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IMPLEMENTATION OF SEISMIC-BASED QUALITY MANAGEMENT OF FLEXIBLE PAVEMENTS

By

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Research Report 5-1735-01-1

**Performed in Cooperation with the
Texas Department of Transportation and
The Federal Highway Administration**

Research Project 5-1735-01

**Quality Management of ACP and Base Using
Project 1735 Findings**

February 2006

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ABSTRACT

Under this project several field protocols and test equipment, which in a rational manner, combine the results from laboratory and field tests with those used for quality control during construction, are evaluated by TxDOT personnel with the assistance of UTEP. The significance of the protocols is more rational methods for quality control during construction, at the same time, feedback to the pavement design engineer can be provided in terms of the assumption made to design the pavement. The protocols proposed provide the first step towards developing performance-based specifications.

This report contains the results of the implementation of the devices in the day-to-day operation of TxDOT by TxDOT personnel. Based on the feedback and modifications done to the protocols, the methods are quite feasible for implementation

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CHAPTER ONE – INTRODUCTION

Aside from traffic and environmental loading, the primary parameters that affect the performance of a flexible pavement section are the modulus of each layer. Current TxDOT procedure for structural design of flexible pavements considers these parameters. The state-of-the-art equipment to perform laboratory resilient modulus tests on AC, base and subgrade materials have also been acquired. TxDOT can perform nondestructive field tests to estimate the in-place moduli of different layers. Unfortunately, the construction specifications and acceptance criterion are not based on the same engineering properties. The acceptance criteria are typically based on adequate thickness, and adequate density of the placed and compacted materials. To successfully implement any mechanistic pavement design procedure and to move toward performance-based specifications, it is essential to implement tools that can measure the modulus of each layer in the field.

The primary goal of this project has been to implement field test protocols and equipment, which in a rational manner, combine the results from laboratory and field tests with those used for quality control during construction. A series of simplified laboratory tests that are compatible with the field tests have been evaluated. All these tests have several features in common. They can be performed rapidly (less than three minutes), they are inexpensive and their data reduction processes are simple and almost instantaneous. These technologies have been evaluated by TxDOT personnel in the last three years.

The significance of this project is evident. These types of tests are one of the major components needed to develop a mechanistic pavement design and performance-based construction specifications. A gradual transition from the existing specifications to performance-based specifications has been recommended. Performing the simplified laboratory and field tests on pavement materials will allow us to develop a database that can be used to smoothly unify the design procedures and construction quality control.

The report consists of four chapters. A brief description of each device and method is included in Chapter 2. The tasks achieved during this project are summarized in Chapter 3. Summary and conclusions are described in Chapter 4.

CHAPTER TWO – SUMMARY OF OVERALL PROTOCOL

The proposed quality management procedure consists of four steps. The first step consists of selecting the most suitable material or mix for a given project. The second step is dedicated to determining the variation in modulus with the primary parameter of interest and determining the target modulus. For base and subgrade materials, this step may consist of developing a moisture-modulus curve (similar to moisture-density curve). For a particular hot mix asphalt (HMA) mixture, this step may consist of developing air voids-modulus curve. In the third step, the variation in modulus with environmental factors is considered. For example, the variation in modulus with moisture of a base layer can be determined in the laboratory. In the case of a HMA layer, the variation in modulus with temperature is important. The fourth and final step is to compare the field modulus with the acceptable laboratory modulus.

Step 1: Selecting the Most Suitable Material

For the last century, the focus of the highway agencies has been towards placing the most durable pavement layers. Even though the durability of a material cannot be directly included in the structural design of a pavement, the durability definitely do impact the performance of that pavement. We cannot over-emphasize that the material selection should be based on the existing collective experience acquired by the highway community. The following steps, even though more quantitative, do not replace this knowledge.

Step 2: Selecting the Target Moduli

The modulus can be related to one of the primary construction parameters. For HMA materials, the modulus can be related to the compaction effort (i.e. air voids) similar to Figure 2.1a. The modulus corresponding to the air voids at placement (typically 8%), and the modulus at design air voids from the job mix formula (JMF, typically 4%) are selected. The modulus at placement is used by construction engineer for field quality control as described in Step 4. The modulus at the design air voids is used by the pavement engineer to determine the modulus that should be used in structural design.

For base and subgrade layers, this modulus can be determined by relating seismic modulus to moisture content. The specimens with different moisture contents prepared for moisture-density can be used to develop a moisture-modulus curve as shown in Figure 2.1b. The moisture content at which the maximum seismic modulus is obtained should be specified as the desired moisture content for construction.

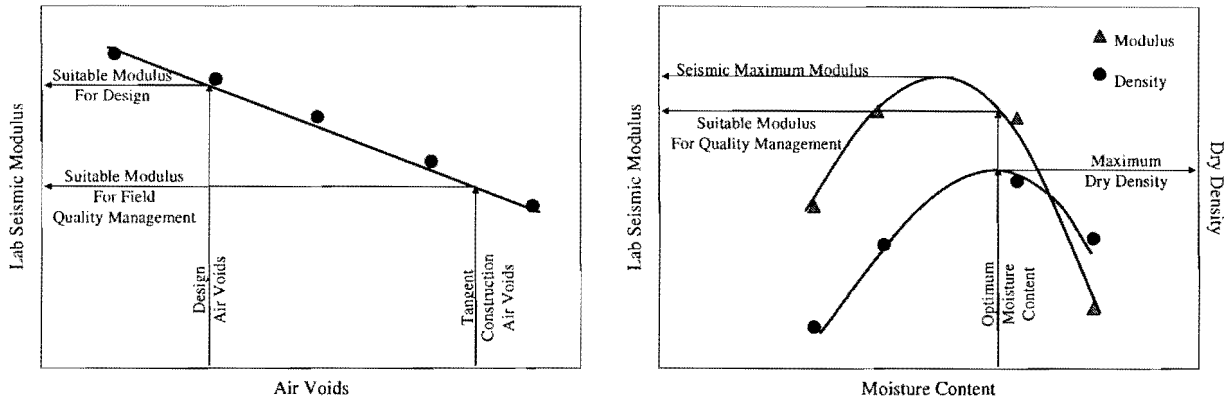


Figure 2.1 - Determining Target Moduli

Step 3: Characterizing the Variation in Modulus with Environmental Parameters

For HMA, the simplest way of relating modulus to temperature consists of preparing two specimens: one at the JMF air voids and another at the target placement air voids. These specimens are subjected to a sequence of temperatures. At the end of each temperature sequence, the specimens are tested with a seismic device. An example for the variations in modulus with temperature for one mixture is shown in Figure 2.2a.

Most base and subgrade materials may be exposed to different moisture regimes during their performance lives. A specimen is prepared at the optimum moisture content and placed in an oven normally used for moisture content specimens and dried for at least four days (the drying cycle) at 105°F (40°C). The specimen is weighed, and tested daily. The specimen is then placed in a pan filled with water for six days (wetting cycle). The gain in weight of the specimen and the change in modulus with time are monitored daily. By inspecting the change in modulus with moisture content, the behavior of the material can be judged (see Figure 2.2b).

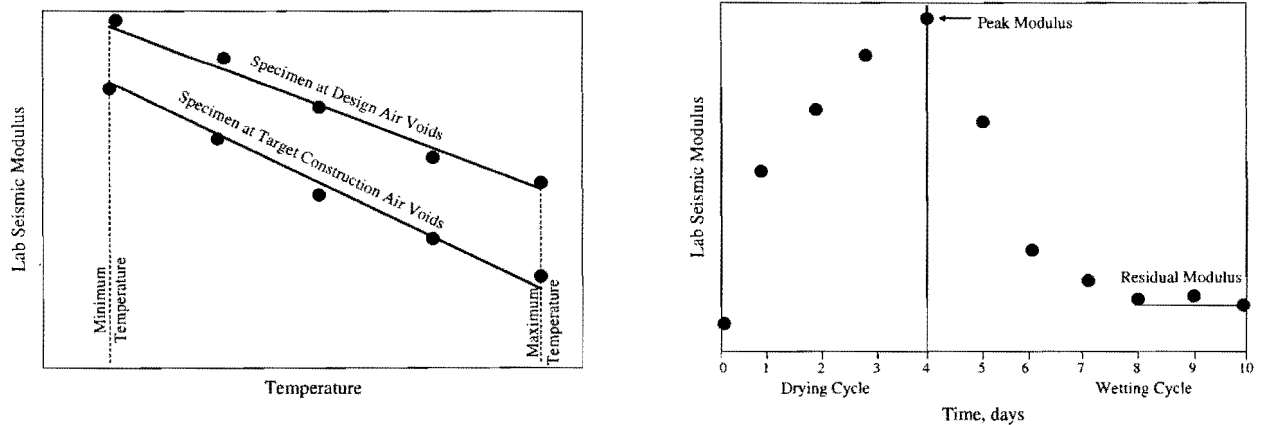


Figure 2.2 - Characterizing Variation in Modulus with Environmental Parameters

Step 4: Field Quality Control

Tests are carried out at regular intervals or at any point that the construction inspector suspects segregation, lack of compaction, or any other construction related anomalies. The field moduli

should be greater than the target laboratory seismic modulus determined at the placement air voids in Step 2.

Test Devices

The focus of the study has been on measuring moduli with four inter-related devices. Two of these devices are used in the laboratory: the free-free resonant column device for testing base and subgrade specimens and the ultrasonic device for testing HMA cores and molded specimens. The other two devices are the Portable Seismic Pavement Analyzer (PSPA) for testing HMA layers nondestructively in the field and a version of it that works on the base and prepared subgrade materials (affectionately called DSPA for Dirt Seismic Pavement Analyzer). Each device is described below.

Free-free Resonant Column Test

The free-free resonant column (FFRC) test is a simple laboratory test for determining the modulus of pavement materials (Figure 2.3). When a cylindrical specimen is subjected to an impulse load at one end, seismic energy over a large range of frequencies will propagate within the specimen. Depending on the dimensions and the stiffness of the specimen, energy associated with one or more frequencies are trapped and magnified (resonate) as they propagate within the specimen. The goal with this test is to determine these resonant frequencies. Since the dimensions of the specimen are known, if one can determine the frequency(ies) that are resonating (i.e. the resonant frequencies), one can readily determine the modulus of the specimen.

Ultrasonic Test Setup

The ultrasonic test methods were first used to evaluate the quality of concrete more than 50 years ago. The elastic modulus of a specimen is measured using a device containing a pulse generator and a timing circuit, coupled with piezoelectric transmitting and receiving transducers (Figure 2.4). The timing circuit digitally displays the time needed for a wave to travel through a specimen. Knowing the travel time, the dimensions and the mass of the specimen, the modulus can be readily calculated.

Portable Seismic Pavement Analyzer

The Portable Seismic Pavement Analyzer (PSPA), as shown in Figure 2.5, is a device designed to determine the average modulus of a concrete or asphalt layer in the field. The PSPA consists of two receivers and a source packaged into a hand-portable system, which can perform high frequency seismic tests. The device measures the velocity of propagation of surface waves that can be readily translated to a modulus. The PSPA has been modified so that it can be functional on base materials as well as prepared subgrade. This version of PSPA, which is affectionately called the Dirt SPA, DSPA, only differs in the source and some electronic components.

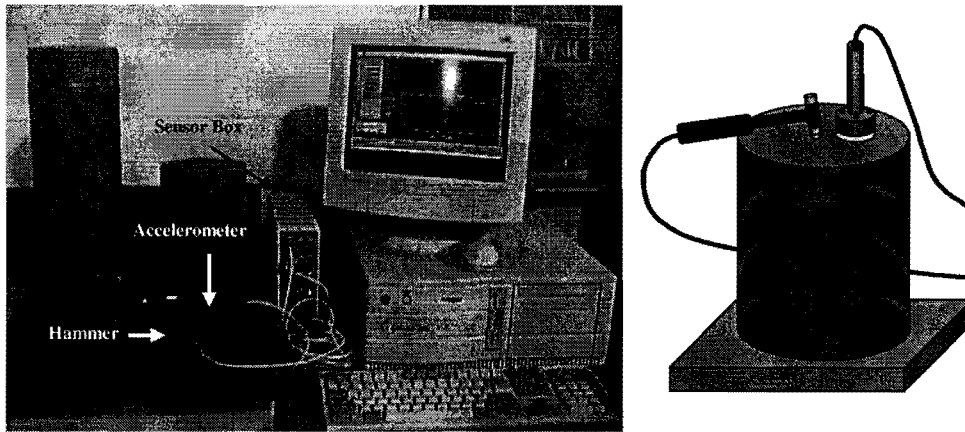


Figure 2.3 - Free-Free Resonant Column System

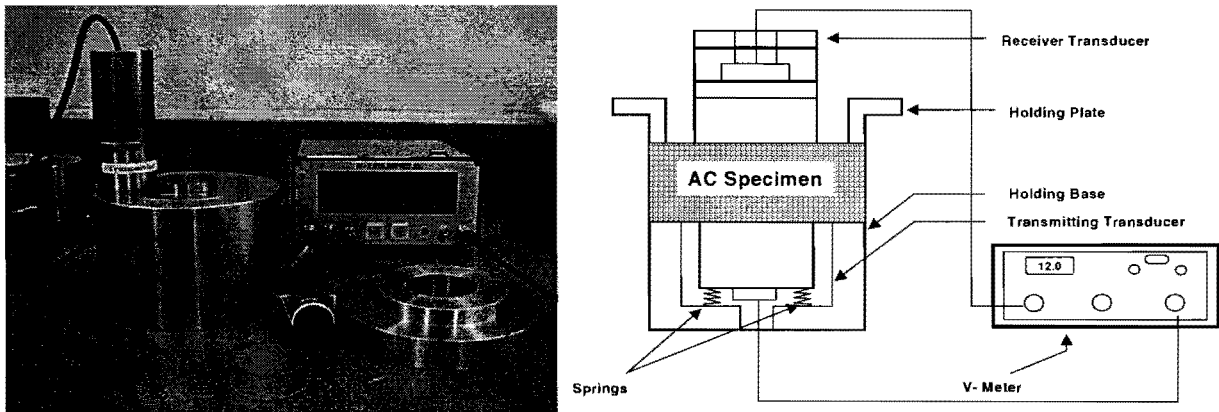


Figure 2.4 - Ultrasonic Testing System

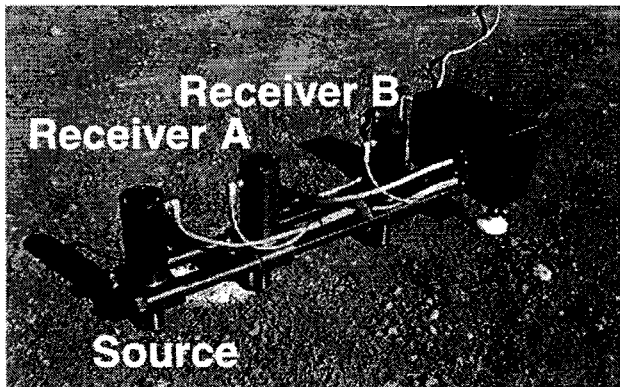


Figure 2.5 - Portable Seismic Pavement Analyzer

CHAPTER THREE – PRESENTATION OF RESULTS

The following tasks were associated with this project:

1. Develop a comprehensive short course and training course
2. Deliver at least four training courses
3. Assist TxDOT personnel to evaluate and modify procedures and test equipment to ensure their usefulness, user friendliness and versatility
4. Modify the equipment, protocols and software based on the outcome of the study
5. Compare the existing QC/QA results with the outcome of this method
6. Recommend the specifications

The activities carried out with each task are described below.

Developing a Comprehensive Short Course and Training Course

The activities associated with this task consisted of developing a DVD for training of TxDOT personnel, as well as training materials for a two-day-long hands-on training of district technicians. The DVD contains the step-by-step procedures for assembling and testing of the specimens. The pertinent section for each device can also be copied on the laptop computer used for tests, so that the occasional user can refresh his/her understanding of the procedures.

Delivering Training Courses

Four two-day long training sessions were delivered to TxDOT personnel in Fort Worth, Atlanta, Odessa and El Paso districts, as well as one in Austin for the Construction Division staff. The reaction from the technicians and engineers attended the training course was that the combination of the training DVD and the training course were adequate to conduct the tests with some level of confidence.

Assisting TxDOT Personnel to Evaluate and Modify Procedures

Feedback from the technicians and engineers involved in this project after some hands-on experience was used to make several changes to the software and hardware. Generally, the users were happy with the ease of use, test flow and the interpretation of the results. However, requests for improvements in three areas were requested.

First, a series of excel work sheets were developed to simplify the reporting and presentation of the results. In these worksheets the results from different devices are cut and pasted so that the graphs shown in Chapter 2 could be readily obtained and relevant information could be obtained. An example is included in Figure 3.1 for testing HMA specimens and for relating the modulus to air voids.

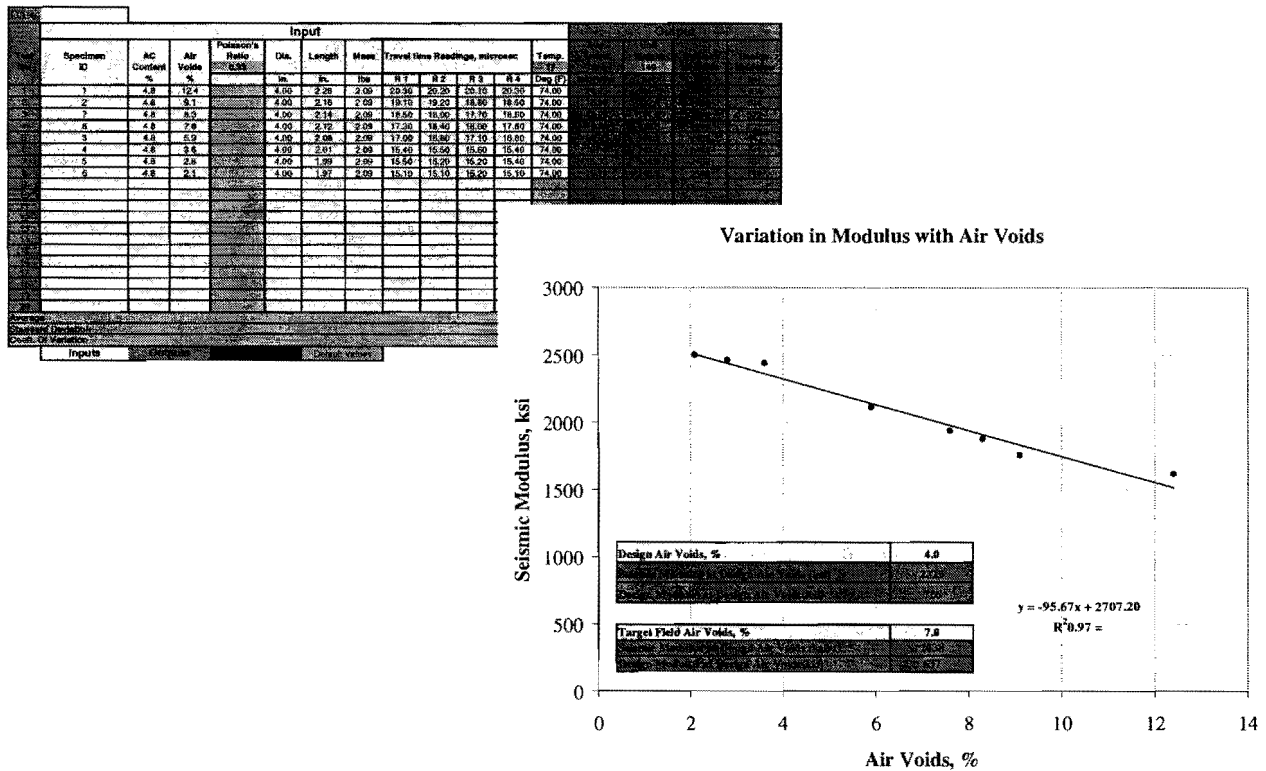


Figure 3.1 – Typical Worksheet for Developing Reports

The second improvement consists of developing a more convenient receiver for the free-free resonant column tests. Based on the initial tests by staff of the Construction Division, a more convenient way of placing the sensors on the specimens was developed. The new source can be placed with a uniform pressure on the specimen, minimizing the technician-dependency of the results.

The third modification consisted of improving the PSPA software to alert the users about the seating of the equipment and the quality of the interpretation of the results. Two sets of green-yellow-red indicators were added to the software so that the user could easily be warned about the quality of the placement and interpretation of the results.

Comparing Existing QC/QA Results with Outcome of Seismic Method

The personnel from three districts and the Construction Division as well as UTEP were involved in this task. More than a dozen sites were tested for this purpose. The materials covered consisted from clayey and sandy subgrade and embankment materials to about half-dozen different base materials and several HMA layers.

Tests were generally carried out after the materials were accepted under the current TxDOT specifications. Typical results from a reclaimed base tested by the Odessa district are presented

in Figure 3.2. All points passed the density tests. However, the moduli vary significantly. Up to Station 307+00, moduli generally exceed the target modulus shown by the solid line. Passed that station, the moduli are generally less than the target modulus. A sample obtained from materials Between Stations 307+00 and 384+00 was retested in the laboratory. The target modulus for that region is significantly lower than the rest of the section, as reflected in the figure.

Figure 3.3 contains the results from tests on an embankment carried out by the El Paso District. The target relative density was about 90%. The measured moduli are significantly lower than the target modulus throughout the project.

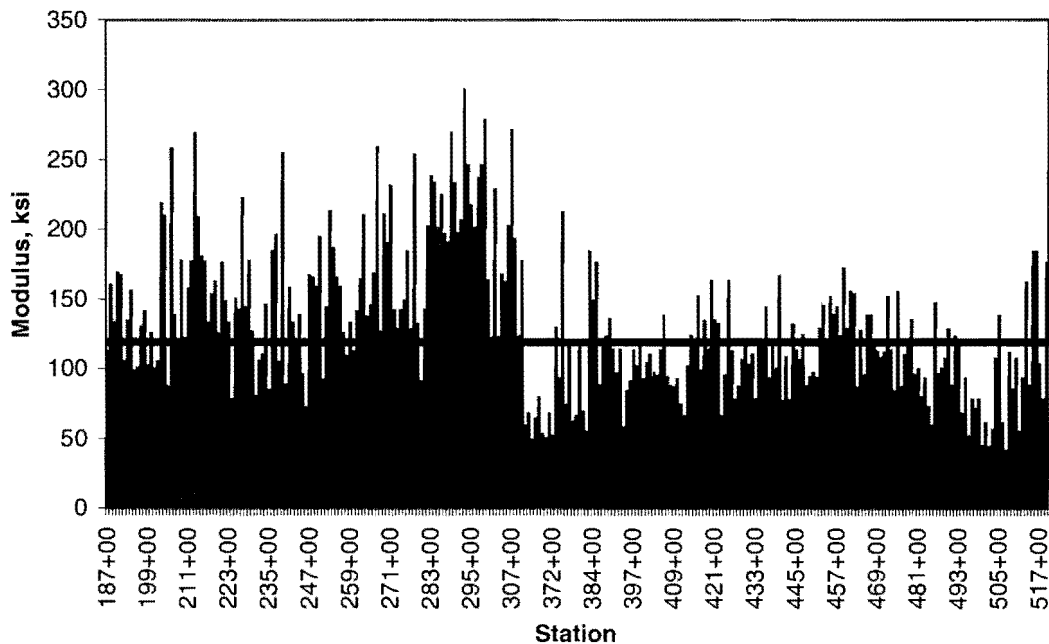


Figure 3.2 – Example Quality Management with Seismic Method on a Base from Odessa

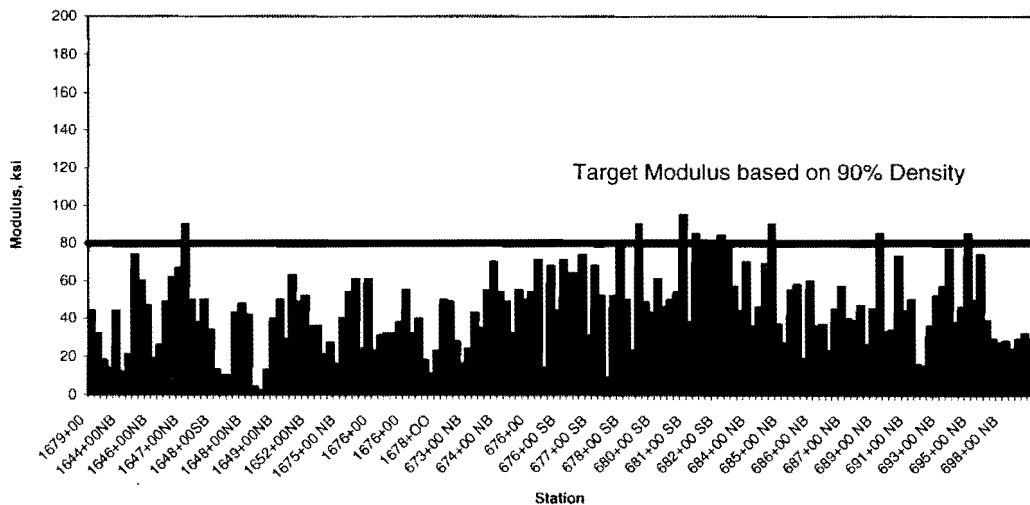


Figure 3.3 - Example Quality Management with Seismic Method on an Embankment from El Paso

Finally Figure 3.4 is an example of the quality management carried out by the Atlanta District. There is a good correlation between the relative density and the seismic moduli measured at the site.

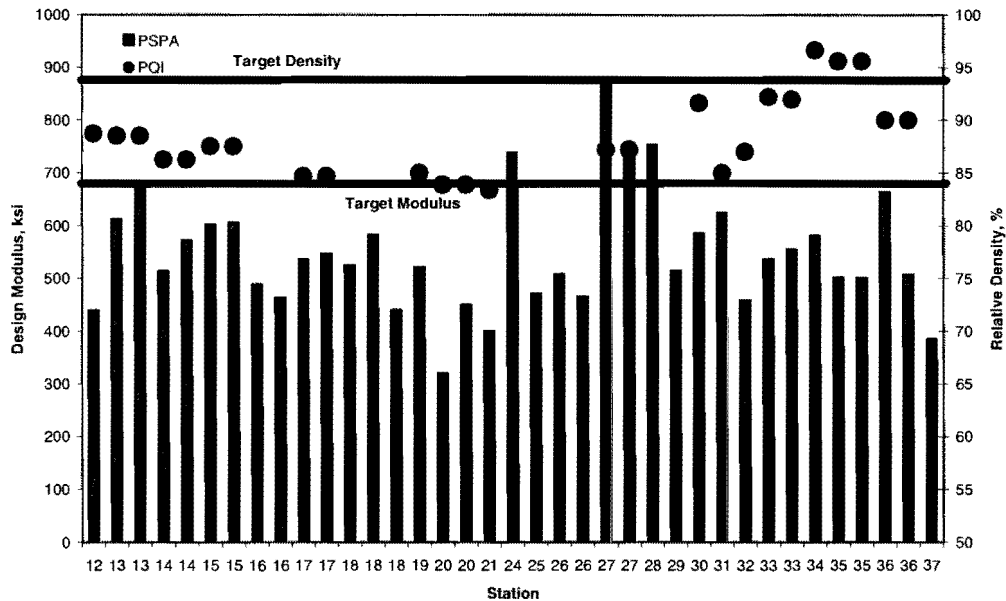


Figure 3.4 - Example Quality Management with Seismic Method on an HMA from Atlanta

In general, it was found that in a number of cases, even though the densities were adequate, the moduli varied significantly. In some cases, the moduli were below the desired values.

Recommend Specifications

A comprehensive set of test procedures and preliminary specifications have been developed and delivered to TxDOT. In close collaboration with Construction Division, these procedures and specifications are being finalized.

CHAPTER FOUR – SUMMARY

Under this project several field protocols and test equipment, which in a rational manner, combine the results from laboratory and field tests with those used for quality control during construction, are evaluated by TxDOT personnel with the assistance of UTEP. The significance of the protocols is more rational methods for quality control during construction, at the same time, feedback to the pavement design engineer can be provided in terms of the assumption made to design the pavement. The protocols proposed provide the first step towards developing performance-based specifications.

This report contains the results of the implementation of the devices in the day-to-day operation of TxDOT by TxDOT personnel. Based on the feedback and modifications done to the protocols, the methods are quite feasible for further implementation