The Use of Deflection Measurements in Pavement Management of the Primary Road Network of Wallonia, Belgium.

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ABSTRACT

The road authorities of the primary road network of motorways and main roads in Wallonia (Belgium) determined the priorities for road maintenance from surface characteristics such as roughness, skid resistance and rutting. Recently, they added the structural health (and primarily the bearing capacity) as a criterion for pavement management. The "structural health" of the road sections is estimated from deflection measurements obtained with Falling Weight Deflectometer and Curviameter.

This paper presents the approach used to transform deflection measurements on rigid, semi-rigid and flexible pavements into several "structural indicators" that combine into a global indicator for residual life time expectance. For each of the measurement devices, three indicators were developed that evaluate some aspect of structural health of the road. Two indicators were developed that express the importance of traffic on the road. These five indicators are combined into a global indicator that allows classifying the road sections. The classification gives results similar to an evaluation by back-calculation as shown in the paper on a limited number of road sections. The approach described in the paper is a successful example of how to introduce the evaluation of structural performance in pavement management using the technique of simple computations from rough data collected by deflection measurement devices.

1. INTRODUCTION

The road authorities of the primary road network of motorways and main roads in Wallonia (Belgium) determined the priorities for road maintenance from surface characteristics: roughness, skid resistance, rutting. Recently, they added the structural health (primarily the bearing capacity) as a criterion for pavement management, estimated from deflection measurements obtained with Falling Weight Deflectometer (FWD) and Curviameter.

This paper presents the approach used to transform rough deflection measurements into several "structural indicators" that combine into a global indicator for residual life time expectance.

On network level the knowledge of the road layer materials in place and their thicknesses is incomplete. For network evaluation, it is impossible to apply back-calculation to the large amount of collected deflection data from over the whole network without completing them with detailed information on the road structures in place. Even when all information is available, back-calculations are not straightforward, hence time-consuming for highly skilled personnel of road authorities, draining them from other tasks. Instead, we choose an approach that consists in the direct determination of indicators from the collected data by Curviameter or FWD, without need for details on road structures and that can be generated automatically and almost instantly.

A first indicator (KPI1) expresses the bearing capacity of the road structure. A second indicator (KPI2) expresses the quality of bonding between layers. A third indicator (KPI3) expresses the cohesion of the road structure.

Two traffic indicators were developed: one expresses the number of vehicles on the road section (KPI4); the other expresses the aggressiveness of the heavy traffic on it (KPI5). All indicators are combined to a global structural indicator (GI) that allows classifying the road sections.

Section 2 of paper describes how FWD and Curviameter monitored and divided road sections in "homogeneous segments". In Section 3 all indicators are presented and their definition is motivated. In Section 4 examples show how the indicator values relate to the estimations of bearing capacity and residual life-time expectance obtained from back-calculation. This illustrates that the approach described in the paper is a successful example of how to introduce the evaluation of structural performance in pavement management using the technique of simple computations from rough data collected by deflection measurement devices.

2. FWD AND CURVIAMETER AT NETWORK LEVEL

The road manager provided a list of roads to investigate. Part of the roads was constructed in concrete. The FWD was used on all rigid roads and on some semi-rigid roads. The Curviameter was used only on semi-rigid and flexible roads since its geophone is not sensitive enough for measuring deflections smaller than 20µm.

The distance between two consecutive FWD measurements was 100m; the applied force was 100kN on rigid roads and 65kN on semi-rigid roads. The deflection measured by the geophone at x millimeters from the center of impact will be denoted by D(x). The applied force F is measured at each point.

The distance between two consecutive Curviameter measurements is 5m. The force applied by the wheel of the Curviameter-truck was 65kN (a load of 13T on the rear axle). The Curviameter measurements deliver a deflection bowl represented by 100 points. The maximum deflection measured on a deflection bowl will be denoted by Dmax or D(0); R0 will denote the radius of curvature of the deflection bowl curve at the position where Dmax occurs. In a first post-processing step the quality of an individual measurement is verified and some may be rejected. We will refer to those not rejected as “of good quality”.

2.1.Homogeneous segments

Maintenance interventions are planned by the road manager on road segments with similar structural properties. Standard procedures exist for the determination of “homogeneous segments” derived from maximum deflections. A value for each indicator is associated to each homogeneous segment.

For FWD measurements, dynamic segmentation by the cumulative sum method (see [*1*]) is recommended in [*2*] as procedure for the determination of homogeneous segments. Each maximum deflection measured on the road is “normalized” to a reference force FN. In this case FN = 100kN or 65kN. The “normalized” deflection is defined as DN(x) = D(x).F/FN. The method uses the cumulative sum of variables on the “normalized” deflections. The segments are delimited by hand at places where the slope of the graph of the cumulative sums changes significantly – as judged by the experienced human operator.

Homogeneous segments are determined from Curviameter measurements by a statistical analysis of the maximal deflections (cf. [*3*], [*4*]). For a segment of at least 200m long the “characteristic deflection” is defined as $\mathrm{Dc} = \mathrm{ave}(\mathrm{D0}) + 2.\sigma$, where ave(D0) is the average of all maximal deflections measured along the segment and where σ is its standard deviation.

2.2.Network Evaluation: Some Other Approaches

The use of the residual life of the road structure as indicator for its structural performance is recommended in [*5*].

In [*6*] the maximum deflections measured by an FWD are translated into an equivalent deflection DB as if it was measured with a Benkelman Beam with the formula in [*7*]. Using the relationship between DB, current traffic load and residual pavement life, the latter is determined from formulas in [*8*]. For the integration into a PMS three classes are defined relating rehabilitation only to road sections with a residual life less than 5 years, maintenance only to road sections with a residual life of more than 12 years and allowing any treatment for the other road sections.

The "Tragfähigkeitszahl" Tz is defined in [9] by $Tz = \sqrt{\frac{R0}{D(0)}}$, where R0 is the radius of curvature determined from the deflection curve at D(0). An algorithm is proposed in [9] for the computation of R0 from FWD deflections. Starting from the elasticity theory of [*10*], [9] shows a relationship between Tz and the E-modulus of the half-space.

In [*11*] the development of the "Modified Structural Index (MSI)" for flexible pavements, derived from FWD measurements is presented. The report also discusses previously developed indicators for structural performance that are calculated from deflection measurements with Benkelman Beam or FWD.

Recent uses of the structural number (SN), determined from deflections measured by an FWD at different radial distances according to several models and formulas are reported in [*12*] and [*13*].

A thorough study of simplified deflection-based analytical techniques for rapid automated screening of pavement structural capacity for the evaluation on network level can be found in [*14*].

3. INDICATORS USED FOR THE PRIMARY ROAD NETWORK IN WALLONIA

For the road network in Wallonia a pragmatic approach was chosen: three structural indicators (KPI1, KPI2 and KPI3) were defined that can be computed directly from the measurement data, hence without a need for detailed knowledge about the road structure. The definitions combine published results on interpretation of measurement data with proper experiences of the BRRC team. Some parameters were molded when the formulas were applied to part of the collected data. Each indicator categorizes a segment from good (0) to bad (5). Combined with 2 traffic indicators (KPI4 and KPI5), a global indicator (GI) expresses the residual life of the homogeneous road segment.

3.1.KPI1 And Tz: Bearing Capacity

Since the FWD is too slow for the execution of measurements on points significantly closer than 100m away from each other, the statistical approach leading to Dc cannot be applied to FWD data. However, when the radius of curvature R0 is computed for FWD data, Tz and R0.D(0) can be determined. Although Tz ([*9*]) and R0.D(0) ([*15*], [*16*], [*17*]) are only proven to be significant indicators for flexible or bituminous roads, we apply them to rigid concrete roads as well.

In [*9*] a way for the computation of the radius from FWD deflections is proposed using the description of a deflection bowl given in [*18*]. Alternative techniques usually apply simple arithmetic on the deflections (e.g. [*19*]). It was preferred to develop a new iterative approach with the theoretical model f(x) of a deflection bowl expressed by the formula: $f(x) = \frac{a_0 + a_1 x^2}{1 + a_2 x^2}$, for which the radius is: $R0 = \frac{1}{2.(a_1 - a_0.a_2)}$.

We set a0 = D(0) and we look for a1 and a2 such that $\sum_i (f(i) - D(i))^2$ is minimal when summed over all measured deflections. Initial values in the process are computed from D(0), D(600), D(900) and D(1500): these must be available when the recommendations in [*2*] are followed during FWD measurements. The computed radius is accepted (or said “of good quality”) if the difference between measured and computed value for D(300) is smaller than 3,5% of the measured value.

An excellent correlation between Dc and Tz was found based on the large amount of Curviameter data gathered on the primary road network in Wallonia. The same correlation was observed for Dc and Tz obtained from FWD on rigid roads on homogeneous segments long enough for Dc to be computed.

The definition of KPI1 uses a criterion based upon the product R0.D(0). For each homogeneous road segment we compute$\mathrm{RA} = \sigma(\mathrm{R0.D(0)})/\mathrm{ave}(\mathrm{R0.D(0)})$, with ave(R0.D(0)) the average of product R0.D(0) on the segment and σ(R0.D(0)) its standard deviation. When there are less than 5 good quality measurements in the segment, RA is set to 0.

When $(\mathrm{RA} > 0.25)$ the structural performance is considered “bad” since an almost constant value for product R0.D(0) is expected in case of a healthy road structure. In this case KPI1 is defined as $\mathrm{KPI1} = \min(5\,;\ 1.75 + 5.\mathrm{RA})$.

When $(\mathrm{RA} \leq 0.25)$ and if $(\mathrm{ave}(\mathrm{R0.D(0)}) < \mathrm{LIM})$, where LIM=150,000, R0 is expressed in meters and D(0) in µm, KPI1 is defined as $\mathrm{KPI1} = \min(5\,;\ 3 + \mathrm{LIM}/\mathrm{ave}(\mathrm{R0.D(0)})\ )$. In [*15*] it is stated that for fully flexible roads ave(R0.D(0)) should be higher than 55,000 and it was observed in the data collected on the road network of Wallonia that this value is too low as a criterion for the mostly semi-rigid and rigid roads in the network.

All other segments must have a “normal” structural behavior, which does not mean that the bearing capacity is still sufficient. For these segments following formulas are applied for KPI1. With $T = 2 - \min(\ 2\ \ ;\ ave(T_z)/T_z^{max}\ )$, if $(\mathrm{T} < 1{,}65)$ then $KPI1 = \min(4\,;2{,}43\ .T)$ and otherwise $KPI1 = \max(4\,;2{,}86.T - 0{,}72)$. T_z^{max} is constant and set to 5; ave(Tz) is the average of Tz computed from all measurement data of “good quality” available in the road segment.

3.2.KPI2: Bonding Between (Upper) Layers

A small R0 may indicate lack of bonding between the upper layers in the road structure (see [*20*], [*21*]), and so does a large difference between D(0) and D(300) in the case of FWD data. For Curviameter data we observed that the “road noise indicator” (IBR) can indicate a lack of bonding between the upper layers. The IBR is computed on the raw signal coming from the geophone and expresses the “cleanliness” of the signal. The electrical signal expressed in Volts/mm/s represents the speed of mechanical vibration at the road surface while the Curviameter-truck passes by. The computer stores 100 points $s_1, s_2, \ldots, s_{100}$ on each signal. Only the 41 points $s_{55}, \ldots, s_{95}$ and their average S are used for the determination of the IBR, defined as: $IBR = \frac{1}{41}\sum_{j=55}^{95} ABS(\bar{s_j})$, where $\bar{s_j} = s_j - S$ and where ABS(x) is the absolute value of x. The value of IBR is usually smaller than 25 and lack of bonding can be excluded for (IBR < 2.5).

For KPI2, the ratio $RR = \text{decile2(R0)/ave(R0)}$ is computed, with decile2(R0) the second decile of R0 and ave(R0) the average of R0, only considering good quality data in the homogeneous segment. When (RR < V) for V = 0.75, it is considered that the variation of R0 is too important, indicating a great risk of lack of bonding in the top layers. In this case $KPI2 = 5 - (2/V).RR$ and otherwise, KPI2 is defined in different ways from FWD or Curviameter data as follows.

From FWD data $L = median\,(\frac{D(0)-1{,}15\,.D(300)}{D(0)})$ is determined, using all points in the segment. When (L≤0), $KPI2 = \max(0\,;2 + 13.4\,.L)$, otherwise $KPI2 = \min(5\,;2 + 1.3\,.L)$.

From Curviameter data, KPI2 is defined with the average value ave(IBR) of the IBR computed over all measurements in the segment: $KPI2 = \min\left(\frac{ave(IBR)}{10}.3;3\right)$.

Low values for KPI2 indicate poor bonding.

3.3.KPI3: Cohesion Of The Road Structure

The response of each geophone and of the force sensor of the FWD is stored over a period of 60ms, which gives the hysteresis curve for each geophone (see [*22*] on the interpretation of such data). Surface E(x) inscribed in the hysteresis curve represents energy. Also slope S(x) of the line through the origin and the point with the maximal deflection recorded by that geophone is used in the definition of KPI3.

From FWD data, KPI3 is defined as follows:

- When all energies E(x) have an absolute value less than 1:

  $$KPI3 = ABS(ave(\text{ABS(E(0))}))$$

  averaging over all points in the homogeneous segment, ABS(E(0)) being the absolute value of E(0).

- When all energies E(x) are larger than 15:

  $$KPI3 = \min(5\,;\ 3 + ave(\text{E(0)})/15)$$

  averaging over all points in the homogeneous segment.

In the other cases, “jumps” in energies and slopes are computed. For this, only the geophones at 0, 900, and 2100mm distance from the center of force impact are considered. When the ratios between consecutive energies and slopes are great, this may indicate a lack of cohesion in the “upper part” or in the “lower part” of the road structure:

- If (ABS(ABS(E(g0) – E(g900)) – ABS(E(g0)/2))>0,2.ABS(E(g0))), then count 1 jump for the energy in the “upper part”,
- If (ABS(ABS(S(g0) – S(g900)) – ABS(S(g0)/2))>0,25.ABS(S(g0))), then count 1 jump for the slope in the “upper part”,
- If (ABS(ABS(E(g900) – E(g2100)) – ABS(E(g900)/2))>0,2.ABS(E(g900))), then count 1 jump for the energy in the “lower part”,
- If (ABS(ABS(S(g900) – S(g2100)) – ABS(S(g900)/2))>0,25.ABS(S(g900))), then count 1 jump for the slope in the “lower part”.
- If the total number of jumps NTS (energy and slope counted together) in the same homogeneous segment is larger than 2 times the number of points NP in the segment, then $KPI3 = 2 + 2.(NTS/4)/NP$ (a value between 3 and 4),

- Otherwise, if the number of jumps in the “lower part” NINF (energy and slope counted together) in the same homogeneous segment is at least 1, then $KPI3 = 2 + 2.(NINF/4)/NP$ (a value between 2 and 3),
- Otherwise, denote if the number of jumps in the “upper part” (energy and slope counted together) in the same homogeneous segment by NSUP and $KPI3 = 1 + 2.(NSUP/4)/NP$ (a number between 1 and 2).

For Curviameter data the form of the deflection bowl is used. This curve is non-symmetric near the maximum deflection due to viscoelastic behavior of the bituminous layers at the road surface. Since the device starts measuring at 1m away from the rear axle, part of the bowl is not registered. We therefore ignore a little area around the maximal deflection and the second half of the measured curve. Define energy E(0) as $E(0) = ABS(\frac{\left(\sum_{i=1}^{25-shift} d_i - \sum_{i=26+shift}^{50} d_i\right)}{500})$, with d_1, d_2, d_3,…, d_{100} the 100 points representing the deflection bowl, n such that Dmax = d_n and shift = $|25 - n|$. The definition of E(0) is inspired by and analogous to the energy captured by a hysteresis curve of a geophone of the FWD. For each homogeneous segment, the average Em of all E(0) and the standard deviation σE is computed. Only measurements of “good quality” are considered. From Curviameter data, KPI3 is defined as follows:

- If (Em>Emax): $KPI3 = 3 + \min(\frac{Em}{Emax}\ ; 2)$,
- Otherwise, if (Em<Emin): $KPI3 = \max(Em/Emin\ ; 0)$,
- Otherwise, if ((σE/Em) <0.5): $KPI3 = 1 + \min(\frac{2}{Emax-1}.(Em-1); 2)$,
- Otherwise: $KPI3 = 3 + \min(\frac{2}{Emax-1}.(Em-1); 2)$.

We set Emin=8 and Emax=40.

3.4.Traffic Indicators

Indicator KPI4 is computed from the number of vehicles N_{vj} that use the homogeneous road segment per day: $KPI4 = 5.N_{vj}/N_{max}$. For the network in Wallonia N_{max}=120,000 is chosen, slightly more than the highest number of vehicles per day counted in 2006 on the network.

Indicator KPI5 must express the aggressiveness of heavy traffic. For this, traffic is divided into 5 categories:

A. Motorcycles (2 or 3 wheels, with or without side-car, with a 50cm^3 cylinder motor or more),
B. Cars (maximum 9 seats) and light vans (maximum 1.5T utility charge), with or without trailer,
C. Trucks (utility charge over 1.5T), trucks with trailer, tractors with trailer,
D. Busses,
E. Special vehicles (bulldozers, agricultural vehicles, military vehicles, exceptional convoys,…).

We disposed of the average composition of traffic on main roads and motorways according to these categories for each of the 5 provinces in the region. Per province we also disposed of the average percentage of heavy traffic (categories C, D and E together) w.r.t. the total traffic on main roads and on motorways separately. For almost all road sections we disposed of the total number of vehicles and the percentage of observed trucks.

Considering these 5 categories, the “aggressiveness” coefficient C of the traffic is defined by: $C = \sum f_X \,.\, \left(\frac{P_X}{P}\right)^{\gamma}$, where f_X is the frequency of the presence of vehicles of category X, P_X is the load of an axle of a vehicle in category X and P is the load of the “standard axle”.

With $I5 = n_{ess} \,.\left[\left(\frac{100-W}{100-H}\right).\left(f_B.\left(\frac{P_B}{P}\right)^{\gamma}\right) + \left(\frac{W}{H}\right).\left(f_C.\left(\frac{P_C}{P}\right)^{\gamma} + f_D.\left(\frac{P_D}{P}\right)^{\gamma} + f_E.\left(\frac{P_E}{P}\right)^{\gamma}\right)\right].N_j$, $KPI5 = min(5\,;\, I5/7{,}500{,}000\,.5)$, where $P_B = 0.75$, $P_C = P_D = 10$, $P_E = 11.5$, $P = 13$, $n_{ess} = 2.7$ (representing the average number of axles of truck using the considered road network), $\gamma = 4$ (other than rigid road) or $\gamma = 14$ (rigid road, [*23*]), f_X (for X=B, C, D or E) the proportion of category X in the spectrum of traffic in the province, H the average percentage of heavy traffic in the province, W the percentage of trucks observed during a counting campaign on the particular road section or estimated otherwise (with W=H if no information is available), and N_j the average of the total number of vehicles in the province.

In the case of a road with more than one lane in the same direction, we did not take into account the traffic distribution over the different lanes. The scale factor 7,500,000 approximates the largest number that could be expected for a road in the considered network.

3.5.The Global Indicator

Global indicator GI is to express the residual life of the road structure. Since KPI1 expresses the bearing capacity of the road structure, only KPI1 is weighed using traffic indicators KPI4 and KPI5.

Let D and M be defined by $\mathrm{D} = \mathrm{DIV(KPI1; 1)}$ and $\mathrm{M} = \mathrm{MOD(KPI1; 1)}$ so that $KPI1 = D + M$. The weighted indicator KPI1m is defined by: $KPI1m = min\left(5; D + min\left(1\,;\, M.(1 + KPI4.KPI5/25/5)\right)\right)$ and a combined indicator CSI is defined as: $= \frac{KPI1m+KPI2+KPI3}{3}$.

Global indicator GI is determined from CSI. When (CSI>3), the road segment is considered to be at the end of its life time. In that case, CSI is rescaled to a value for GI between 4 and 5 by the formula: $GI = 4 + \frac{1}{2}\,.\,(\,CSI - 3)$. When (CSI≤3), the cubic effect of the characteristic deflection on the life time of the road expressed in standard axles is introduced in the formula for GI: $GI = \frac{1}{16}.(CSI + 1)^3$.

4. CLASSIFICATION OF ROAD SECTIONS FROM INDICATORS

In contrast to the information needed for back-calculation of E-moduli, the computation of the global indicator is an operation easy to implement without need for road structure details and gives similar results when the objective is to identify homogeneous roads segments, to classify road sections to the type of intervention needed and to prioritize road works as we will show in this section.

4.1.Applying The Indicators To A Road Network

A total road lane length of approximately 1500km was measured with either FWD or Curviameter, about half of them being rigid structures. This resulted in the identification of 611 homogeneous segments with the FWD and of 956 homogeneous segments with the Curviameter.

All measurements were executed during autumn or spring (from autumn 2012 to early spring 2014). Temperatures were recorded during the measurements so that this information is available for finer exploitation of the data at project level, but for the calculation of the indicators no temperature corrections were applied.

4.2.Reading The Indicator Values

Indicator GI allows ranking and categorizing the homogeneous segments as a global assessment at the network level, where segments with (G≥4) are considered as having reached their "end of life". More information can be extracted from KPI1, KPI2 and KPI3 about the possible cause(s) of the ranking of a segment with (GI<4). This allows a first analysis for further investigations on project level. Indicator GI is an expression of "structural health". Bearing capacity is evaluated with KPI1 whereas KPI2 and KPI3 help identify possible weaknesses at different levels in the road structure. These two indicators may also point in the same direction of such weaknesses, being it rather weak bonding in the upper part or lack of cohesion in the lower part of the structure. Other intermediate data such as product R0.D(0), Tz and RR can support further interpretation of causes of distress. Collected deflections can be used for back-calculation of E-moduli in preparation of a particular rehabilitation project.

4.3.GI And Expected Residual Life-Time

The link was examined between GI and the expected residual life-time, where the latter was computed through back-calculation using the software Qualidim (formerly "DimMET", cf. [*24*], [*25*]) or Alizé (cf. [*26*]). Comparisons were made for 53 homogeneous segments on 8 road sections with different road structures, ages and qualities. They cover a rather wide range of types of road structures but were primarily selected in function of the availability of data on materials and layer thicknesses. For each segment, back-calculations were performed and the residual life expectancy was estimated. These were then compared to the values obtained for GI and an analysis was made of the possible causes of distress, both from the interpretation of the indicators leading to GI as from the interpretation of the obtained E-moduli. Note that life-time expectance resulting from back-calculations is not always accurate so that the comparisons made for this study cannot result in a true correlation between GI and real residual life-time. The objective was rather to demonstrate that GI gives a reasonable indication of the expected residual life-time so that it can be used for pavement management.

Rather than comparing the indicator values with the estimated residual life by back-calculation, the road manager would want to know what may be the cause of distress on the road. Often similar conclusions about the general state of the road segments are obtained from both approaches, as illustrated by the following two examples.

The first example is a motorway composed of a bituminous layer with thickness varying between 226 and 315mm (evidence from coring) on a base layer of estimated thickness of 200mm. Curviameter data resulted in 8 homogeneous segments. Back-calculation and expected life-time estimation was done using Qualidim. The results are presented in TABLE 1. For the last segment, two hypotheses were used resulting in different life-time expectations: $^{(1)}$ for a base layer of bound material, $^{(2)}$ for a base layer with unbound material. Results show that the conclusions from the indicators are very similar to the expected life-time estimation: GI ≥ 4 indeed corresponds to "end-of-life". In the 5th segment KPI1 is in accordance to the higher life-time expectation (KPI1 < 4) but additional information is revealed by KPI2 indicating bad bonding (increasing the GI). The road structure is in bad shape over almost all segments.

TABLE 1: Semi-Rigid Motorway: T zand Indicators from Curviameter Data, Estimated Life-Time Expectance by Back-Calculation with Qualidim.

start	end	Tz	KPI1	KPI2	KPI3	KPI4	KPI5	GI	Life-time in years
134.793	134.359	1.11	4.4	2.2	2.6	3.046	1.166	4.023	0
134.354	131.565	1.79	4	1.9	2.4	2.765	1.166	3.336	1
131.56	130.772	1.71	4	2.6	2.6	3.082	1.05	4.041	0
130.767	129.01	2.34	3.7	1.9	2	2.544	1.05	2.783	4
128.586	127.977	2.91	3.4	3.2	1.9	2.841	1.05	3.542	9
127.927	126.071	1.94	3.9	1.7	2.2	2.599	1.05	2.914	1
125.312	124.749	2.52	3.6	0.3	1.9	1.959	1.05	1.62	5
124.699	124.025	2.25	3.8	0.6	2	2.135	1.05	1.926	14(1) or 4(2)

The second example is a rigid, concrete motorway. The sub-base is 300mm thick; the base layer is made of 200mm thick lean concrete; on top there is a 200mm thick layer of continuous concrete. At some locations, this structure is covered with a bituminous layer of 40 or 90mm. Deflections were measured with the FWD and Alizé was used for back-calculation. The values for the indicators and the expected life-time estimations are presented in TABLE 2.

TABLE 2: Rigid, Concrete Motorway: indicators from FWD Data, expected life-time from Back-Calculations with Software Alizé (2 or 3 different computations).

place	bituminous layer	Tz	KPI1	KPI2	KPI3	GI	Life-time in years: three back-calculations		
							1	2	3
90293	90mm	6.07	1.91	2.04	2.17	1.755	16	40	
91004	90mm	6.07	1.91	2.04	2.17	1.755	>40	>40	
91604	40mm	2.7	3.55	3.14	2.5	4.032	23	14	13
92407	40mm	4.48	2.68	3.24	2.21	3.196	>40	35	29
94505	40mm	4.75	2.55	3.44	2.51	3.523	32	>40	>40
96801	40mm	4.75	2.55	3.44	2.51	3.523	28	40	13
97102	40mm	3.36	3.23	3.01	2.35	3.597	26	31	11
97603	40mm	3.36	3.23	3.01	2.35	3.597	>40	>40	31
101806	no	2.45	3.67	1.57	2.13	2.577	1	>40	
102407	no	3.95	2.94	3.22	2.08	3.293	>40	>40	
102809	no	2.17	3.8	3.3	2.5	4.101	0	>40	
104004	no	3.42	3.17	3.9	2.3	4.063	>40	>40	
104103	no	2.69	3.55	3.83	1	3.416	>40	>40	

Different parameter settings for bonding between layers in the model of Alizé gave different life-times and therefore two or three estimated life-time expectancies are presented for each measurement point. From the indicators it can be concluded that the structures with bituminous layer have a good bearing capacity but that the structure with the 40mm layer may have weak bonding. For the structure without bituminous layer the global indicator varies a lot. The high values for KPI2 may indicate that the lean concrete is severely cracked (rather than indicating a problem with bonding). Back-calculation shows a similar tendency. For the structure with the 90mm bituminous layer the expected residual life corresponds to KPI1 and somewhat less to GI under the influence of KPI2 and KPI3. For the third point in TABLE 2 the value for the global indicator seems to be too pessimistic w.r.t. the expected residual life. For the structure without bituminous layer, back-calculation delivers extreme results due to the very low E-modulus value for the base layer (computation 1) or for the sub base layer (computation 2).

5. CONCLUSIONS

In this paper we presented a transformation of rough deflection measurements on rigid, semi-rigid and flexible pavements into several “structural indicators” that combine into a global indicator for residual life time expectance. This approach was applied to the primary road network in Wallonia, Belgium in order to help the road manager in his decision making process on network level. We compared the values obtained for the indicators with the traditional back-calculation method used at project level and discussed the similarities. We conclude that the indicators can be used for categorizing road segments and for prioritizing structural maintenance interventions. They also give a first insight in possible causes of distress. The determination of values for the indicators is much simpler than the computations for the estimation of residual life time from back-calculations and is therefore better suited to an evaluation on network level than the back-calculation technique. The latter can still be done with the collected deflection measurements and comparing the E-moduli and the residual life estimate with the indicators can give a better understanding of the local situation at project level.

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REFERENCES

[*1*] Austroads Research Report. Consistency in Approaches to Road Network Segmentation and Data Aggregation – Review of Current Practice. *Austroads Publication No. AP–R276/05* (ISBN 1 921139 07 2). 2005.

[*2*] COST 336, Use of Falling Weight Deflectometers in Pavement Evaluation. *Final Report of the Action, Main Report, 2nd Edition,* April 2005.

[*3*] M. du Mesnil-Adelée, J.Peybernard. Traitement automatique des résultats de mesure en continu, *Bulletin de liaison des Laboratoires des Ponts et Chaussées N° 130,* March-April 1984, pp. 76-81 (in French).

[*4*] J.Lebeau. Traitement automatique de mesures pour un découpage de routes en zones homogènes, *rapport de stage de DESS,* étudiant de l'Université Paris VI sous la direction de Y.Lerolle du CEBTP, Octobre 1992 (in French).

[*5*] J. Litzka et.al., The way forward for pavement performance indicators across Europe *Final Report of COST Action 354,* July 2008.

[*6*] M. Crispino, G. Olivari, M. Poggioli, I. Scazziga. Including Bearing Capacity into a Pavement Management System. *Proceedings of the 7th International Conference on the Bearing Capacity of Roads, Railways and Airfields,* Trondheim, Norway, 27-29 June 2005.

[*7*] COST 324. Long term performance of road pavements. *Final report of the action COST 324.* – European Commission, Directorate general transport, Brussels, 1997.

[*8*] Entretien des chaussées. *Norme Suisse,* SN 640733b 1997.

[*9*] S. Jendia. Bewertung der Tragfähigkeit von bituminösen Straßenbefestigungen. *Veröffentlichungen des Institutes für Straßen- und Eisenbahnwesen der Universität Karlsruhe (TH),* Heft 45, 1995 (ISSN 0344-970-X, in German).

[*10*] M. J. Boussinesq. Application des potentiels à l'étude de l'équilibre et du movement des solides élastiques. *Gauthier-Villaars,* Paris, 1885 (in French).

[*11*] J.M.Bryce, G.W.Flintsch, S.W.Katicha, B.K.Diefenderfer. Developing a Network-Level Structural Capacity Index for Structural Evaluation of Pavements, *Final Report VCTIR 13-R9,* Virginaia Center for Transportation Innovation and Research, online reports, March 2013, see http://www.virginiadot.org/vtrc/main/online_reports/pdf/13-r9.pdf (Accessed Nov. 20, 2014).

[*12*] Z. Zhang, M.R. Murphy, S. Peddibhotla. Implementation Study of a Structural Condition Index at the Network Level. *Proceedings of the 8th International Conference on Managing Pavement Assets,* Santiago, Chile, 15-19 November 2011.

[*13*] A. L. Crook, S. R. Montgomery, W.S. Guthrie. Use of Falling Weight Deflectometer Data for Network-Level Flexible Pavement Management. *Transport Research Record: Journal of the Transportation Research Board, N° 2304,* TRB of the National Academies, Washington D.C., 2012, pp. 75-85.

[*14*] R.Carvalho, R.Stubstad, R.Briggs, O.Selezneva, E.Mustafa, A.Ramachandran. *Simplified Techniques for Evaluation and Interpretation of Pavement Deflections for Network-Level Analysis,* Federal Highway Administration, Report N° FHWA-HRT-12-023, December 2012.

[*15*] P. Autret. Utilisation du produit Rd pour l'auscultation des chausses à couche de base traitée. *Bulletin de liaison des Laboratoires des Ponts et Chaussées N° 42,* Déc. 1969, Réf. 740, pp.67-80 (in French).

[*16*] P. Autret, J.-P.Christory (presentation R.Sauterey). Méthodologie d'auscultation des assises traitées, *Bulletin de liaison des Laboratoires des Ponts et Chaussées N° 72 (Réf. 1455),* IFSTTAR, 1974 (in French).

[*17*] P.Keryell, P.Autret. Le renforcement de la déviation de Montargis, Constatations de laboratoire sur la chaussée existante. *Bulletin de liaison des Laboratoires des Ponts et Chaussées N° 47, pp.75-79,* 1970. (in French).

[*18*] M. Hossain, J. P. Zaniewski. Characterization of Falling Weight Deflectometer Deflection Basin. *Transport Research Board, 70th Annual Meeting,* Washington D.C., 13-17 January 1991.

[*19*] E. Horak, S. Emery. Falling Weight Deflectometer Bowl Parameters as Analysis Tool for Pavement Structural Evaluations. *Proceedings of 22nd ARRB Conference,* Canberra, 29 Oct. – 2 Nov. 2006.
[*20*] S. Chea, J.Martinez. Détection des défauts d'interfaces entre couches de chaussées à l'aide de la déflexion de surface, *24èmes Rencontres Universitaires de Génie Civil,* La Grande 1-2 juin 2006 (in French).
[*21*] R. Kobisch. Guide CFTR diagnostic et conception des renforcements de chaussées, *Presentation at the LCPC Séminaire "Durabilité structurelle des chausses: pathologies et entretien",* 9 Sept. 2008 (in French).
[*22*] C.A.Lenngren. Going beyond elastic response while evaluating falling weight deflectometer data. *Proceedings of the 8th International Conference on Bearing Capacity of Roads, Railways and Airfields* (ISBN 978-0-415-87199-0), Urbana-Champaign, IL, 2009.
[*23*] V. Veverka. Dimensionnement des chaussées à revêtement en béton de ciment - méthode de calcul. *Comptes Rendus de Recherche CR27/85,* Belgian Road Research Centre (in French).
[*24*] M. Lemlin, A. Jasienski, F. Van Cauwelaert, O. Pilate, B. Berlémont. Walloon Design Method for Concrete Pavements, Improvements since 2003. *Proceedings of the 10th International Symposium on Concrete Roads,* 18-22 Sept. 2006, Brussels.
[*25*] J. Maeck. Dimensionering van wegen met behulp van de software DimMET. *Proceedings of the XXIst Congrès belge de la Route,* Ghent, Sept. 2009 (in Dutch).
[*26*] Commercial software, see http://www.itech-soft.com/alize/ (Accessed Aug. 12, 2014).