GDOT RP 12-07: Measurement of Dynamic and Resilient Moduli for MEPDG in Georgia – Phase I

Sung-Hee (Sonny) Kim, Ph.D. P.E.
Southern Polytechnic State University, Marietta, Georgia

Background

To perform the structural analyses of existing flexible pavements using Mechanistic-Empirical Pavement Design Guide (MEPDG) or Pavement ME, the accurate measurements of dynamic modulus (E*) for asphalt materials and resilient moduli (MR) for unbound materials are mandatory. E* is a direct input of ME software since it explains the viscoelastic behavior of HMA, which is the function of the loading rate and temperature. The resilient behavior of aggregate and subgrade layers is the nature of granular material behavior and thus, MR is one of the most important material properties, that is directly related to the structural performance of flexible pavement.

GDOT needs to determine E* of typical HMA layers and the resilient moduli of base and subgrade layers for successful implementation of MEPDG in the State. The measurement of the moduli are required to correctly identify E* and MR to analyze the existing pavement and to design new pavement using Pavement ME software.

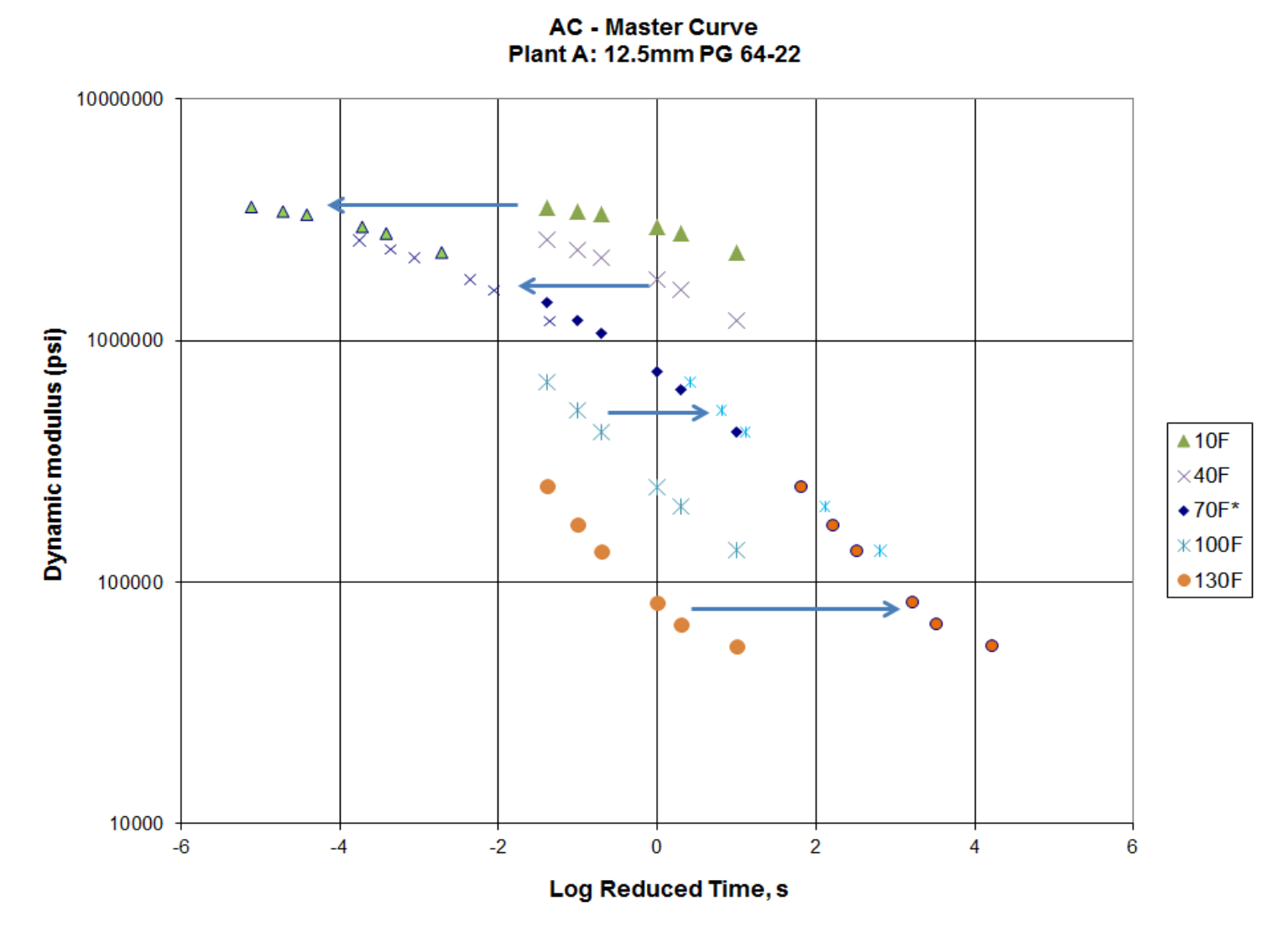
Measurement of HMA Dynamic Modulus (E*)

E Master Curve*

For a Level 1 flexible pavement design using the MEPDG, dynamic modulus (E*) of Hot Mix Asphalt (HMA) is required as an input value. Dynamic modulus is defined as the absolute value of the complex modulus that can be obtained by dividing the peak stress by the peak strain as follows:

$$|E^*| = \frac{\sigma_0}{\varepsilon_0}$$

The measured E* at different test temperatures and frequencies are then used to construct master curve based on the principle of time-temperature superposition at a reference temperature of 70oF.

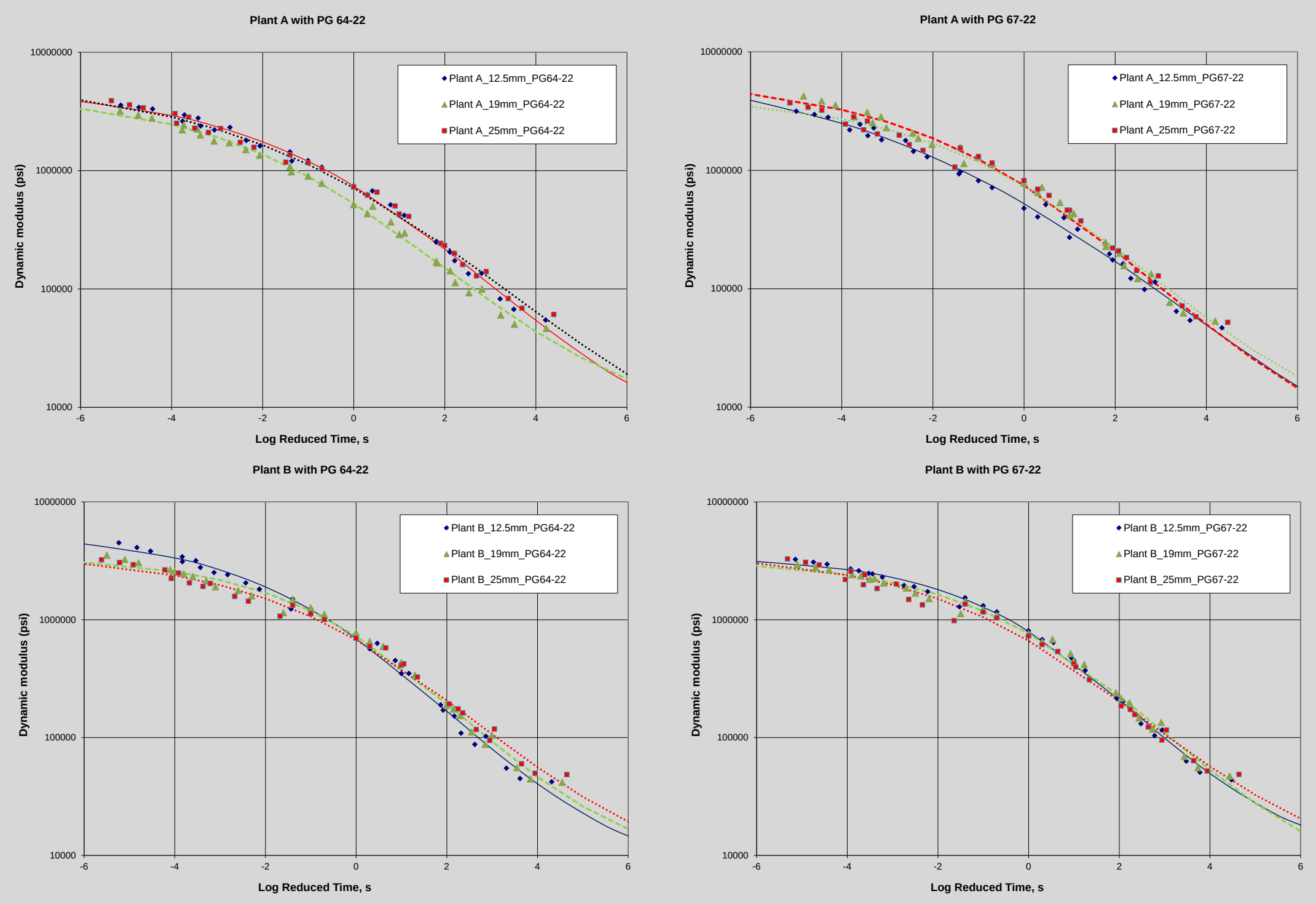


$$\log(E^*) = d + \frac{\propto}{1+e^{\beta+\gamma(\log t_r)}}$$

Where,
tr = reduced time of loading at reference temperature
δ= minimum value of E*
δ+α= maximum value of E*
β, γ= parameters describing the shape of the sigmoidal function

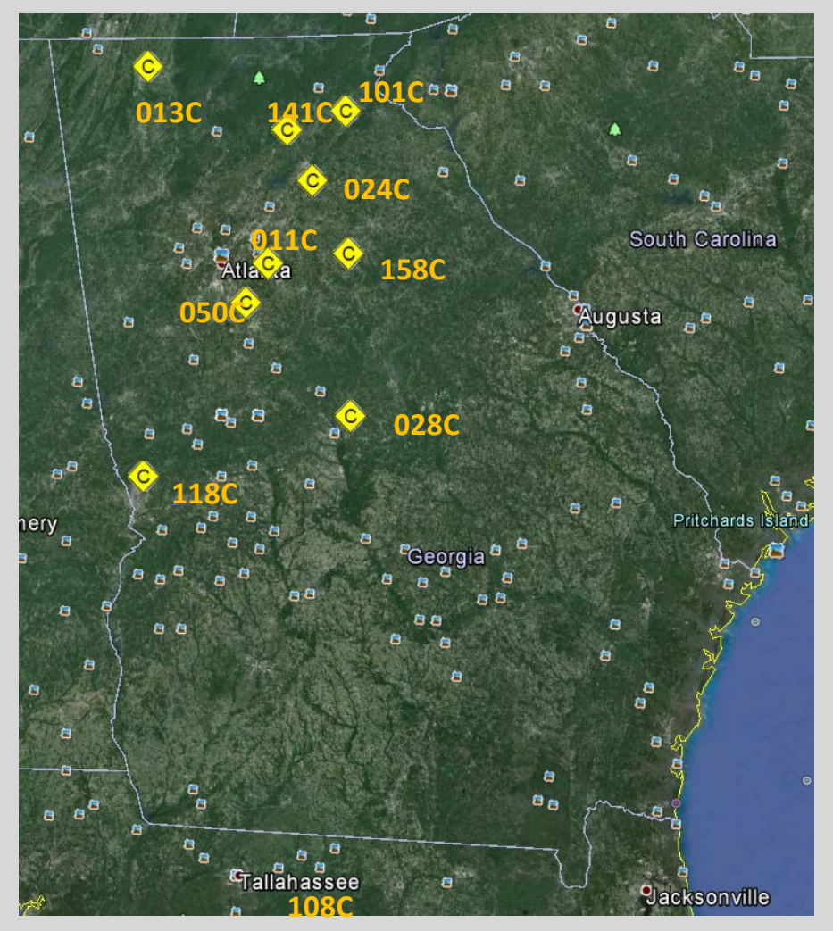
AASHTO T 342 E* Measurements

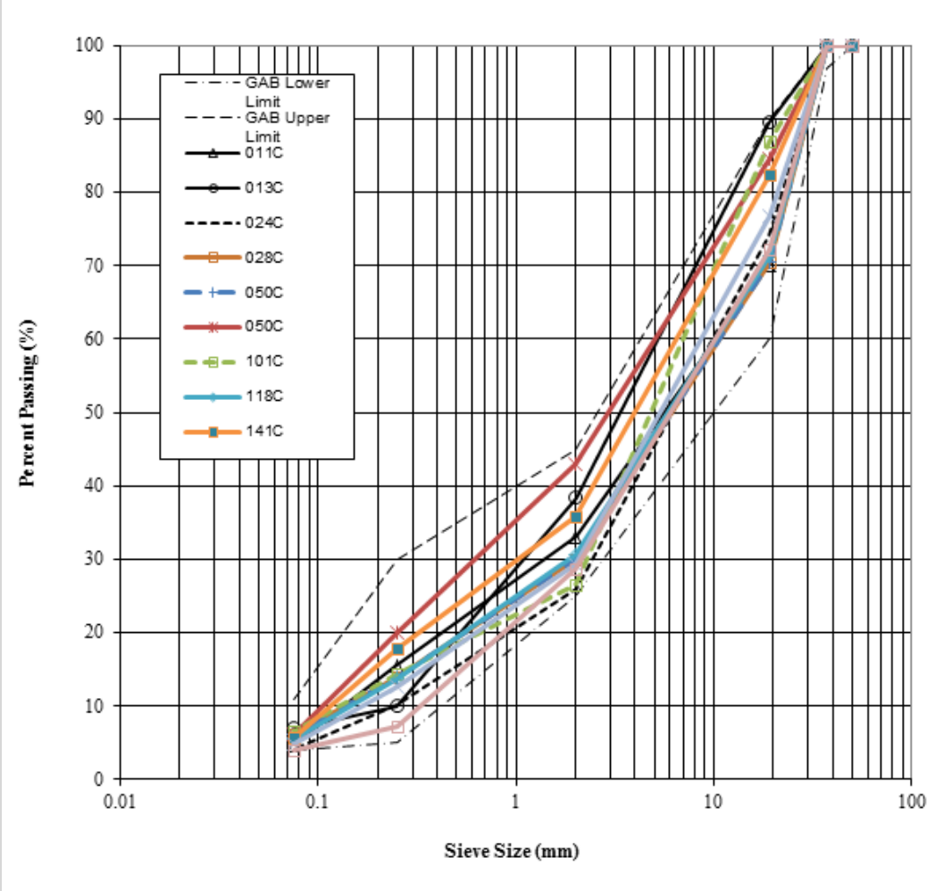
The HMA specimens were prepared based on JMF in accordance with AASHTO PP 60-09 "Preparation of Cylindrical Performance Test Specimens using Superpave Gyratory Compactor (SGC)". A SGC produced initial cylindrical specimens with a 6" (diameter) by 7" (height). The specimens were then cored and sawed to a size of 4" (diameter) x 6" (height) for dynamic modulus test. The target air void of the prepared specimens was 4% ± 0.5%. A total number of 36 tests was conducted.



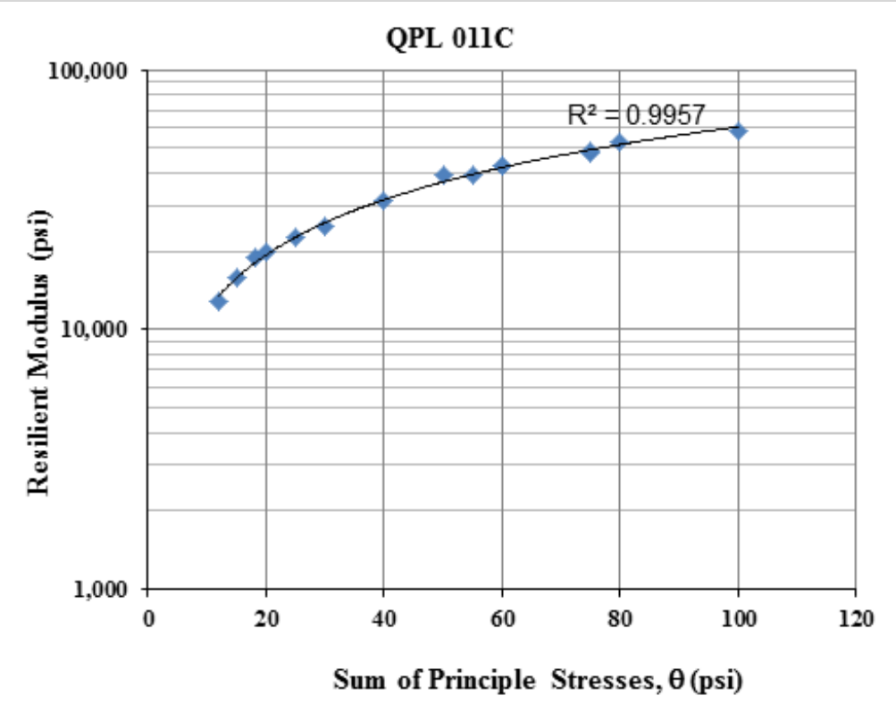
Measurement of GAB Resilient Modulus (M_R)

GAB Materials (11 GAB Materials)



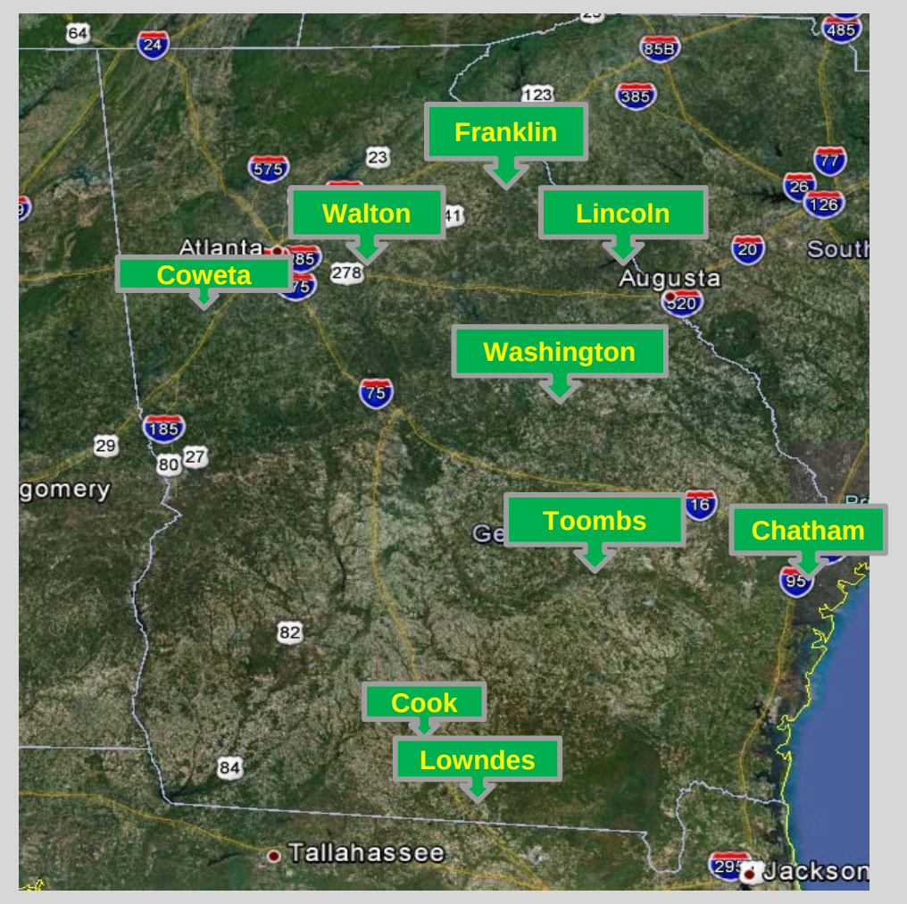


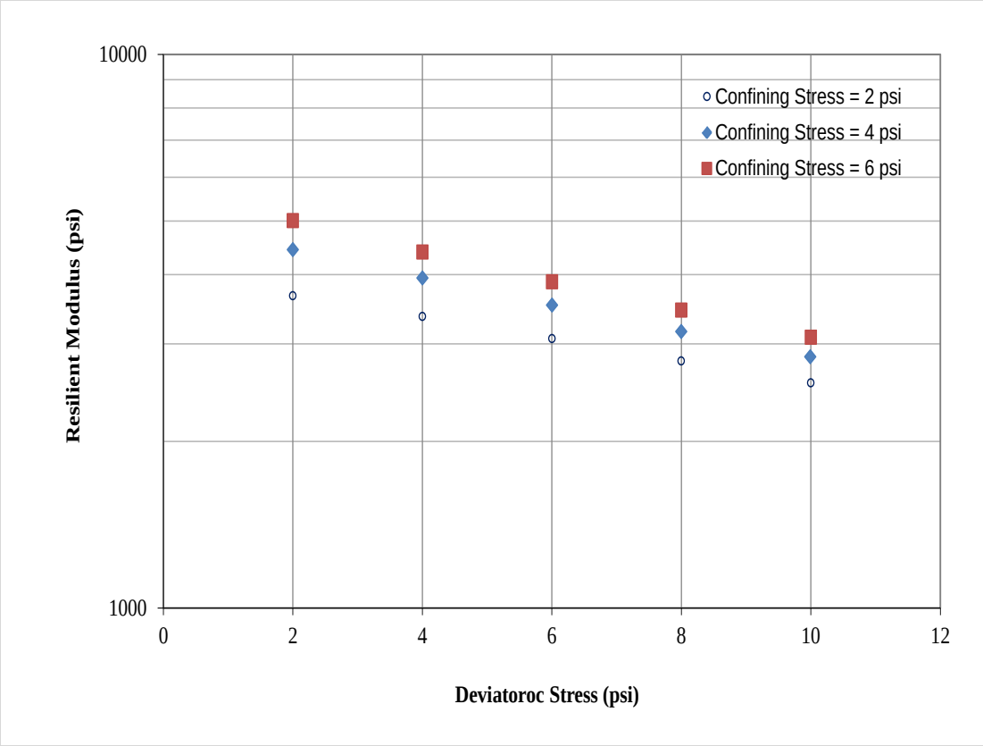
QPL ID	k_1	k_2	k_3	R^2
011C	1049	0.716	-0.041	1.00
013C	1031	0.659	-0.145	0.99
024C	739	0.797	-0.012	0.98
028C	996	0.591	-0.046	0.99
050C	969	0.522	-0.022	0.99
101C	674	0.734	-0.014	0.99
108T	803	0.862	-0.012	0.96
118C	782	0.801	-0.084	0.99
141C	643	0.767	-0.111	0.99
158C	965	0.564	-0.010	0.99
165T	1173	0.626	-0.019	0.99



Measurement of Subgrade Resilient Modulus (M_R)

Subgrade Materials (9 Subgrade Materials)

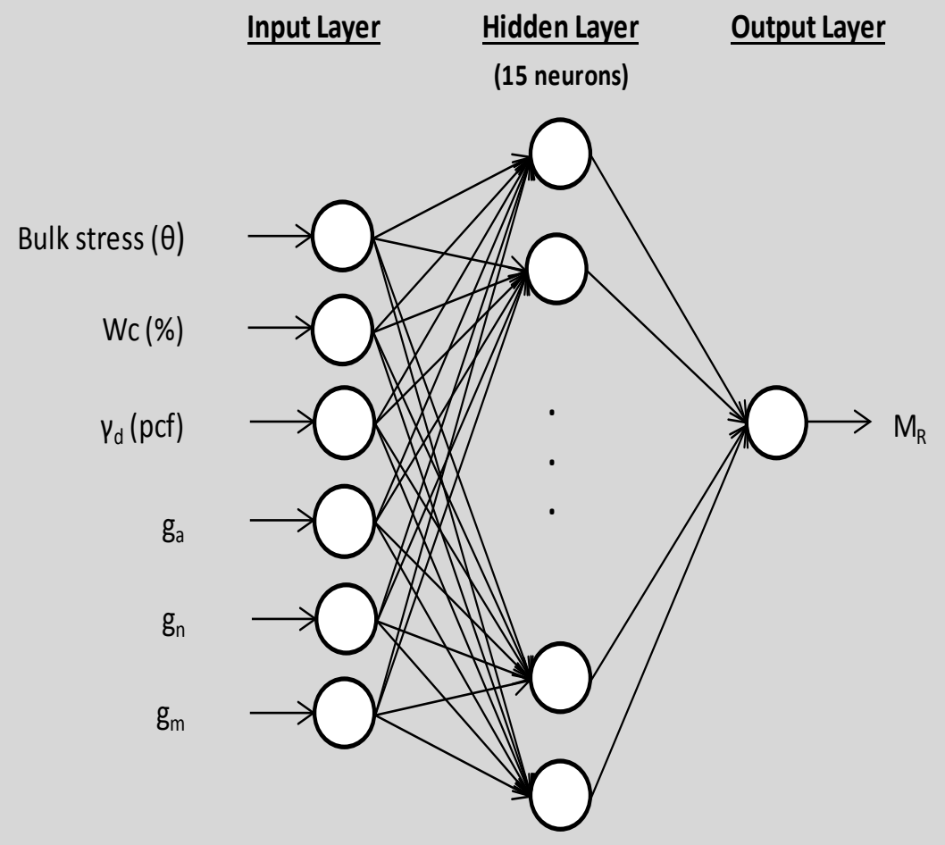




Subgrade No.	Source Location	GA Soil Class	USCS Symbols	AASHTO Soil Class	Statistics	k-values		
						k1	k2	k3
1	Lincoln	IIB4	SC	A-4	Maximum	634	0.327	-1.884
					Minimum	559	0.026	-3.350
					Average	618	0.164	-2.831
2	Washing	IIB2	SM	A-2-4	Maximum	1209	0.542	-0.123
					Minimum	1079	0.182	-1.061
					Average	1156	0.330	-0.508
3	Coweta	IIB3	SC	A-2-7	Maximum	681	0.306	-1.724
					Minimum	578	0.231	-2.048
					Average	619	0.257	-1.836
4	Walton	IIB4	SC	A-7-6	Maximum	1217	0.352	-2.278
					Minimum	906	0.196	-2.906
					Average	1031	0.285	-2.679
5	Chatham	IIB4	SM	A-2-4	Maximum	1241	0.352	-2.852
					Minimum	1241	0.352	-2.852
					Average	1241	0.352	-2.852
6	Lownds	IA2	SP	A-2-4	Maximum	1298	0.535	-0.148
					Minimum	1288	0.509	-0.438
					Average	1293	0.522	-0.293
7	Franklin	IIB3	SC	A-2-4	Maximum	495	0.419	-2.773
					Minimum	357	0.341	-3.407
					Average	426	0.380	-3.090
8	Cook	IIB2	SM	A-2-4	Maximum	1153	0.255	-0.369
					Minimum	1153	0.255	-0.369
					Average	1153	0.255	-0.369
9	Toombs	IA1	SP	A-1-b	Maximum	1468	0.316	-2.476
					Minimum	1285	0.240	-2.521
					Average	1386	0.277	-2.499

Artificial Neural Networks

An ANN comprises a large number of simple processing elements named neurons. Each neuron in an ANN is an independent processing element, having its own inputs and output. Each neuron is connected to other neurons by means of directed links with associated weights. The weights acquired through the training process represent abstracted information from the data set, which is used by the ANN to solve a particular problem.



Neuron Activation Function

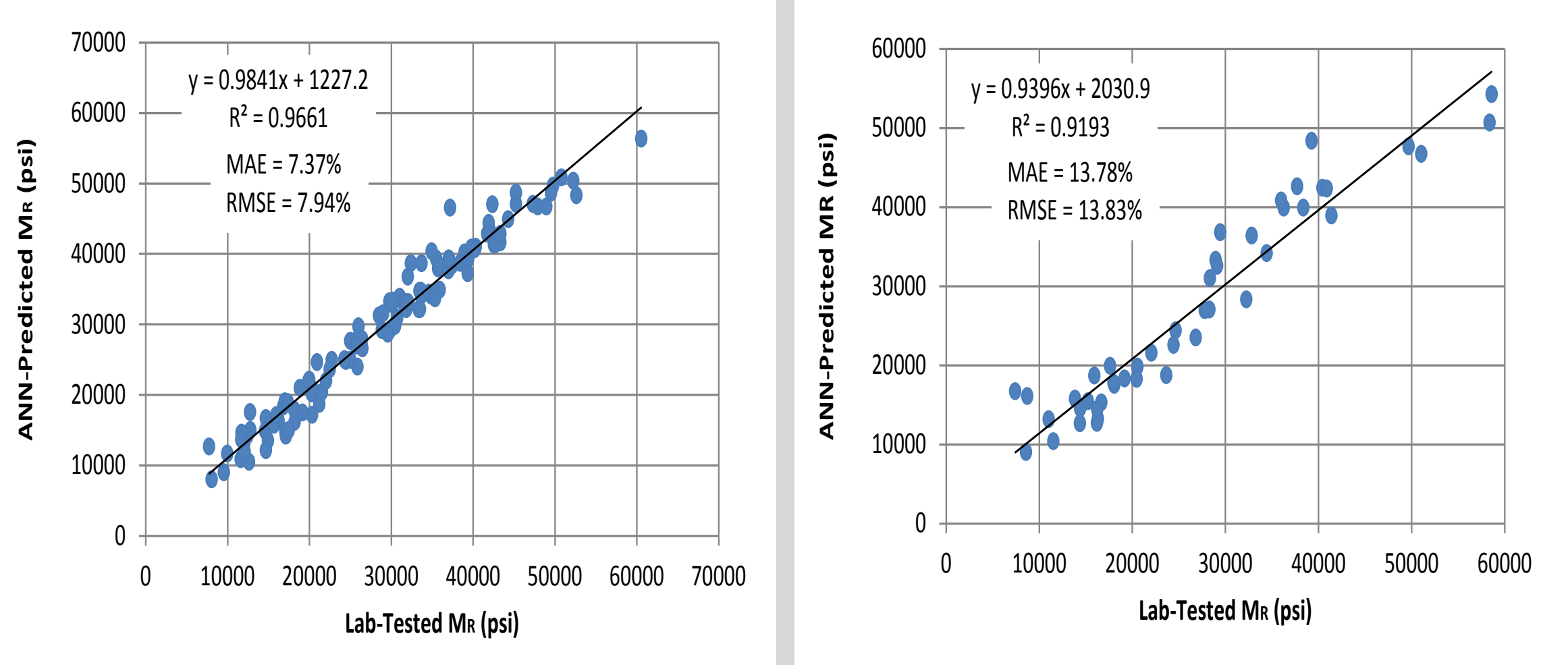
$$y = f(x) = \frac{1}{1+e^{-a\left(\sum_{i=1}^{n} w_i x_i\right)}}$$

Error Function

$$E = \frac{1}{2}\sum_{r=1}^{p}\sum_{k=1}^{m}\left(T_k^{(r)} - Y_k^{(r)}\right)^2$$

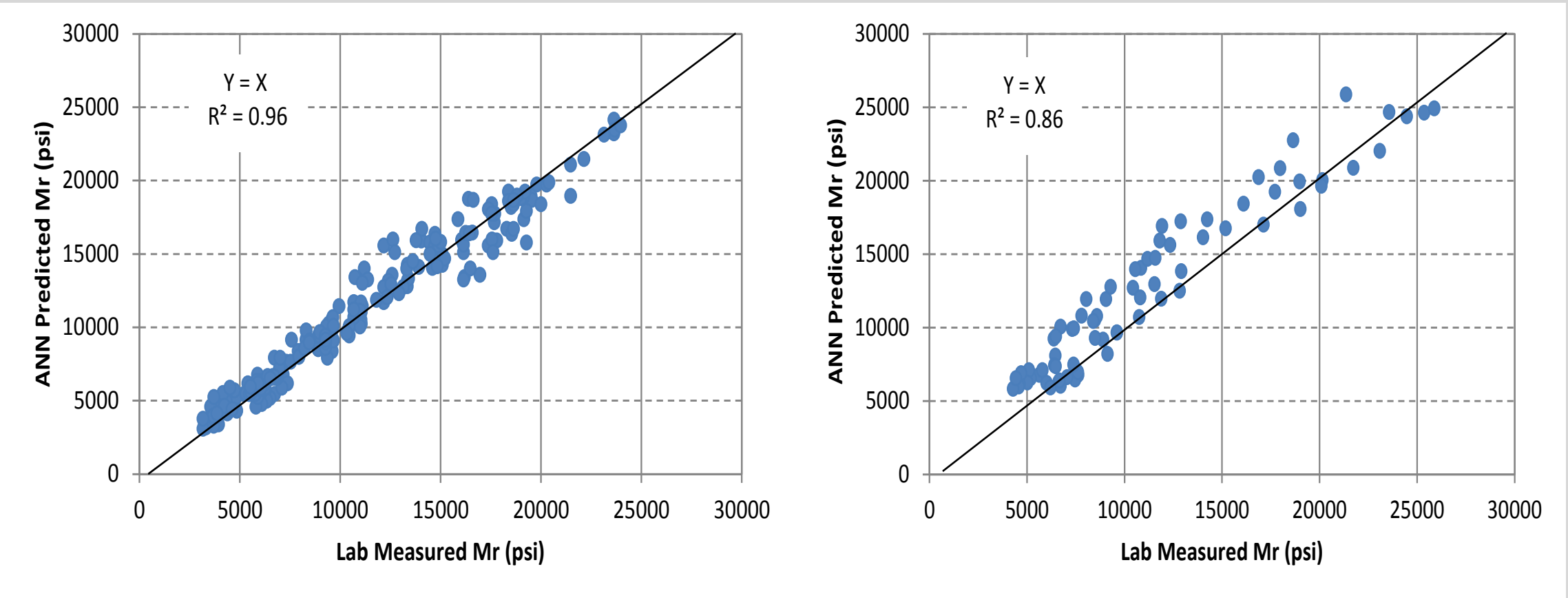
The total error was minimized during the training process by adjusting weights.

GAB ANN Training, Testing, and Validation



The training and testing results indicate that the ANN was able to generalize the relationship underlying GAB M_R and these explanatory variables considered. Good correlations between measured and predicted M_R were observed with the high R^2 values, which assures that aggregate physical properties and stress state are significant factors influencing the resilient behavior of aggregate base materials. Since the predicted M_R represents the knowledge generalized from the lab data, the developed model could be utilized to estimate the M_R needed for MEPDG level 2 input.

Subgrade ANN Training, Testing, and Validation



The ANN-estimated M_R were plotted against the lab measured MR for both training and test sets. As shown in above Figs, there is a fairly good alignment between the ANN-estimated MR and the lab-measured M_R. The slightly lower R^2 for test set is intuitive as the test data were not seen by the neural network as part of the training. As shown, both the training and testing results indicate a fairly high accuracy of the ANN model in estimating M_R based on the subgrade physical properties and the stress state.

Acknowledgments

This research was sponsored by the Georgia Department of Transportation. Any opinions, findings, and conclusions or recommendations expressed herein are those of the authors and do not necessarily reflect the views of the sponsoring agency.

Contact information

Dr. Sung-Hee Kim, Ph.D., P.E..

Civil & Construction Engineering
1100 South Marietta Pkwy
Marietta, GA 30060

T: 678.915.5491
F: 678.915.5527
E: skim4@spsu.edu