Roadway translation plan

Based on the traffic pattern, volume and pavement design information for Qingyin expressway, this paper provided the translation design. The primary design parameters included 75cm horizontal translation and 2.9 year translation time. The translation design plan was implemented. The condition survey results indicated that there is good safety and it delays maintenance by 1.5 years.

CONCLUSIONS

To preserve pavement resources, this paper presents the expressway roadway translation method which is based on asphalt pavement rutting model. Using viscoelastic creep material model, this paper proposed roadway translation design method. A case study was discussed using Qingyin expressway as an example. Based on the traffic pattern, volume and pavement design information, this paper provided the translation design. The primary design parameters included 75cm horizontal translation and 2.9 year translation time. The condition survey results indicated that there is good safety and it delays maintenance by 1.5year.

The expressway translation method is sound in theory, clear in design procedure and simple in operation. It has important theoretical and practical value by offering a completely new way of expressway maintenance management.

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Application of Intelligent Compaction Technology for Estimation of Effective Modulus for a Multilayered Asphalt Pavement

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ABSTRACT

In this paper, a procedure for estimation of effective modulus of a multilayered HMA pavement using Intelligent Compaction (IC) is investigated. A complete coverage of the level of compaction of each of the asphalt pavement layers was recorded using the Intelligent Asphalt Compaction Analyzer (IACA) at an Interstate Highway (I-35) in Norman, Oklahoma, USA. The collected IACA data allow determination of the level of compaction (density) at any selected location, for each layer. Considering the IACA estimated density, dynamic modulus of each of the selected locations for an individual pavement layer was measured from laboratory developed master curves. Thereafter, effective modulus of the three layer pavement system was calculated for all of the selected locations using Odemark's method. The proposed technique was verified by conducting FWD tests at these selected locations. Analyses of the results show that the proposed intelligent compaction technique may be promising in estimating the effective modulus of the pavement layers in a non-destructive manner.

INTRODUCTION

Quality Assurance procedures that are commonly used during the construction of asphalt pavements require extraction of roadway cores from the finished pavement and may additionally require several measurements using a point-wise density measurement tool such as a Nuclear Density Gauge (Zambrano et al., 2006). While the density measured from the cores provide an accurate indication of quality, these tests are destructive in nature and a source of some of the performance issues, such as potholes that reduce the useful life of pavement (Maupin, 2007). In addition, any quality issues that are identified during this process cannot be easily rectified after the pavement has cooled down. Spot tests using nuclear or non-nuclear density gauges provide a quick measurement of the level of compaction, but have inherent limitations that reduce their effectiveness as QA methods. Furthermore, the above QA methods are time-consuming to perform and are only helpful in determining the density of pavement layer at discrete number of points (Maupin, 2007).

The complexity of asphalt pavement compaction and the limitations of the spot tests have led researchers to develop advanced compaction technologies for improving the as-built quality of the pavements (Zambrano et al., 2006). Intelligent Compaction (IC) is a promising technology that can improve the quality of the road being constructed while reducing the associated cost and adverse environmental impacts. It provides a real-time complete coverage of the compaction area, and also reduces compaction costs resulting in significant overall construction cost saving (Maupin, 2007; Zambrano et al., 2006; Singh et al., 2011; Commuri et al., 2009a, 2009b). As a result, several agencies in the United States have launched programs to evaluate different technologies and determine the maturity of such technologies for implementation.

In this paper, a procedure to estimate effective modulus of pavements during construction is demonstrated. Given a location on the pavement, the estimated modulus of each layer is used to determine the effective modulus of the combined pavement layers. The estimated modulus at the selected location is then verified through FWD measurements.

INTELLIGENT ASPHALT COMPACTION ANALYZER (IACA)

The IACA functions on the hypothesis that the vibratory roller and the underlying pavement layers form a coupled system (Singh et al., 2011; Commuri et al., 2009a, 2009b). The response of the roller is determined by the frequency of its vibratory motors and the natural vibratory modes of the coupled system. Compaction of a pavement increases its stiffness and as a consequence, the vibrations of the compactor are altered. The knowledge of the properties of the mat and the vibration spectra of the compactor can, therefore, be used to estimate compacted modulus of the mat. The detailed information on IACA can be found elsewhere (Singh et al., 2011; Commuri et al., 2009a, 2009b).

Training IACA to Estimate the Level of Compaction

The IACA has to be trained and calibrated prior to its use to determine the compaction levels achieved. For that purpose, a 10 meter long control strip is constructed first. The vibrations of the roller are measured using an accelerometer mounted on the axle of the drum. The power content in the vibration signals during each roller pass is then calculated, and the lowest and the highest power levels are determined (Singh et al., 2011; Commuri et al., 2009a, 2009b). Five equally spaced power levels between the lowest and the highest power levels are identified and the features corresponding to these five power levels are used to train the ANN

Calibrating IACA to Measure Modulus

After the IACA is trained to classify the vibrations into different levels of compaction, it is calibrated to reflect the modulus of pavement layer after construction. In order to accomplish this, dynamic modulus tests for the mix used in the construction of the asphalt mat are performed according to the AASHTO TP 62-03 test method. From the master curves, the modulus value (M_T) at the target density of the compacted mix (from the mix design sheet) is noted at selected temperature and frequency. This modulus value is assumed to be the highest modulus that can be achieved during the compaction of pavement. Likewise, the lowest modulus value observed, (M_{ld}), is assumed to correspond to the lay down density of the asphalt mat at same temperature and frequency. The modulus estimated by the ANN model, (M^i_{NN}), at location P_i $(i = 1,..,n)$, is then approximated as a linear relationship between stiffness of pavement and the observed levels of vibration.

$$M^i_{NN} = M_{ld} + k \times l^i_{NN} + off. \tag{2}$$

where, M^i_{NN} = modulus estimated by the neural network, k = slope, off = offset, and l^i_{NN} = compaction level estimated by the neural network. The initial slope is assumed to be equal to $(M_T - M_{ld})/$(number of compaction levels), and the initial offset is set to zero. All the modulus values that are used during calibration (M_T and M_{ld}) correspond to the standard temperature and frequency at which FWD measurements are provided (21C and 5Hz). Therefore M^i_{NN} or the IACA estimated modulus value is at 21^{o}C and 5 Hz. It should be noted that the determination of the highest and lowest modulus values that can be achieved during the compaction of pavement for calibration purposes can be done through alternative methods. The modulus estimated by the IACA after the initial calibration is based on the assumption that the target modulus for the specified mix is indeed achieved during the compaction in the field. However, several factors such as the compaction equipment, rolling pattern, lay-down temperature of the mix, lift thickness, etc., influence the actual modulus of pavement at any given location. In order to account for these deviations, measurements are taken using a FWD on the compacted pavement and the slope and offset in Eq. (2) are recalculated to minimize the error between the estimated and measured values. If the modulus measured at location P_i is represented by M^i_{FWD}, then the measurement error is given by e_i and can be calculated as

$$e_i = M^i_{NN} - M^i_{FWD} = M_{ld} + k \times l^i_{NN} + off - M^i_{FWD}. \tag{3}$$

Minimizing the mean square error (MSE), one obtains the desired slope '*k*'.

$$k = \frac{\sum_{i=1}^{n}\left[\left(M^i_{FWD} - M^i_{ld} - off\right) \times l^i_{NN}\right]}{\sum_{i=1}^{n}\left(M^i_{NN}\right)^2} \tag{4}$$

The new offset is calculated as the mean error between the estimated and the measured stiffness, that is

$$off = \frac{1}{n}\sum_{i=1}^{n}\left(M^i_{FWD} - M^i_{NN}\right) \tag{5}$$

It should be noted that the M^{i}_{FWD} values are obtained from the calibration stretch.

FIELD TESTING AND VELIDAITON

Material Collection and Sample Preparation

The ability of the IACA in estimating the dynamic modulus of a multi-layer HMA pavement was investigated during the construction of Interstate I-35 in Norman, OK. This project involved the expansion of the existing highway, stabilizing the subgrade to a depth of 200 mm using 10% cement kiln dust (CKD), followed by 200 mm thick aggregate base. The base layer was consisted of 100 mm thick asphalt layers of 19 mm Nominal Maximum Aggregate Size (NMAS) S3 (64-22 OK), while 2nd and 3rd layers were constructed with 19 mm NMAS S3 (76-28 OK) consisted of 100 mm and 75 mm thickness, respectively. The gradations of all HMA mixes are given in Table 1. Three replicates of specimens with 100 mm in diameter by 150 mm in height were prepared at 6, 8, 10, and 12% ±1% target air voids levels using a Superpave Gyratory Compactor (SGC).

Table 1 Aggregate Gradations

Material (%)	Base Layer	2nd and 3rd Layer
25 mm Rock	20	22
Manufactured Sand	44	50
Sand	11	13
RAP	25	15
Sieve Size (mm)	Gradation (% Passing)	
25	100	100
19	98	98
12.5	87	87
9.5	80	80
4.75	58	62
2.36	37	40
1.18	25	27
0.6	19	20
0.3	12	12
0.15	4	5
0.075	2.9	2.8

Dynamic Modulus Testing and Master Curves

Dynamic modulus was measured for all collected mixes at four different air voids: 6%, 8%, 10%, and 12%. The wide range of air voids were selected to capture variation in the compaction quality during the construction of a pavement in the field. Two linear variable differential transducer (LVDTs) were mounted on the specimen. The test was run on each test specimen at four different temperatures, namely, 4, 21, 40, and 55^{o}C and six different frequencies namely, 25 , 10, 5, 1, 0.5, 0.1 Hz. The data was recorded for the last 5 cycles of each sequence. Dynamic modulus tests were performed according to the AASHTO TP62-03.

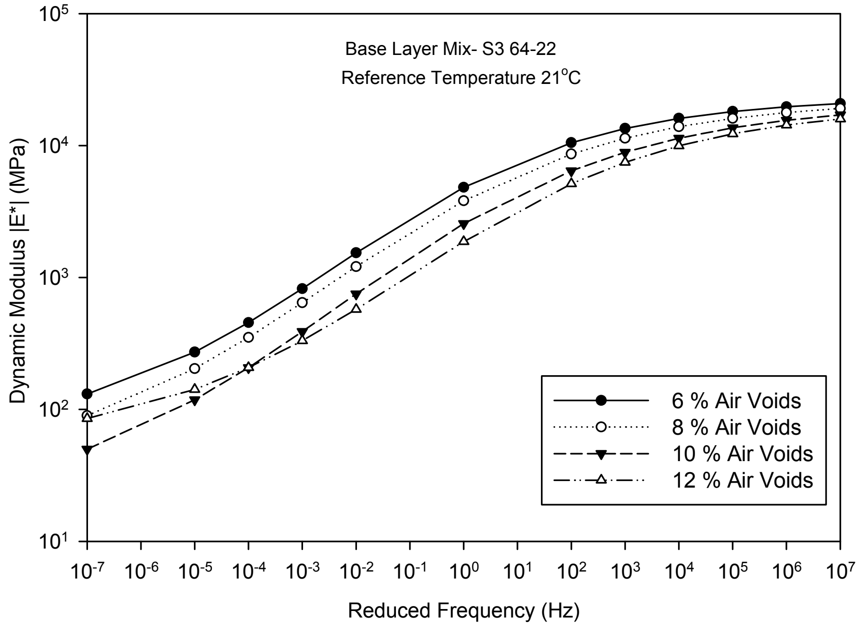

Figure 1 Master Curves for Base Layer Mixes (S3 64-22)

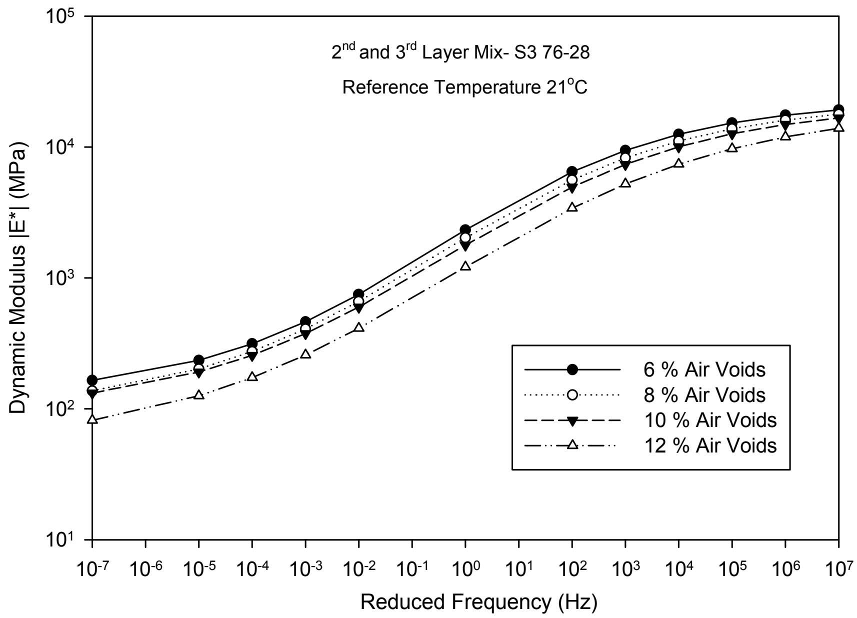

Figure 1 Master Curves for 2nd and 3rd Layers Mixes (S3 76-28)

The master curve is generated at a reference temperature of 21°C using the procedure outlined in Bonaquist et al. (2005). The constructed master curves for base, 2nd, and 3rd layers mixes are shown in Figure 1 and Figure 2, respectively. It can be seen from these figures that dynamic modulus decreases as air voids increases.

RESULTS AND DISCUSSION

Estimating Dynamic Modulus of each Pavement Layer

A validation section, approximately 150 meters in length, was selected and seven test locations, approximately 20 meters apart, were marked in the middle of the lane for verification analysis. The IACA was used to collect the GPS data and the density readings during the compaction of the all three layers (base, 2nd, and 3rd layers). First, the test points were marked on base layer, and the IACA data was collected. The GPS location of these points was recorded to locate these test locations on each pavement layer. Similar points were marked on 2nd and 3rd layers and the IACA data was collected during the compaction of each of these layers. Considering the IACA estimated density, dynamic modulus of each of the selected locations for an individual pavement layer was measured from laboratory developed master curves.

Estimating Effective Modulus of Pavement Layers

Odemark method was used to transform a system consisting of layers with different moduli into an equivalent system where the thicknesses of the layers are altered but all layers have the same modulus. The transformation assumes that the stiffness of the layer remains the same, i.e. I x E / $(1 - \mu^2)$ remains constant where I = moment of inertia; E = layer modulus; and μ= Poisson ratio (Odemark, 1949; Ullidtz, 1998). This approach is used in the present paper to calculate the effective modulus of the three layers that constitute the pavement on I-35. The effective modulus ($E_{effective}$) of three layers of pavement was calculated using Equation 6. The effective moduli were calculated at 21°C and 5 Hz frequency. The similar approach was used by several other researchers to find the effective modulus for layered system of pavement (Loulizi et al., 2007; Shalaby et al., 2004).

$$E_{effective} = \left[\frac{C_2\left(C_1 h_1 \sqrt[3]{E_1} + h_2 \sqrt[3]{E_2}\right) + h_3 \sqrt[3]{E_3}}{h_1 + h_2 + h_3}\right]^3 \tag{6}$$

where E_1, E_2 and E_3 are dynamic modulus of 3rd (top layer), 2nd, and base layer, and h_1, h_2, and h_3 are the thickness of respective layers. C_1, and C_2 are the correction factors to obtain better agreement with exact theory of elasticity (Ullidtz, 1998). The value of correction factors depend on the layer thicknesses, modular ratios, Poisson ratios and the number of layers in pavement structure. In the present study correction factors were taken as C_1 =1 while C_2 =0.8.

Verification of Effective Modulus

A verification of the IACA measured modulus (effective modulus using Odemark method) was done by conducting FWD testing on seven test locations that were marked before for estimating density using the IACA. In the present study the FWD test was conducted on 3rd layer of pavement using a Dynatest FWD test system. The backcalculated modulus is often called the effective modulus because the value represents the effect of the layer within the whole pavement structure. The effective modulus was calculated at 21°C to compare this modulus with laboratory measured effective dynamic modulus. Since, the FWD loading induces a pulse of duration of 0.03 s (Loulizi et al., 2002), which is equivalent to a test frequency of 5.3 Hz (1/0.03/2π), hence, the comparisons in this paper are performed using modulus values calculated at 21°C and 5 Hz frequency. It can be seen from Figure 3 that the ratio between FWD to IACA effective modulus is close to 1, indicating that proposed approach is capable of measuring effective modulus of a multi-layer pavement system. However, the FWD readings show about 30% variation in the measured modulus for locations with identical density. Such reduction in the modulus values at certain locations might be due to variation in the subgrade, thickness of each layer, and inconsistency in the mix (Gedafa et al., 2010).Therefore, the error between the measured and estimated modulus is within the range of the measurement accuracy of the FWD device. However, future validation must be done to further validate this approach by doing testing on different types of pavement (considering different thickness, mix type).

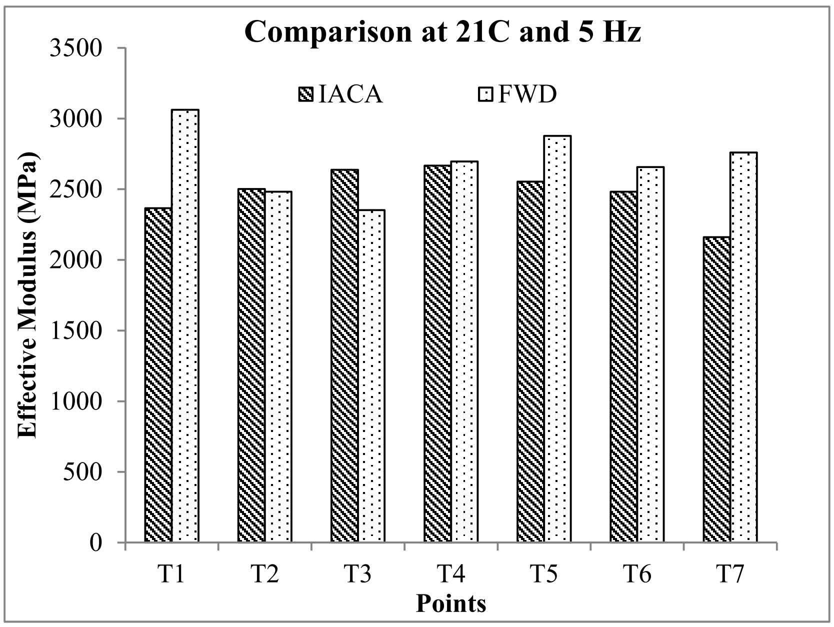

Figure 2 Comparison of Effective Modulus and FWD Modulus

CONCLUDING REMARKS

The following conclusions can be drawn based on the results and discussion presented in the paper.

- IACA estimated real-time density can be converted into the stiffness using master curves, and IACA can provide the stiffness values over the entire pavement in a non-destructive manner. The proposed approach was validated using FWD.

- Comparison of IACA effective modulus with FWD modulus indicated that proposed technique can estimate the effective modulus of the pavement layers in real time during the construction process.

Research is currently underway to validate the performance of the IACA during the compaction of Warm Mix Asphalt pavements and during the compaction of stabilized soil subgrades.

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Research of the Evaluation Indicators and Methods of Asphalt Pavement Surface Segregation Based on Six Sigma

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ABSTRACT: Adopting six sigma theories as the theoretical basis, this paper starts with the improvement of the quality inspection standards and then puts forward the six sigma standard of asphalt pavement construction quality inspection based on the surface segregation and the evaluation methods and steps of six sigma standard of the depth of the surface structure based on normal distribution. Finally, the evaluation index and method of asphalt pavement surface segregation based on six sigma are established.

Key Words: asphalt pavement; six sigma; surface segregation; the depth of the surface structure; quality inspection standards

INTRODUCTION

With the rapid development of the expressway, the quality defects of asphalt pavement occur frequently, and the quality problems of poor durability are appeared. On the other hand, with the improvement of people's living standard, people's requirements to the driving comfort are becoming higher and higher. According to the definition of construction quality [1], pavement durability and comfort can not meet the people's requirements, which illustrate that the asphalt pavement construction exists quality defects. Reducing the construction quality defects and improving the satisfaction on pavement comfort largely depend on raising the level of construction management. Six sigma is in the pursuit of "zero defect" perfect quality and is to improve customer satisfaction as the core target management philosophy, which reflects the high level of management [2]. The rapid development of lean manufacturing in engineering industry and constantly improvement of the levels of construction of mechanization and technology also provide the good external condition for the implementation of six sigma in the engineering field.