Improve Material Inputs into Mechanistic Design Properties for Reclaimed HMA & Recycled Concrete Aggregate (RCA) Roadways

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MEPDG Analysis Process

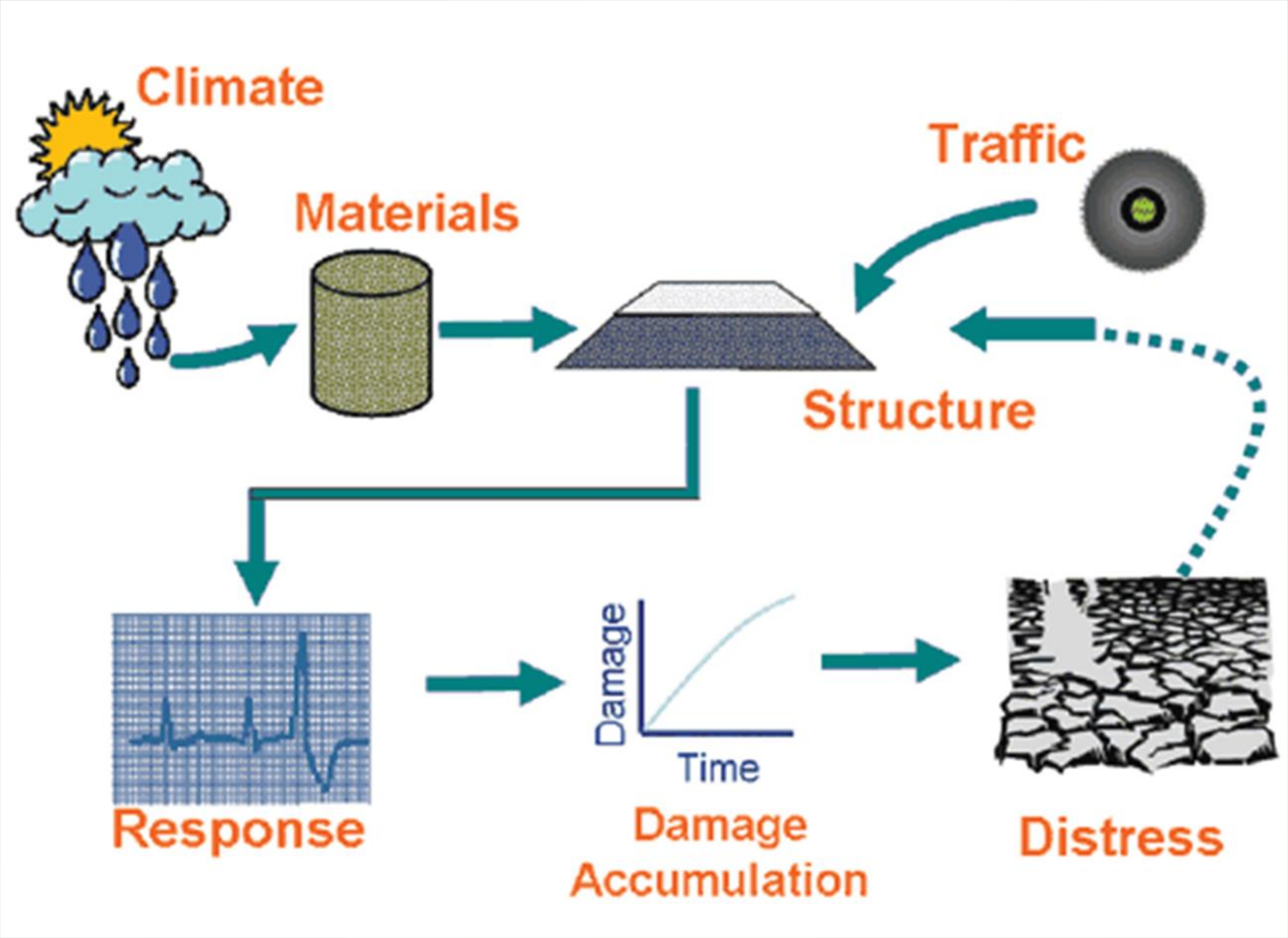
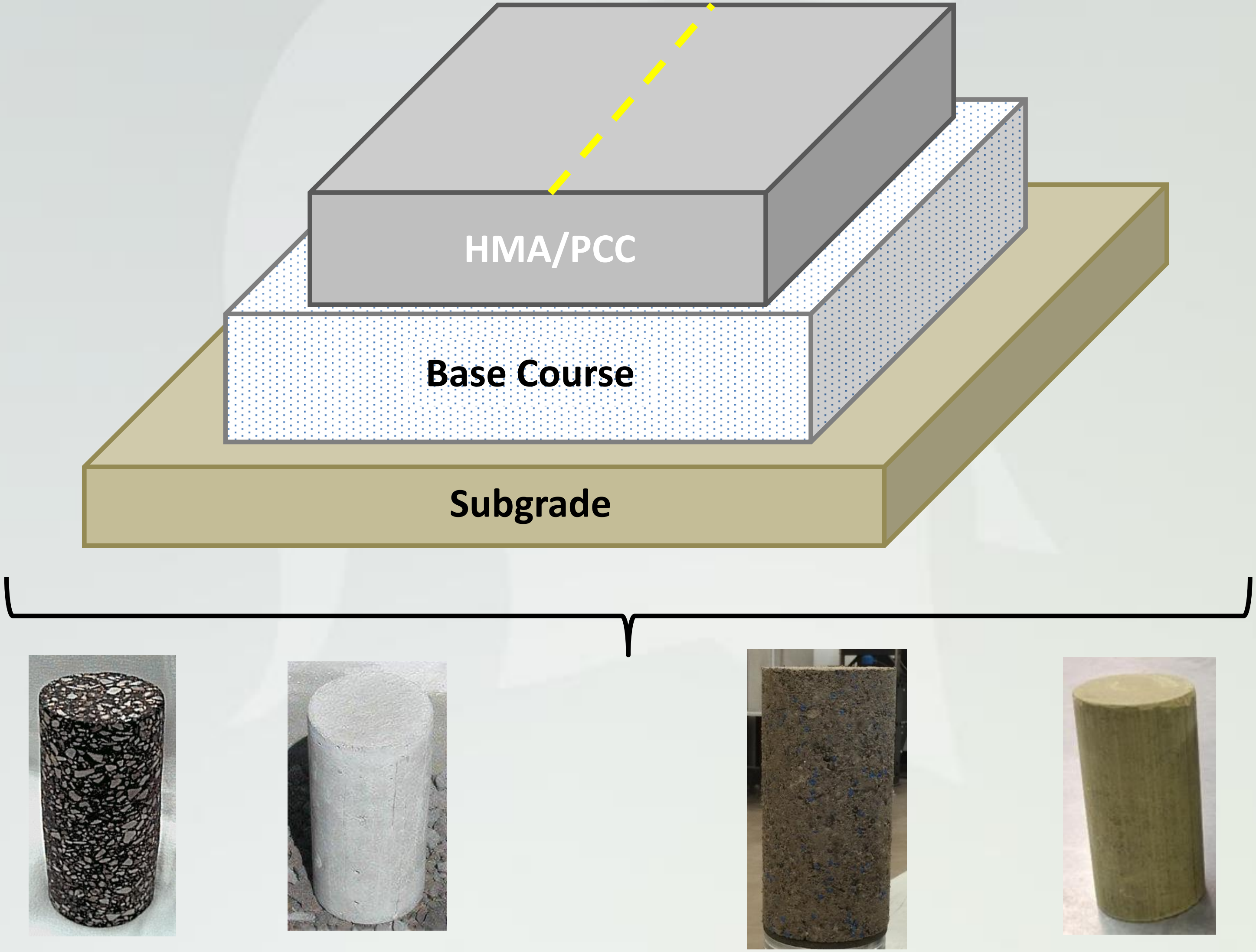


Figure from http://www.fhwa.dot.gov/pavement/concrete/cptu603.cfm

MATERIALS INPUT



MATERIALS INPUT

Range of Materials

Unbound Materials

Fine-Grained Soils

Chemically Stabilized Soils

Recycled Concrete Aggregate

Reclaimed Asphalt Pavement Material

Macadam

MATERIALS INPUT FOR PAVEMENT ME

Strength/Stiffness Parameters:

- ❑ Resilient Modulus (M_R)
- ❑ California Bearing Ratio (CBR)
- ❑ Permanent Deformation(PD)
- ❑ Angle of Friction and cohesion

Index Parameters:

- ❑ Gradation Characteristics
- ❑ Binder/Mortar Content
- ❑ Absorption
- ❑ Density
- ❑ Moisture Content

Drainage Parameters:

- ❑ Hydraulic Conductivity

OBJECTIVES

1st Goal – Collection of Material Input Data

- M_R, CBR, Shear strength, hydraulic conductivity of RAP & RCA
- Index properties
  - Gradation
  - Density
  - Moisture
  - Absorption

2nd Goal – Sensitivity Analyses on Pavement Performance

Overview of Research Plan

- **Task 1** – Initial Memorandum on Expected Research Benefits and Potential Implementation Steps
- **Task 2** – Data Collection
- **Task 3** – Sensitivity Analyses (Pavement M-E Analyses)
- **Task 4** – Final Report

TASK 2 – DATA COLLECTION

List of data that has been collected:

- Index Properties
  - Gradation characteristics
  - Atterberg limits
  - Moisture
  - Density
  - Binder/mortar content
  - Specific gravity

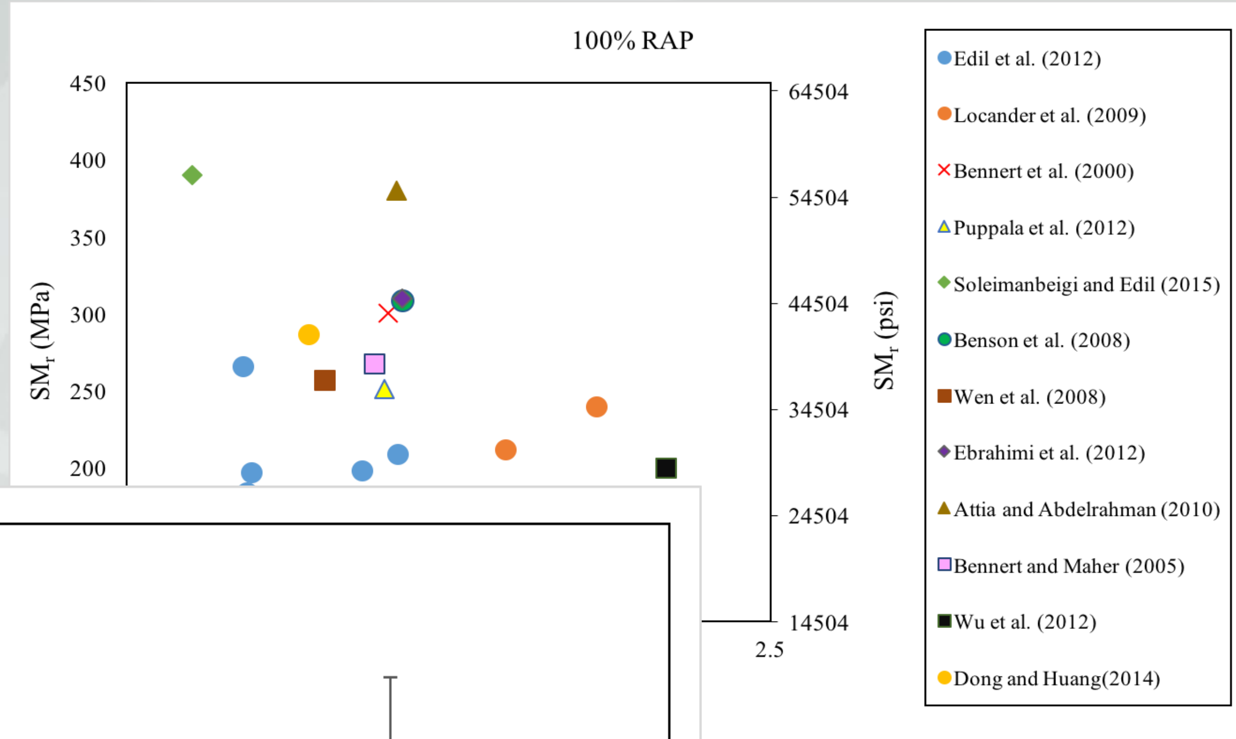
- Strength/Stiffness Properties
  - California Bearing Ratio (CBR)
  - Angle of friction, cohesion
  - Resilient Modulus (M_R)
  - Permanent Deformation

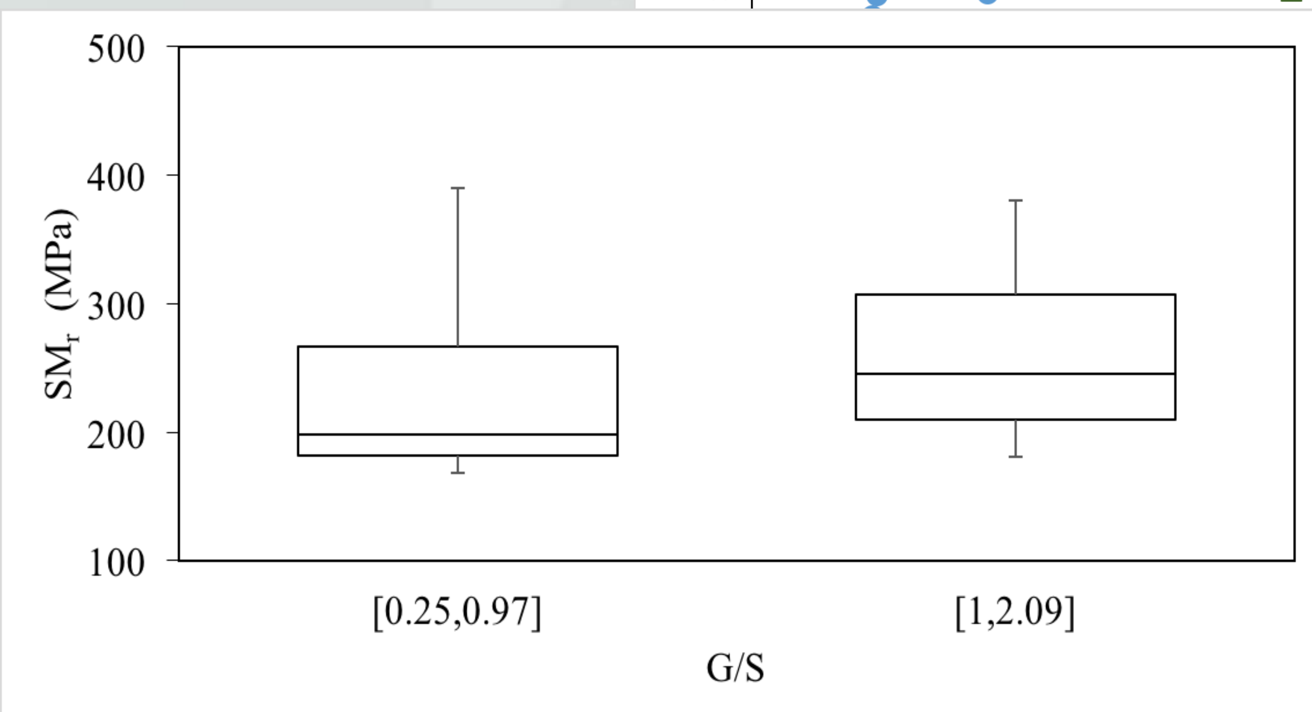
- Hydraulic Conductivity

SUMMARY OF RAP & RCA CHARACTERISTICS

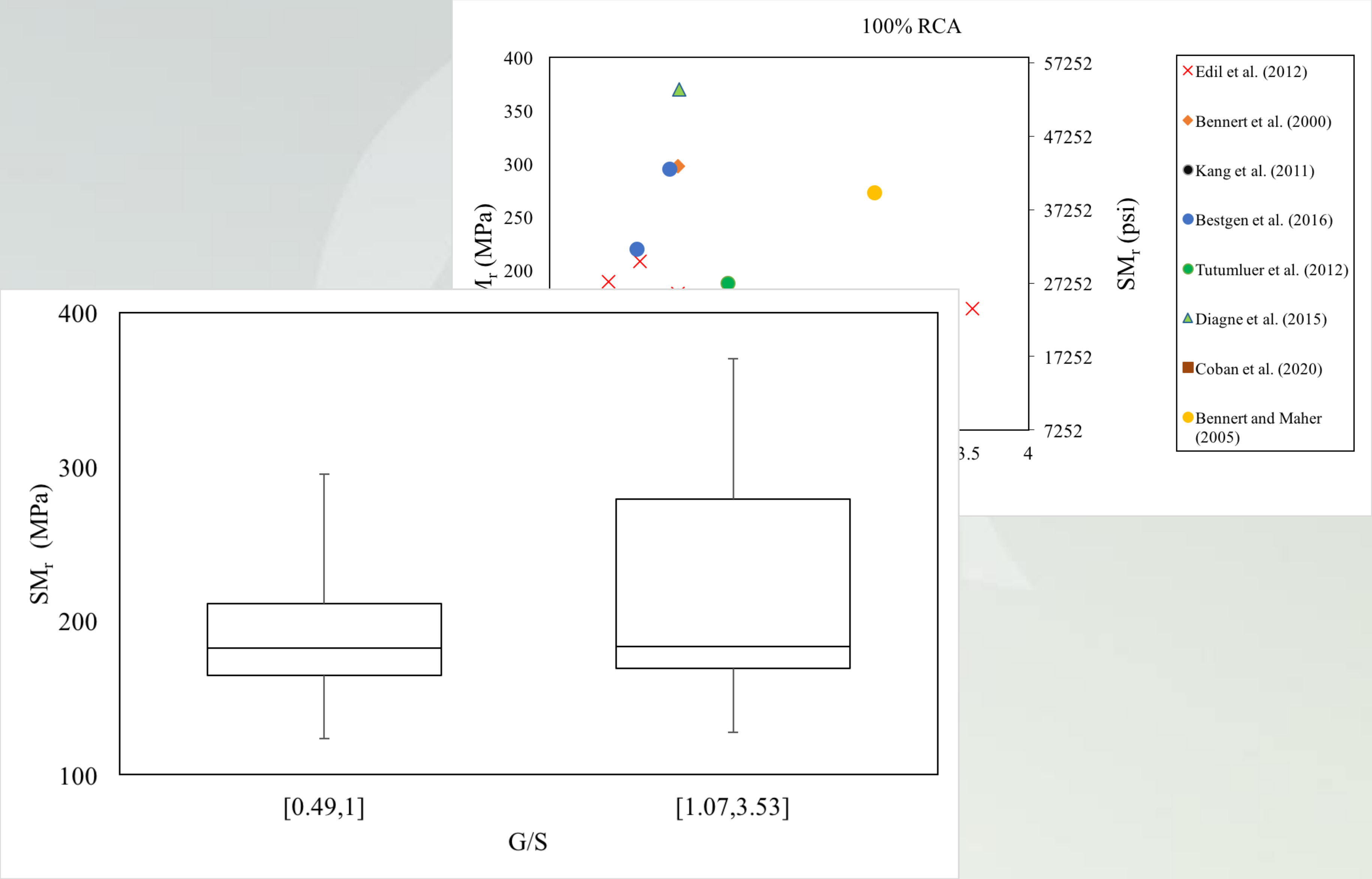
Characteristics	RAP			RCA		
	Lower Limit	Median	Upper Limit	Lower Limit	Median	Upper Limit
% Gravel	3	45	68.1	31.8	51	94.1
% Sand	28.1	54	97	4.9	46.3	64.9
% Fines	0	1	11	0.1	2.8	12.8
D_{10} (mm/inch)	10^{-1}/ $3.9x10^{-3}$	$5x10^{-1}$/ $1.96x10^{-2}$	1/ $3.93x10^{-2}$	10^{-1}/ $3.9x10^{-3}$	$2.3x10^{-1}$/ $9x10^{-3}$	$4.3x10^{-1}$/ $1.7x10^{-2}$
D_{30} (mm/inch)	$8x10^{-2}$/ $3.1x10^{-3}$	1.5/ $6x10^{-2}$	4.9/ $1.9x10^{-1}$	$2x10^{-1}$/ $7.9x10^{-3}$	1.2/ $4.72x10^{-2}$	6.5/ $2.56x10^{-1}$
D_{60} (mm/inch)	$1.5x10^{-1}$/ $5.9x10^{-3}$	4.82/ $1.89x10^{-1}$	10.4/ $4.09x10^{-1}$	$6x10^{-1}$/ $2.36x10^{-2}$	6.8/ $2.67x10^{-1}$	16.3/ $6.42x10^{-1}$
C_u	5	10.65	40	2.1	32	66
C_c	0.21	1.2	8	0.14	1.4	6
G_s	2.19	2.395	2.87	2.12	2.39	2.7
MDU (kN/m^3)/(pcf)	17.2 (110)	19.6 (126)	24.1 (155)	18.3 (118)	19.7 (127)	21.7 (140)
OMC(%)	4	6.05	10.7	6.1	10.8	14.8
SM_r (MPa/psi)	168/ 24366.3	261.5/ 37927.36	400/ 58015.1	123.4/ 17897.65	183/ 26541.9	370/ 53664
CBR (%)	18	28	68	58	146	169
Hydraulic conductivity (m/s/ft/hr)	$1.8x10^{-7}$/ $2.12x10^{-3}$	$6.89x10^{-5}$/ $8.14x10^{-1}$	$1.14x10^{-3}$/ 1.35x10	$1.05x10^{-6}$/ $1.24x10^{-2}$	$1.7x10^{-5}$/ $2.01x10^{-1}$	$1.2x10^{-3}$/ 1.42 x10

G/S ratio vs. SM_r – RAP

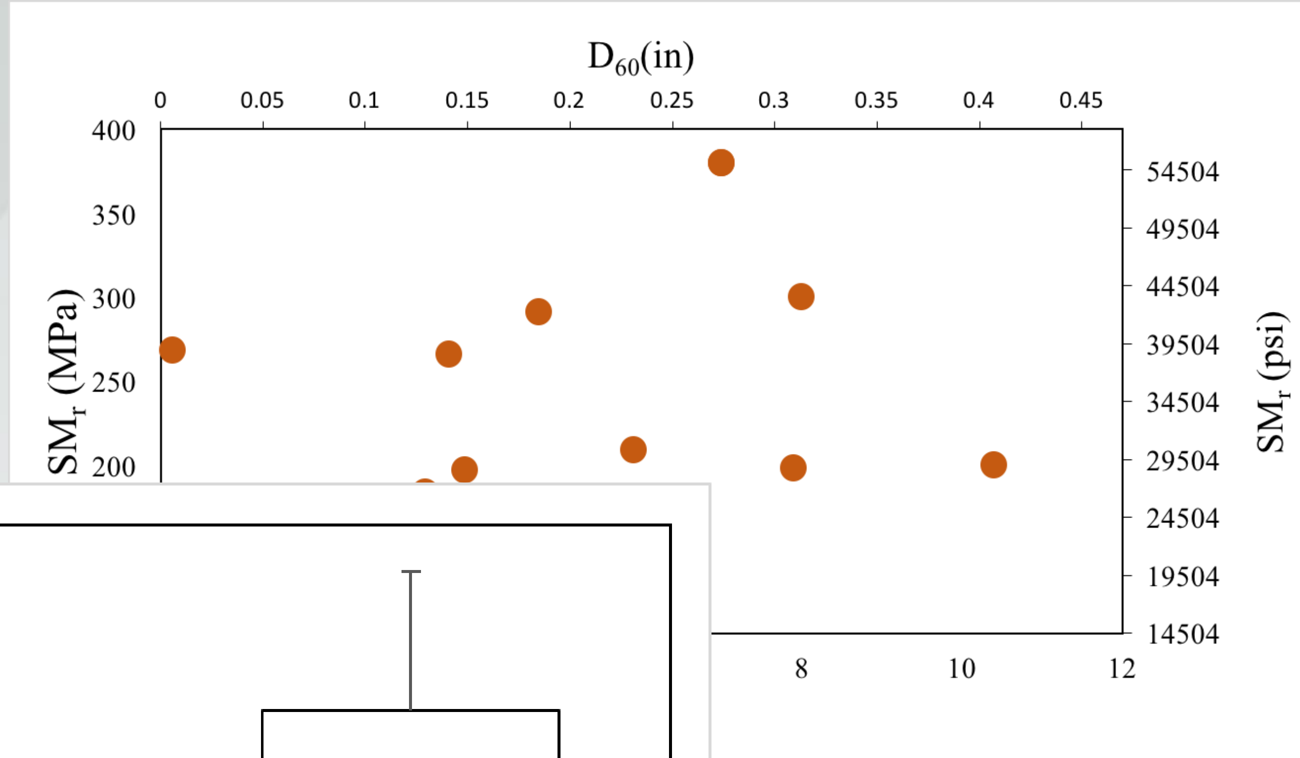


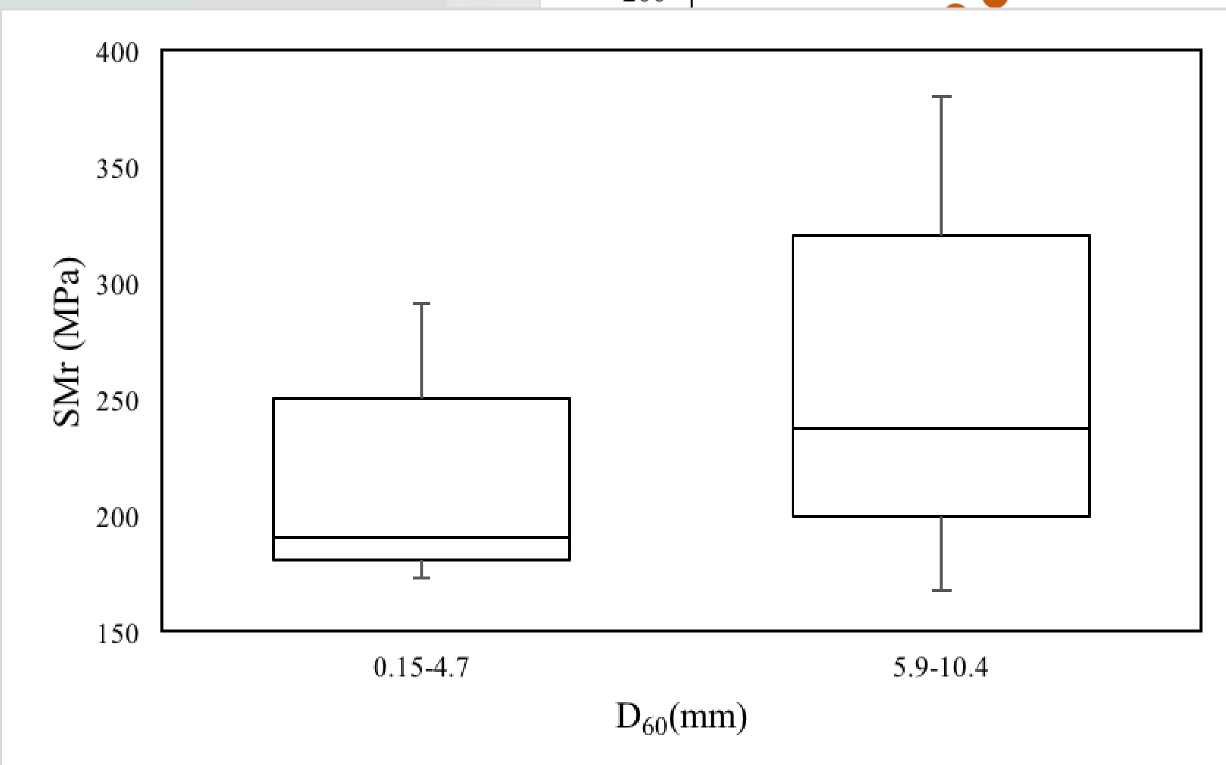


G/S ratio vs. SM_r – RCA

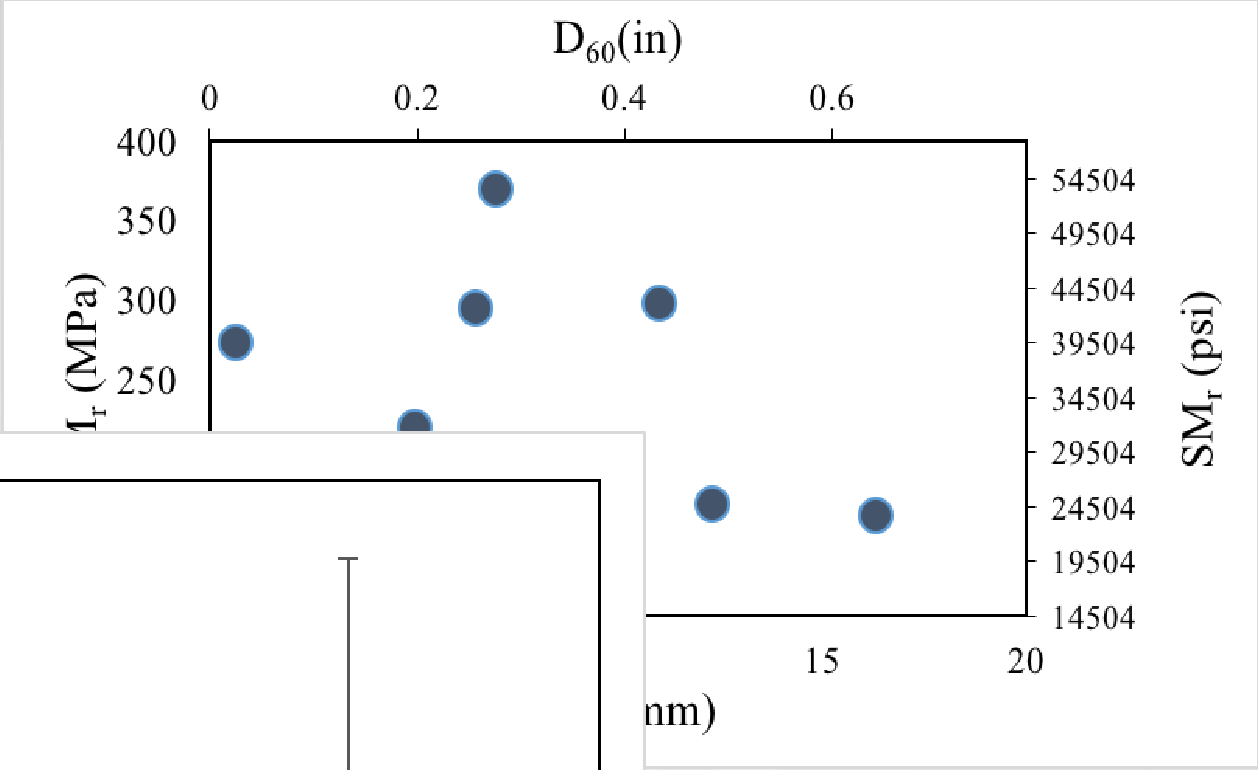


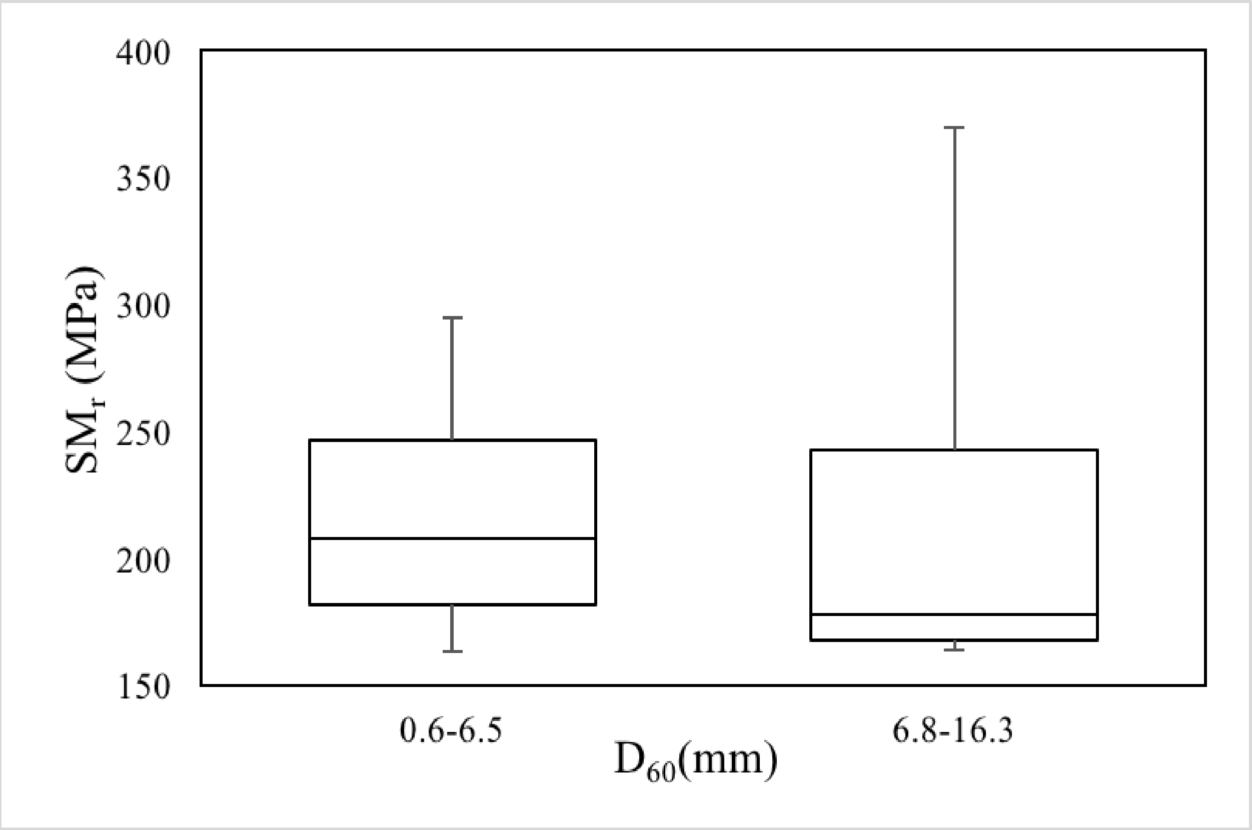
D_{60} vs. SM_r – RAP





D_{60} vs. SM_r – RCA





General Trends seen in RAPs

- Higher D_{30}, D_{60} and G/S ,C_u ➡ Higher SM_r
- Higher fines content ➡ No effect on SM_r
- Higher OMC ➡ Lower SM_r
- Higher temperatures ➡ Lower SM_r unless thermal preloading is applied
- Higher D_{10} ➡ Higher hydraulic conductivity
- Higher fines contents ➡ Lower hydraulic conductivity
- Higher RAP content ➡ Higher SM_r , Lower CBR
- Higher RAP content ➡ Lower OMC of blends
- Higher RAP content ➡ Higher permanent strain

General Trends seen in RCAs

- Higher G/S, C_u → Higher SM_r
- Higher fines content → Lower SM_r
- Higher MDU → Higher SM_r
- Higher OMC → Lower SM_r
- Higher RCA content → Lower hydraulic conductivity
- Higher RCA content → Lower MDU
- Higher RCA content → Higher OMC
- Higher RCA content → Lower permanent deformation
- Higher temperature → No trend in SM_r
- SM_r of RCA > SM_r of virgin aggregates

Pavement M-E Analyses

Pavement ME

- Requires several inputs
  - Hourly climate data, materials, location, pavement structure, traffic
- Calculates pavement performance parameters
  - Asphalt – IRI, Rutting, and Longitudinal, Thermal, and Alligator Cracking
  - Concrete – IRI, Transverse Cracking, Joint Faulting

Figures from:
http://www.aashtoware.org/Pages/default.aspx
http://www.pavementinteractive.org/article/Rutting/
http://brc-amps.wikidot.com/brc-road-condition-assessment-manua
http://blackdiamondpaving.com/terms-you-should-know/

General inputs

Input	Value
Design Period	20 years
Climate	Minnesota
SM_r of Subgrade	15000 psi
Subgrade Gradation	A-1-b
Groundwater Depth (ft)	10
Flexible Pavement Input	
Binder Grade	Super Pave PG 58-34
Base Poisson’s Ratio	0.35
HMA Poisson’s Ratio	0.35
Rigid Pavement Input	
PCC Unit Weight (pcf)	150
PCC Poisson’s Ratio	0.15

Traffic inputs

Inputs	Low Traffic	Medium Traffic	High Traffic
AADTT	1000	7500	25000
Number of Lanes in Design Direction	2	3	3
Percent of Trucks in Design Direction (%)	50	50	50
Percent of Trucks in Design Lane (%)	75	55	50
Operational Speed (mph)	50	50	50
Asphalt Thickness in flexible pavement (in)	2	3	4
Base Thickness in flexible pavement (in)	8	10	12
PCC Thickness for rigid pavement (in)	8	9	11
Base Thickness in rigid pavement (in)	4	6	8

Distresses

Parameter	Target value	Reliability (%)
Terminal IRI (in/mile)	172	90
Mean Joint Faulting (in)	0.12	90

Parameter	Target value	Reliability (%)
Terminal IRI (in/mile)	170	90
Total Pavement Rutting (in)	0.75	90

Pavement ME

- Varied input parameters of Recycled Base
  - Resilient Modulus (M_R)
  - Gradation Characteristics
    - Fines Content
    - Sand Content
    - Gravel Content
    - D_{60}, D_{30}, D_{10}
    - Hydraulic Conductivity
- Calculate pavement performance parameters
  - Flexible Pavements – IRI and Total Rutting
  - Rigid Pavements – IRI and Joint Faulting

Impact of Resilient Modulus on Pavement Performance

Inputs for RAP

Data Value	Varied Parameter (SM_r, psi)	Gravel Percent (%)	Sand Percent (%)	Fines Content (%)	MDU (pcf)	OMC (%)	Hydraulic conductivity (ft/hr)
Lowest*	24366	49.3	50.4	0.4	138	5.2	2.73
Median	37927	45	54	1	126	6.1	0.71
Highest**	58015	51	48.6	0.4	134	5.5	-

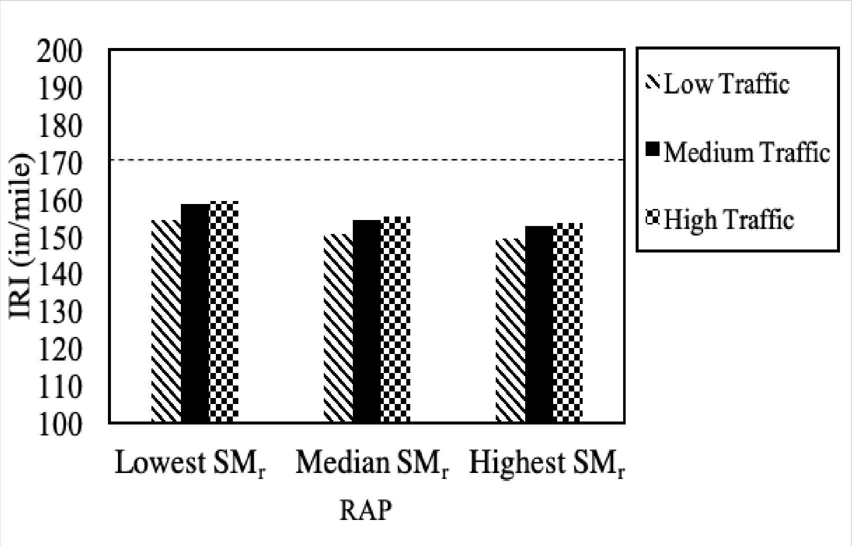
*Edil et al. (2012a), **Attia and Abdelrahman (2010a)

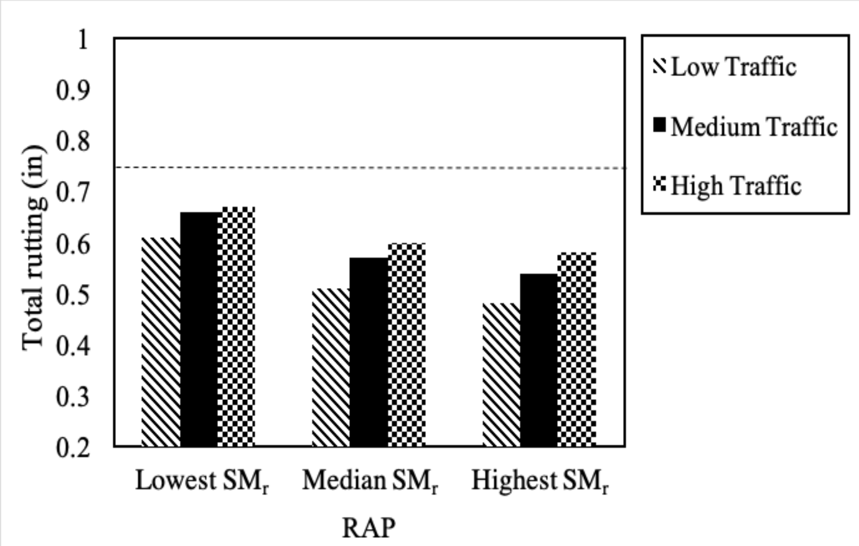
Inputs for RCA

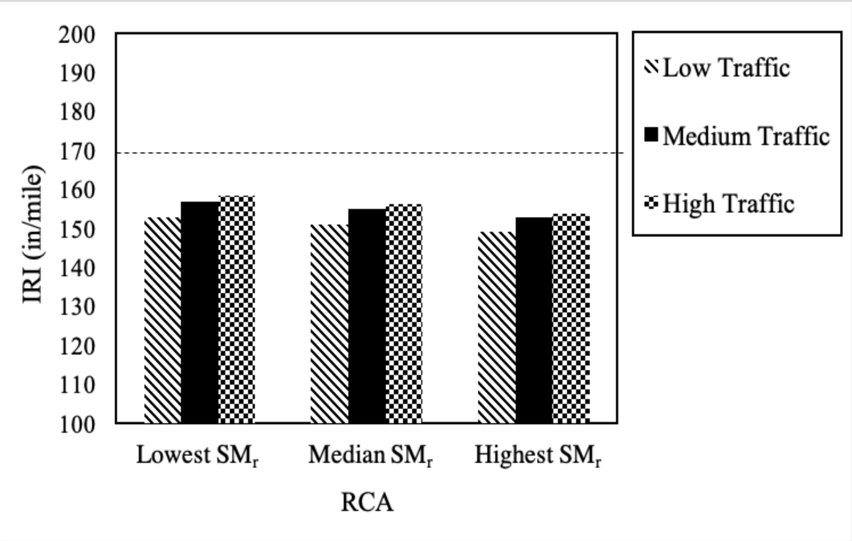
Data Value	Varied Parameter (SM_r, psi)	Gravel Percent (%)	Sand Percent (%)	Fines Content (%)	MDU (pcf)	OMC (%)	Hydraulic conductivity (ft/hr)
Lowest*	17898	38.3	54.6	7.1	123	11.1	0.06
Median	26542	50.8	45.5	3	127	10.8	0.2
Highest**	53664	47.2	48.6	1.8	134	6.1	0.35

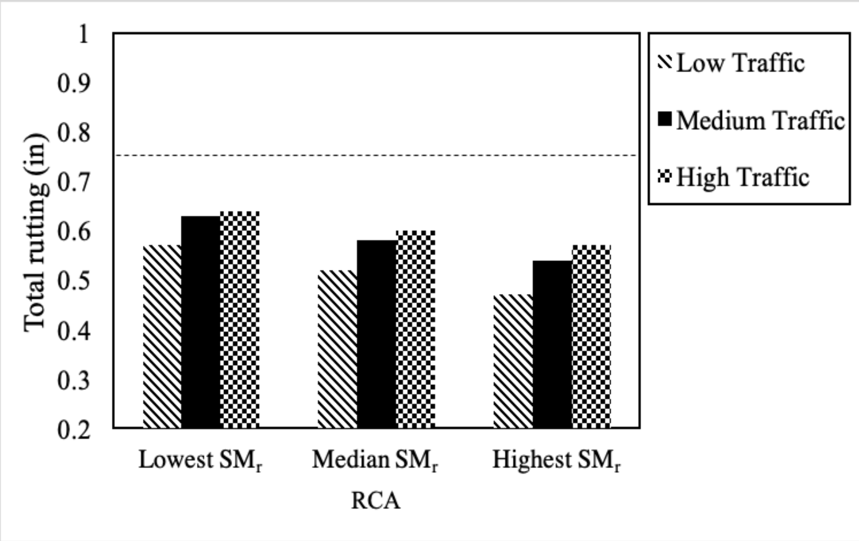
*Cetin et al. (2020), **Diagne et al. (2015)

Impact of Resilient Modulus on Flexible Pavement Performance

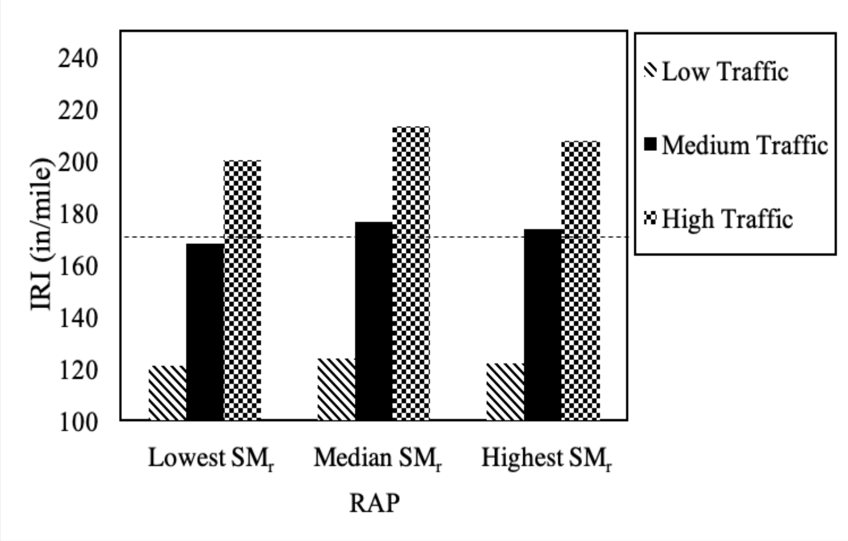


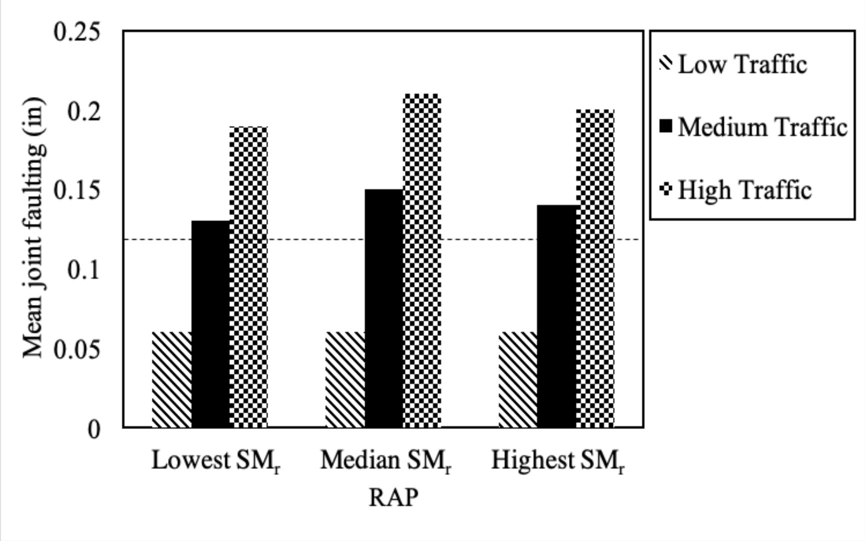


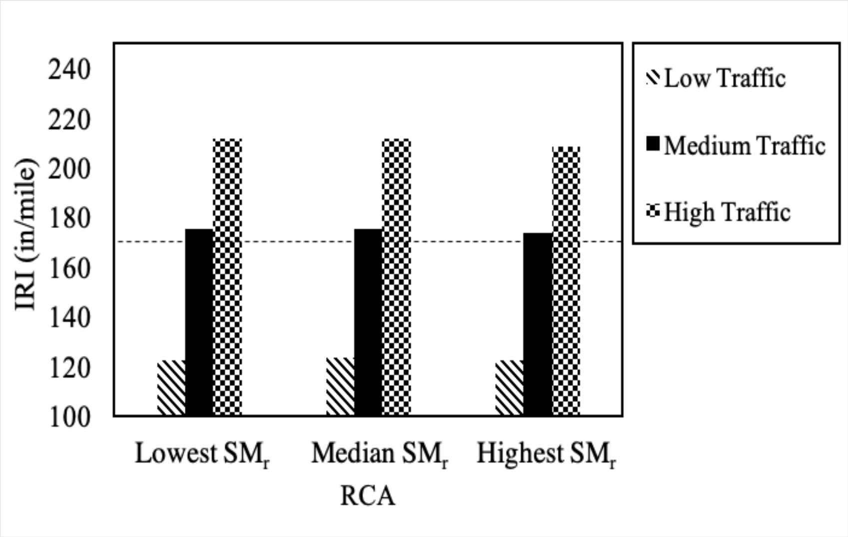


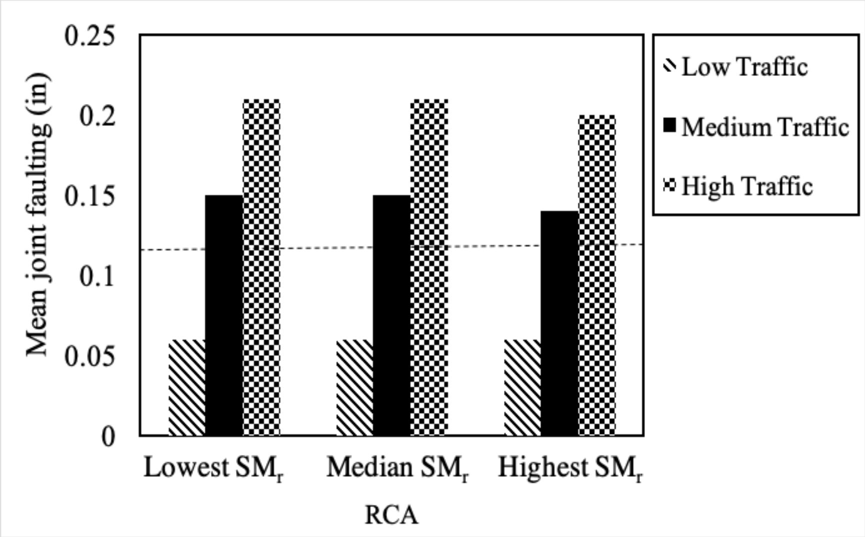


Impact of Resilient Modulus on Rigid Pavement Performance









Impact of Fines Content on Pavement Performances

Inputs for RAP

Data Value	Varied Parameter (Fines content, %)	Gravel Percent (%)	Sand Percent (%)	MDU (pcf)	OMC (%)	Hydraulic conductivity (ft/hr)	SM_r (psi)
Lowest*	0	3	97	-	-	-	39349
Median	1	45	54	126	6.1	0.71	37927
Highest**	11	46	43	136	7.5	-	44962

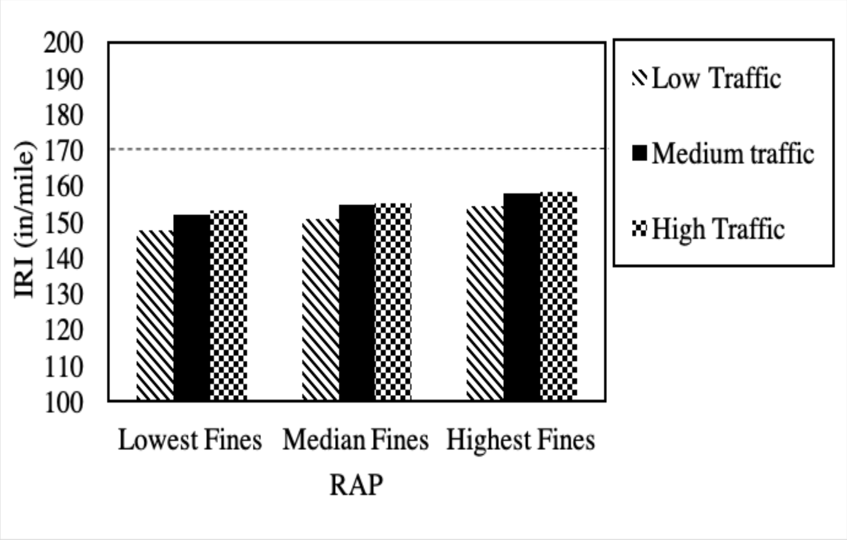
*Alam et al. (2010), **Camargo et al. (2013)

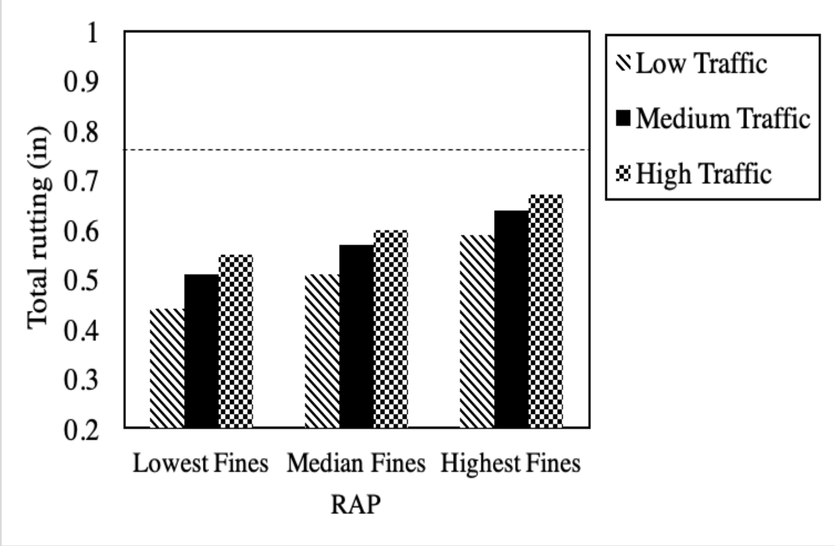
Inputs for RCA

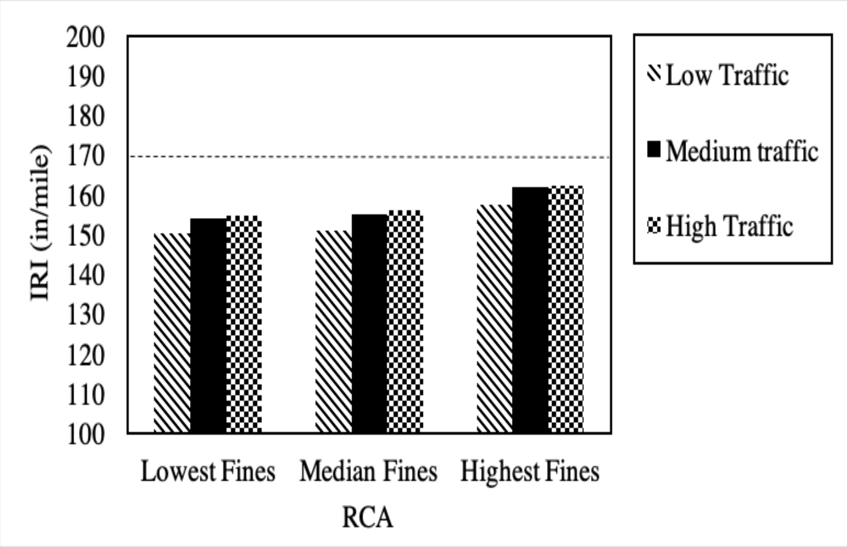
Data Value	Varied Parameter (Fines content, %)	Gravel Percent (%)	Sand Percent (%)	MDU (pcf)	OMC (%)	Hydraulic conductivity (ft/hr)	SM_r (psi)
Lowest*	0.1	68.8	31.1	127	14.4	-	-
Median	3	50.8	45.5	127	10.8	0.2	26542
Highest**	15	41	44	121	11.9	-	27412

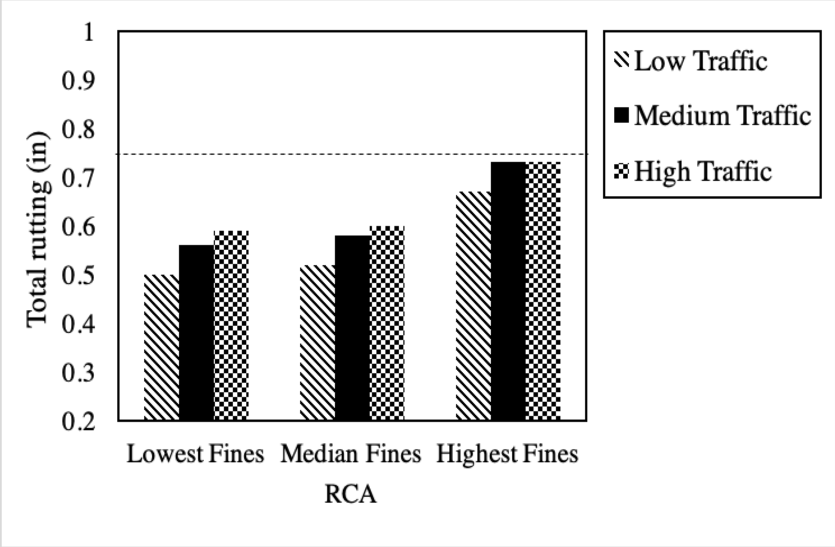
*Mahedi and Cetin (2020), **Chen et al. (2013)

Impact of Fines Content on Flexible Pavement Performance

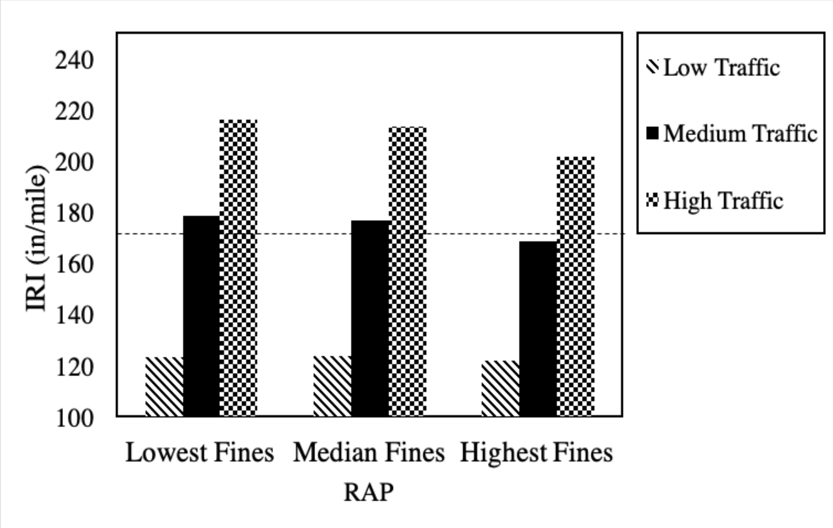


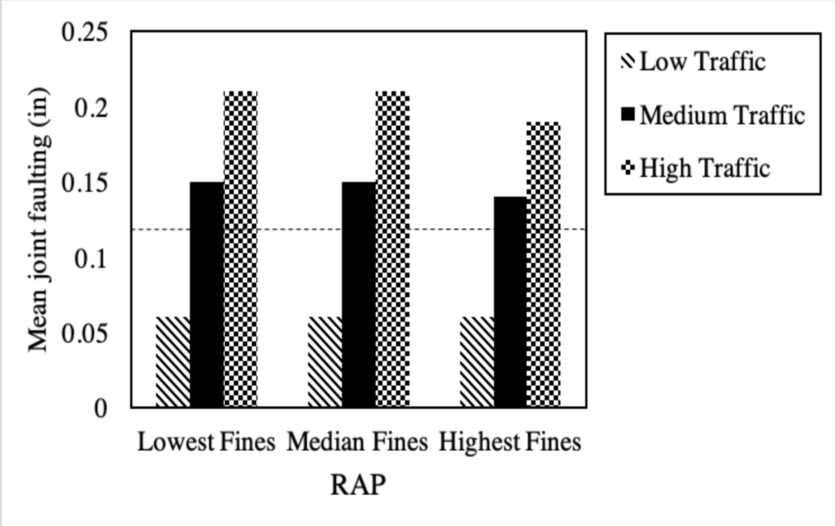


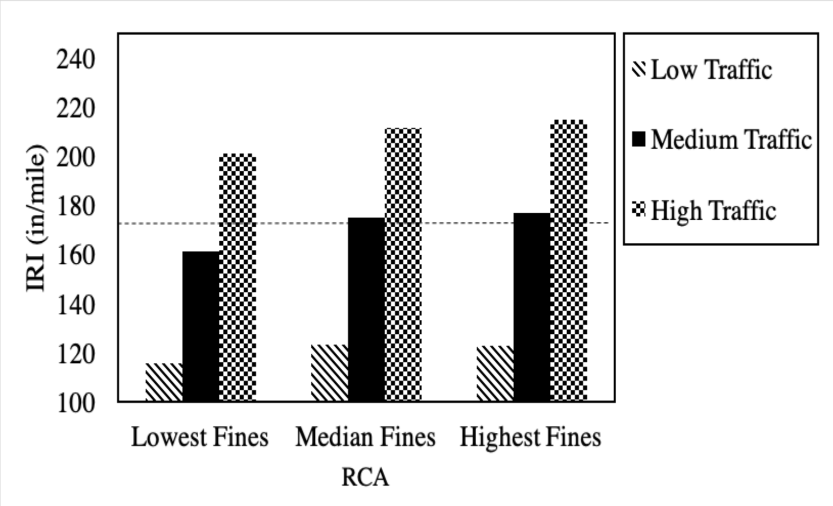


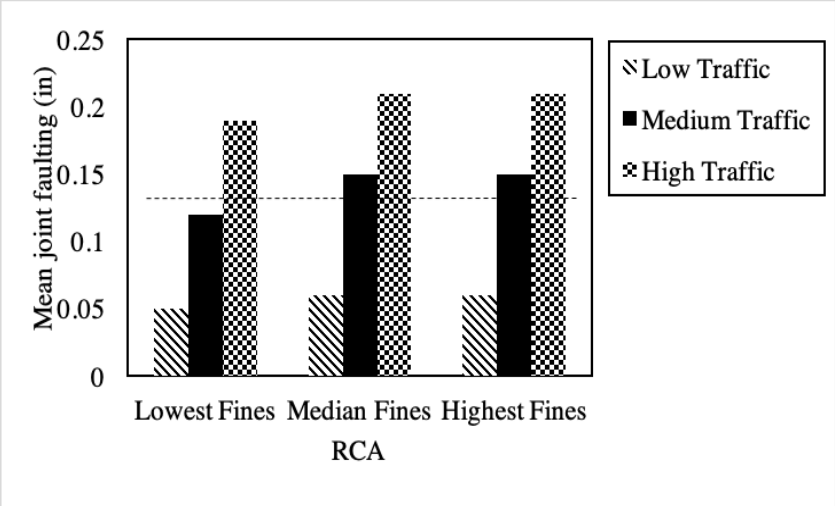


Impact of Fines Content on Rigid Pavement Performance









Conclusions

- SM_r values of recycled base layer aggregate had the greatest influence on the pavement performance among other material inputs.
- No trend was observed between D_{60} values with pavement performances.
- Summary resilient modulus (SM_r) and gradation of base has an influence on flexible pavement design.
- More damage was observed with higher AADTT values.
- Higher fines content, lower SM_r and lower sand content ➡ Higher total rutting in RAB
- Higher fines contents ➡ higher IRI in RABin flexible pavements
- In rigid pavements, all cases with RAB as base course materials in low traffic volume satisfied the minimum required IRI and mean joint faulting distresses.

Implementations & Overall Recommendations

- All cases in flexible pavement pass the IRI and total rutting criteria indicating that the use of RAB materials as base in flexible pavements result in satisfactory results
- It is recommended to determine the **gradations** and summary **resilient modulus of** RAB materials for pavement design.
- Rigid pavement results were not conclusive.
- Database created can be used for pavement design and analyses.

THANK YOU