Rehabilitation of roads containing cobblestone pavements covered with a bituminous layer.

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ABSTRACT: Historically, many roads in Belgium were constructed using cobblestones. In the past, cobblestone roads used by a limited amount of heavy traffic were sometimes covered with a bituminous layer. For numerous reasons it is often recommendable to replace the cobblestones when rehabilitating these roads. With their low budget or for urgent interventions, road managers sometimes prefer replacing the bituminous layer by a new one. One approach for the evaluation of structure rehabilitation was in use in Belgium since the late 1970ies and consists of the computation of a theoretical single layer model equivalent to the existing multilayer structure. Based on traffic expectations and an abacus of life-time expectations of a standard road structure, the optimal thickness of a bituminous overlay can be estimated. When the existing multilayer structure contains a cobblestone layer, the main difficulty with this approach arises from the choice of the "equivalence factor" for the cobblestone layer. When using back-calculation software, the main difficulty encountered is the choice of realistic parameters modelling the cobblestone layer. Values for parameters such as the layer thickness, the Poisson coefficient of the material, the degree of bounding with the other layers, and the initial guess for the E-modulus of the layer have to be introduced in the software for the cobblestones. Once the back-calculation delivered E-moduli for all layers in the introduced road structure model, a direct computation can estimate life-time expectance after repairs or the appropriate rehabilitation of the existing structure for a considered future traffic load. Both approaches were used and compared in real cases of rehabilitation design. In this contribution the limitations of road rehabilitation conserving a cobblestone layer below the surface layer will be discussed. Examples will illustrate the difficulties experienced when trying to estimate bearing capacity from FWD measurements and how they were dealt with.

KEY WORDS: Structural rehabilitation, cobblestones, falling weight deflectometer, ground penetrating radar.

1 INTRODUCTION

Historically, many roads in Belgium were constructed using cobblestones. In the past, cobblestone roads used by a limited amount of heavy traffic were sometimes covered with a bituminous layer. In this paper we will discuss evaluation techniques that allow evaluating life time expectance of rehabilitated road structures containing an old layer of cobblestones. The two techniques used in this paper are described in Sections 2 and 3. In Section 2 we present the approach for the evaluation of structure rehabilitation based on the "equivalent one-layer model" of the road structure. In Section 3 we present the back-calculation and rehabilitation approach on a multi-layer road structure model. Both techniques are applied to two cases in Section 4. In Section 5 we discuss issues related to the cobblestone layer. From these experiences we will present conclusions on realistic values for parameters modelling the cobblestone layer and on the influence of the overall state of the layer on bearing capacity.

2 EQUIVALENT SINGLE LAYER MODEL

One approach for the evaluation of structure rehabilitation was in use in Belgium since the late 1970ies and consists of the computation of a theoretical single layer model equivalent to the existing multilayer structure. This approach is described in BRRC report R56/85 (CRR R56/85), where detailed information is given for different types of materials. For this approach, an equivalent thickness for the imaginary one-layer model is computed using formula (1):

$$h_e = \Sigma\, a_i \,.\, h_i \qquad (1)$$

where h_e is the equivalent thickness, a_i are equivalence factors and h_i are the thicknesses of the different layers in the multi-layer model. In Table VII, on p.38 of CRR report R56/85 values are given for the a_i of different materials. In particular, for new bituminous materials $a_i = 2.70$ and for cobblestones $a_i = 1.25$ when in good condition and $a_i = 1.00$ if they move under heavy traffic load. Alternatively, the equivalence factor can be computed from formula (2):

$$a_i = \sqrt[3]{(E_i/500)} \qquad (2)$$

where E_i is the elasticity modulus for the corresponding layer. Hence, the imaginary layer has an E-modulus of 500 MPa and the cobblestone layer is supposed to have an E-modulus between 1000 MPa ($a_i = 1.25$) and 500 MPa ($a_i = 1.00$).

Then, the traffic parameter (kN_c) is to be computed with formula (3):

$$(kN_c) = k_p \,.\, N_p + k_f \,.\, N_f \qquad (3)$$

where $k_p = 1$ and $k_f = 1$ for a road with width larger than 3 m, N_p the estimated number of vehicles that have already made use of the road, and N_f the estimated number of vehicles that will do so in future. When the traffic has been counted, formulas (4) and (5) can be applied:

$$N_p = J \,.\, N \,.\, (\,(1+t)^x - 1\,) \,/\, (\,t \,.\, (1+t)^x\,), \qquad (4)$$

$$N_f = J \,.\, N \,.\, (\,(1+t)^y - 1\,) \,/\, t, \qquad (5)$$

where J (number of days in the year), N (number of heavy vehicles per day), t (yearly increase factor of traffic, in percentage), x the number of years the current road structure is in service, and, y the number of years the improved structure is expected to last.

3 APPROACH BY BACK CALCULATION

The modern approach for the evaluation of structure rehabilitation used in Belgium today makes use of software that implements the behaviour of a multi-layer model of the road structure. One of the software tools in use is the software DimMET© presented in previous publications (cf. (Lemlin et al. 2006) and (Maeck 2009)). This kind of software is well-suited for common road structures in Belgium and commonly used road materials for which the behaviour is well-studied. The software DimMET© for instance comprises a database with mechanical parameters for the different road materials used in Belgium.

In the case of an ordinary structural evaluation of an existing road structure followed by the design of improvement for that structure, the following steps are taken. First, information is gathered about the materials that are present in the existing structure. This is often done by coring and sometimes combined with Ground Penetrating Radar (GPR) measurements (when structure variations are expected or in order to see the continuity of the structure between the cores). Then deflection measurements with the FWD are carried out. The deflections measured by the FWD are then used in a back calculation procedure in which the road structure is modelled (and often somewhat simplified) by a multi-layer system. These computations give an estimate for the elasticity moduli of the different layers considered in the multi-layer model. Rehabilitation strategies are modelled by modified versions of the multi-layer system used for back calculation: the user can try out direct calculation with different thicknesses for the new layers. Direct computation uses information about the performance of new materials, takes into account available information about traffic and gives estimates for life time of the improved road structure. However, the cobblestone layer is not an ordinary base course layer and parameters for cobblestones as road material in a multi-layer model are not well-known. In the book of B. Shackel (Shackel 1990) we find ranges from 500MPa to 7000MPa and more for the E-modulus of typical block pavements determined from Falling Weight Deflectometer (FWD) measurements. In the cases reported in this paper, we did use the software DimMET© for back calculation and for life time estimation of a rehabilitation of the exiting road structure and compared the obtained results with those obtained with the first approach.

4 CASES OF REHABILITATION DESIGN

Both approaches were used and their results were compared on several cases. In all cases, deflections were measured in late spring time with the FWD of the BRRC. In the case of the local road, an investigation was done with the GPR of the BRRC. In both cases, information about the road structure in place was gathered by the road administrator by coring. In the case of the secondary road, a short campaign of traffic counting was done by the road administrator. The results of the FWD deflection measurements were treated as prescribed in the final report of COST 336 (COST 336) for the determination of “homogeneous zones”.

4.1 Case 1: a Secondary Road

The secondary road under investigation was originally built with cobblestones on the ground. Later, the cobblestones were covered with an asphalt layer of 60 to 100 mm thick. Since the opening of a distribution center of goods for a supermarket chain nearby, the road is used by a greater number of trucks going to and from this distribution center. The road administrator planned a rehabilitation of the road structure aiming at a service life of about 20 years. He would have liked to keep the cobblestones in place and to improve the structure by the replacement of part of the asphalt layer by a thicker one.

We considered that mainly two types of degradation could occur of the structure in place: fatigue of the asphalt layer in place (due to the ageing of the material and the high traffic loads) including the appearance of reflection cracks at the joints between the cobblestones, and a lack of bonding between the asphalt layer and the cobblestones.

First, back calculation with DimMET© gave an estimate of elasticity moduli from FWD deflection measurements. The structure given in Table 1 was used in the computations.

Table 1: Multi-layer model of the road structure

Road structure layers	Thickness (in mm)	Initial EModule (in MPa)	Poisson coefficient	Bonding to next layer (0.1 to 1.0)
Layer 1 (asphalt)	90, 100 or 120	15000	0.35	0.10 or 0.50
Layer 2 (Cobblestones)	100	3000	0.20	0.50
Layer 3 (ground)	-	60	0.50	-

The results of the calculations are given in Tables 2 and 3 (one for each road direction). The obtained estimations of the E-moduli of the three layers are given in the last three columns of Tables 2 and 3 (E1 for the asphalt layer, E2 for the cobblestone layer and E3 for the ground).

Table 2: Back calculation results in road direction 1

Point id.	Thickness layer 1 (in mm)	Thickness layer 2 (in mm)	Bonding layer 1 to 2 (0.1 to 1.0)	Bonding layer 2 to 3 (0.1 to 1.0)	E1 (in MPa)	E2 (in MPa)	E3 (in MPa)
12	100	100	0.50	0.50	25358	757	135
8	100	100	0.50	0.50	59028	83	146
9	100	100	0.50	0.50	24125	102	125
25	100	100	0.10	0.50	11073	1976	96
25	100	100	0.50	0.50	6315	1870	96
49	100	100	0.10	0.50	12406	2986	127
49	100	100	0.50	0.50	6503	2763	128
44	100	100	0.10	0.50	16258	31	74
44	90	100	0.50	0.50	21785	30	74

Table 3: Back calculation results in road direction 2

Point id.	Thickness layer 1 (in mm)	Thickness layer 2 (in mm)	Bonding layer 1 to 2 (0.1 to 1.0)	Bonding layer 2 to 3 (0.1 to 1.0)	E1 (in MPa)	E2 (in MPa)	E3 (in MPa)
10	100	100	0.10	0.50	9831	5840	108
3	100	100	0.50	0.50	16666	875	159
3	100	100	0.10	0.50	19108	1123	159
7	100	100	0.50	0.50	7716	2877	94
7	100	100	0.10	0.50	12752	3507	93
21	100	100	0.10	0.50	2625	7854	108
21	100	100	0.50	0.50	3038	4042	109
36	100	100	0.50	0.50	3737	54935	115
16	100	100	0.50	0.50	7031	618	84
52	100	100	0.50	0.50	30477	80	157
47	100	100	0.10	0.50	42013	8100	174
47	100	100	0.50	0.50	7533	20192	177
47	120	100	0.50	0.50	14954	6924	175
45	100	100	0.50	0.50	18238	138	128
45	120	100	0.50	0.50	11345	106	129

Since back calculation is an iterative process toward a local optimum solution for the computations, the results are not always very stable: small variations in the input parameters give different results or prevent conversion. Also, some of the results are not very realistic from an engineering point of view. Hence the results of the computations must only be considered as some helpful information in the decision making process by the engineer!

In direction 1, the solution for point 8 is unstable and not very realistic. For points 25 and 49 the bond factor 0.50 gave a better match between measured and computed deflections than the bond factor 0.10. For point 44, no stable solution could be found with asphalt thickness equal to 100 mm and bond factor 0.50.

In direction 2, the computation for point 10 would not converge for better bonding. The solution for E2 at point 21 seems more appropriate when the bond factor 0.50 is chosen. The results for point 36 are not realistic. For points 45 and 47 the computations were done for a thicker asphalt layer of 120 mm. In the case of point 45, the asphalt layer thickness only influences the E-modulus of that layer. However, for point 47 a situation with a thinner asphalt layer and bad bonding is probably the most realistic hypothesis.

As a next step, the thickness of an overlay was determined using the two different approaches described in the previous sections.

For the first approach, Table 4 of traffic counted on the road under investigation was interpreted.

Table 4: Traffic on the secondary road

Weight (estimate in T)	Number of axles	Percentage of traffic
5 to 6 (incl.)	169	2.4%
6 to 7 (incl.)	477	6.9%
7 to 8 (incl.)	1348	19.5%
8 to 9 (incl.)	2445	35.3%
9 to 10 (incl.)	929	13.4%
10 to 11 (incl.)	1064	15.4%
11 to 12 (incl.)	494	7.1%

We combined the last column of Table 4 with a number of heavy vehicles equal to N = 200 per day over J = 300 days a year and we considered a yearly traffic increase of 5% (t = 0.05). We considered 3.94 axles per vehicle, which corresponds with the counted traffic. We arbitrarily chose x = 25 years, for the number of years that the old structure is already in place. This gives us a value for the traffic parameter (kN_c) of approximately $2.8 \,.\, 10^6$.

For the values of the equivalence factors a_i we compared the values given in Table VII of CRR report R56/85 with values computed from the E-moduli estimated by back calculations with DimMET©. We chose an average value for the equivalence factors a_i corresponding to the average performance of the road structure in place, and an extreme value for a_i corresponding to locations where the bearing capacity of the road structure in place seemed weaker than average. Table 5 gives the chosen values for equivalence factors a_i and the resulting equivalent thickness of the one-layer model:

Table 5: Equivalence factors

Layer	Thickness h_i (mm)	a_i average	a_i extreme
1. bituminous	100	2.70	1.70
2. cobblestones	100	1.25	0.50
h_e equivalent thickness:		h_e = 395 mm	h_e = 220 mm

With the graphs established in 1991 (Figures 12 and 13) in CRR report R56/85, ideal thickness $H_e = \Sigma\, a_i \,.\, H_i$ of the bituminous layer for rehabilitation purposes can be determined. We determined the following values of ideal thickness:

H_1 = 180 mm (bituminous layer, a_1 = 2.70), H_2 = 230 mm (layer of crushed stone base, a_2 = 1) et H_3 = 180 mm (layer of granular material, a_3 = 0.75) and hence an ideal equivalent thickness of H_e = 851 mm. When we take as a hypothesis that the rehabilitation is executed by simply putting a bituminous layer on top of the existing structure, formula (6) allows computing the thickness of the overlay:

$$W = (H_e - h_e) / 2.7 \tag{6}$$

where the factor 2.7 is the equivalence factor for bituminous materials. For the parts of the road with average performance, W is then equal to 168.8 mm and equal to 233.7 mm for the part of the road with poor performance. The execution of such a thick overlay seems completely unrealistic.

For the second approach, we took the climate into account as yet another parameter influencing the computations. In our computations we selected the appropriate climate characteristics provided by the database of DimMET©.

The software DimMET© allows modeling the evolution of bonding between layers over time. For bonding between different bituminous layers, we chose a constant and perfect bonding. For the bonding between the bituminous layer and the "unbound base course" representing the cobblestones, we set an initial bonding of 0.1 or 0.5 according to the results of the back calculation and a bad bonding of 0.1 after 10 years.

For the computations, we kept 40 mm of the original asphalt layer in place and considered that the overlay must be at least 40 mm thick.

The objective was finding an overlay that guarantees an expected life-time of 20 years, given the spectrum of the expected traffic. We used the E-moduli obtained from back calculation and chose bituminous mixtures that are typically used on Belgian roads and for which data are available in the database of DimMET©: split mastic asphalt SMA 10 70/100 (SMA-C1) and bituminous concrete with granularity 0/14 and binder 50/70 (BB-3B). Most of the time, 40 mm of SMA-C1 on top of 40 mm of BB-3B was sufficient, but at some points the expected life time was not reached as illustrated by Tables 6 and 7.

Table 6: Estimated life time (in years) for particular overlays (in direction 1)

Point ref.	SMA-C1 (mm)	BB-3B (mm)	Existing layer (mm)	Expected lifetime
25 (a)	50	40	40	17
25 (b)	80	40	40	16
49 (b)	60	40	40	17
44	70	40	40	19

Table 7: Estimated life time (in years) for particular overlays (in direction 2)

Point ref.	SMA-C1 (mm)	BB-3B (mm)	Existing layer (mm)	Expected Lifetime
7	40	40	40	13
16	70	40	40	6
45 (a)	40	40	40	13
45 (b)	80	40	40	19

This may lead to the conclusion that an overlay of at least 80 mm is necessary and that this is not sufficient in all places. Indeed, in order to reach the expected lifetime of 20 years in all places, our computations with DimMET© suggest an overlay of 120 mm thick.

4.2 Case 2: a Local Road

The second case under investigation was a local road that was already rehabilitated. The old bituminous layer on top of a cobblestone layer was replaced by a new one. The objective of the measurements and computations for this case was double: evaluate whether the structural behavior was homogenous or not and identify structural weakness if present.

The road administrator provided information on the thickness of the new bituminous overlay, obtained by coring at 3 different places. This information was completed by measurements with the ground penetrating radar of the BRRC. An extract of the resulting GPR profiles is shown in Figure 1. Deflection measurements were performed using the FWD of the BRRC. From these data, E-moduli were estimated using the back calculation module of the DimMET© software. The 4-layer model used for back calculation is given in the first column of Table 8. The sand layer was very dense, so we chose a high Poisson coefficient equal to the coefficient of the soil. In this model the type of materials was considered identical for all back calculations but the thicknesses of the different layers varied and matched with the observations from the cores as given in Table 8. For the thickness of the new bituminous layer, we also used the GPR data for the back calculations.

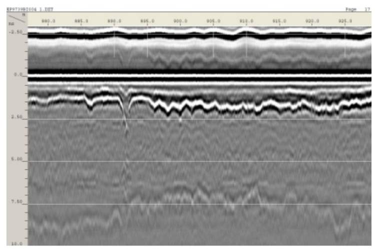

Figure 1: A short part of the GPR profile measured on the local road.

Table 8: 4-layer model for back calculation

Materials in the layers	Poisson coefficient	Bonding to layer below (0.1 to 1.0)	Thickness core 1 (mm)	Thickness core 2 (mm)	Thickness core 3 (mm)
Bituminous	0.35	0.8 to 0.1	120	140	100
Cobblestones 16/16/17	0.20	0.9	170	170	160
Sand	0.50	1	260	240	170
Clayey soil	0.50	-	-	-	-

The back calculation was executed on several points where FWD measurements were done in the vicinity of the locations of the cores. Some of the results of our computations are given in Table 9. For the point with id number 687 the iteration only converged when fixing the E-modulus for the first layer. For the point with id number 689 the iteration only converged when fixing the E-modulus for the soil. The last line in Table 9 was obtained when setting the Poisson coefficient for layer 2 to 0.40. Table 9 also indicates the thickness of layer considered in the individual computations, as they were determined from GPR measurements.

However, we observed great differences between the deflections measured at the different points. At some points the maximal deflection was as high as 900 µm and at other points as low as 160 µm with an average of about 600 µm. The ratio between the deflection measured at 300 mm from the place of impact and the maximal deflection was about 0.7. These observations may be explained by a weak bonding between the bituminous layer and the cobblestone layer or by some instability of the cobblestone layer.

Table 9: Back calculation results

Point id.	Core nearby	Thickness layer 1 (mm)	E1 (MPa)	E2 (MPa)	E3 (MPa)	E4 (MPa)
312	1	122	6558	23977	6412	167
367	1	100	3531	1206	11	111
682	2	102	5780	611	51	89
686	2	120	5239	2571	34	527
687	2	120	5915	1613	316	604
689	2	120	4302	671	27	100
687	2	138	4500*	1804	261	608
689	2	133	2621	1264	4	110*
1131	3	122	6604	60	6356	103
1131	3	100	10770	50	2765	101

In this case the average E-modulus obtained for the cobblestone layer is roughly about 1400 MPa when ignoring the most extreme values given in Table 9. This corresponds to an equivalence factor $a_2 = 1.41$. As an extreme value for a_2 we could consider 0.46 (for point with id. number 1131, last line in Table 9) or 1.07 (for point with id. number 682). The extreme value corresponding to a very low E-modulus may indeed confirm that there are places where the cobblestone layer is not very stable.

In this case, no traffic measurements were available. We considered two options: 50 or 200 trucks a day, during 300 days per year, with a 5% yearly increase and 4 axles per truck. In DimMET© this is translated in a standard traffic spectrum. The option of 50 trucks per day is closer to reality but we consider more traffic in order to estimate the influence of traffic on life time expectance. This gives us values for the traffic parameter ($k_f.N_f$) of approximately $4.96 \,.\, 10^5$ and $1.98.\, 10^6$. We arbitrarily chose x = 25 years, for the number of years that the old structure is already in place. This gives us the total traffic (kN_c) of about 7.10^5 (50 trucks per day) and $2.8.\, 10^6$ (200 trucks per day).

First we applied the one-layer equivalence approach. Table 10 gives the chosen values for equivalence factors a_i and the resulting equivalent thickness of the one-layer model:

Table 10: Equivalence factors

Layer	Thickness h_i (mm)	a_i average	a_i extreme
1. bituminous	40	2.70	1.70
2. cobblestones	170	1.41	0.46
3. subbase of sand	240	0.75	0.75
h_e equivalent thickness:		h_e = 528 mm	h_e = 326 mm

With the graphs established in 1991 (Figures 12 and 13 in CRR report R56/85), ideal thickness $H_e = \Sigma\, a_i \,.\, H_i$ of the bituminous layer for rehabilitation purposes can be determined. We determined the following values of ideal thickness: H_1 = 110 to 140 mm (bituminous layer, $a_1 = 2.70$), H_2 = 190 to 210 mm (layer of crushed stone base, $a_2 = 1$) and H_3 = 150 mm (layer of granular material, $a_3 = 0.75$) and hence an ideal equivalent thickness of H_e = 600 mm (for 50 trucks per day) and H_e = 700 mm (for 200 trucks per day). When we take as a hypothesis that the rehabilitation is executed by simply putting a bituminous layer on top of the existing structure, formula (6) allows computing the thickness of the overlay, where the factor 2.7 is again the equivalence factor for bituminous materials. For the parts of the road with average performance, W is then in the range between 26.6 mm and 101.2 mm (for 50 trucks per day) and between 64.0 mm and 138.6 mm (for 200 trucks per day). Hence, for a low traffic amount the overlay thickness is reasonable and can probably be executed whereas the estimated thickness for more traffic is less realistic. The range of needed thickness is very wide since the E-moduli obtained from back-calculation vary a lot. This shows the importance of the stability of the cobblestone layer for its bearing capacity.

We used the data given in Table 9 where we rounded off thickness of layer 1 to 10 mm, and where we used standard bituminous material types for the overlay. The computations with DimMET© resulted in the estimated life time expectances given in Table 11, for future traffic ($k_f.N_f$) of $4.96 . 10^5$ and $1.98. 10^6$ respectively.

Table 11: Calculation of life expectance with DimMET©: results

Point id.	Core nearby	Thickness layer 1 (mm)	Life time for 50 trucks per day (years)	Life time for 200 trucks per day (years)
312	1	120	more than 20	more than 20
367	1	100	18	6
682	2	100	8	2
686	2	120	more than 20	more than 20
687	2	120	more than 20	more than 20
689	2	120	19	7
687	2	140	more than 20	more than 20
689	2	130	more than 20	13
1131	3	120	15	5
1131	3	100	12	3

From these results we can conclude that the bearing capacity of the cobblestone layer is generally good enough for a designed life time expectancy of about 20 years. However, at some places, where we have strong indications that the cobblestone layer is unstable or where the bonding with the bituminous layer is insufficient, we can see that the life time expectance is much shorter. This means that the road manager will face the necessity for some local repairs within the first 10 years. Moreover, for a higher traffic volume the life time expectance by design would be insufficient.

5 COBBLESTONES: LIMITATIONS AND DIFFICULTIES

The cases show well that both approaches of structural evaluation of the rehabilitation of a road structure containing a layer of cobblestones have their difficulties and limitations. All cases presented indicate that keeping cobblestones in place is not just a matter of bearing capacity but also a problem of a non-homogeneous behavior, of bonding and of layer stability.

5.1 The difficulties of keeping cobblestones in the structure

When a cobblestone layer is in good shape, the bearing capacity of this layer can very well be sufficient for certain types of roads. In order to evaluate the bearing capacity both approaches presented above can be used. However, a cobblestone layer can also be unstable, as already taken into consideration by the oldest of both approaches when computing the service life with different values for the equivalence factor. Also back calculation can help in evaluating the differences in bearing capacity. But certainly other problems may occur when an unstable cobblestone layer is playing the role of base course such as the appearance of local depressions and premature cracking at the joints between the numerous cobblestones.

5.2 Limitations of bearing capacity evaluation in presence of cobblestones

The evaluation of bearing capacity taking into account the presence of an old layer of cobblestone is hazardous. In the case of the one-layer equivalence approach, the choice of the equivalence factor for the cobblestone layer is based on an appreciation of the stability of the layer or on the estimated E-modulus from back calculations. The latter is only an estimate and all computations based upon it are thus sensitive to an, at times, rather large imprecision of the E-modulus. Moreover, movements in the cobblestone layer may easily reduce the quality of bonding with the bituminous layer on top of it and thus result in a quicker loss of bearing performance.

6 CONCLUSIONS

Both computation methods used in this paper give similar results w.r.t. the life time expectance of road structures with a cobblestone layer. The equivalent layer method is somewhat less precise and can give an overestimate for the overlay thicknesses needed. The paper shows that a rational approach using numerical tools and field data are necessary to analyze non-conventional road structures using non-traditional materials. On both examples presented in this paper, both methods show that the stability of the cobblestone layer influences greatly the bearing capacity and that local weaknesses will inevitably have to be treated by local repairs.

The E-modulus corresponding to equivalence factor 1.25 (given in CRR report R56/85 for a stable layer of cobblestones, hence approximately 1000 MPa) seems to be an underestimate for a competent cobblestone layer. From the computations presented in this paper we would rather propose a value for the E-modulus between 1400 and 2000 MPa. The E-modulus corresponding to equivalence factor 1 seems too high for an unstable layer of cobblestones since we estimated lower values for the E-modulus in the cases presented in this paper. From our experience we conclude that the expected life time can be sufficient for low traffic roads but local repairs may well be needed much earlier (illustrated by case 2: local deficiencies after 8 years).

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