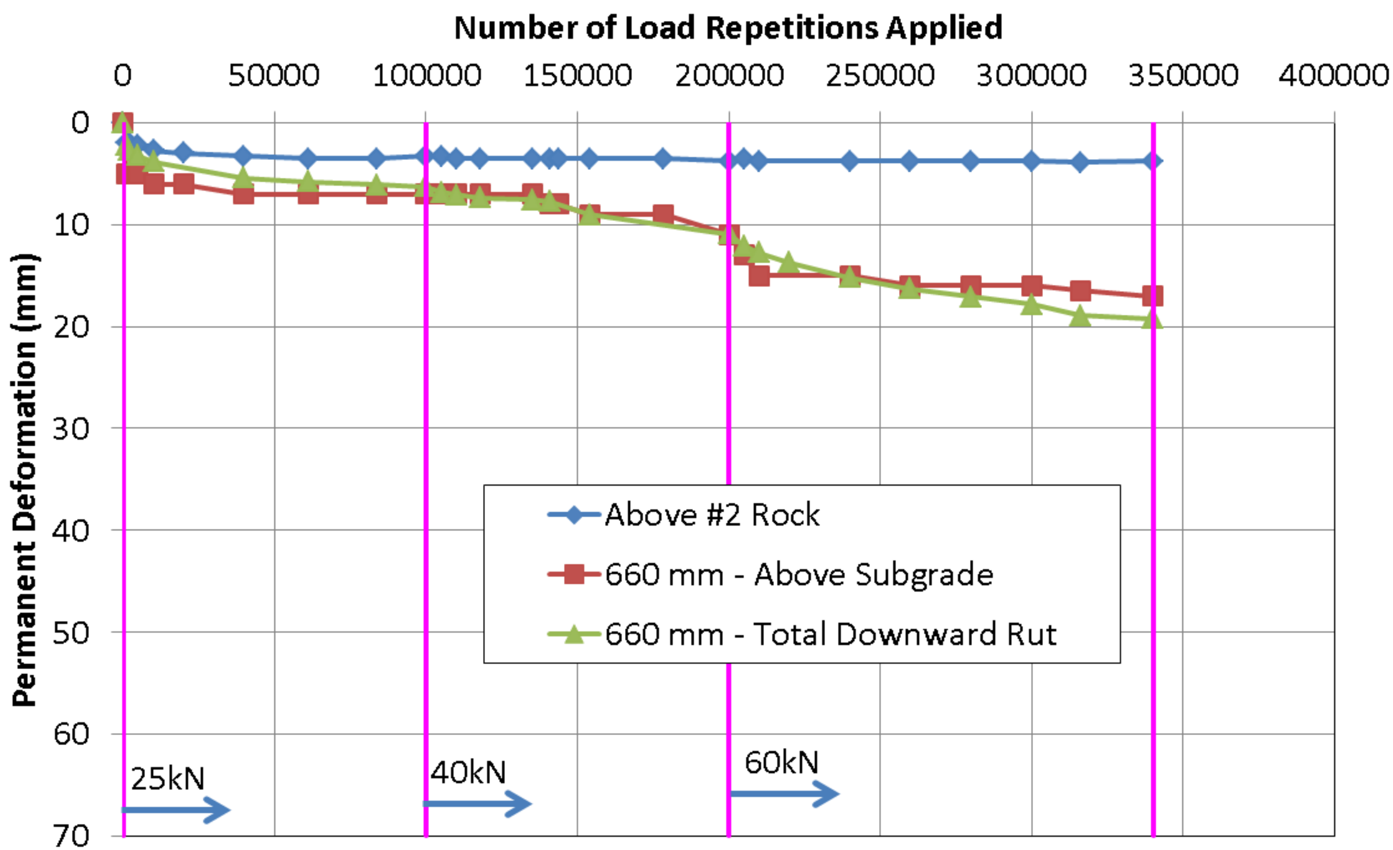
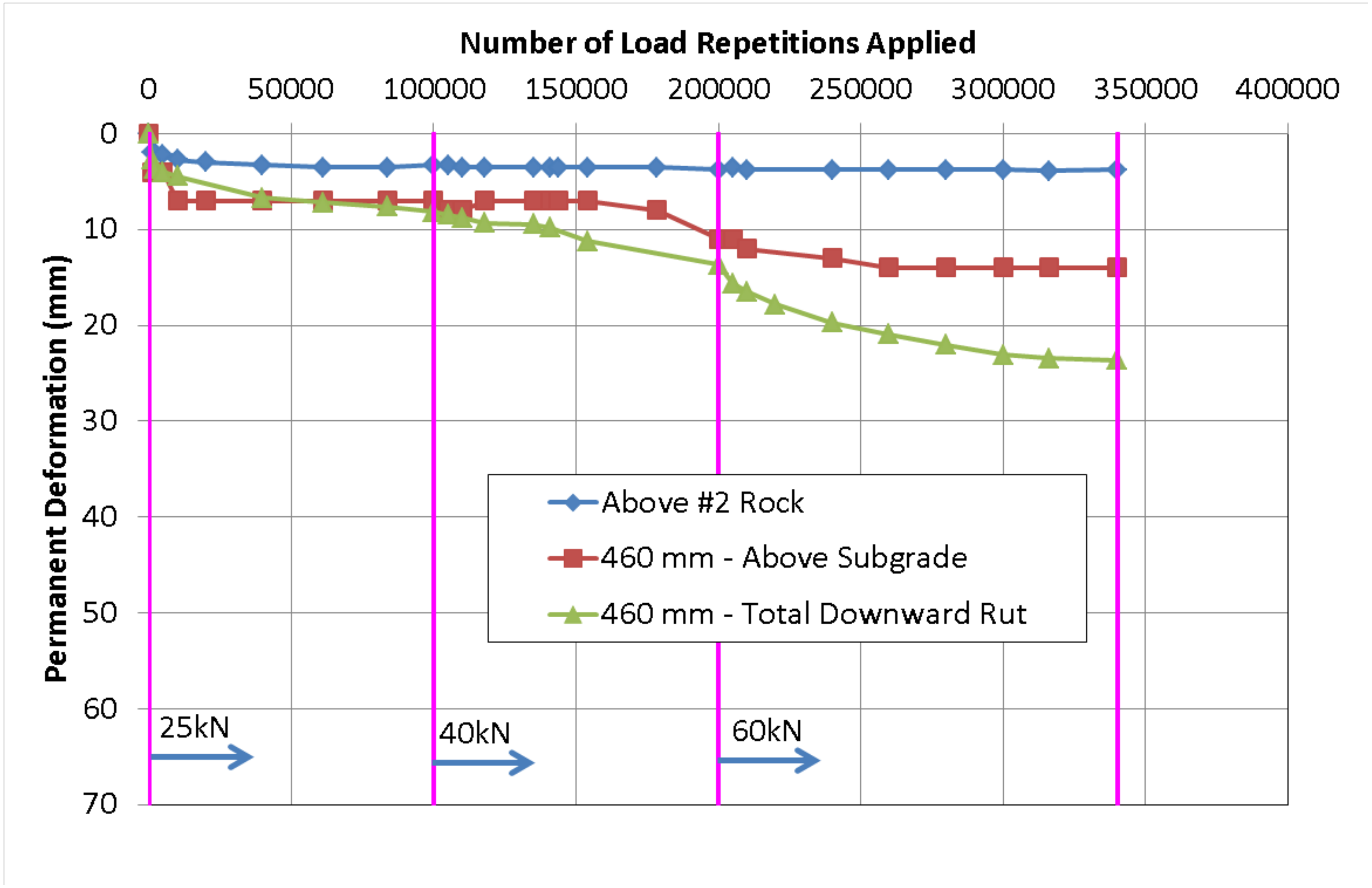
APT Test Results – Downward Rut: Dry@ 660mm



APT Test Results – Downward Rut: Dry@ 460mm



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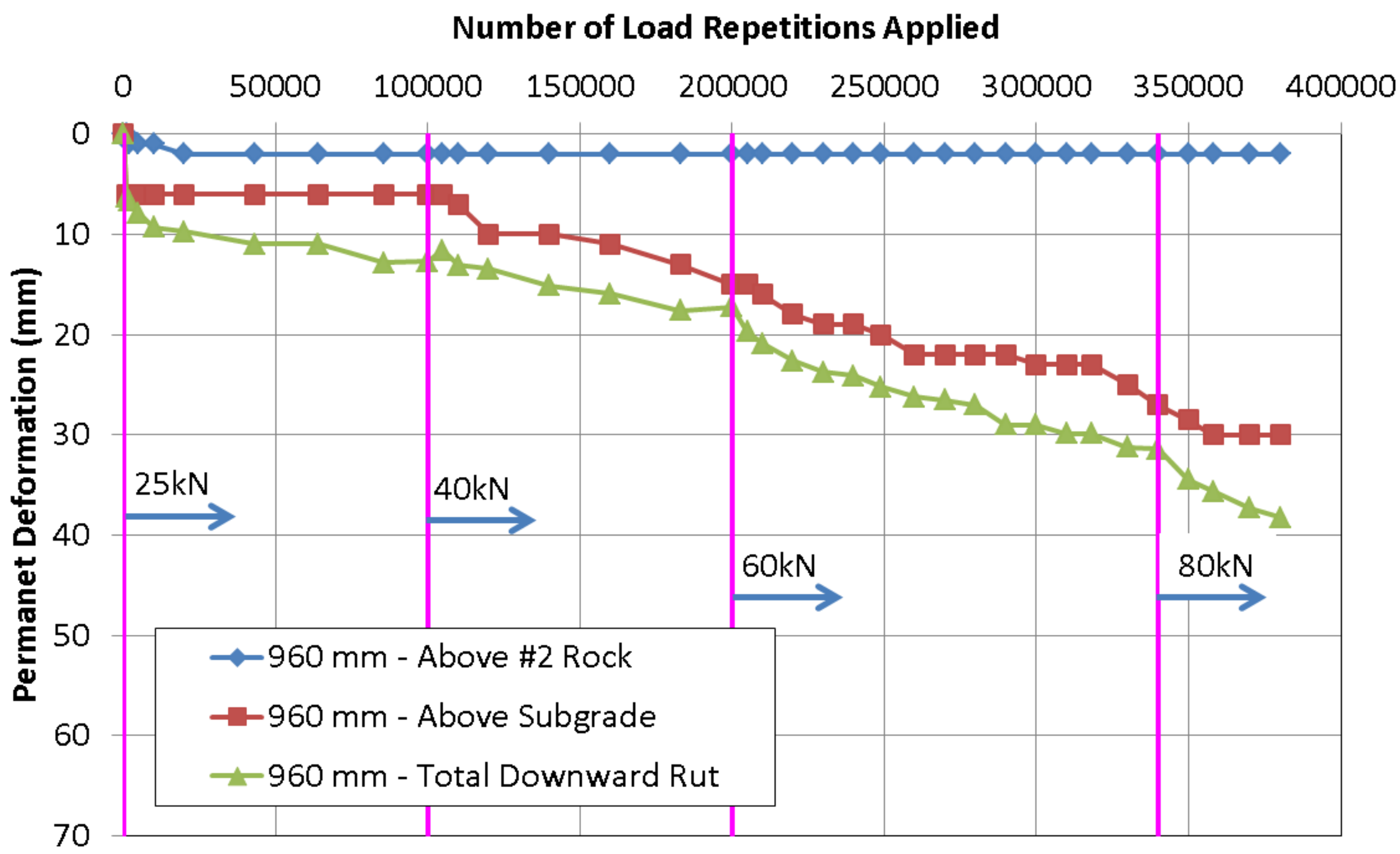
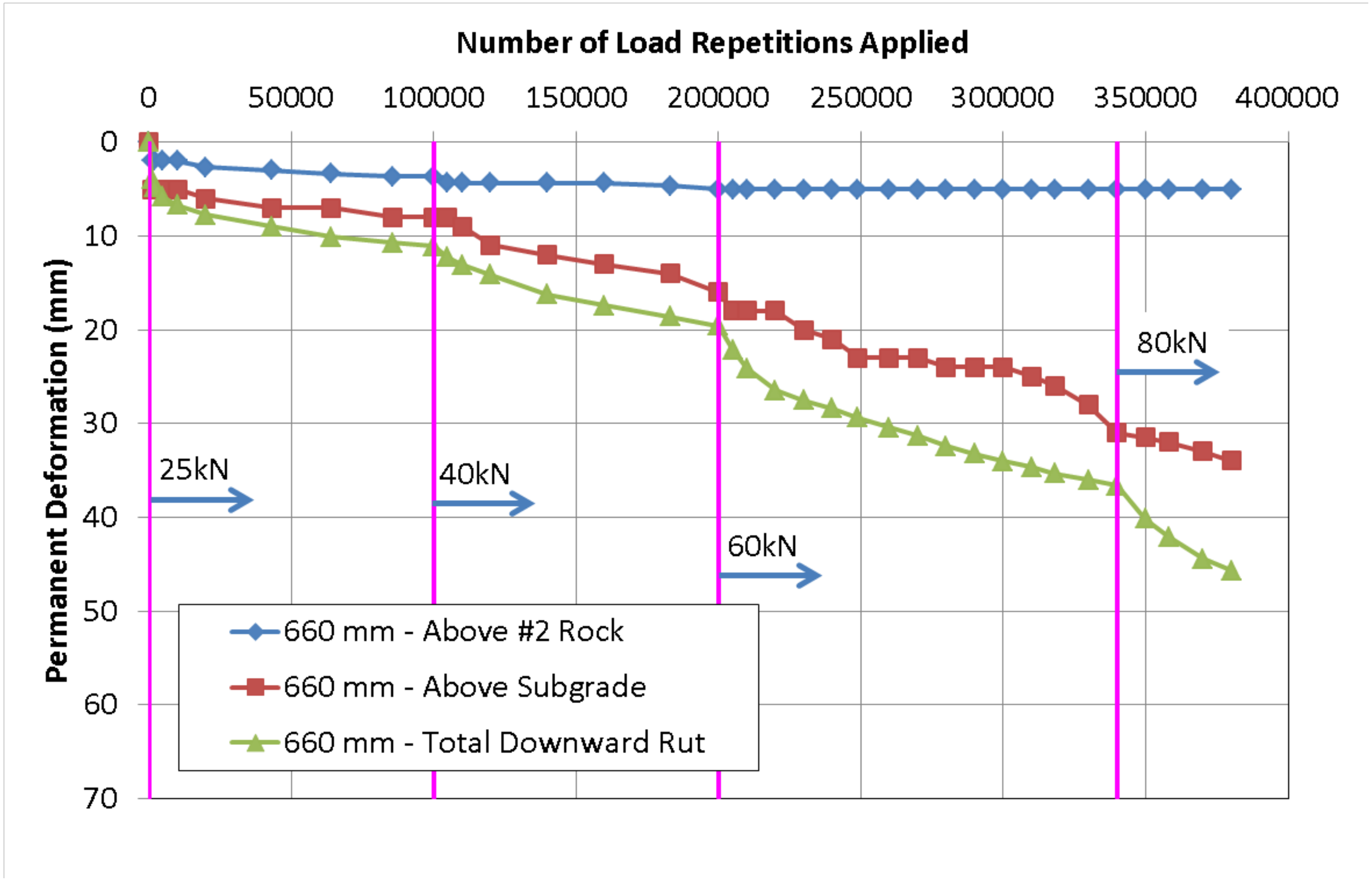
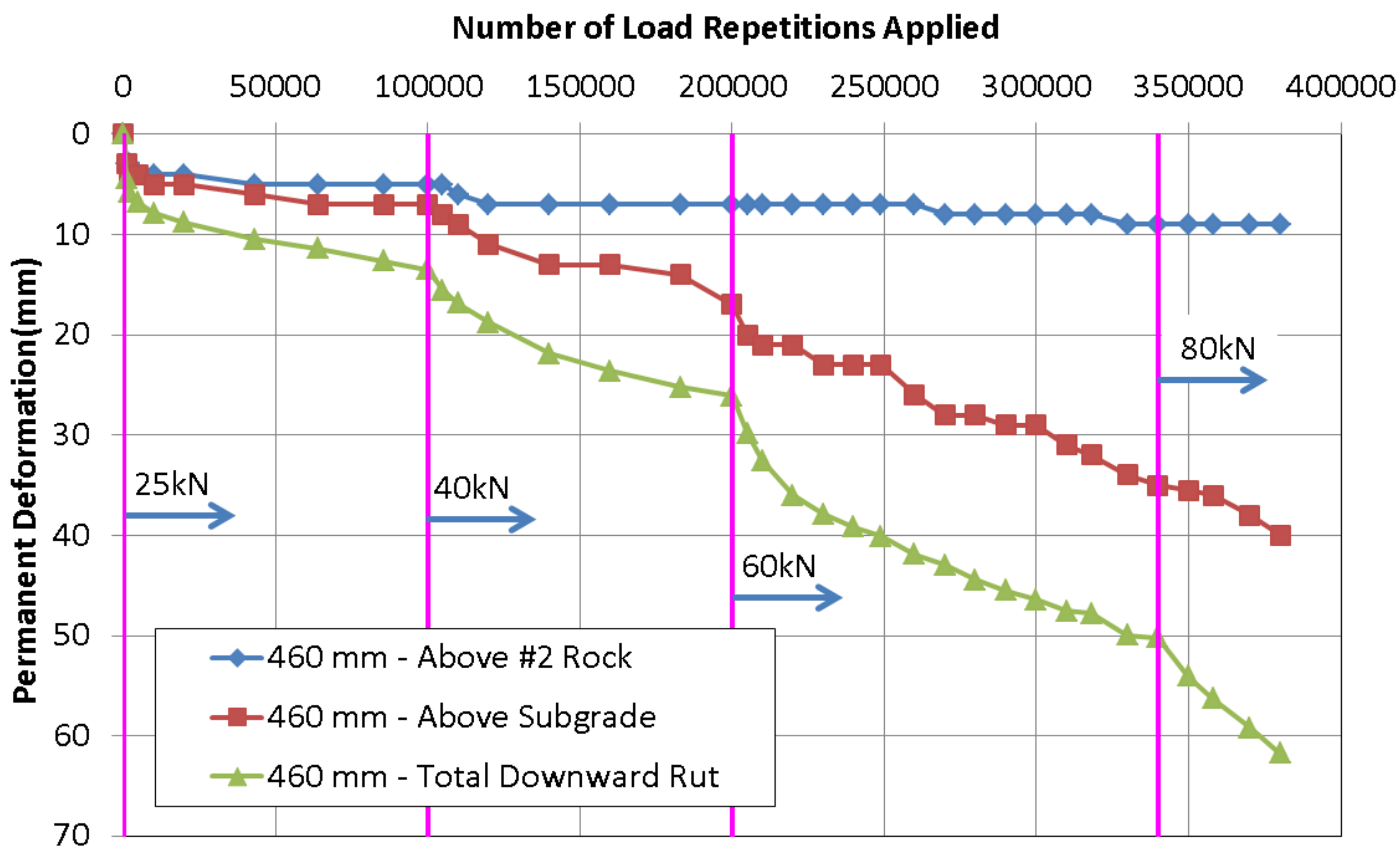
APT Test Results – Downward Rut: Wet@960mm



APT Test Results – Downward Rut: Wet@660mm



APT Test Results – Downward Rut: Wet@460mm



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APT Test Findings – Overall

- **Significant difference in wet and dry testing**
- **Limited testing under drained condition shows performance trend similar to dry condition**

APT Test Findings – Dry Test

- **460 mm Subsection**
  - Rutting occurred in both the subbase (10 mm rut) and subgrade (13 mm rut)
- **650 mm and 950 mm Subsections**
  - Rutting occurred mostly in the subbase

APT Test Findings – Wet Test

- **Rutting occurred in both the subbase and the subgrade on all subsections**
- **Rutting in the subbase consistent across all three sections (~25 mm).**
- **Rutting in the subgrade differed between sections**
  - Thicker subbase thickness leads to less subgrade rut

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APT Testing Conclusions

- **Effect of subbase thickness**
  - Influence rutting in the subgrade
  - Does not influence rutting in the subbase itself
- **Therefore**
  - Need to have enough thickness to reduce rutting in subgrade
  - Need to have quality aggregate and good construction to reduce subbase rutting

APT Testing Recommendations -Design Tool

PICP Design Tool

Input

Section	Layer	Moisture Condition	Thickness (mm)	Stiffness (MPa) [1]	Poisson's Ratio	c (kPa)	ϕ (°)
Structure & Materials	Surface (80 mm concrete paver plus 50 mm #8 bedding and 100 mm #57 base)	Wet	230	87	0.35	-	-
		Dry		110	0.35	-	-
	Subbase (ASTM #2)	Wet	450	73	0.35	0	30
		Dry		122	0.35	0	45
	Subgrade (Clay)	Wet	-	37	0.35	9	15
		Dry		60	0.35	15	25
Climate	Number of Days in a Year When the Subbase has Standing Water (Wet Days) [2]						
	50						

[1] The wet stiffness to dry stiffness ratio can be assumed as 0.8, 0.6 and 0.6 for surface, subbase abd subgrade layers, respectively.

[2] Seasons when the subbase has standing water.

Traffic

Traffic Volume Calculation	Axle Type	Axle Load (kN)	Axle-Load Distribution (%)	Lifetime Repetition: Wet Season [2]	Lifetime Repetition: Dry Season	Lifetime Repetition: Total	Lifetime Repetition: ESALs	Lifetime ESALs (Millions)
AADT (two-way)	Single	10	3.25	9,959	62,740	72,699	18	0.50
5,700		20	5.97	18,286	115,200	133,486	521	
Percent Trucks, T		30	5.83	17,850	112,456	130,307	2,577	
10.0%		40	4.43	13,568	85,481	99,050	6,191	
Direction Distribution Factor, D		50	3.23	9,896	62,345	72,241	11,023	
0.5		60	2.80	8,574	54,019	62,593	19,805	
Lane Distribution Factor, L		70	3.13	9,594	60,443	70,037	41,054	
0.8		80	2.40	7,363	46,388	53,751	53,751	
Annual Growth Rate, r		90	0.85	2,594	16,340	18,933	30,327	
3.0%		100	0.15	445	2,804	3,249	7,931	
Design Life (years), Y		120	0.03	94	594	688	3,485	
20		160	0.01	31	194	225	3,596	
Traffic Safety Factor, TSF	Tandem	20	1.59	4,887	30,788	35,675	17	
1.0		40	5.79	17,734	111,727	129,461	1,011	
Truck Traffic Volume, *V*		60	6.76	20,729	130,591	151,319	5,985	
2,236,814		80	4.48	13,720	86,437	100,158	12,520	
$V = 365 \times AADT \times T \times D \times L \times (1+r)^{Y/2} \times Y \times TSF$		100	3.42	10,472	65,971	76,443	23,329	
		120	3.86	11,815	74,432	86,247	54,578	
		140	4.12	12,630	79,569	92,199	108,091	
		160	1.94	5,946	37,460	43,406	86,813	
		180	0.29	900	5,670	6,570	21,048	
		200	0.05	154	973	1,128	5,506	

Outcome — Rut Depth

Layer	Moisture Condition	Shift Factor	Rut Depth by Layer (mm)	Expected Total Rut Depth (mm)	Allowable Rut Depth (mm)	Satisfactory ?
Surface (80 mm concrete paver plus 50 mm #8 bedding and 100 mm #57 base)	Wet	1.00	1.1	65.3	25.0	*N*
	Dry	1.00	3.3			
Subbase (ASTM #2)	Wet	1.23	15.0			
	Dry	1.10	25.0			
Subgrade (Clay)	Wet	1.23	9.0			
	Dry	1.10	12.0			

Calculate Rut Depth | Design Subbase Thickness

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Questions?

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