Use of NDT data for Predicting Pavement Deformation

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ABSTRACT: Permanent deformation is a serious distress in an asphalt pavement that can have a great impact on its structural condition and serviceability. Prediction of pavement deformation is a complex task due to the fact that it is affected by many factors, including environmental and traffic conditions, structural characteristics, etc. Proper prediction of deformation can anticipate pavement deterioration and may offer valuable information for maintenance purposes. Numerous models have been developed for pavement deformation prediction and amongst them the VESYS (Visco-Elastic SYStem) is a well-known and widely used model for the simulation of pavement behavior and the prediction of pavement damage. The present paper investigates an effective method to predict deformation depth while reducing the bias between predicted and real data. For this purpose a road experiment was conducted. During the experiment a pavement section was tested during two phases: a) shortly after its construction and b) one year later. Deformations are predicted for one year of traffic utilizing the VESYS tool and by using firstly a theoretical approach to pavement design and secondly an approach based on in-situ data collected after construction using Non-Destructive Methods. For both cases, the predicted deformation values are compared with respective real values measured with a Laser Profiler system. The comparison results produce evidence in support of the statement that in-situ NDT data could be used effectively for predicting pavement deformation.

KEY WORDS: pavements, permanent deformation, viscoelasticity, VESYS, NDT.

1 INTRODUCTION

Excessive permanent deformation and associated problems are of major importance for proper pavement management. Prediction of future pavement deformation is a countermeasure to the deformation problem and can elicit solutions for reducing the cost of road maintenance and the improvement of traffic safety. There have been multiple studies centered on the pavement deformation problem (e.g. Claessen et al. 1977, Southgate et al. 1977 and Thrower 1977) and a number of models have been developed for predicting future deformation (e.g. Barksdale 1972 and Romain 1972). A typical example of a permanent deformation study in flexible pavements lies in the Sousa et al. (1991) report. However, the procedures for the development of predictive models have remained stagnant in recent years. This may be due to the fact that prediction is a complicated task as the pavement deformation is affected by such a number of factors, including pavement materials properties, weather conditions, field moisture, loading etc. In fact, this complexity is beyond the predictability of many existing models and may result in bias between the predicted and the real deformation depth.

In view of the above, this paper investigates an effective way to predict deformation depth while reducing the bias between predicted and real data. For this purpose the VESYS (Visco-Elastic SYStem) tool (Kenis 1977 and 1978, Kenis et al. 1982), which is a well-known and widely used model for the simulation of pavement behavior and the prediction of pavement damage, is used. In order to "feed" the VESYS model with the appropriate parameters for the prediction, a road experiment was conducted. During this experiment a pavement section was tested in two phases: a) shortly after its construction and b) one year later. Deformations are predicted for one year traffic utilizing the VESYS tool and by using as a first approach, the theoretical data of pavement design and as a second one, the in-situ pavement data that was collected after pavement's construction based on Non Destructive Testing (NDT) methods. In both cases, the predicted deformation values are compared with respective real values measured with a Laser Profiler system. Finally, the main conclusions of the overall research that took place are summarized.

2   PAVEMENT DEFORMATION ASPECTS

Pavement permanent deformation is a serious distress in asphalt pavements. Its development may be affected by many factors. Asphalt mixture features, for example, have a serious effect on the development and the transmission of deformations. These features may concern asphalt viscosity, mixture stiffness, volumetric ratios of asphalt and aggregates, air voids etc. The materials' mechanical properties such as resilient modulus and Poisson's ratio have also a major impact on pavement distortion. Moreover, environmental conditions (temperature and moisture), and traffic conditions (wheel load and tire pressure) may contribute to pavement deterioration (Sousa et al. 1991, Tarefder et al. 2002).

Permanent deformation can be displayed with the formation of rutting, roughness or local depressions in the upper pavement layers. In particular, rutting develops gradually under the repeating loading, usually appearing as longitudinal depressions in the wheel paths accompanied by small upheavals to the sides. It is caused by volume reduction and shear deformations (Sousa et al. 1991). On the other hand, roughness is related to fluctuations along the pavement surface and it is defined as the total of longitudinal pavement discrepancies from the real flat surface (Sayers and Karamihas 1998).

Permanent deformation is highly undesirable in a pavement for several reasons. As far as the structural side is concerned the development of permanent deformation worsens the total pavement structure and results in further damage. Thus pavement life is reduced and the pavement may fail earlier. Moreover, permanent deformation has a serious impact on user's road safety, comfort and riding quality and may lead to loss of pavement serviceability. Another significant consequence is the risk of hydroplaning due to water remaining in the ruts on the pavement surface. Extended pavement deterioration can also cause an increase of fuel consumption and tire wear (Dawson and Kolisoja 2004). The owner or the manager of the road network may also face problems due to the cost increase of pavement rehabilitation.

From the above, it is concluded that there is an urgent need for the prediction of pavement deformation not only at the design stage but also during its life. However, the prediction of permanent deformation is a rather complex problem. There have been made attempts to develop predictive models that may rely on statistical, empirical or mechanistic procedures. Yet, mechanistic models are considered to be more accurate and to provide a better simulation of permanent deformation evolution. These models may rely on elastic, viscoelastic or advanced methods such as viscoplastic procedures (Sousa et al. 1991). Although advanced methods are more accurate, their complexity and software lack makes them non useable.

Many researchers such as Brown and Bell (1977), Kirwain et al. (1977), Monismith et al. (1977) and Meyer and Haas (1977) have developed predictive models based on elastic theory.

Viscoelastic methods have been used by Barksdale and Leonards (1967), Battiato et al. (1977), Huschek (1977) Kenis (1977 and 1982) and others, whilst viscoplastic models have been developed by Goacolou (1987) and Mahboub and Little (1988). Between elastic and viscoelastic models, the latter examine better pavement behavior and hence they can simulate pavement responses better. Such a model is the VESYS which is utilized for the purpose of the present research.

3   THE VESYS MODEL

The VESYS model (Kenis 1977 and 1978, Kenis et al. 1982) is based on multi-layer viscoelastic theory. The main assumption is that all responses of the pavement can be stated in terms of: the geometry of the pavement structure, the physical properties of the materials layers and the effect of climate and load on these properties (Kenis 1977 and 1978). Thus, material property changes over the seasons of the year have been studied (Kenis et al. 1982).

According to Kenis et al. (1982) the permanent strain $\varepsilon_p(N)$ for all layer materials can be expressed as:

$$\varepsilon_p(N) = \varepsilon \mu N^{-a} \qquad (2)$$

where α and μ = permanent deformation properties; e = peak haversine load strain for a load pulse of duration d=0.1 sec measured at the 200th repetition; and N = number of load applications

Zhou and Scullion (2005) have dealt with the VESYS model and described the equations that are used to predict permanent deformation:

$$R_D(N) = \left(W^+ - W^-\right) * \frac{\mu}{1-\alpha} N^{(1-a)} \qquad (3)$$

$$R_{sub}(N) = W_{sub}^+ * \frac{e_t}{e_s} \frac{\mu}{1-\alpha} N^{(1-a)} \qquad (4)$$

where $R_D(N)$ = permanent deformation level after N load repetitions for each pavement layer except the subgrade; W^+, W^- = elastic deflection amplitudes of the top and bottom surfaces of the layer, respectively; α, μ = laboratory permanent deformation parameters for each layer material; W_{sub}^+ = deflection at top of the subgrade due to single axle load; e_t = strain at top of the subgrade due to axle group; and e_s = strain at top of subgrade due to single axle.

Kenis (1977 and 1978) suggested the Incremental Static-Dynamic Test for the determination of the material properties and the permanent deformation properties α and μ using the results from the incremental static tests. The parameters α and μ of permanent deformation are obtained from the linear regression line when the cumulative permanent strain and number of load repetitions are plotted on a log-log scale. The parameters α_i and μ_i for each layer material are expressed from the following equations (Zhou and Scullion 2004):

$$\mu_i = \frac{IS}{e} \qquad (5)$$

$$a_i = 1 - S \qquad (6)$$

where a = intercept with permanent strain axis; S = slope of linear regression line; $I = \log \varepsilon_{p_i}(N=1)$ and e = resilient strain.

VESYS is used to analyze the primary response of pavements; it can also calculate distress of pavements, in terms of stress, strain, deflection, rutting, roughness and cracking damage.

4   USING NDT DATA: A CONCEPTUAL APPROACH

The ability to predict the amount and growth of permanent deformation in flexible pavements is a major issue of pavement design given that early detection of deformations is very important for preventive maintenance programs and design of rehabilitation strategies. Commonly, the existing predictive models are based on laboratory data used for pavement design. However, the use of these data may result in unrealistic deformation predictions since the development of permanent deformation depends on field conditions, truth pavement structure and in-situ material properties that may vary along the pavement.

Alternatively, in the present paper, it is suggested to utilize in-situ data for the prediction of permanent deformation as an attempt to limit the differences that may occur between predicted and real deformations. Such data is mainly obtained with Non Destructive Testing (NDT). Quantitative data from NDT include physical and material properties of each pavement and subgrade layer that can be used to evaluate the structural performance of a pavement or investigate strengthening options. Once physical and material properties, such as layer thickness and modulus of elasticity (E) respectively, are computed, structural evaluations of existing pavements and design structural improvements can be conducted.

5   DATA COLLECTION

5.1   Pavement data

The present research was applied on a newly constructed motorway section of 600 meters. As a first step, the pavement design data model was considered as described in the pavement model of Figure 1.
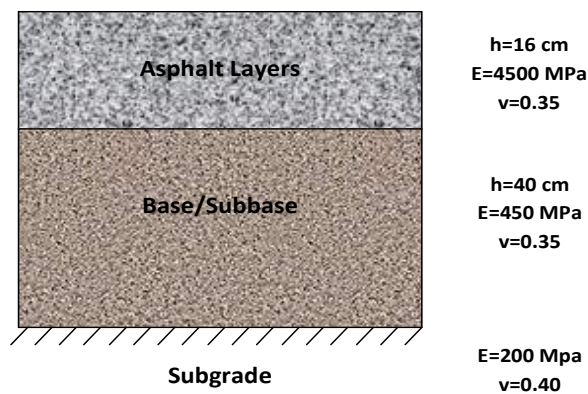

Figure 1: Pavement model

The test section was divided in sub-sections of 20 meters. At each sub-section NDT measurements were conducted. The applied NDT included both deflection and nondeflection testing. Specifically, Falling Weight Deflectometer (FWD) (NCHRP, 2008) was used for deflection measurements, while Ground Penetrating Radar (GPR) as nondeflection testing equipment was used for the detection of the pavement layers' thicknesses (Loizos and Plati 2007). Both tests were conducted after pavement post-compaction, about one month later. This was done due to the fact that there would be no more compaction of the pavement structure due to traffic loads and hence permanent deformation would not be occur from densification (volume changes).

It is worthwhile to mention that during FWD testing temperature data was also acquired as it is essential for the estimation of pavement materials properties.

One year after the first set of testing, permanent deformations were measured in terms of rutting, along the pavement surface of the test section, utilizing a Laser Profiler (LP) system. In the following sections, the measured deformations will be compared to the predicted ones.

5.2 Other data

For the prediction of pavement deformation, traffic data is crucial and commonly a lot of assumptions are considered (traffic growth etc). For the present experiment, the traffic for the first year including vehicles categories was known. Thus, local environmental data were acquired, including the average monthly temperature and average monthly moisture. As far as the parameters α and μ of permanent deformation are concerned, these were determined based on available laboratory data.

6 DATA ANALYSIS AND COMPARISON RESULTS

GPR data was processed and analyzed in order to obtain pavement thicknesses for each testing location under consideration (i.e. each 20 m). These thicknesses were also used for the backanalysis of the FWD deflections and the determination of elastic moduli at each testing location. Both thicknesses and moduli results varied along the test section. This variation was significant in the case of moduli proving that the in-situ condition of material properties was not stable along the test section (Table 1).

Table 1: Coefficient of variation values

	Coefficient of Variation (CV)	
	Thicknesses CV (%)	Moduli CV (%)
Asphalt layers	4.3	13.6
Base/subbase	4.2	53.8
Subgrade		63.6

On the other hand, the consideration of the pavement design model suggests an assumption that the physical and mechanical properties of the pavement layers are stable along the test section. So, when utilizing the VESYS tool with the pavement design data, the result is the prediction of standard deformation (d_{P_PD}) on the pavement surface of 1.19mm (Figure 2). This gives conservative results.

Contrary to the above, by using NDT data for VESYS's predictions, the result is deformation values (d_{P_NDT}) that vary along the test section. This is more interesting when compared with measured deformations (d_M). Figure 2 illustrates that d_{P_NDT} curve follows in a way the trend of the d_M curve. An additional remark is that d_{P_NDT} values give more accurate results but still underestimating the measured values, d_M. The observed differences might be due to the variations of traffic and environmental conditions in each month of prediction as average conditions have been considered. The effect of the accuracy rate of thickness and modulus estimations could be also a reason. The quantification of the observed differences provides a root mean square percentage error (RMSPE) of 25.7%, while the respective one when compare the d_{P_PD} values with the d_M ones is 27.4%. Both errors considered to be reasonable.
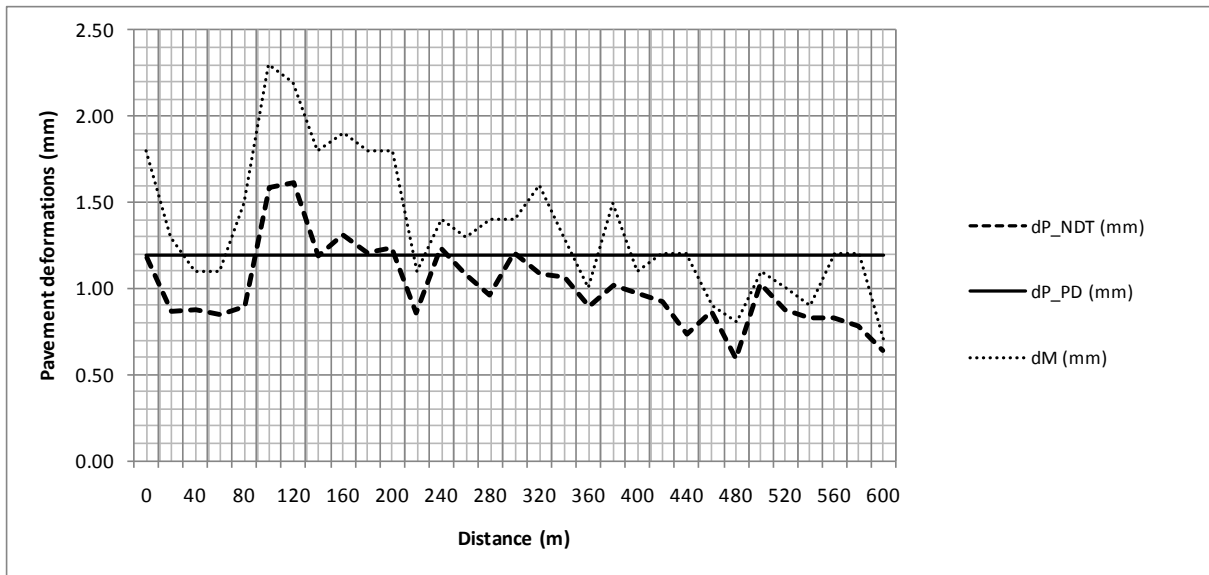
Figure 2: Pavement deformations comparison

Further to the above, the correlation of d_{P_NDT} values with d_M ones is quite satisfactory (Figure 3). Constraint concerning the accuracy rate of in-situ data estimations is still remaining, while the use of a viscoelastic model such as the VESYS for predicting pavement deformations may have drawbacks that affect the predictions. Of course the latter is a huge issue for research and discussion, beyond the scope of the present research.
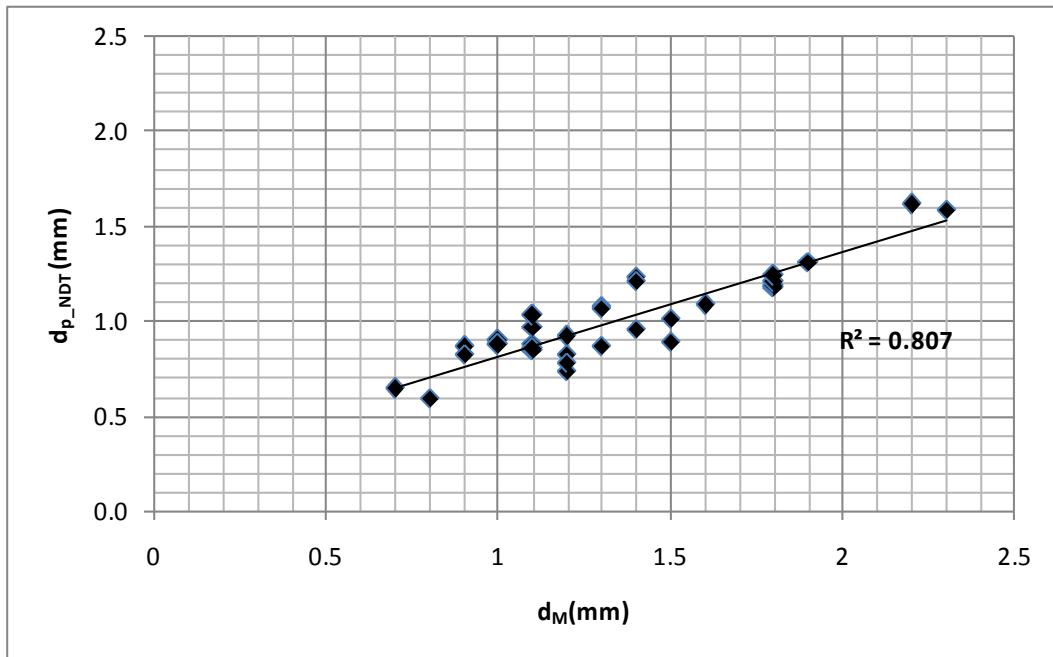

Figure 3: Correlation of predicted (based on NDT data) and measured deformations

Given the analysis and comparison results, it could be stated that the use of in-situ NDT data can facilitate the process of predicting pavement deformations; especially, when issues related to pavement maintenance management activities must be handled.

7 CONCLUSIONS

The prediction of pavement deformations is a complex and a rather difficult task. Among the existing permanent deformation models, models based on visco-elastic theory seem to be adequate for the prediction of pavement deformations. As such a model, the VESYS provides a practical tool for the prediction of pavement permanent deformations not only for design but also for maintenance purposes.

In the present research, the VESYS was utilized to introduce the suggested approach according to which in-situ NDT data is used instead of pavement design data for the prediction of pavement deformations. On this basis, predicted deformations as a result of both pavement design data and in-situ NDT data were compared to respective measured ones. The comparison showed that while pavement design data leads to a standard value of predicted deformation along the test section, the NDT data produces a deformation curve that almost follows the curve produced by the measured deformations. In any case, the observed errors considered to be reasonable. Furthermore, the correlation of predicted deformations based on in-situ NDT data with measured deformations is quite satisfactory supporting the evidence of their relationship.

In summary, the findings of the research prove that in-situ NDT data could be used effectively for predicting pavement deformation. Further research is needed.

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