Pavement Technology Project in Thailand

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Preface .......................................................................................................................... 5

Summary ...................................................................................................................... 6

1. Introduction ............................................................................................................ 7

2. Field and Laboratory Testing ............................................................................... 10
   2.1 Asphalt Concrete properties determined from Laboratory Testing ................. 10
       2.1.1 Repeated Load Indirect Tensile Testing ................................................... 10
       2.1.2 Resilient Modulus Testing ........................................................................ 10
       2.1.3 Fatigue Testing ......................................................................................... 10
   2.2 Asphalt Concrete properties from Non-destructive Field Testing ..................... 11
       2.2.1 Falling Weight Deflectometer (FWD) Testing......................................... 11
       2.2.2 Backcalculation Analysis ......................................................................... 11
       2.2.3 Comparison of Empirical and Analytical Design methods ...................... 11

3. Implementation of FWD Technology and Analytical Pavement Design .......... 12
   3.1 The overall objectives of the project ................................................................. 13
   3.2 Research Topics ................................................................................................. 14

4. Technical Reports from the Pavement Technology Project ............................... 16

5. Acknowledgements ................................................................................................. 17

6. References .............................................................................................................. 18
Within the last few decades a swell of international research interest and movement has grown and quickened towards partial and full implementation of analytical (also known as mechanistic-empirical) procedures for determining the existing strength (bearing capacity) of road pavements, for analysing and designing new road pavements and for rehabilitating existing road pavements. Failure of road pavements is often indicated by cracking of the asphaltic surfacing due to excessive stresses induced by traffic loading that may not be accompanied by permanent deformation or loss of shape. An indication of the stresses developed in road pavement layers may therefore be obtained from the curvature and elastic deflections of the road surface beneath the loaded dual wheels of a truck or under dynamic applied loads that closely simulate truck tyre loading. Two common field-testing procedures employed for measuring these curvatures and deflections are the Benkelman Beam (BB) test and the Falling Weight Deflectometer (FWD) test. Benkelman Beam surveys have been carried out over 25 years in Thailand; however, the introduction and implementation of FWD technology and analytical pavement analysis and design methods are the primary technological objectives of this Project.
Summary

Thailand is characterised by rapid economic development, which has brought with it some major road infrastructure problems. To address these issues, between 1999 and 2001, the Department of Highways (DOH), Thailand, undertook the three-year Pavement Technology Project (PTP), with assistance from the Danish Road Directorate (DRD), Ministry of Transport, Denmark. The main objectives of the project for evaluating the structural condition of flexible pavements, were introducing and implementing Falling Weight Deflectometer (FWD) technology and Analytical Pavement Design in Thailand.

The Department of Highways is responsible for monitoring the condition of the nation’s primary road network of approx. 60,000 km. One technical issue tackled was that for more than 25 years, determination of the strength of existing flexible road structures and overlay design has been based on Benkelman Beam testing, which is no longer suitable for the heavily trafficked highways of Thailand. A second issue is that since the traffic volumes and gross vehicle weights of heavy transport vehicles on many major roads in Thailand now exceed the limits of the current national flexible pavement design method, a new analytical design method suited to the climatic and traffic conditions in Thailand is urgently required.

The overall objectives of the Project were: to increase pavement evaluation measurement efficiency; to extend pavement evaluation measurements to include heavily trafficked highways; to reduce pavement maintenance costs; to reduce pavement evaluation team size and to improve their safety during testing; to introduce and develop an analytical pavement design method for overlays and new roads; to monitor road surface roughness; to introduce advanced modern technologies to road sector management; and to research and prepare reports that will form a basis for a future design method and for determining the structural maintenance requirements of the national road network.
1. Introduction

Within the last few decades there has been a strong swell of international research interest and a movement in many countries towards partial and full implementation of analytical (also known as mechanistic-empirical) procedures for determining the existing strength (bearing capacity) of road pavements, for analysing and designing the pavements of new roads and for rehabilitating existing road pavements.

The Pavement Technology Project (PTP) in Thailand was a three-year research project undertaken jointly by the Department of Highways and the Danish Road Directorate that commenced in 1999. The project had the overall objective of reducing the maintenance costs on the national road network by implementing Falling Weight Deflectometer Technology and developing and implementing analytical pavement analysis and design methods, based on pavement performance and by determining the structural properties of the road pavement materials tested in existing road pavements and in laboratory investigations.

During the last fifteen years, Falling Weight Deflectometers (FWD) and the measurements made using this type of non-destructive testing equipment have gained their own place in pavement management. A technology that was originally developed for scientific research has now become a fully developed tool utilised for general pavement evaluation, and, subsequently, used in pavement management systems. Falling Weight Deflectometers (FWD) are now used to test the bearing capacity of individual roads and road networks as part of routine road management practices in many countries.

Figure 1. Five Falling Weight Deflectometers (Dynatext model 8000) and towing vehicles supplied to the DOH.
Failure of flexible road pavements is often indicated by cracking of the asphaltic surfacing due to excessive stresses induced by traffic loading that may not be accompanied by permanent deformation or loss of shape. An indication of the stresses developed in road pavement layers may therefore be obtained from the curvatures and elastic deflections of the road surface beneath the loaded dual wheels of a truck or under dynamic applied loads that closely simulate truck tyre loading. Two common field-testing procedures employed for measuring these curvatures and deflections are the Benkelman Beam (BB) test and the Falling Weight Deflectometer (FWD) test. Benkelman Beam surveys have been carried out over a number of years in Thailand; however, implementation of FWD technology and introduction of analytical pavement analysis and design methods were the primary technological objectives of this Project. Bearing capacity evaluation of road pavements using FWDs is an analytically based method. The advantages compared with more empirical methods are that FWD analyses may be used on any type of material and structure, and under all climatic conditions, whereas empirical methods should only be used under those conditions for which the empirical relationships were originally developed.

Figure 2. Falling Weight Deflectometers on twin-axle trailers.
With Falling Weight Deflectometers, a falling mass induces, via a buffer system, a load on a circular loading plate positioned on the road surface. The falling mass, the drop height, and the buffer system, are selected to simulate the stresses produced in a pavement structure by a heavy truck travelling at 60 km/h. The peak impact force and the surface deflections at the centre and up to eight radial distances from the load centre are recorded. These measurements, combined with information on material characteristics, layer thicknesses, and test temperatures, enable computer calculations to be made of the stresses and strains within the pavement that would be induced in the layers from a standard axleload of, for example, 80 kN (8.2 tonne) at the specified design conditions.

The analytical method of calculating strengthening design is based on the concept that a pavement is composed of several, more-or-less linear-elastic layers. The stress and strain distributions under a wheel load in an infinite half-space of homogeneous isotropic elastic materials are defined by equations developed by J. Boussinesq in the 1870s. The analytical program, ELMOD, developed by Dynatest, utilises Boussinesq’s equations to calculate stresses and strains in each layer and to relate them to the critical stress and strain values that are appropriate for the pavement materials. Based on a specified design period and the estimated traffic volume for the design period, the program is then able to estimate the residual structural lifetime, and if required, the necessary overlay thickness at each measurement point.
2. Field and Laboratory Testing

Before introducing a new technology, it is necessary to adjust/calibrate the technology to local conditions. Calibration is necessary because pavement materials, pavement uniformity, climatic conditions, and subgrade properties are very different from one country to another. These were issues that were clarified by the Pavement Technology Project carried out by the Department of Highways, before routine testing of the bearing capacity of the national highway network could be commenced.

2.1 Asphalt Concrete properties determined from Laboratory Testing

To investigate the engineering properties of AC mixtures used, 75 existing road sections with varying ranges of properties (subgrade soil, pavement age, traffic volume, and asphalt surface thickness) distributed over five Regions of Thailand were selected as project test sections.

2.1.1 Repeated Load Indirect Tensile Testing

Five AC surfacing cores were bored from each test section. Two of the five cores were tested to obtain the Repeated Load Indirect Tensile (RLIT) strength at 25 °C. The remaining three cores were used in Resilient Modulus tests followed by Fatigue tests. The results from the Repeated Load Indirect Tensile Tests (RLITT) were used to specify the load levels to be used with other laboratory tests, such as the Resilient Modulus and Fatigue tests.

2.1.2 Resilient Modulus Testing

To investigate the range of the Resilient Moduli of AC mixtures used in road construction in Thailand, the Resilient Moduli of three cores from each test section were investigated. As Thailand is located in a hot climate zone, the values of the Resilient Moduli at high temperatures are of most concern. In the study, therefore, four test temperatures were specified: 15, 25, 35 and 45 °C. One core from each section was tested at 25 °C using the RLITT method to determine the maximum tensile strength of AC cores from each test section. The maximum tensile strength was then used to specify the stress levels for the Resilient Modulus tests. 20 %, 15 %, 10 % and 5 % of the maximum RLIT strength were used as the stress levels for the Resilient Modulus test conducted at 15, 25, 35 and 45 °C, respectively, in which only the horizontal deformations were measured. In the resulting analyses, a Poisson’s ratio of 0.35 for Asphalt Concrete was assumed to remain for the Resilient Modulus test at 15 and 25 °C, and 0.40 for the Resilient Modulus test at 35 and 45 °C. Each specimen was tested in two positions, 90 degrees apart. The load frequency was applied at 1.0 Hz with a load duration of 10 percent of each load cycle.

2.1.3 Fatigue Testing

After Resilient Modulus testing, the same specimens were used for RLIT and Fatigue testing. The objective of these tests was to evaluate the fatigue behaviour of Asphalt Concrete used in Thailand, in particular, the strain capacity in relation to the number
of loads applied. The tests were carried out at 25 °C in a constant stress mode using the RLITT configuration. Three stress levels: 0.25, 0.30 and 0.35 MPa, were used in this study. Failure was defined to be reached when the Resilient Modulus of each specimen dropped below 50 % of the initial Resilient Modulus value. The failure strains and the number of load repetitions to failure were measured and reported.

2.2 Asphalt Concrete properties from Non-destructive Field Testing

2.2.1 Falling Weight Deflectometer (FWD) Testing
Seventy-five test sections were tested both by Falling Weight Deflectometer, using a Dynatest FWD, and simultaneously by the Benkelman Beam equipment previously used routinely by the DOH. In addition, five of the 75 sections were selected for investigating the temperature-dependency of Asphalt Concrete E-modulus measured by FWD. The measurements were conducted at five successive test points, 25 metre apart, every hour from 8 a.m. to 16 p.m., to cover a wide range of daily temperatures. Before each FWD test, the Asphalt Concrete temperatures were measured at 50 mm depth below the surface. The FWD tests were performed using a test setup comprising three seating drops followed by four repeated drops at each of four increasing stress levels; the FWD surface stress levels applied were: 378 kPa, 566 kPa, 754 kPa and 1,006 kPa, corresponding to dual wheel axleloads of 52.4 kN, 80.0 kN, 106.6 kN and 142.2 kN. A Borescope (an instrument for viewing the sides of a 22 mm diameter hole bored in the pavement to a depth of about 650 mm) was used for determining the thicknesses of the pavement layers.

2.2.2 Backcalculation Analysis
FWD deflection data were analysed using the backcalculation program, ELMOD4, to calculate the layer E-moduli. ELMOD4 is a backcalculation program developed by Dynatest that was supplied with the FWDs. To improve the accuracy of the results for the AC E-moduli, the calculations were done twice. Firstly, the program’s curvature-fit option was used to obtain an approximate E-modulus and this value used as a start value (seed) for optimising the result of the backcalculation. ELMOD4’s backcalculation routine required data on the thicknesses of each pavement layer, which was available from Borescope field measurements and AC surfacing layer thicknesses determined from cores taken from each test section.

2.2.3 Comparison of Empirical and Analytical Design methods
For a period of 25 years preceding the PTP study, the DOH had been using an empirical design method that utilised field data from Benkelman Beam testing and was based on the Asphalt Institute’s Thickness Design method, including the added constraint of a Base layer thickness of 200 mm. Comparisons were made using the Method of Equivalent Thickness (MET) with materials models proposed by National Association of Australian State Road Authorities (NAASRA) and SHELL. It was found that the empirical design method results in relatively high total pavement, AC surfacing and Base layer thicknesses that are nearly independent of the traffic volume over the design lives of the roads considered.
3. Implementation of FWD Technology and Analytical Pavement Design

The Pavement Technology Project was the Danish Road Directorate’s (DRD) primary international assignment during 1999-2001. The “Implementation of Falling Weight Deflectometer Technology and Development of Analytical Pavement Design Project” was initialised by an agreement reached between the Department of Highways, Thailand, and the Danish Road Directorate in October 1998.

The overall objective of the project was to reduce the maintenance costs for the Thai national road network by implementing Falling Weight Deflectometer Technology and developing and implementing analytical (also known internationally as mechanistic-empirical) pavement analysis and design methods, based on pavement performance and elasticity modulus evaluation of pavement materials. To meet this objective, five FWDs and towing vehicles (which are the command centres for operating the FWDs) were supplied by Dynatest A/S (Denmark) to the DOH, Thailand (one FWD + towing vehicle unit was supplied in 1994 and four new units in 2000). Extensive technical assistance and training of Thai engineers, both in Denmark and in Thailand, was organised and provided by the Danish Road Directorate.

It was initially estimated that the project will reduce future pavement maintenance costs by as much as 20% due to improvements in the calculation methods that will be implemented for new pavement and overlay designs and because it will be possible to reduce current staffing levels by approximately 50%. Furthermore, by introducing FWDs for pavement evaluation and testing in place of Benkelman Beam procedures, the bearing capacity measurement efficiency will be increased by a minimum factor of 2 - 3 and the safety of the FWD crews during field operations will also be significantly improved.

By introducing this advanced pavement technology to the road sector in Thailand the research engineers of the DOH will also have the opportunity to carry out more advanced research in the fields of road pavement analysis and road construction materials.
3.1 The overall objectives of the project

- To increase the efficiency of pavement evaluation measurements.
- To extend pavement evaluation measurements to highways with high volumes of heavy traffic.
- To reduce pavement maintenance costs.
- To reduce staffing levels for pavement evaluation measurements.
- To improve the safety of the FWD testing teams.
- To develop an analytical pavement design method for overlays and new roads.
- To monitor longitudinal road surface roughness.
- To bring advanced modern pavement technologies into practical use in the road transport sector in Thailand.

The three-year research project commenced in January 1999; more specifically, the major components of the project during this period were:

- Tendered procurement and supply of four new FWDs (model 8000), manufactured by Dynatest A/S of Denmark, in addition to supplying and equipping four new towing units and supplying five sets of FWD operation and ELMOD4 backcalculation software (also by Dynatest).
- Upgrading the first FWD (a Dynatest FWD), in addition to upgrading the towing unit (both were supplied to DOH in 1994) to the same FWD control equipment standard as the new towing units.
- Commencing a three-year maintenance contract with Dynatest A/S for the five FWD units and control systems in the five towing vehicles.
- Training DOH staff (in Denmark and in Thailand). The training was provided jointly by technologists and academics from the Technical University of Denmark and the Danish Road Directorate.
- Optimising Dynatest FWDs for use in Thailand.
- Field testing, and field measurements of pavement characteristics.
- Evaluating the results of FWD testing of 75 selected road sections evenly distributed throughout five regions representative of the Thai road network.
- Introducing the Universal Asphalt Testing Machine UTM-5P and the SERVOPAC Gyratory Compactor, manufactured and supplied by Industrial
Process Controls (IPC) Ltd, Australia.

- Monitoring longitudinal road surface roughness, which is related to the bearing capacity of road pavements.
- Developing an analytical pavement analysis and design method for asphaltic (bituminous) overlays and new roads that is suited to Thai conditions.
- Providing Technical Assistance and guidance for a period of two and a half years.

3.2 Research Topics

In a meeting between DOH and DRD held in 1999, research topics were identified that would be undertaken during the project. For instance, one of the research topics identified was comparison of Benkelman Beam (BB) and FWD measurements, so that future FWD and historic BB measurement records can be interrelated and used in existing Pavement Maintenance and Management Systems (PMMS) and in the future development of such systems. Furthermore, the methods and procedures followed were documented for the benefit of the ongoing and continual monitoring of the Thai road network by the DOH. Historic and ongoing BB field surveying information would thereby complement backcalculated FWD test data collected by an extensive field program during the Project period. This data generated during the project was input into the re-engineered and updated database containing the pavement structure, construction and maintenance records set up in a relational database using Microsoft Access.

Identifying the research activities to be undertaken during the project period was therefore very important. It was anticipated that the following benefits would be achieved through the joint research activities carried out by DOH and DRD during the project period:

- Forming and training a study group that were provided with relevant information and literature concerning research into pavement materials, pavement analysis and design methods. The study group was also instructed about production and laying of road construction materials and road maintenance, to establish a uniform level of knowledge of analytical road pavement analysis and design procedures and an understanding of practical aspects of road construction.
- FWD testing to determine the relationships between temperatures and the E-moduli of asphaltic materials on selected flexible road test sections within the Thai road network.
- Researching methods of evaluating the bearing capacity of jointed concrete pavements using FWD technology.
- Assembly and calibration of the SERVOPAC Gyratory Compactor and UTM-5P equipment manufactured and supplied by IPC of Australia. Initiating a research
project into evaluation of the E-moduli of Asphalt Concrete (AC) in accordance with the Department of Highways (DOH) specifications. Evaluating cored specimens from selected road sections of different ages and levels of damage in order to determine E-moduli and Poisson’s ratios for the main types of asphaltic (bituminous) surfacing and bound and unbound granular materials used in Thailand.

- Introducing and developing analytical road pavement analysis and design methods for Thai road conditions.

- Initiating discussions with road maintenance officers in order to develop efficient and practical means of classification, ranking and costing of road defects and criteria for road rehabilitation and maintenance works using visual road condition descriptions.

Planning and organising several workshops and seminars for sharing the results and experiences from the road pavement research generated by the PTP project in Thailand, nationally and internationally.

Figure 4. The Universal Asphalt Testing Machine (UTM-5P) manufactured by IPC Ltd, Australia.
4. Technical Reports from the Pavement Technology Project

Eight Technical Reports and five Manuals, in addition to the Final Report, were prepared as part of the Project:

**Technical Report No. 1:** Temperature Correction of Asphalt Concrete Moduli from Falling Weight Deflectometer Measurements

**Technical Report No. 2:** Reproducibility and Repeatability of FWD Measurements

**Technical Report No. 3:** Impact of FWD Test Point Spacing on the Pavement Evaluation

**Technical Report No. 4:** Comparison between Pavement Evaluation using the Falling Weight Deflectometer and the Benkelman Beam

**Technical Report No. 5:** Feasibility Study for the Quality Control of Unbound Layers from FWD Testing during Construction

**Technical Report No. 6:** Evaluation of the Effect of Traffic and Seasonal Variations on the E-moduli of Pavement Layers

**Technical Report No. 7:** Measured E-moduli and Fatigue Properties of Asphalt Concrete from Laboratory Tests

**Technical Report No. 8:** Results from FWD measurements on Jointed Concrete Pavements

**Manual No. 1:** Performance Testing of Asphalt Concrete using the UTM-5P Test Machine

**Manual No. 2:** Operation, Service and Maintenance of FWD Equipment

**Manual No. 3:** Analytical Design of New Flexible Pavements in Thailand

**Manual No. 4:** Analytical Design of Overlays for Flexible Pavements in Thailand

**Manual No. 5:** Evaluation of Portland Cement Concrete Pavements using the Falling Weight Deflectometer

**Final Report:** Concluding report on the main results of the Project.
5. Acknowledgements

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Professor Dr. Per Ullidtz of the Technical University of Denmark is also acknowledged for his support and participation in the Project, both in Denmark and in Thailand.
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Danish Road Testing Machine RTM3: 1999
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(edited by: Gregers Hildebrand)
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