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Data Processing, Storage, and Analysis: Applying Computational Procedures to the Case of a Falling Weight Deflectomer (FWD)

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Data Processing, Storage, and Analysis: Applying Computational Procedures to the Case of a Falling Weight Deflectomer (FWD)

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Abstract-- In the field of civil engineering, the adoption and use of Falling Weight Deflectometers (FWDs) is seen as a response to the ever changing and technology-driven world. Specifically, FWDs refer to devices that aid in evaluating the physical properties of a pavement. This paper has assessed the concepts of data processing, storage, and analysis via FWDs. The device has been found to play an important role in enabling the operators and field practitioners to understand vertical deflection responses upon subjecting pavements to impulse loads. In turn, the resultant data and its analysis outcomes lead to the backcalculation of the state of stiffness, with initial analyses of the deflection bowl occurring in conjunction with the measured or assumed layer thicknesses. In turn, outcomes from the backcalculation processes lead to the understanding of the nature of the strains, stresses, and moduli in the individual layers; besides layer thickness sensitivity, the determination of isotropic layer moduli, and establishing estimates in the subgrade CBR. Overall, impositions of elastic and low strain conditions foster the determination of resilient modulus and the analysis of unbound granular materials. Hence, FWD data processing, analysis, and storage gain significance in civil engineering because it informs the nature of designing new pavements and other rehabilitation design options.

1. Introduction

A Falling Weight Deflectometer (FWD) refers to a testing device responsible for the evaluation of a pavement's physical properties. Specifically, FWD yields an understanding of vertical deflection responses upon subjecting surfaces to impulse loads. As such, the device is used by civil engineers and its data aids in estimating the structural capacity of a pavement in terms of overload possibilities and informing the overlay design (Tarfder and Ahmad, 2014). Some of the sites at which FWD gains application or usage include railway tracks, harbor areas, airport pavements, local roads, and highways. According to Choubane and McNamara (2000), load impact systems of FWD exist in two forms. These forms include the double-mass (such as KUAB) and the single-mass that includes PaveTesting, Carlo Bro, and Dynatest. In the single-mass system, weights can be dropped onto single buffers and the latter have connections top load plates that, in turn, rest on surfaces to be tested. As such, the force of the load is transferred via this plate to create deflections responsible for stimulating wheel loads (Lee, 2014). However, the double-mass system operates in such a way that weights are dropped onto double-buffer systems. Indeed, the system constitutes first buffers that precede second weights that eventually culminate into second buffers. The implication is that FWD's double-mass systems tend to produce extended loading durations that represent wheel loads in a more precise manner (Domitrovic & Rukavina, 2013). Similarly, double-mass systems have been observed to exhibit higher reproducibility while yielding more accurate outcomes on soft-soil pavements. From this documentation, it remains inferable that single-mass systems are likely to overestimate pavement capacities in regions found to contain soft soils. Despite this limitation, single-mass systems have been vowed to be faster, cheaper, and smaller (State Highway Administration, 2016). Figure 1 represents illustrates the outlook of an FWD device.

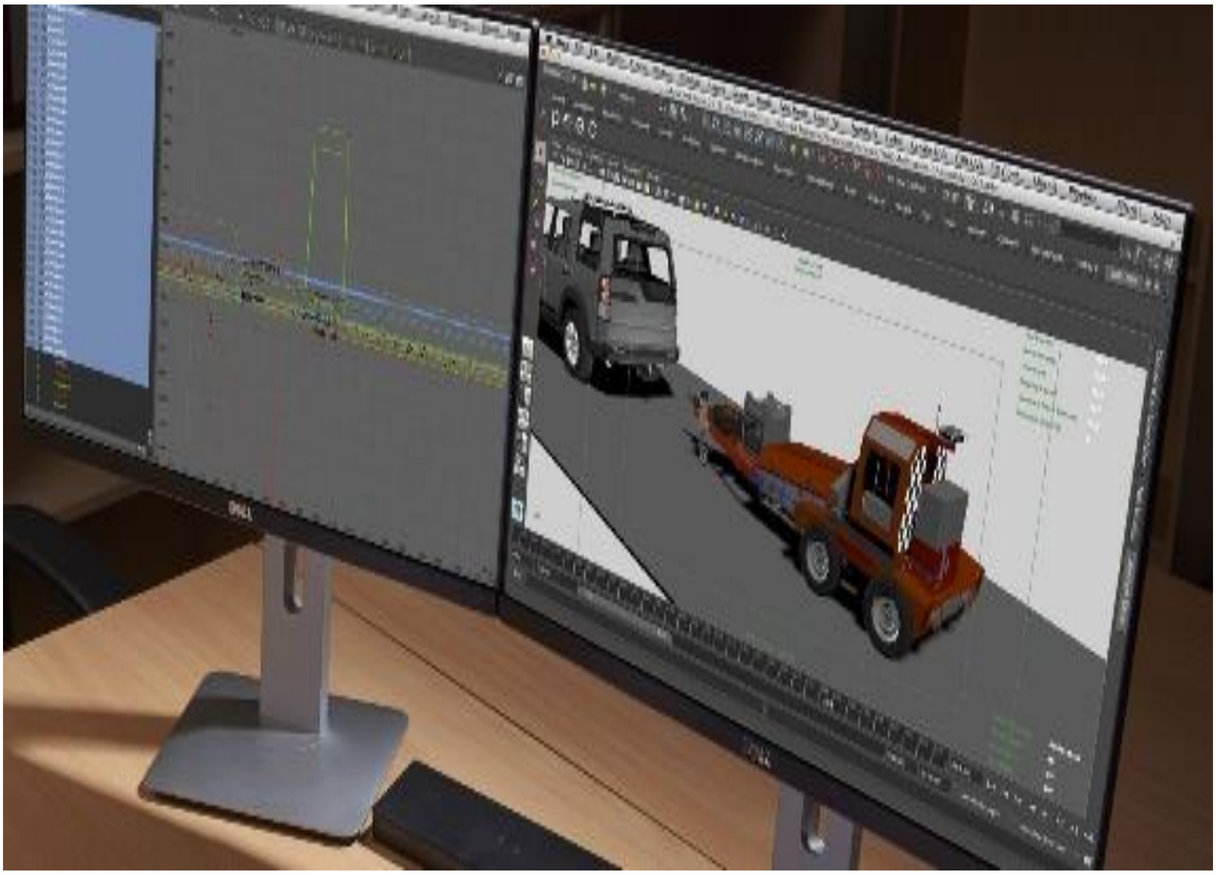

Figure 1: FWD field data collection and analysis via computerized systems

Source: Domitrovic and Rukavina (2013)

2. Interpretation of FWD Data

In the pavement design industry, FWD gains application for various reasons. For example, the device aids in identifying regions of weak pavement, aids in backcalculating layer properties to inform the perceived utilization of overlay designs, and aids in the estimation of the remaining life of a given structure (Varman, 2015). When FWD is used on pavements, the operators apply impulsive loads on road or pavement surfaces before adjusting the area of loading, the duration, and the magnitude of the load. The aim of this procedure lies in the need to allow the load to correspond to the loading effect arising from in-service pavement's standard axle (Lee, 2014). In turn, the road surface's instantaneous deflections are measured at various points and distances. As noted by Choubane and McNamara (2000), these measurements are done radially outward, with the falling weight's centre being the focal point. The aim of this procedure is to obtain the shape of deflection bowls while FWD data backcalculation forms an analysis through which the operators obtain results on structural health condition (Tarfder and Ahmad, 2014). Figure 2 illustrates the field functionality of FWD.

A. Understanding the Backcalculation Process

Primarily, the role of backcalculation lies in the need to establish different pavement layers' in-situ elastic moduli (E) (Kutay, Chatti and Lei, 2011). Indeed, the operators calculate the outcomes of deflection values in relation to the assumed elastic moduli results before comparing the findings with the deflection values that have been observed. In turn, adjustments are made to the assumed moduli values for iterations that follow (Domitrovic & Rukavina, 2013). It is also worth highlighting that the iterations continue up to a point where a closer match is obtained for the observed and calculated deflection values. As documented by the State Highway Administration (2016), thickness values of the pavement layer may also be unknown. As such, the operators estimate these values iteratively via the backcalculation procedure. Figure 3 illustrates how the backcalculation procedure is conducted while seeking to establish the in-situ elastic moduli (E).

From figure 3, an analysis of the structure of a pavement involves idealizations. The implication is that iterations are likely to introduce numerical errors. The problem's inverse nature has also made it difficult to attain a unique solution during the backcalculation procedure. However, recent observations suggest efforts being made to develop and implement a backcalculation scheme perceived to be robust and capable of reaching the solution quickly, reliably, and accurately (Varman, 2015). The main methods of backcalculation include optimization techniques and the regression methods. Whereas the former approach takes lengthy iteration processes, the latter technique has been found to be fast but remains prone to the provision of inaccurate outcomes (Kutay, Chatti and Lei, 2011). Figure 4 highlights the process through which field results due to FWD application are collected and analyzed via computerized systems.

3. FWD Site Functionality

As mentioned earlier, FWD simulates pavement surface deflections to reflect a similar situation as that which may be felt in the case of a fast-moving truck. Upon dropping a weight, FWDs generate load impulses. In turn, these load pulses are transmitted to the pavements via circular load plates expected to be 300 millimeters in diameter (Domitrovic & Rukavina, 2013). According to Lee (2014), FWD's generation of load pulses yield momentary deformations of pavements beneath the load plates and end up forming bowl or dish shapes. When envisioned from side views, shapes of the deformed pavement surfaces can be likened to deflection basins (Park, Park and Hwang, 2009).

Indeed, pavement stiffness can be estimated based on the deflection basin's shape and the stiffness of the pavement being investigated. Knowledge of individual layer stiffness can also lead to the calculation of the stiffness of those layers. Furthermore, FWD aids in determining degrees of interlocks between adjacent slabs. However, this degree is mostly achieved on pavements perceived to constitute Portland adjacent cement (PCC). Often referred to as the load transfer efficiency (LTE), the degree of interlock is achieved through the placement of FWD load plate tangents to the side of joints being examined (Shirazi, 2015). Afterward, load pulses are generated before measuring equidistant deflections on either side of the joints. The expectation is that equal deflections result when joints are perfectly efficient. However, some studies reveal that most of the joints would have deflections on the loaded slabs being higher than the unloaded slabs (Tarawneh & Nazzal, 2014).

It is further notable that primary measurement devices for FWDs exist in two forms. The first type constitutes load cells located directly above load plates. The role of these cells is to obtain measurements of forces being imparted to the surface. The second category involves deflection sensors or deflectors (State Highway Administration, 2016). In situations where Long-Term Pavement Performance (LTPP) operates FWDs, deflection sensors come in the form of geophones. To measure the deflection basin's shape, the geophones are placed at fixed distances from load plates (Shirazi, Abdallah and Nazarian, 2009). Apart from these primary devices, LTPP FWDs constitute two other types of measurement devices. One of these additional devices is the distance measurement instrument (DMI) whose role lies in obtaining distances that the FWD covers along a given roadway; also acknowledged as a high-accuracy odometer (Choubane & McNamara, 2000). The second and additional type of measurement device is the temperature sensor (infra-red surface-temperature sensor and the air temperature sensor). In conjunction with information from the nearest weather stations, the results of temperature sensors aid in estimating values in different materials of the pavement structure (Kutay, Chatti and Lei, 2011). According to Varma, Kutay and Chatti (2013), an understanding of the pavement structure material temperatures is critical for the analysis process. The importance is demonstrated in the example whereby asphalt tends to be ductile and soft when temperatures are high while low temperatures make the material to be brittle and hard. Thus, this knowledge allows the FWD operators to correct the stiffness calculated in relation to such temperature effects (Wang and Al-Qadi, 2013). FWD testing also attracts manual measurements by the LTPP FWD operators. An example is a case in which the load-transfer testing process prompts the taking of joint width measurements and the use of a hand-held device to take subsurface temperature measurements. Non-equipment related conditions attract additional operator comments in relation to their implication on anomalous measurements. Some of these site-specific and non-equipment related conditions include cracks and other related distresses experienced on the pavement surface (Varna, 2015).

4. The FWD Test Procedure

Prior to the arrival at the site, FWD operators fill out copies of forms referred to as FWD Operations Planning and the filling process is specific to the individual or separate test sections. Afterward, the arrival at the site is followed by inspections of test sections to establish evidence of maintenance activities. In turn, possibly defaced or missing site markings are replaced. An evidence of recent maintenance requires one to contact regional support contractors to confirm the effectiveness of the maintenance (Tarefder & Ahmed, 2014). In turn, the before-operations checks are conducted and include the removal or trays, unlocking transport locks, ensure that the geophones remain well-seated in their holders, checking the level of hydraulic oil, confirming the level and tightness of buffers that ought to be free of silts and cracks, and removing hitch pins from the front sensor guides (Domitrovic & Rukavina, 2013). The process is followed by preparations of temperature gradient holes, buffer warm-up sequences, position the FWD to allow the load plate's center to lie on section start limits, and set the "Test Setup" before opening new data files in the data collection software. The testing sequence starts after entering lane specifications. Upon completion, the operators move to the next point and the procedure is repeated until all the test points are examined. Later, the data file is closed and followed by after-operations activities such as engaging transport locks, replacing hitch pins in front of sensor bar guides, securing and replacing pans, locking the trailer access doors, stowing other supplemental testing equipment, and filling out, dating, signing, and filing paper forms (Lee, 2014). Figure 5 illustrates the FWD assembly.

5. Analyzing and Interpreting FWD Data and Field Outcomes

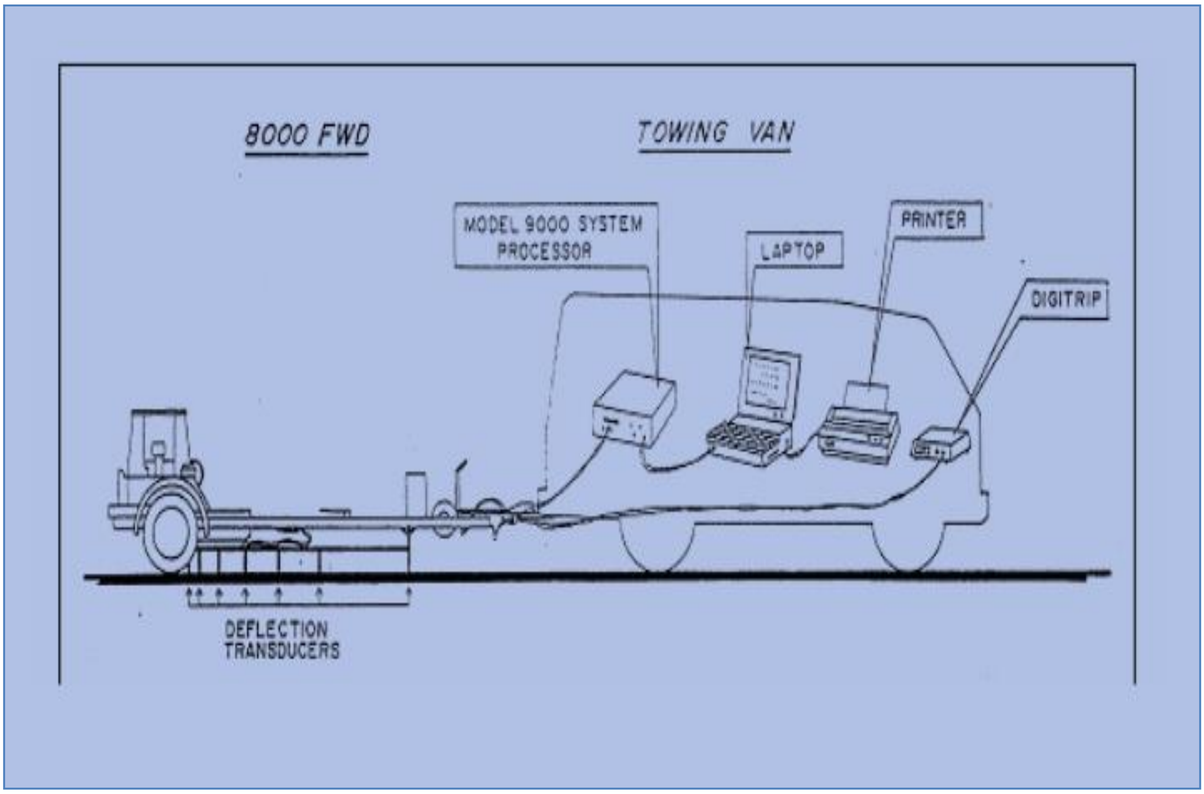

Figure 2: FWD Assembly

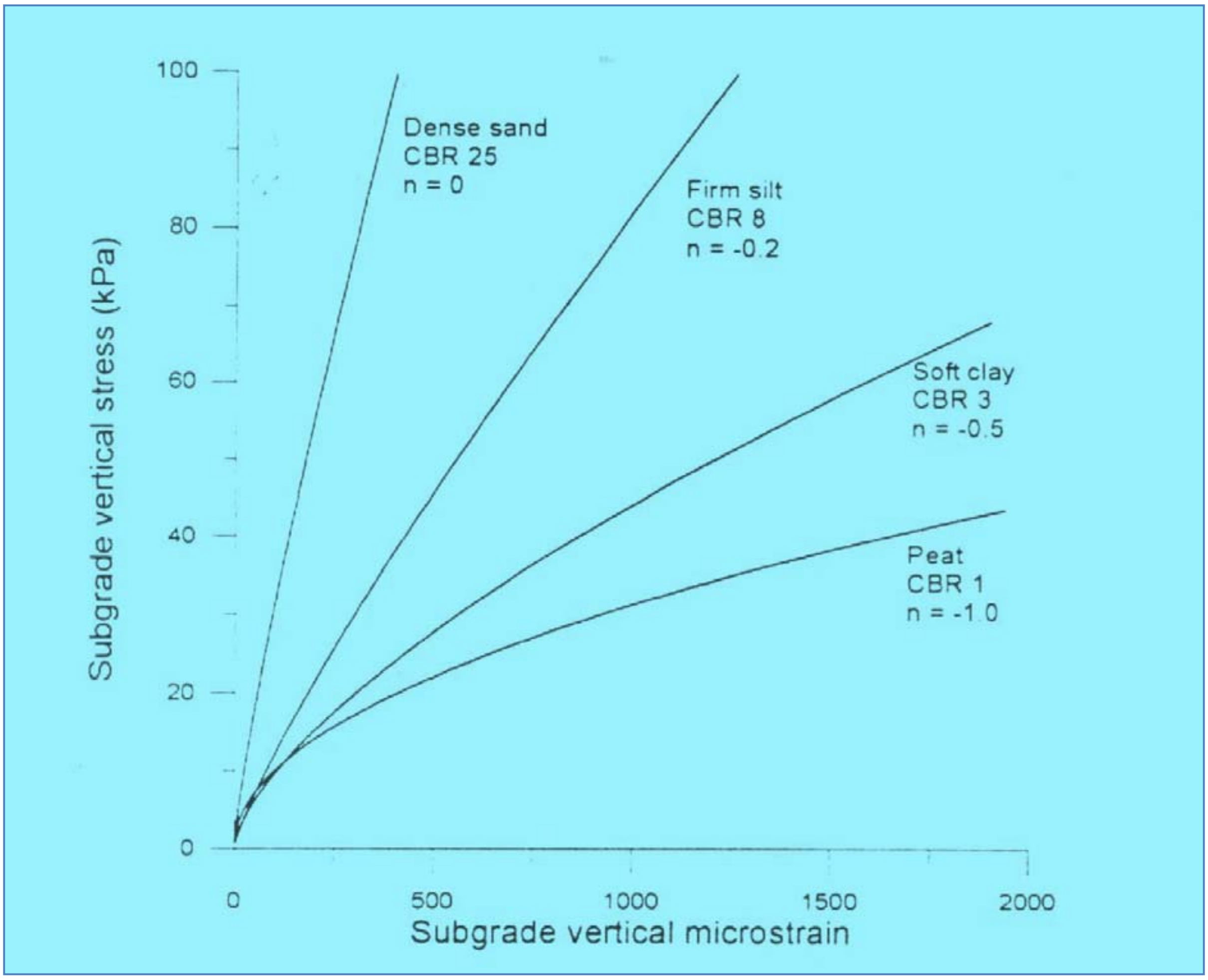

Figure 3: FWD backanalyses in relation to stress-dependency and typical subgrade moduli

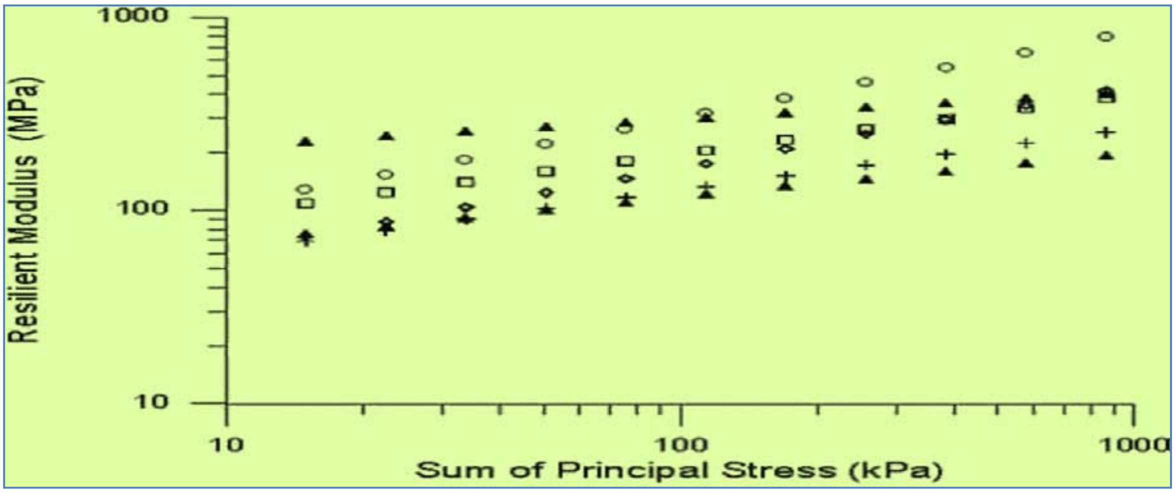

Figure 4: Resilient moduli versus sound basecourse mean stress

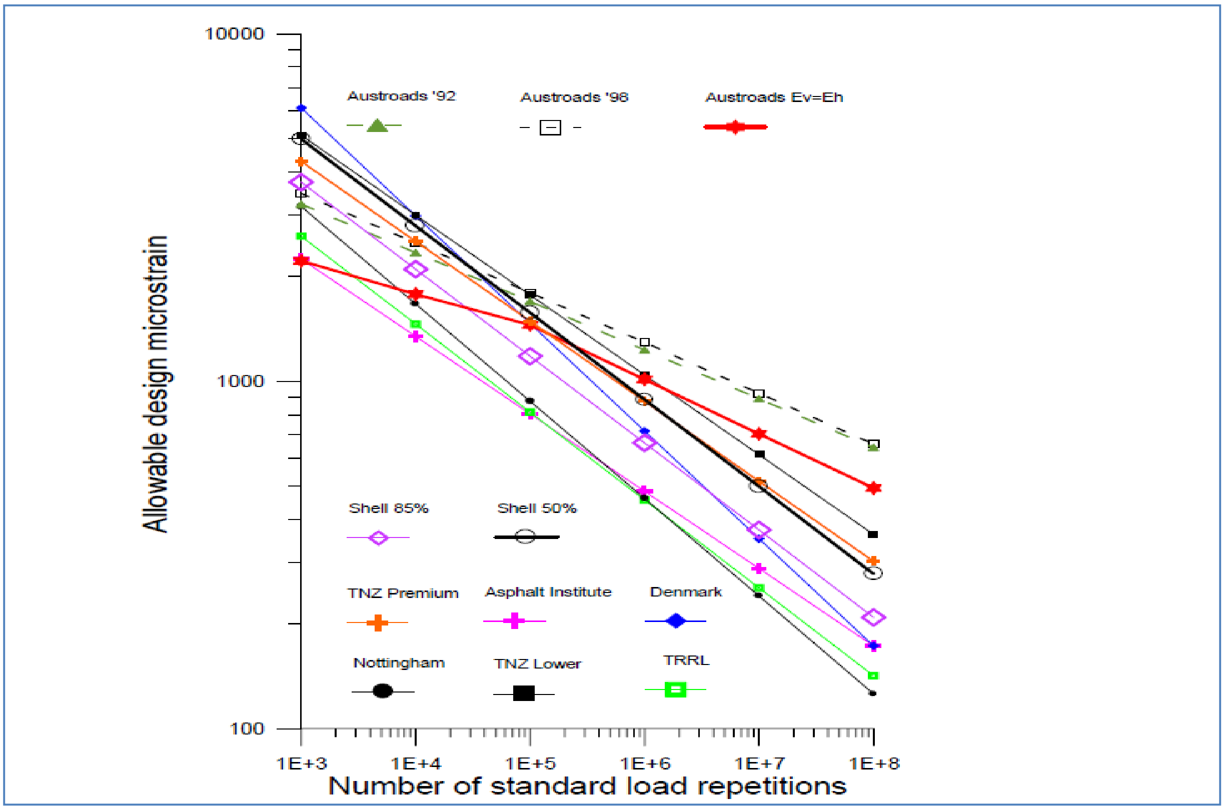

Figure 5: Permissible strain versus the number of load repetitions

A pavement's detailed structural analysis has insights about its detailed structural analysis gained from the shapes of deflection bowls. Basically, subgrade stiffness is defined by outer deflections (Park, Park and Hwang, 2009). On the other hand, bowls that are broad with little curvatures depict stiffness in the pavement's upper layers (in relation to the subgrades) (Shirazi, 2015). In addition, bowl shapes found to be close to FWD's loading plates support pavement analyses of near surface layers. Related observations by Tarawneh and Nazzal (2014) indicated that bowls found to have high curvatures around FWD's loading plates but with same maximum deflections suggest weaker upper layers in relation to the subgrades. Upon identifying critical layers, potential or existing distress mechanisms are established and pave way for the design of treatments that are the most fitting.

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