Submission to Academia Letters

LEMaC-DE01/16: Methodology for determining effective structural contribution in unpaved roads using Light Weight Deflectometer (LWD) without geophones and back-calculation according to AASHTO93 Guide

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Abstract

The use of LWD in flexible pavement structural designs is increasing. The LWDs are offered under 2 typologies; with or without geophones to set the deflection bowl. LWDs with geophones allow to apply mechanistic analysis directly, but LWDs without geophones not.

For this reason, the LEMaC Center for Road Research UTN FRLP - CIC PBA (Argentina) analyzes this problem through a research project; their results allow the use of LWD without geophones in pavement design using the AASHTO93 Guide.

This ''short report'', as allowed by the Letters Academy, presents a summary of the tasks performed and the work procedure developed. No section of conclusions and exhaustive antecedents and studies of the models presented are included, due to the limit imposed on the number of words for these ''short reports''. This information can be consulted in the ''Correlation model for the use of modulus back-calculation on LWD measurements'' (Rivera & Alderete, 2012).

Keywords: Low Traffic Roads, Light Weight Deflectometer, AASHTO93 Guide, Back-calculation, Pavements

Introduction and background

Standard multilayer flexible structural packages are common in paving roads with low traffic volumes.

When designing it, the engineer considers that is applied on different subgrades. In addition, depending on the associated hydraulic project, there are levels of the pavement that determine subgrade cut, profiling or fill, originating different structural responses.

The solution adopted is to establish a ‘‘calculation response’’ that is exceeded by a given number of the points analyzed (to give safety), indicating a percentile greater than 50%, with a higher initial investment (AASHTO, 1993).

Other aspects also condition the designer. One of them is that although a typology is established for the sub-bases and bases, a tolerance is specified in their compaction, resulting in a new range of structural contribution values on site.

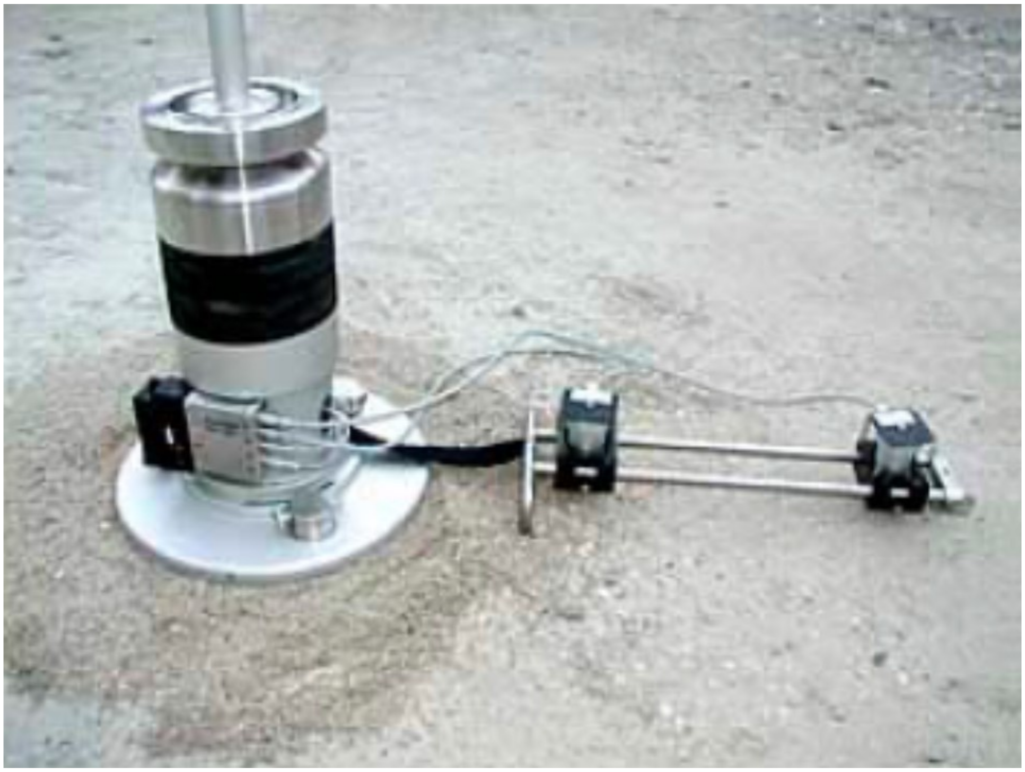
By this, the engineer takes safety decisions, designing oversized structural packages to most of the roads of a particular paving program, with the corresponding economic implications.

The solution to this is obtained by modifying the way in which these tasks are contracted, specifying a typical pavement up to the finished base level and different alternatives of separate bearing layer (surface treatment, asphalt layer in 5 cm or 7 cm, etc.) that are expeditiously assigned in each section by back-calculation, with the response of the particular subgrade presents and the real structural contribution on the finished bases, reducing costs.

As on-site AASHTO93 Guide implies the use of the Falling Weight Deflectometer (FWD) to this task, and this aspect is not economically justifiable, the use of LWDs with geophones has been implemented, with plate diameters and masses that allow simulating the semi-axle load (40 KN) (Figure 1).

Figure 1. LWD with geophones (ICENOGLE & KABIR, 2013)

But these devices are significantly more expensive than versions without geophones (Figure 2). For this reason,



some researchers seek to use the latter through calibration constants, as Fleming et al. (2002), with a coefficient of 1.031 between FWD and LWD that has R2 of 0.6.

Figure 2. LWD without geophones (https://terratest-lwd.com)

Other studies have determined that the modulus with the LWD is between 0.65 and 1.60 times the modulus with FWD (Van Gurp et al., 2000). Combined studies between the USDA Forest Service, the US Army ERDC Cold Regions Laboratory, the New Hampshire DOT and the University of Maine, on low-traffic roads, have arrived at R2 of 0.7 (Kestler et al., 2004). Nazzal (2003) obtains better results, with a correlation of 0.94 with a coefficient of 0,97 between FWD and LWD.

In all cases, a single correlation coefficient is sought. But in reality, when having different dynamic loads

between FWD and LWD, different deviating tensors d would be exerted, which are related to the modular response in a not necessarily proportional way. Therefore, in materials with relations Mr versus d with different types and curvature, it would correspond to use different correlation constants (Rivera et al., 2012). The aforementioned means that it is more appropriate to think in a correlation between both determinations with variables models and not with a constant.

Because LWD without geophones does not allow the measurement of the deflection bowl, necessary to apply the back-calculation models, an adaptation in its use related to the correlation models are implemented; arrive at this procedure and models are the goals of the LEMaC research and development project that gives rise to this publication.

Methodology and Results

The methodology foresees, on test sections with different subgrade and bases, the use of LWD equipment without geophone to carry out deflection measurements. These deflections are correlated with the results of virtual deflections with FWD equipment. The virtual deflections with FWD are simulated by elastic layer theory, from the results of samples tested to obtain resilient modulus in the laboratory.

It is then necessary, access to roads up to the base level, with different constituent materials and on subgrades of different characteristics. As the LEMaC has been responsible for the controls and accessories on paving in the city of La Plata (Argentina), an agreement is generated with its Municipality to include in its paving programs 12 test sections, that allow the instrumentation of the tasks planned (Figure 3).

Figure 3. Analysis of the test sections (self-made)

LWDs with geophones use a single stroke load and the measurement of deformations at different distances with the geophones. A different way of working is designed for LWDs without geophones. A loading stroke is first generated on the surface of the finished base. Then the base is removed to the subgrade. Finally, a new loading stroke is performed at that level, considering that the modular response is not disturbed in this way.

Through these steps, a deflection on the base and a LWD resilient modulus of the subgrade are recorded. These values can be correlated to determine, for the back-calculation, the combined modulus of the existing structure Ep and the resilient modulus of the subgrade that would virtually be achieved with a FWD, respectively.

It should be noted that a two-layer package (subgrade and base) is contemplated through the methodology to be complemented as a three-layer package with the asphaltic layer. It is to be understood there, and throughout this document, that the ‘‘base layer’’ may consist of one or more layers.

In summary, the study methodology includes:

Selection of road sections with the combination of subgrade and bases of diverse structural contribution.

Realization on the finished bases of the analysis with LWD to determine the deflection on the base.

Determination of the density and humidity of the base, and removal in 0.5 m by 0.5 m.

Determination with LWD of Mr.

Determination of the density and humidity of the subgrade and taking of a sample.

Re-molding of subgrade and base samples with measured moisture and density.

Determination of the constitutive equations of the base and subgrade samples taken.

Inclusion of the constitutive equations in the elastic layer model, simulation of the 40 KN load, and Mr and deflection obtainable with FWD determination.

Obtaining the correlation models.

For the development of the correlation models, the results shown in Figure 4 and Figure 5 are obtained, in which the maximum R2 for the masses of 10 kg and 15 kg provided with the equipment are observed, being its optimal range of useful modules from 15 to 70 MPa and from 70 to 120 MPa, respectively.

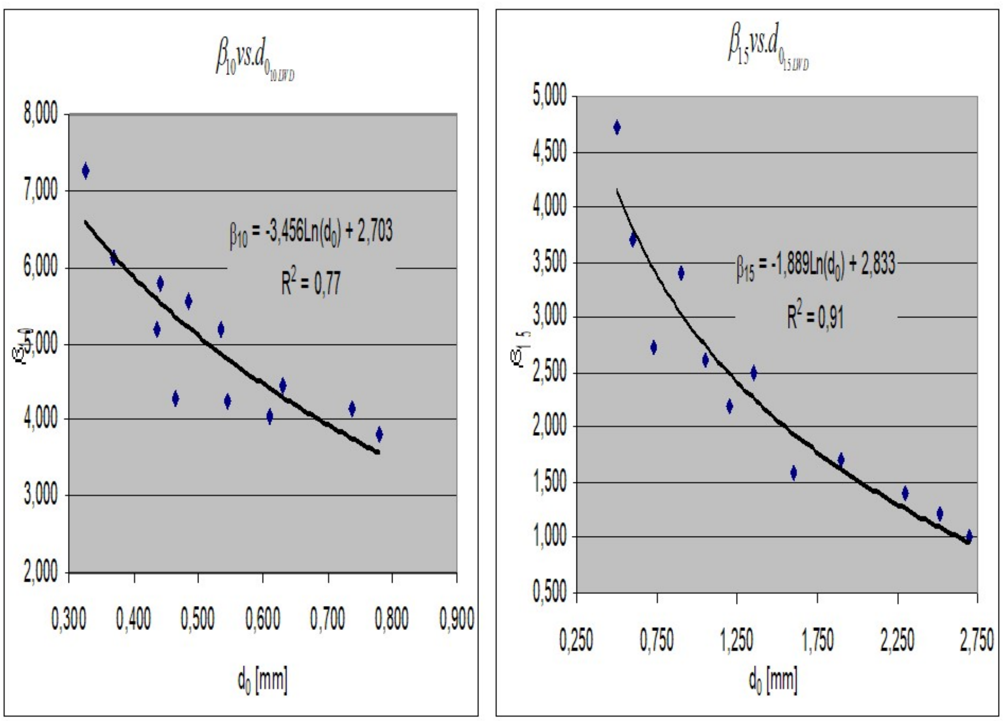


Figure 4. Graph coefficient versus d0 for the mass of 10 kg (left) and 15 kg (right) (self-made)

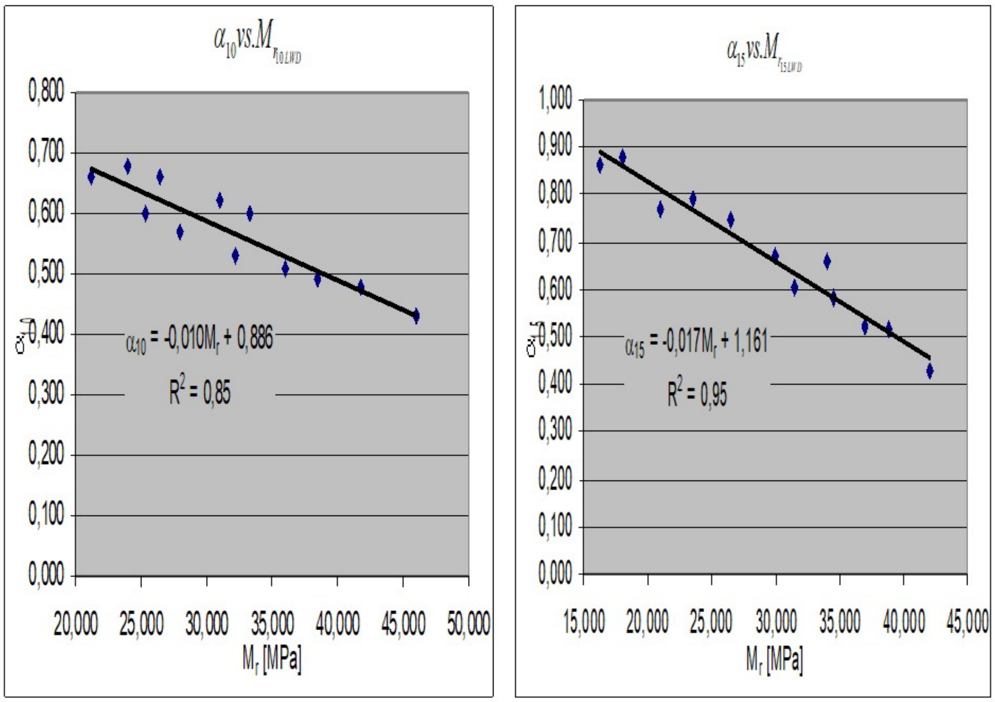


Figure 5. Graph coefficient versus Mr for the mass of 10 kg (left) and 15 kg (right) (self-made)

References

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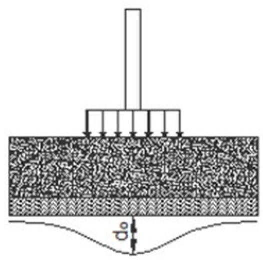
ICENOGLE, P. & KABIR, S., ‘‘Evaluation of non-destructive

LEMaC-DE01/16 PROCEDURE (LEMaC, 2019)

Scope:
The methodology is applicable for the determination of the effective structural number (SN_{ef}), in mm, in unpaved roads where there is an unbound layer (or set of them) of base material over the subgrade.

Elements:
Light Weight Deflectometer (LWD) without geophones, supplied with 10 kg or 15 kg masses.

Use:
Step 1: Determine with LWD the deflection on the finished surface ($d_{0_{LWD}}$).



Deflection according to Step 1 (self-made)

Step 2: Excavate a surface of 50x50 cm to the subgrade level.

technologies for construction quality control of HMA and PCC in Louisiana'', Louisiana Transportation Research Center, FHWA/LA.12/493, USA, 2013.

KESTLER, M., EATON, R., BERG, R., STEINERT, B., SMITH, C., ALDRICH, C. & HUMPHREY D. ``Handheld in-situ testing devices for estimating the stiffness of trails and low volume roads''. Transportation System Workshop, Ft. Lauderdale, USA, 2004.

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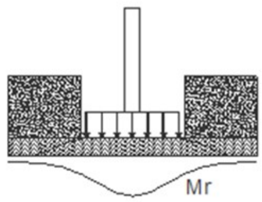
Step 3: Determine the thickness of the current existing package (D), from the subgrade level to the finished surface.

Step 4: Determine with LWD the subgrade resilient modulus (Mr_{LWD}).



Deflection according to Step 4 (self-made)

Step 5: Correct the measurements with LWD to those obtainable with the reference impact deflectometer (FWD), using Equation 1 to Equation 6 as a function of the mass used.

$$Mr_{FWD} = \alpha . Mr_{LWD} \quad (1)$$

$$d_{0_{FWD}} = \beta . d_{0_{LWD}} \quad (2)$$

Where:

Mr_{FWD} = Subgrade resilient modulus obtainable with the FWD

NAZZAL, M.D. ‘‘Field Evaluation of In-Situ Test Technology for QC/QA During Construction of Pavement Layers and Embankments’’. M.S. Thesis, Louisiana State University, Baton Rouge LA, USA, 2003.

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RIVERA, J.J., BRIZUELA, L.G., ALDERETE, N. & VILLANUEVA, M.R. ‘‘Avances en el desarrollo de la metodologa para valoracin por retroclculo de capas no ligadas mediante la utilizacin del Light Weight Deflectometer’’ (T014). XVI Congreso Argentino de Vialidad y Trnsito (ISBN 978-987-28682-0-8),

Mr_{LWD} = Subgrade resilient modulus obtained with the LWD

$d_{0_{FWD}}$ = Deflection obtainable with the FWD over the base

$d_{0_{LWD}}$ = Deflection obtained with the LWD over the base

$\alpha;\beta$ = Resulting correlation coefficients as a function of the Mr_{LWD} and $d_{0_{FWD}}$ measured

$$\alpha_{10} = -0.010 \times M_{r_{10LWD}} + 0.886 \quad (3)$$

$$\alpha_{15} = -0.017 \times M_{r_{15LWD}} + 1.161 \quad (4)$$

$$\beta_{10} = -3.456 \times \ln d_{0_{10LWD}} + 2.703 \quad (5)$$

$$\beta_{15} = -1.889 \times \ln d_{0_{15LWD}} + 2.833 \quad (6)$$

It is observed that the formula for β_{10} is used up to $d_{0_{LWD\,10}} \leq 2.0$ mm and that of β_{15} for $d_{0_{LWD\,15}} \leq$ 4.0 mm. Furthermore, for both masses, the correction formulas for Mr_{LWD} are applied in a measurement range between 15 MPa and 40 MPa.

Step 6: Give value iteratively to the combined module of the existing structure (E_p) until Equation 7 is balanced.

Argentina, 2012.

VAN GURP, C., GROENENDIJK J. & BEUVING E. ''Experience with various types of foundation tests''. 5th Int. Symp. on Unbound Aggregates in Roads (UNBAR 5), USA, 2000.

$$d_{0_{FWD}} = 1.5 \cdot p \cdot a \left\{ \frac{1}{Mr_{FWD}\sqrt{1+\left(\frac{D}{a}\sqrt[3]{\frac{E_p}{Mr_{FWD}}}\right)^2}} + \frac{\left[1-\frac{1}{\sqrt{1+\left(\frac{D}{a}\right)^2}}\right]}{E_p} \right\} \quad (7)$$

Where:
a = Loading plate radius = 15 cm
p = Contact pressure of half reference axis (40 KN) = 1.13 MPa

Step 7: Carry out the SN_{ef} calculation using Equation 8.

$$SN_{ef} = 0.0024 \times D \times (E_p \times 1000)^{1/3} \quad (8)$$

Where:
D = Thickness from subgrade to finished base level (mm)
E_p = Combined module (MPa)