STRUCTURAL AND MONETARY EVALUATION OF FLEXIBLE PAVEMENTS ON THE BASIS OF REMAINING LIFE

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ABSTRACT

Structural pavement evaluation in Germany is currently done on the basis of surface characteristics. However, parameters like age, climate and loading are not involved. Therefore, a reliable conclusion concerning the condition of the pavements´ structure can not be made although this is important in connection with performance based contracts.

A new approach to include these structural parameters is to determine the remaining life of flexible pavements and to use it for structural evaluation. For the determination of remaining life two methods are used.

First method is the inversion of an existing software tool which is able to dimension flexible pavements on the basis of multi-layer-theory. Knowing layer thicknesses, cumulative loading and traffic growth rate, the time of failure can be estimated. The second method is the superposition of fatigue curves. The underlying assumption is that because of traffic loading fatigue in the wheel tracks has proceeded more than in between. Superposing the two fatigue curves shall give information about the remaining cumulative axle loads and the remaining life.

Test results show that the above mentioned assumption can not be approved and fatigue curves are not absolutely similar. Therefore, the second method is not practicable. In consequence, remaining life is only determined by means of the inversion of the software tool.

Subsequent to the determination of remaining life, a background for structural as well as monetary evaluation of the pavement is developed. Latter gives the possibility to the client to award the contractor or to claim compensation depending on whether the contractor has met contract requirements or not.

Basis for the study are 220 core samples taken from 10 German autobahn sections. The underlying research project is carried out in cooperation with Dresden University of Technology and ordered by the Federal Highway Research Institute (BASt).

Keywords: pavement management, structural evaluation, monetary evaluation, fatigue

1. INTRODUCTION

The way of contracting road constructions and road maintenance is currently subject to a major change in Germany. Traditional contracts, which included the construction of the road and a five year warranty, shall be replaced by so called performance based contracts. Within these contracts the contractor has to build the road and maintain its functions for a given period of time, which is agreed by contract (10 -30 years). Therefore, it is obvious that contractors seek to construct accurately and to apply efficient maintenance strategies. This is leading to a longer total service life at minimized costs. However, precondition for a successful establishment of performance based contracts is the reliable detection of pavement condition and its evaluation. For contractors this indicates if and which measures have to be applied. For clients, in turn, evaluation is an instrument to check whether the contractor meets the contractual requirements. Especially at the end of the contract, when the construction is being handed over to the client, this aspect is very important. It seems obvious that pavement evaluation for this purpose should give an overall view of the complete pavement structure. This implies the surface as well as structural condition. However, there are only few methods to evaluate the structural condition of a pavement. Previous approaches rest upon loading capacity detected by the Falling Weight Deflectometer (BECKEDAHL et.al. 1996, JENDIA 1995) or the Benkelman-Beam (NORMAN et al. 1973) or the application of equivalent layer thicknesses (SCHMUCK et.al. 1993). Problems arising with these methods are due to their empirical character. In addition, there is a broad discussion whether bearing capacity can give reliable information about the structural condition of the pavement at all (OEFNER et al. 2000). In fact, bearing capacity rather describes the condition of the sub-grade.

In the absence of an adequate method, structural pavement evaluation in Germany is currently done on the basis of surface characteristics. However, parameters like age, climate and loading are not involved and therefore, a reliable conclusion concerning the condition of the pavements´ structure can not be made.

A new approach to include these structural parameters is to determine the remaining life of flexible pavements and to use this value for structural evaluation. A research project currently carried out at Stuttgart University (Chair of Road Construction, Prof. Ressel) in cooperation with Dresden University of Technology (Chair of Pavement Engineering, Prof. Wellner) and on behalf of the German Federal Highway Research Institute (BASt) is dealing with this topic. Besides the determination of remaining life, which is done at Dresden Technical University, the development of an evaluation background is taken care of. This evaluation background serves two purposes: to include the remaining life in the existing evaluation framework (structural evaluation), and to estimate the monetary value of the pavement (pecuniary evaluation). Latter has an important meaning within the before mentioned performance based contracts. The idea is to award constructions with a better quality than expected and to penalize low quality constructions in turn. This shall be an appeal for the contractors to build high quality pavements.

The present paper is divided into two parts. The first part includes a general description of the method used to determine the remaining life and a short discussion of the results. The second part focuses on the development of an evaluation background for structural and monetary evaluation of flexible pavements.

2. DETERMINATION OF REMAINING LIFE

2.1 Methodology

The behaviour of flexible pavements can be characterized by the resistance against deformation (rutting) and against the formation of cracks (fatigue). In this context, the following mechanical asphalt properties are important: modulus of elasticity, plastic deformation behaviour and fatigue behaviour. Currently, asphalt technology seeks to improve the deformation behaviour to avoid immense rutting, however, cracks for example transversal to the wheel tracks can be observed very often and are one of the main damages of flexible pavements. That is why the description of fatigue behaviour seems to be the crucial element to describe the structural condition of a flexible pavement and therefore to determine its remaining life.

The study is based on 220 core samples taken from 10 autobahn test sections in Germany. The requirements the test sections had to meet were a high number of cumulative axle loads and a high percentage of heavy vehicles. In addition, design should be according to the German Guidelines dating from 1986 respectively 1989 (RStO 86, 86/89) with bituminous base course on unbound material (frost protection layer). Tests carried out with the samples include the determination of the modulus of elasticity, the fatigue curve as well as the acceptable cryogenic stresses (tests were carried out at Braunschweig Technical University). Additionally, bearing capacity in the drill holes was determined.

In a first step, remaining life was determined on the basis of the test results and by means of the existing pavement design tool (PaDesTo1.2) developed at Dresden University of Technology (Chair of Pavement Engineering). This tool is able to design flexible pavements according to multi-layer-theory. By means of a general fatigue curve representing the deterioration, the layer thicknesses depending on the traffic volume and the expected service life are defined. Since the layer thicknesses, cumulative loading and traffic growth rates are known in the study, remaining life can be determined by a back-calculation using the specific fatigue curve of each test section.

A second method to determine remaining life was proposed by Zander (ZANDER 2001). The central assumption is that due to concentrated traffic loading fatigue in the wheel track has proceeded more in comparison to the area in between, and therefore a lower modulus of elasticity and a smaller number of bearable axle loads is expected there (core samples were taken in equal numbers from both areas). Figure 1 shows the steps of the procedure. By comparing respectively superposing the two different but similar fatigue curves of the material from the wheel tracks F_w and in between the wheel tracks F_{bw} it is possible to estimate the bearable axle loads until failure. The time of failure is defined by the formation of the first macro cracks. Knowing the ADT values and traffic growth, remaining life can be determined.

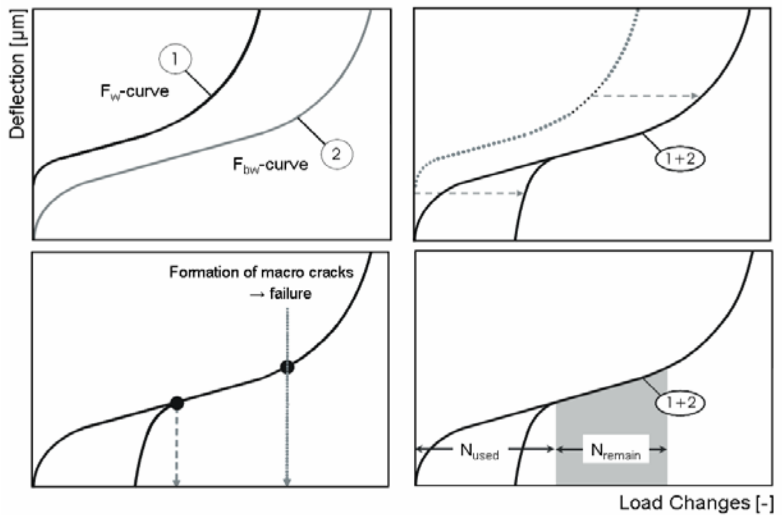

Figure 1 Method of superposing fatigue curves (ZANDER 2001)

2.2 Test Results

The modulus of elasticity was determined for each layer separately and for three different temperatures. Results show that the values in the wheel tracks are higher may be due to subsequent compaction by traffic. This tendency disappears when looking at the other layers. A clear tendency approving the above mentioned assumption of a lower modulus in the wheel tracks does not exist either though.

Fatigue curves were also determined for three different temperatures and three different stress amplitudes. The curves were established by determining the load changes for the time of failure (formation of macro cracks) for each core sample in dependency of the initial elastic strain caused by applying the stress level. The fatigue curve was then established with a regression between these points. The results show that there also is no significant tendency approving the assumption of higher fatigue in the wheel tracks. Figure 2 shows the fatigue curves of two different test sections for one temperature level, in each case for the material taken from the wheel tracks and in between. It is obvious that for the first test section the assumption can be approved: the material in the wheel tracks can bear a smaller number of axle loads. For the other test section the results are contrary.

In consequence of the fact that no clear tendency is identifiable, modulus of elasticity and the fatigue curves were no longer regarded separately for the wheel track and in between the wheel tracks to create a bigger population. By means of these input parameters remaining life could be estimated with the software tool PaDesTo 1.2. However, the fact that the fatigue curves were obtained by regression and the different fatigue curves were combined leads to the conclusion that the estimation of total service life is a relatively uncertain process. Therefore a method was developed which estimates the total service life on the basis of a Gaussian distribution. This distribution was proved by means of the Kolgomorov-Smirnoff and Chi^2-Test. The total remaining life could then be calculated considering different probabilities of error.

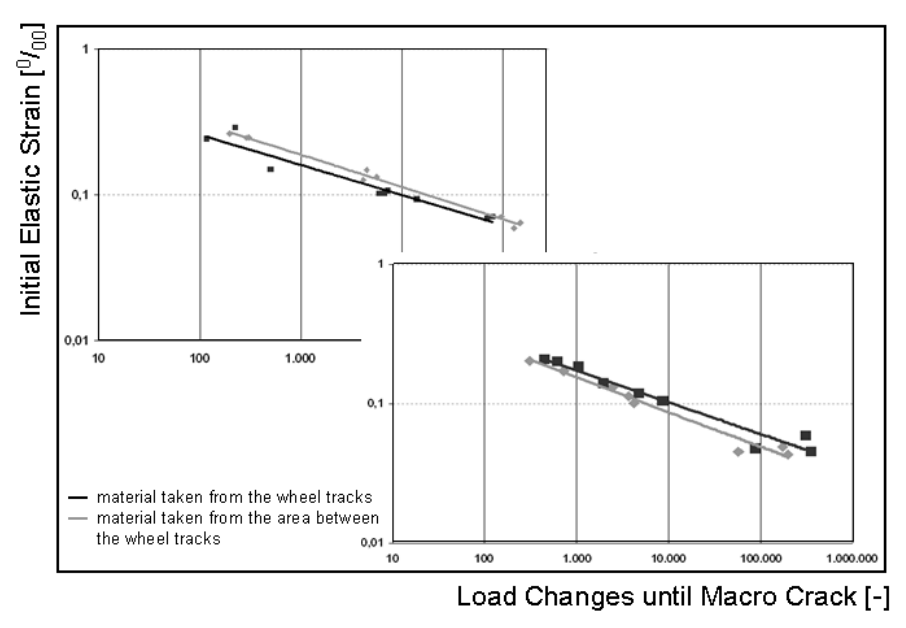

Figure 2 Fatigue curves obtained by regression (logarithmic scale)

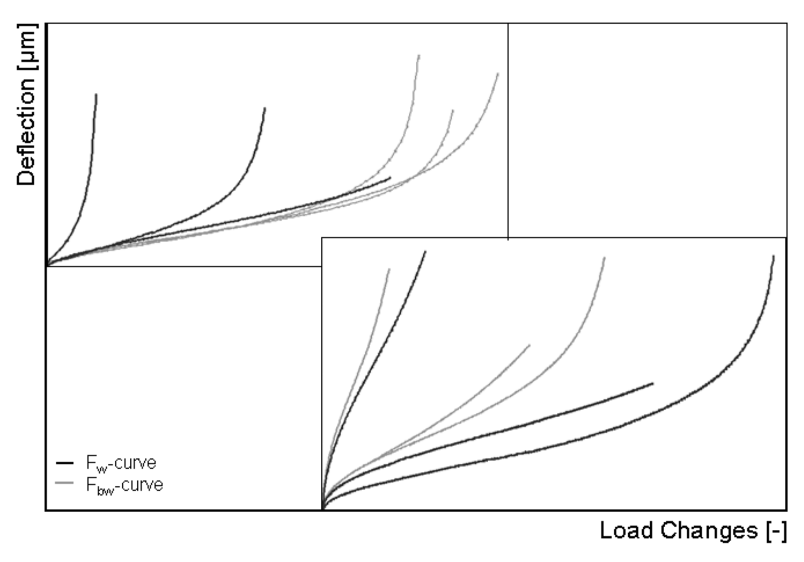

Figure 3 Fatigue curves obtained by monitoring deflection with increasing load changes

For the application of the method proposed by Zander only the fatigue curves for the lowest stress level and one temperature level are considered. In contrast to the fatigue curves shown in figure 1, these curves were established by monitoring the deflection (plastic deformation) with increasing number of load changes. The resulting curves for the same test sections as in figure 2 are shown in figure 3. It is evident that the results are subject to an immense variation keeping in mind that only results for one temperature level are shown. Although there are curve pairs with a similar shape, superposition would lead to a very low number of bearable axle loads and to a low value for remaining life which is contrary to the results obtained from the back-calculation. This is due to the fact that curves are hardly parallel in the linear section. Therefore, similarity is not reached until the first macro cracks start to form. However, this linearity is a prerequisite for the successful application of the method, see also figure 1. Furthermore, results of the first method seem more appropriate when considering a total expected service life of 30 years because the two test sections have only been in service for 11 and 16 years by the time of evaluation. So, a remaining life of 15 years can be expected.

Even merging of all curves did not come up with a better result. Conclusive it can be said that the method, at least in this study, has failed. Therefore, only results obtained by the first method are considered further.

3. DEVELOPMENT OF A METHOD FOR STRUCTURAL AND MONETARY EVALUATION

3.1 Existing Evaluation Framework

In Germany, pavement evaluation is done within the framework ZEB (Zustandserfassung und Bewertung). The framework is based on periodic measurements and visual detections of the pavement. Hereby, defined attributes (e.g. grip) describing the condition of the pavement are referred to suitable condition variables (e.g. roughness). By means of a normalisation these condition variables, which are influenced by their dimension, are changed in to dimensionless condition values. These condition values symbolize an evaluation scale from 1.0 (very good) to 5.0 (very poor). Regarding this scale three values have a special meaning:

1.5: this value represents the critical value for handing over after construction
3.5: present damages should be analysed and appropriate maintenance measures should be applied if required
4.5: constructional measurements should be considered

Moreover, values smaller than 1.5 equal 1.0 and values greater than 4.5 equal 5.0. The condition values received by normalisation are weighted and combined to a certain sub-goal value. Sub-goals used in ZEB are: preservation of substance and navigability. The ultimate overall state value of a pavement is defined by the maximum value of one of the two sub-goals (the evaluation which is worse governs the total result). For structural evaluation the sub-goal “preservation of substance” is crucial. It includes the attributes: alligator cracking, patches and ravelling. As mentioned earlier, these attributes only refer to the surface and there is no secure correlation to the real structural condition especially when recent maintenance measures such as the renewal of the wearing course indicate a sound structure without any visible surface damages. Therefore it is necessary to define a new attribute which is able to clearly describe the structural pavement condition. The related condition variable of this attribute can be remaining life or a variable which is derived from it. For this condition variable a normalisation curve has to be developed, and critical values for taking over at the end of the contract have to be defined.

3.2 Derivation of a Condition Variable

In a first step, it seems most convenient to take the remaining life as condition variable. However, problems arise from this assumption. First of all, remaining life always has to be evaluated in context with evaluation time and the resulting total service life. Remaining life as a single value is hardly meaningful. A second problem is that the reduction of substance – in the following named deterioration - is mostly due to traffic loading. Indeed, there are other factors like climate and ageing which influence deterioration but their influence can not be quantified. That is why traffic loading should be considered in the evaluation process. Otherwise test sections with 4% increase of heavy vehicles and a shorter total service life would be evaluated worse than sections with a 2% increase with a longer total service life.

Generally, the hypothesis of Miner is used to describe the dependence of deterioration and traffic loading. It implies that each axle load induces the same damage. Regarding one year as time step including all climatic differences and changes in traffic composition, deterioration could be considered constant. However, traffic and especially heavy vehicle traffic is also subject to change and in most cases it is growing. Therefore, deterioration is a progressive process which is besides traffic volume mainly influenced by the growth rate of heavy vehicle traffic.

Considering the problems mentioned above a suitable condition value can be developed from the ratio of the cumulative axle loads during the service period until the evaluation and during the total service life. This ratio describes the percentage of substance which has already been used up. In turn, the complementary value describes the percentage which is still available for usage. Hereafter this value shall be named “Remaining Substance” (RS) and it can be described by the following equation:

$$\mathrm{RS} = \left(1 - \frac{\sum_{i=1}^{T_E} \mathrm{ADT}^{(HV)} \times (1 + \frac{p_i}{100})^i}{\sum_{i=1}^{TSL} \mathrm{ADT}^{(HV)} \times (1 + \frac{p_i}{100})^i} \right) 100\,[\%] \qquad \text{(Eq. 1)}$$

where:

RS: Remaining Substance [%]

T_E: Evaluation time (or contract length)

TSL: Total Service Life = RS + T_E

$\mathrm{ADT}^{(HV)}$: Average Daily Heavy Traffic

p_i: Growth rate of $ADT^{(HV)}$ in year i

Since there is only one basic ADT value used in the calculation, ADT can be left out. Transforming the equation by means of the rules for the geometric series the following equation can be obtained:

$$RS = \left(1 - \frac{(1+\frac{p_{av}}{100})^{T_E} - 1}{(1+\frac{p_{av}}{100})^{TSL} - 1} \right) 100[\%] \qquad \text{(Eq. 2)}$$

Herein, p_{av} equals the average growth rate until the evaluation (nominator) but it is also used for the calculation which refers to the total service life period (denominator). This assumption is permitted if the same growth rate is used in the back-calculation and the determination of the remaining life. The resulting total service life does not categorically correspond to reality – if traffic growth or decline is assumed – it rather gives the total expected service life under steady conditions. Since steady conditions are presumed in the design guidelines and the evaluation background (see chapter “Critical Values for Taking Over”) is based on these guidelines, RS has to be calculated under steady conditions. Otherwise results would not be consistent.

3.3 Normalisation

Normalisation is the most important step in evaluation because it allows to compare and to combine results with different dimensions what leads to an integrated evaluation. Normalisation of the remaining substance value is done linearly because the progressive influence on the deterioration process due to growing traffic is already considered in the calculation of the remaining substance value. In addition, the normalisation is simplified because the range of the remaining substance value is clearly defined by 100% and 0%. The resulting curve and the corresponding equations are shown in the following figure.

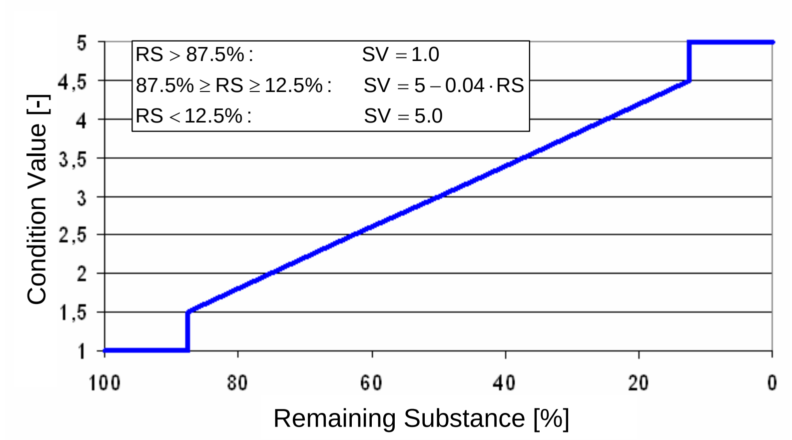

Figure 4 Normalisation curve for remaining substance

3.4 Critical Values for Taking Over

Pavement evaluation and especially structural evaluation is used as controlling instrument by the client and to assess monetary compensations. Therefore, it is necessary to define critical values for taking over. These critical values can be obtained by the establishment of a systematic deterioration curve which is serving as a benchmark. Since the deterioration is already given with the function describing RS only the values for the variables TSL and p_{av} have to be fixed. Thereby, one thing has to be kept in mind: a systematic deterioration curve has to be based on the same criteria as the criteria valid when the pavement was designed. Otherwise, the evaluation becomes unfair. In consequence, the valid criteria proposed in the German Guidelines (RStO 01) are used here. This corresponds to a total service life of 30 years and yearly growth rate of heavy traffic of 3%.

Putting these values in the RS-Equation, T_E is the only declarative variable left. For each T_E, an RS value can be calculated. However, there is a certain instability concerning the estimation of the remaining life as discussed in a previous chapter. That is why it seems not appropriate to set a discrete benchmark. In contrast, it is proposed to set a ranged benchmark. The ranges can be calculated for example by varying the expected total service life. The following graph is showing a systematic deterioration curve and the corresponding ranges. In this case, total service life was changed to 28 and 32 years. This equals a tolerance of 13 %.

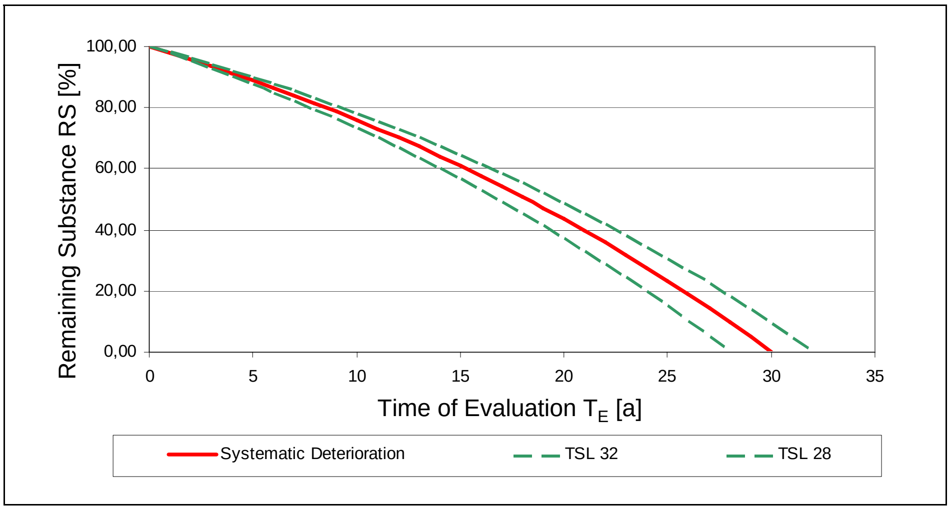

Figure 5 Systematic deterioration curve with corresponding ranges for TSL=28 und TSL = 32 years

As can be seen in figure 5, the range widens with increasing time. Another possibility would be to determine the average range resulting from these curves and establish a constant range over the complete time period. This possibility is refused, however, because the risk for the contractor is getting higher with longer contracts and therefore the widening range seems appropriate.

3.5 Monetary Evaluation

Monetary evaluation of the pavement shall be an incentive for the contractor and at the same time an appeal for high quality constructions. If the condition value is better than required, the contractor is paid a certain amount. If it is worse than expected, the contractor has to pay back a certain amount to the client. Objective of the monetary evaluation is the assessment of these amounts.

In business economics, monetary values are calculated by amortisation. There are three influencing factors: the costs used for amortisation, the time period and the type of amortisation.

Generally, only construction costs or purchase costs are subject to amortisation. That means that only costs in the sense of business-economics are being regarded. For pavements these are the construction and maintenance costs. Since the structural evaluation refers to the base course only – fatigue curves and total service life are only calculated for this layer - , maintenance costs are neglected because in general, there are no maintenance measures being applied to the base course.

Since the estimated total service life is known, this time period is used for amortisation.

In general, there exist three types of amortisation: linear, declining and progressive. Normally, the choice of the type is governed by business-economic goals. In the case of pavement evaluation however, the type of amortisation should be conform to the deterioration process (SCHMUCK 1981). That means a progressive amortisation has to be applied. Assuming the deterioration and amortisation curve are equal leads to a very handy simplification because the remaining substance value is a percentage value depending on time. This percentage can also be used to calculate the monetary value and no extra calculation has to be done.

The monetary value MV can be described as:

$$MV = RS \times CC \times (1 + \frac{q}{100})^{T_E} \qquad \text{(Eq. 3)}$$

Herein, CC represents the construction costs of the base course and q the discounting interest rate. If the pavement is in another condition than expected the compensatory payment CP can be calculated by means of the difference between the expected and the present remaining substance values RS_{exp} and RS_{pres}.:

$$CP = (RS_{exp} - RS_{pres}) \times CC \quad (1 + \frac{q}{100})^{T_E} \qquad \text{(Eq. 4)}$$

If CV is negative the client has to pay the amount to the contractor, if it is positive the contractor has to pay back the amount to the client.

4. CONCLUSIONS

In the introductory chapter of this paper it becomes evident that there is a big need for a more detailed structural evaluation method for flexible pavements. However, test results show that also the new approach including the determination of remaining life has partly failed. The fact that the stated assumption of higher fatigue in the wheel tracks could not be verified displays that the fatigue process of flexible pavements is far from being completely investigated. Other reasons for the unexpected test results may be the very little population of the samples and the sometimes poor data source concerning cumulative loading and the material being used. The method of back-calculation, however, could be a proper method for the determination or remaining life.

The developed method for structural and monetary evaluation seems to be consequent but it has to be tested in practice especially when looking at the monetary evaluation. Otherwise the assessment of the compensatory payments is too vague and contractors as well as clients are not willing to pay the money. Prerequisite for the successful establishment of a structural and monetary evaluation method are reliable results for the remaining life or at least the knowledge about the span of results. Then, the evaluation method can be calibrated. Maybe another study with a higher population can give better results.

Summarizing it can be stated that the study did not come up with the expected results. However, the assumption of higher fatigue in the wheel tracks could be rejected. In general, the results should challenge researchers to have a much deeper look into the mechanisms of fatigue.

REFERENCES

BECKEDAHL, H.; HÜRTGEN, H.; STRAUBE, E. (1996) – Begleitende Forschung zur Einführung des Falling Weight Deflectometer in der Bundesrepublik Deutschland – Bundesministerium für Verkehr, *Forschung Straßenbau und Straßenverkehrstechnik*, Vol. 733, Bonn Bad-Godesberg.

JENDIA, S. (1995) – Bewertung der Tragfähigkeit von bituminösen Straßenbefestigungen, Dissertation, Universität Karlsruhe, Insitut für Straßen- und Eisenbahnwesen.

NORMAN P.J; SNOWDON, R.A..; JACOBS, J.C. (1973): Pavement deflection measurements and their application to structural maintenance and overlay design. *Transport and Road Research Laboratory (TRRL)*, Report LR 571.

OEFNER, G. et al. (2000) – Erweiterung des streckenbezogenen Substanzwertes im System ZEB um die Kriterien Belastung, Aufbau, Alter und Tragfähigkeit - Bundesministerium für Verkehr, *Forschung Straßenbau und Straßenverkehrstechnik*, Vol. 783, Bonn Bad-Godesberg.

RStO86 (1996) - Richtlinien für die Standardisierung des Oberbaues von Verkehrsflächen, FGSV, Arbeitsgruppe Fahrzeug und Fahrbahn, Köln.

RStO86/89 (1989) - Richtlinien für die Standardisierung des Oberbaues von Verkehrsflächen, FGSV, Arbeitsgruppe Fahrzeug und Fahrbahn, ergänzte Fassung von 1986, Köln.

RStO 01 (2001) - Richtlinien für die Standardisierung des Oberbaues von Verkehrsflächen, FGSV, Arbeitsgruppe Fahrzeug und Fahrbahn, Köln.

SCHMUCK A.; BECKER, H.; OEFNER, G. (1981) - Einflussgrößen, Berechnungsansätze und Sensitivitätstests für die Straßenbaulastträgerkosten im Rahmen der Wirtschaftlichkeitsrechnung von Straßenbefestigungen, Bundesministerium für Verkehr, *Forschung Straßenbau und Straßenverkehrstechnik*, Abteilung Straßenbau, Heft 324, Bonn Bad-Godesberg.

SCHMUCK A.; HEHENBERGER, F. (1993) - Mängelursachen, Erhaltungsmaßnahmen und Auswirkungen auf das Zustandsniveau – Entwicklung einer Systematik für das Management der Straßenerhaltung, BMBV (Hrsg.), Forschung Straßenbau und Straßenverkehrstechnik, Abteilung Straßenbau, Heft 682, Bonn Bad-Godesberg.

ZANDER, U. (2001) - Funktionsbauvertrag, Ermittlung des Beanspruchungszustandes, Vertragstext. Bergisch Gladbach: Bundesanstalt für Straßenwesen, unveröffentlicht.