The low-strength interlayer:

a realistic assumption or an expensive approximation in the back-calculation process

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Abstract
From publications it can be concluded that quite often a low-strenght interlayer is being found in the back-calculation process of FWD data. This low-strenght interlayer is either part of the pavement structure or specifically added to create a better fit between the measured and back-calculated deflection profile or surface modulus. However it is intriging to see that thsi low-strength interlayer quite often gets a thickness of 1000mm in a 4-layer model. It appears that this is an arbitrair chosen thickness not having any relationship with the actual pavement structure. For an existing pavement structure a decrease in strenght of a base layer or upper part of the subgrade could be due to infiltration of moist through existing cracks. Quite often supporting information for the existance of a weak (inter)layer is not available or has not been investigated. When however weak (inter)layers are observed as well for new pavement structures this does seem to be questionable.

In this paper does discuss this phenomenon which seem to be attributed to the non-linear behaviour of unbound materilas in the pavement structure. As such the use of a low-strength interlayer does seem to be an accepted method to cope with a non-linear behaviour based on a sharp increase of the surface modulus with depth. Assuming a stiff layer at a certain depth is also used to compensate for non-linear behaviour. No allowance is however made for the fact that that this can have an effect on the calculated stresses and strain at certain critical locations. But more often non-linear behaviour is not recognized when the increase with depth of the surface moduls is less striking resulting in a 3-layer model in a lower stiffness for the unbound base layer in comparison to the stiffness of the subgrade. A lower strength base layer or interlayer due to a non-linear behaviour can result in more expensive maintenance measures. Or in other words an expensive consequence when this low-strenght (inter)layer in reality does not exist.

1. Introduction

In the use of the FWD as well as analysis of the data great care must be applied to the proper functioning of the equipment, quality of the measured data and the related engineering recommendations. Amongst others the CROW Record 17 [1] and the COST 336 publication [2] do supply a good overview starting with the calibration of the FWD equipment up to the analysis of the measured data.

The back-calcualtion of the stiffness of each layer in a pavement structure is one of the most important steps of a FWD measurement because the result will directly influence the the maintenance and rehabilitation recommendations. And almost as important as the analysis as a whole is the measurement of the temperature of the bituminous surfacing. This because the stiffness at the temeprature during the measuremnts will be corrected to a stiffness at the reference temperature. Not to ignore the mecahnical characteristics of the material in the pavement structure such as fatigue relationships.

In the UK as well as in the Netherlands much attention is being paid that the FWD output is reproducible and repeatible in the mandatory correlation trials organized every year or every second year. A factory calibration of the geophones and loadcell is always part of the maintenance procedures before a machine does take part in these trials. Using a FWD that has passed the trails and has the most updated calibration values does however not imply that the reported analysis results are correct as the analysis of the data has many pitfalls to overcome.

2. Surface modulus

In the back-calcualtion process of a modelled pavement structure use is made of the surface modulus to get a better idea of the varaition of stiffness with depth [3]. Figure 1 does show an example of the deflection profile and the related surface modulus for the same test location.

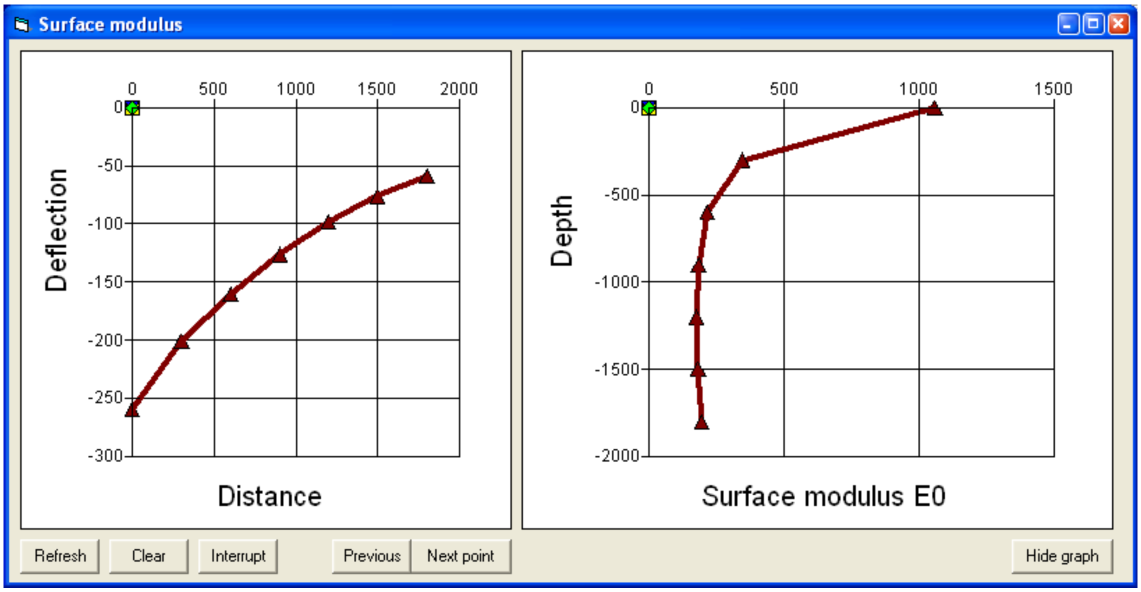

Figure 1: Deflection profiel with surface modulus

The surface modulus in Fugire 1 could be rated a showing a linear behaviour even with the slight increase of the stiffness with depth that can be observed. The three main shapes of the surfaces modulus are shown in Figure 2, namely form left to right: a p[avement structure with a low-strength interlayer, a pure linear behaviour and a non-linear behaviour or the existance of bedrock at a certain depth.

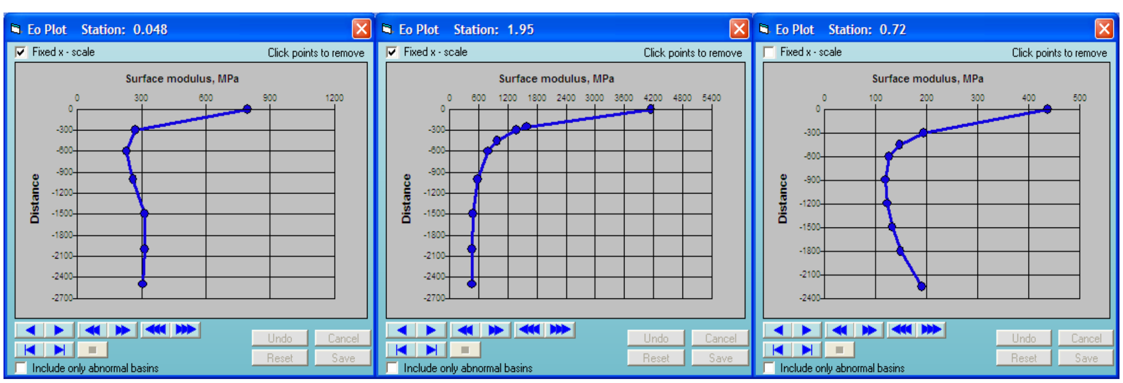

Figure 2:Characteric surface moduli

Software to back-calculate deflection data can be either following a pure linear approach possibly using an additional interlayer to correct for a non-linear behaviour or using a rigid support at a fixed depth such as for instance MODULUS, CARE and PAVERS. There is as well software, like for instance ELMOD, in which non-linear behaviour is integrated in the back-calcualtion process. Table 1 does show the results of the back-calculated layer stiffness between a linear and non-linear approach using the deflections as shown in Figure 1.

Table 1: Result back-calculation layer stiffness

Back-calculation result km 7.735	**Linear**	**Non-linear**
Layer thickness asphalt [mm]	350	350
Layer thickness unbound granular material [mm]	450	450
Stiffness modulus asphalt [MPa]	4926	4283
Stiffness modulus unbound granular material [MPa]	113	258
Stiffness modulus subgrade [MPa]	215	122

The difference in the back-calculated results is obvious whereas the fit [%] is quite similar, namely 1.07 and 1.79. Or in other words a good fit is not synonymous with a correct result. It is common knowledge that a good fit does not stand for a correct answer as there are multiple solutions having the same goodness of fit. It will be the engineer to decide which answer does meet the mechanical characteristic of the materials the best. In this case it concerns a new pavement structure but it is clear that the linear back-calculated results do result in a shorter life time due to the poor strength of the unbound base layer. It appears that at first sight a 'non-suspiceous' pavement structure can show a clear non-linear behaviour having a large impact on the calcualted structural life.

The seond example deals with a road section were the back-calculated result of the software package CARE is compared with the result based on ELMOD 6 with a clear substantial difference in result. Table 2 does show an overview of the pavement structure and back-calculated stiffnesses.

Table 2: Results back-calculation layer stiffness

Terugrekenresultaat wegvak	**CARE**	**ELMOD 6**
Layer thickness asphalt [mm]	320	320
Layer thickness blast furnace slag [mm]	200	200
Stiffness modulus asphalt [MPa]	8029	6840
Stiffness modulus blast furnace slag [MPa]	49	509
Stiffness modulus subgrade [MPa]	213	149

In this case as well the surface modulus does show hardly an increase with depth of the stiffness, however the behaviour is non-linear. The CARE analysis does result in major strengthening whereas the ELMOD results tell that no measure is required. Despite the perfect fit the combination of 49MPa for the blast furnace slag and 213MPa for the sand subgrade analysed by CARE does not seem to be realistic. No additional investigation was put in place to double check the very low strength of the blast funace slag as this low value should have raised some concern when correct.

3. The interlayer

To improve on the analysis of deflection measurements the subgrade is being divided into two layers in case of a strong increase in the surface modulus with depths due to non-linearity. The upper part of the subgrade is given a thickness varying between 0.5 and 1.0 meter whereas the seond layer is infinite with depth. Several publications have been found were this apporach has been adopted. In [6] the construction of a new pavement structure is being explained in which the achieved bearing capacity is being measured using a FWD.
Table 3 summarizes the pavement sructure being built and the back-calculated average stiffness per homogeneous sub-section using PAVERS-PADS based on a 3-layer pavement model.

Table 3: Result back-calculation layer stiffness

Back-calculation result road section	**1**	**2**	**3**
Layer thickness asphalt [mm]	60	60	60
Layer thickness stabilization [mm]	250	250	250
Layer thickness interlayer [mm]	600	600	600
Stiffness modulus asphalt [MPa]	3605	3128	3493
Stiffness modulus stabilization [MPa]	5735	5234	5432
Stiffness modulus interlayer [MPa]	203	148	223
Stiffness modulus subgrade [MPa]	376	399	294

Although real pertinant data about the measured deflections is not supplied the added interlayer does result in a better fit. This interlayer does become almost automatically the weakest layer of the pavement structure. In a second example [7] a new airport pavement is being evaluated using a HWD after a reconstruction has taken place. To get a better fit between the measured and back-calcualted deflection profile using BAKFAA it was decided to use an additional interlayer (see Table 4).

Table 4: Result back-calculation layer stiffness

Back-calculation road section	**G1**	**G2**	**R**
Layer thickness asphalt [mm]	160	160	160
Layer thickness cement stabilization [mm]	200	200	200
Layer thickness unbound + lime stab. [mm]	450	450	450
Layer thickness interlayer [mm]	1000	1000	1000
Stiffness modulus asphalt [MPa]	6930	6790	6394
Stiffness modulus stabilization [MPa]	1468	3240	692
Stiffness modulus unbound + lime stab. [MPa]	434	612	352
Stiffness modulus interlayer [MPa]	99	150	81
Stiffness modulus subgrade [MPa]	324	319	299

In this case as well the interlayer is being used to achieve a better fit with the measured deflection profile. The ratio between the low stiffness of this interlayer and the relatively high stiffness of the subgrade is questionable.

4. The non-linear approach

The surface modulus can have a sharpe increase with depth necessitating an ninterlayer to achieve an acceptable fit between the measured and back-calcualted deflection profile. Figure 3 shows an example of this tyep of surface modulus and the poor fit based on a linear approach in the back-calcualtion process.

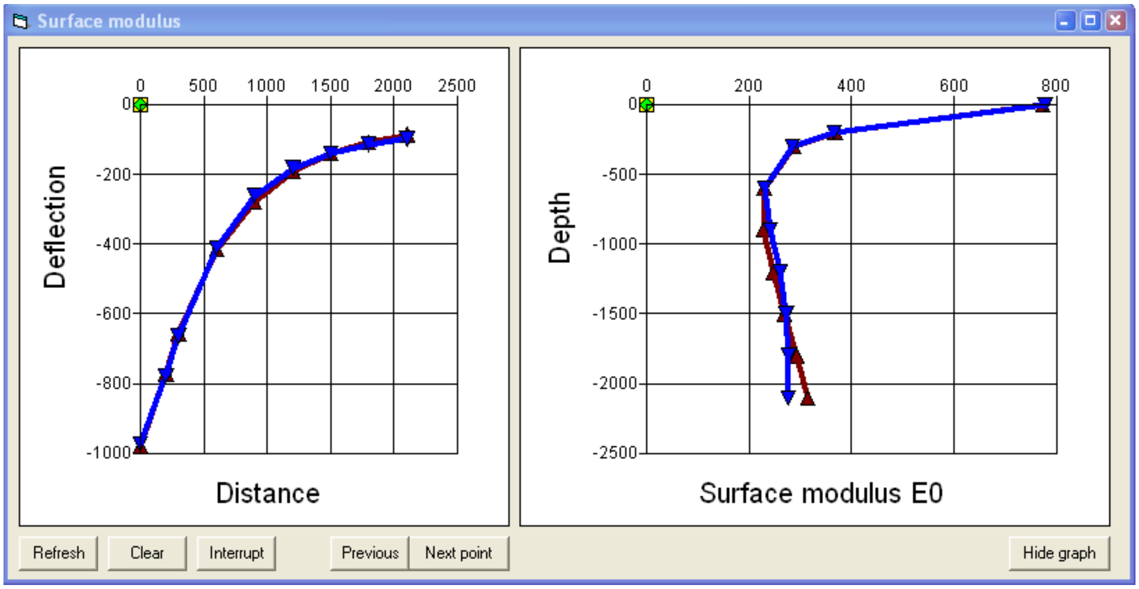

Figure 3: Poor fit linear approach

Using a non-linear approach to start with [8] Figure 4 shows the good fit that can be achieved without the need to introduce an additional interlayer.

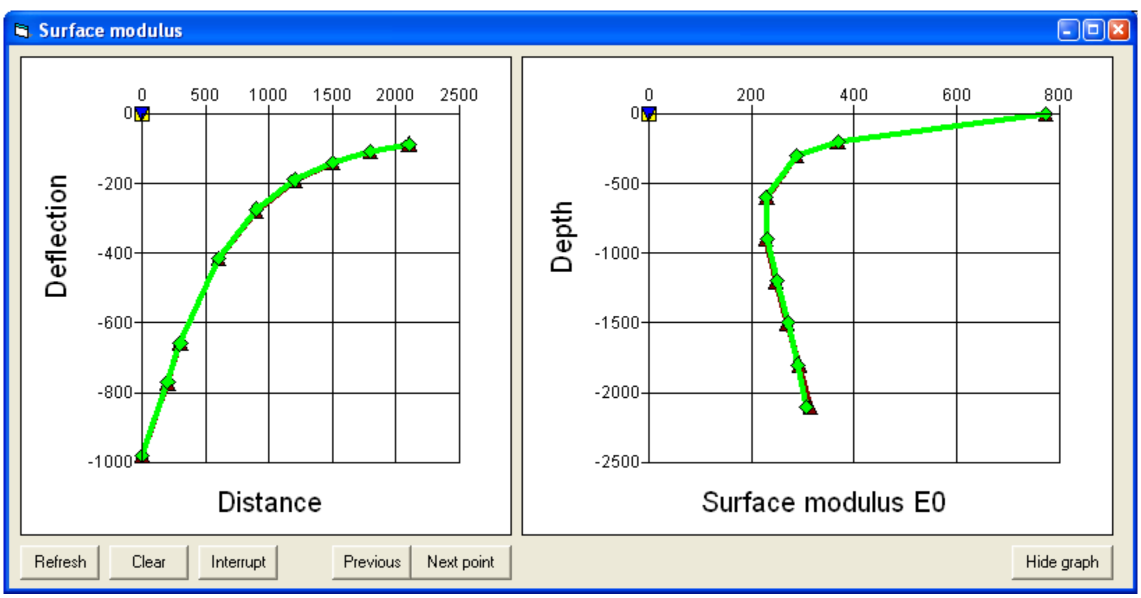

Figure 4: Good fit based on a non-linear approach

As final option Figure 5 shows the fit when an artifical interlayer with a thickness of 1000mm is being adopted.

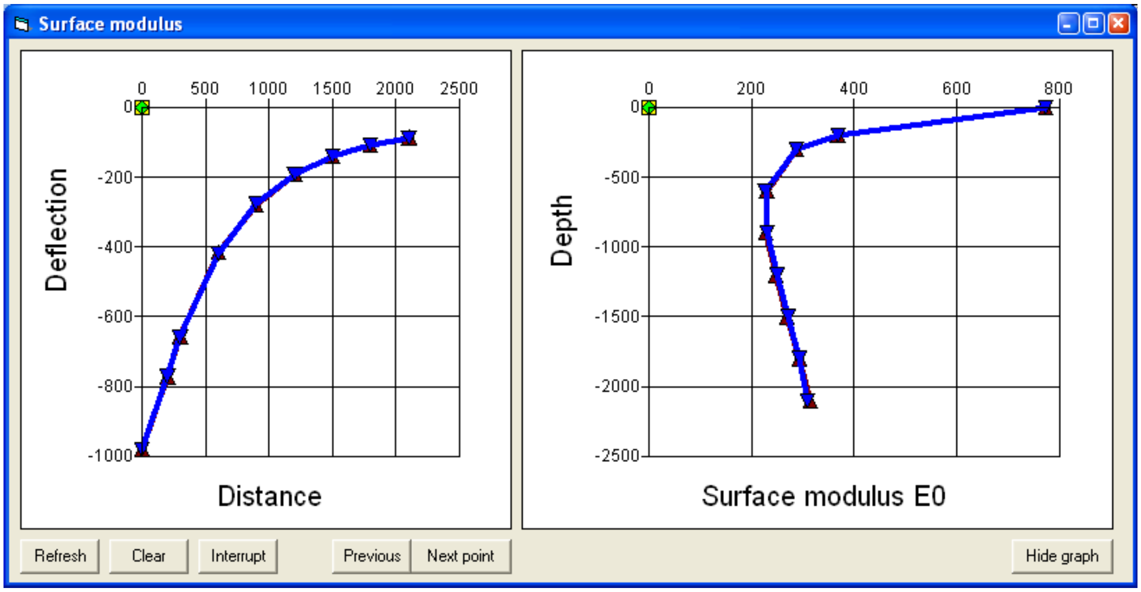

Figure 5: Good fit using a linear approach with additional interlayer

Figure 6 shows that using this additional interlayer does result in a good fit. The back-calculated layer stiffnesses are summarized in Table 5.

Table 5: Result back-calculation layer stiffness with 3 different approaches

Back-calulation result single test location	**Linear**	**Non-linear**	**Interlayer**
Layer thickness asphalt [mm]	200	200	200
Layer thickness base layer [mm]	300	300	300
Layer thickness interlayer [mm]	-	-	1000
Stiffness modulus asphalt [MPa]	4292	3014	3628
Stiffness modulus base layer [MPa]	185	518	339
Stiffness modulus interlayer [MPa]	-	-	175
Stiffness modulus subgrade [MPa]	268	145	310
Fit [%]	>5	1.15	0.89

The examples do show that the layer siffnesses are re-arranged because the measured deflection profile does not change of course. This implies that judging of the results are only realistically possible when additional information is available about the different materials and its strength with depth based on for instance DCP testing. Adding an interlayer always seem to result in a relatively how subgrade strength and relatively low strength of this interlayer.

5. Conclusions

Based on the examples of the linear and non-linear back-calcualtion process of FWD data it appears that the calcualted layer stiffness can have a large influence on the analyzed remaining life or strengthening measure of a pavement structure. Especially when there is insufficient information regarding the actual strength of the different layers in a pavement structure based on for instance a DCP (Dynamic Cone Penetrometer) an incorrect analysis is conceivable. In case of a linear approach the added low-strength interlayer will always be the critical layer for the calcualtion of the remaining life. In case no additional low-strength interlayer has been added the back-calutation process will show a low stiffness for the base layer resulting in a higher strain at the bottom of the asphalt layer making this layer critical in the remaining life calcualtions. A non-linear approach will not show the weak base layer resulting an a different strengthening (thinner or no overlay) requirement. It is questionabel if the inversion of layer stiffness is realistic to accept, in case of a linear approach, when the construction procedures and materilas do meet the QA/QC testing requirements.

The examples show that it is very important to measure a correct deflection profile because of the sensitivity in the back-calculation process. However, it is questionable if correction of the measured deflection, being standard practice in the Netherlands based on the correlation trials, or any other approach that results in not using the actual measured deflection profiles (normalization, averaging multiple drops) should be applied before the back-calcualtion does take place. There is a chance that systematic errors are introduced that can influence the reliability of the analyzed results.

6. References

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