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# ONTWIKKELENDE LANDE – SIVIELE INGENIEURWESE EN VERVOERWESE

# DEVELOPING COUNTRIES – CIVIL ENGINEERING AND TRANSPORTATION

## KONSTRUKSIE EN MONITOR VAN PLAVEISELS/ PAVEMENT CONSTRUCTION AND MONITORING

**VOLUME 3D**

REFERATE/PAPERS

# TOWARDS A CLASSIFICATION SYSTEM FOR THE STRENGTH-BALANCE OF THIN SURFACED FLEXIBLE PAVEMENTS

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SUMMARY

This paper deals with the development of **a universal classification system** for flexible pavements with thin surfacings. This classification is based on the results obtained with the **Dynamic Cone Penetrometer (DCP)** utilising the **strength-balance concept** of pavements. The pavement is classified according to its **strength-balance** in relation to **Standard Pavement Balance Curves (SPBCs)** developed for flexible pavements with relatively thin surfacing layers in South Africa. It is considered that the implementation of this **universal classification system** will enhance the interpretation of DCP results in general. It is further envisaged that the use of this system will not only result in the **classification** of pavements based on its **strength-balance**, but also aid in the **understanding of basic pavement behaviour**. Finally, it is considered that this system will also enhance existing methods of flexible pavement design, especially in the areas of greatest need such as the **developing countries of southern Africa**.

OPSOMMING

In hierdie referaat word die ontwikkeling van 'n **universele klassifikasiestelsel** vir plaveisels met dun oppervlaklae bespreek. Die klassifikasie is gebasseer op die resultate van die Dinamiese **Keëlpenetrometer (DKP)** en is gebaseer op die **sterktebalanskonsep** van plaveisels. Die plaveisel geklassifiseer word volgens sy **sterktebalans** in vergelyking met **Standaardplaveiselbalanskurwes (SPBKs)**, wat vir buigbare plaveisels met betreklik dun oppervlaklae in Suid-Afrika opgestel is. Die implementering van hierdie **universele klassifikasiestelsel** behoort die interpretasie van DKP-resultate in die algemeen te vergemaklik. Dit word verder voorsien dat die gebruik van hierdie stelsel nie alleen tot die **klassifikasie** van plaveisels gebasseer op **sterkte-balans** sal lei nie, maar ook sal meewerk om basiese **plaveiselgedrag meer verstaanbaar** te maak. Laastens word ook voorsien dat hierdie metode bestaande plaveiselontwerpmetodes sal aanvul, veral in die gebiede waar die nood die hoogste is, nl. die **ontwikkelende lande van suider-Afrika**.

## INTRODUCTION

Bituminous surfaced roads comprise approximately 25 per cent of the total road network in the developing countries of the southern African region. In order that these countries can continue to develop towards their full potential they should improve their road networks by upgrading existing roads, constructing new roads and rehabilitating bituminous-surfaced roads which have reached the end of their design lives. There is a need to devise alternative and more cost effective pavement design and analysis methods to aid in solving this problem. Over the past few years, the **Dynamic Cone Penetrometer (DCP)** has established itself as a valuable pavement design and evaluation tool in South Africa and elsewhere[1,2,3,4,5,6].

This DCP-instrument is used mainly on unbound granular and lightly cemented (7-day soaked unconfined compressive strength (UCS) $\leq$ 4 MPa)[7], pavements[2]. The majority of roads in the developing countries fall into this category. It is, therefore, anticipated that the potential use of this portable instrument will be very high, especially where objective data analysis methods exist.

In this paper the development of a **universal pavement strength-balance classification system** based on DCP-results is discussed. Until recently there was no generally accepted method for classifying DCP data. It is the opinion that such a system, similar to some well-known soil classification systems[8,9], is much needed in order to enhance the interpretation DCP data. Such a classification system will increase objectivity in the classification, interpretation and comparison of DCP data in general. This will not only enhance the use of the DCP instrument, but also the understanding of **in situ pavement definition** and **basic pavement behaviour**, especially amongst unexperienced users of the DCP.

Most of the DCP results discussed in this paper originated from pavements with lightly cemented layers, but the principles discussed here are also generally applicable to unbound granular pavement types. The



development of the strength-balance concept of pavements, **including** the **Standard Pavement Balance Curves (SPBCs)**, however, originated from numerous DCP results obtained on unbound granular type pavements[1,2,3,5].
NOTE: The name **Standard Pavement Balance Curves (SPBCs)** in this paper is used instead of the name **Pavement Strength-Balance Curves**, which is used in References 1 to 5 and has got the same meaning.

After a discussion of the pavement strength-balance concept, the classification system will be presented. Finally, various examples will be given to illustrate the different DCP categories in which pavements can be classified in accordance with this system.

## THE CONCEPT OF PAVEMENT STRENGTH-BALANCE

### Background

Fundamentally, the **strength balance** of a pavement structure is defined as the change in the **strength** of the pavement layers with depth[2,4]. Normally, the strength of the pavement decreases with depth and, in principle, if this decrease is smooth and without any discontinuities, the pavement is regarded as **balanced** or **in a state of balance**.
With respect to the DCP, the **average rate of penetration (DN, in mm per blow)** through the various pavement layers, is regarded as a quantitative measure of the in situ shear strength of the different layers.

It is therefore considered that layers of relatively high and relatively low strength, respectively, will be distinguished from each other. Not only will the rates of penetration of the individual layers be known, but also the strength relations between the different layers in the total pavement structure. From this knowledge, the **balance** of the pavement can be evaluated.

During the development of the pavement strength-balance equations[4], a very handy formulation, describing the relation between the **pavement structure number, DSN in %, the pavement depth, D in % and a parameter, B**, describing the **SPBCs**, where obtained. According to this formulation, there are, in theory, an infinite number of **SPBCs** for flexible pavement structures and is used as a basis for the **pavement strength-balance classification system**. This formula is given below :

$$DSN\ (\%) = \frac{D*[400*B + (100 - B)^2]}{4*B*D + (100 - B)^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots 1.$$

where : DSN = pavement structure number, as percentage (%)

B = parameter, defining the standard pavement balance curve (SPBC)

D = pavement depth, as percentage (%)

In Figure 1, a graphic illustration of this formula is given, and the figure indicates that the pavement strength decreases with pavement depth. This decrease in strength is represented by the curve in Figure 1. If B = 0, the balance curve is a straight line from DSN = 0 per cent to D = 100 per cent.

Normally, the **total number of blows** needed to penetrate the total pavement depth, say 800 mm, is indicated as follows: **$DSN_{800}$**, in **blows**. As indicated earlier, there are an infinite number of balance curves (SPBCs), and balance curves other than those discussed above can be obtained graphically by interpolation or by calculation using Equation 1.

In Figures 2(a), 2(b), 2(c) and 2(d), typical examples of various DCP results, plotted in the format discussed above, are indicated. In Figure 2(a) an example of a **balanced pavement structure** is illustrated, whilst in Figures 2(b) and 2(d) examples of **unbalanced pavements** are shown. The **imbalance** is indicated by the deviation of the **DCP data** (DSN data, as a percentage) from the SPBCs.

Although the **normal case** is that pavements **decrease in strength** with **depth** ($B \geq 0$), as is illustrated in Figure 2(a),(b) and (d), pavements can also **increase in strength** with **depth** ($B < 0$) as is illustrated in Figure 2(c) and is normally referred to as "upside down" or inverted pavement structures.





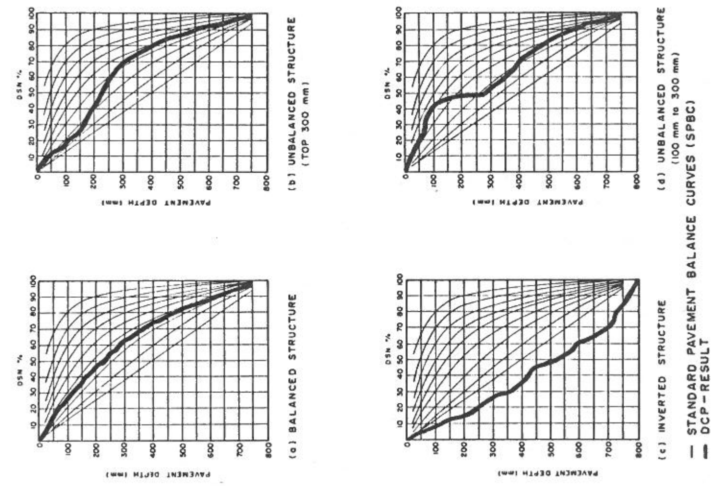
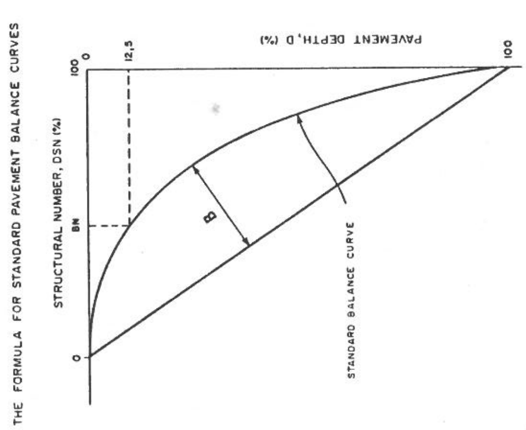



FIGURE 2

*TYPICAL EXAMPLES OF VARIOUS DCP RESULTS*




$$DSN\ (\%) = \frac{D[400B + (100 - B)^2]}{4DB + (100 - B)^2}$$

$$\text{WHERE } B = 100 - \frac{2}{(BN - D)}\left\{[1094\ BN\ (100 - BN)]^{0,5} - 12,5\ (100 - BN)\right\} \text{ IF } D = 12,5\ \%$$

AND B = 0 IF BN = 12,5

FIGURE 1

*GRAPHIC REPRESENTATION OF THE FORMULA FOR STANDARD PAVEMENT BALANCE CURVES (SPBC)*

The parameter B varies, in theory, from $-\infty$ to $+\infty$, which ultimately defines comprehensive SPBCs in this paper. The SPBCs with $B < 0$ is a mirror image of the SPBCs where $B > 0$, as is illustrated in Figure 3, for a pavement depth (PD) of 800 mm. The parameter B varies between -90 and +90, with intervals of 10 units between individual curves. In this approach the parameter B is used to define the various SPBCs. The approach of using the parameter B for defining the SPBCs in this paper is different from the approach used in Reference 4, where the Balance Number, BN, (BN = DSN in per cent at D = 12,5 per cent) is used to define the different pavement strength-balance curves (SPBCs). The selection of B in this paper instead of BN, however was necessary in order to develop the classification system because of its simplicity, as expressed in previous Equation 1.

A further requirement for a universal classification system is that the state of the balance of the pavement structure has to be quantified because most of real pavements are not perfectly strength-balanced. The original method only provides for strength-balanced pavements[4]. In order to quantify the deviation in the strength-balance of real pavements from the standard pavement strength-balance curves (SPBCs), the deviation (area) between the best fit SPBC for the data, and the actual data (DSN data), is used for this purpose. In Figure 4, the method for calculating this deviation in terms of area $A_i$, is illustrated.

The figure also indicates that the best fit SPBC for the DCP data indicated in the figure, is where B = 30. This best fit SPBC is obtained by calculating the total area, A, between the various SPBCs and the DCP data, and finally selecting the SPBC where this area (A) is at a minimum. This SPBC is then regarded as the best fit SPBC for the pavement under consideration.

The area, A, is calculated in a discrete order by calculating the difference between the DSN of the SPBC and the DSN of the DCP data (DSN data). This is done at different depths in the pavement, using increments of 8 mm in this case. These differences are then used to calculate the area of a trapezoid with a width of 8 mm.





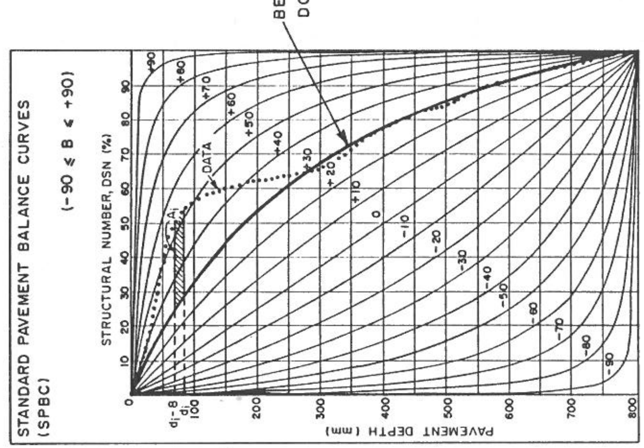



FIGURE 4

CALCULATION OF THE DEVIATION (AREA) OF THE DCP-DATA FROM THE STANDARD PAVEMENT BALANCE CURVES (SPBC)

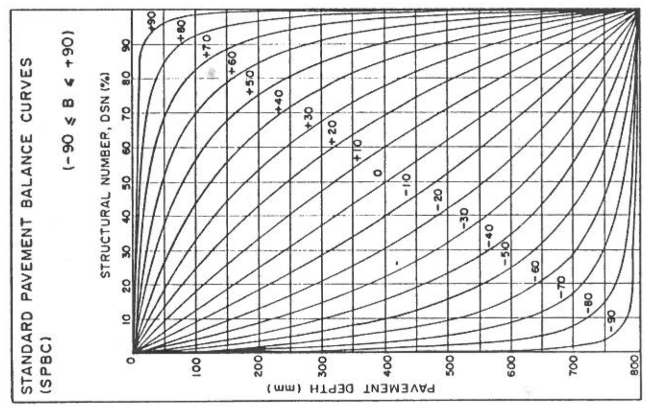



FIGURE 3

COMPREHENSIVE STANDARD PAVEMENT BALANCE CURVES (SPBC)

Finally, these individual areas, $A_i$, are added together and the sum of the areas (A) is then used as the indicator of the state of balance of the in situ pavement structure.

For a pavement depth of 800 mm, the sum total of the areas is as follows:

$$\text{AREA (A)} = \sum_{i=1}^{100} A_i \quad \text{.......... 2.}$$

where A is %. mm

For a perfect strength-balanced pavement, the area A = 0. This means that the deviation (area) between the DCP data balance curve and the "best fit" SPBC of the data, is equal to zero.

From the discussion above it is evident that the two distinct parameters, B and A, are used to define the DCP data. These two parameters, therefore, form the basis for the proposed pavement strength-balance classification system, which will be described in the next section.

## PAVEMENT STRENGTH-BALANCE CLASSIFICATION SYSTEM

### Analysis of some DCP data

Following the definition and description of the two unique parameters, B and A, an analysis of approximately 275 DCP measurements was carried out on both lightly cemented and granular pavement structures.

Figure 5 gives the various DCP data, indicating the spread in terms of balance (B) and deviation from balance (A). These DCPs were measured mainly on three different pavements: on Road 1932 and Road 2212, north of Pretoria, where extensive Heavy Vehicle Simulator (HVS) tests were recently done[10,11], and on granular pavements in the Benoni area.





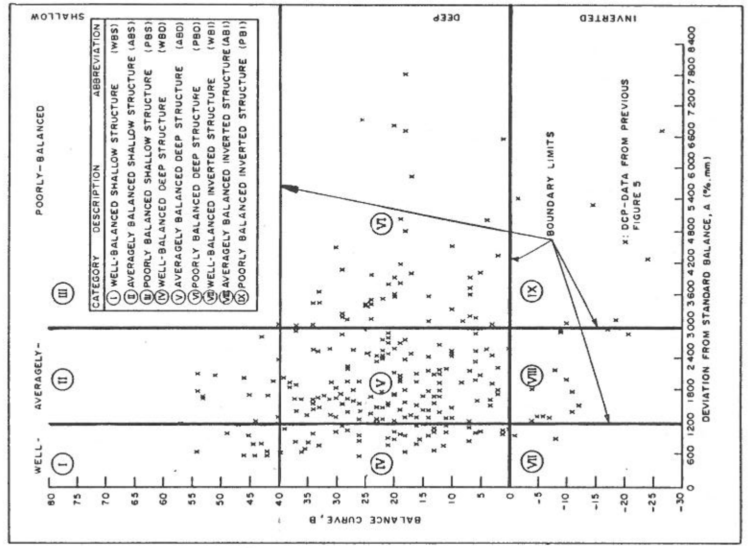



FIGURE 6

*CLASSIFICATION LIMITS IN THE A AND B-PARAMETERS DEFINING THE NINE DIFFERENT CATEGORIES FOR THE DCP DATA*

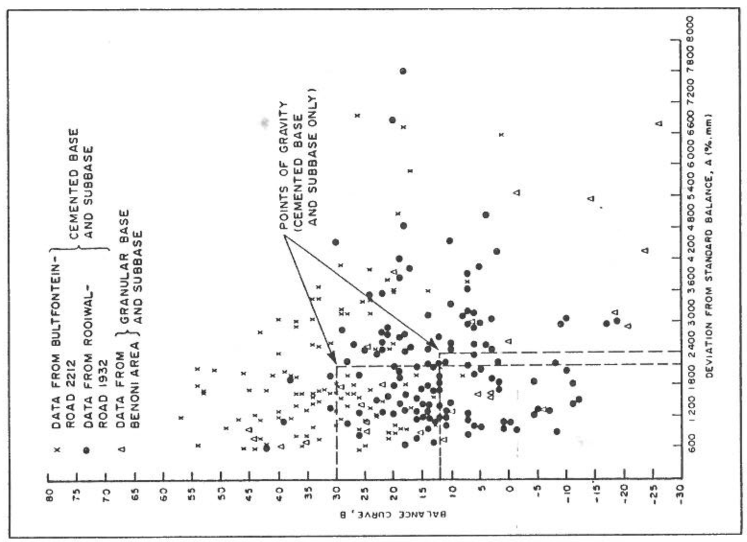



FIGURE 5

*VARIOUS DCP DATA INDICATING THE SPREAD IN THE RESULTS IN TERMS OF BALANCE AND DEVIATION FROM THE STANDARD PAVEMENT BALANCE CURVES*

The figure indicates that parameter B varies between approximately -26 and +60, and parameter A between 600 and 8000 %. mm. The figure also indicates that the centre of gravity of the two sets of data for the cemented roads (1932 and 2212) is at different locations in terms of parameter B, but with approximately the same deviation from the balance, parameter A. This is an indication that the relative strength distribution in the layers of these two pavements is different, but that the state of balance of the two pavements is the same. For Road 2212, with an average B value of 30, the upper pavement layers (base and subbase), contribute relatively more to the total pavement strength, in terms of total number of blows to penetrate the full pavement depth, than the lower layers. For Road 1932, however, with an average B value of 12, there is a relatively greater contribution by the lower layers to the total pavement strength. Thus the higher the value of B parameter, the greater the contribution to the total strength from the upper layers, and vice versa. From this example it is clear that the **higher the B parameter the "shallower" the pavement structure** and the **lower the B parameter the "deeper" the pavement structure**. (This is analogous to the BN parameter used in Reference 4.)

Although most of the above data originated from pavements incorporating lightly cemented layers, parameters B and A of unbound granular pavement types also fall between the following limits:

$$-90 \leq B \leq +90 \quad \text{and}$$

$$0 \leq A \leq 10\,000$$

As indicated earlier, **positive** B values (or BN $\geq$ 12,5 %) are indicative of pavements **decreasing** in strength with depth, as is the case for most of the DCP data. On the other hand, **negative** B values (or BN < 12,5 %) are indicative of pavements **increasing** in strength with depth. This is generally the case where relatively weak upper layers and/ or rocky underlying layers are present within the defined pavement structure.





## LIMITS FOR DEFINING THE VARIOUS PAVEMENT STRENGTH-BALANCE CATEGORIES

From experience with the balance curves of various DCP data it was decided to define three distinct ranges for both parameters A and B. In order to group together pavements with the same **strength** distribution from the top of the pavement to the full depth of the pavement, it is convenient to distinguish between **shallow pavements**, **deep pavements** and **inverted pavements**. This was accomplished by selecting the following **limits for parameter B:**

| | | | |
|---|---|---|---|
| SHALLOW PAVEMENTS | : | $B \geq 40$ | ;(BN $\geq$ 42 %)* |
| DEEP PAVEMENTS | : | $0 \leq B < 40$ | ;(12,5 % $\leq$ BN < 42 %) |
| INVERTED PAVEMENTS | : | $B < 0$ | ;(BN < 12,5 %) |

In order to group pavements with the same state of **"balance"** together, it is convenient to distinguish between **well-balanced**, **averagely balanced** and **poorly balanced** pavement structures by selecting the following **limits for parameter A:**

| | | |
|---|---|---|
| WELL-BALANCED | : | $0 \leq A \leq 1200$ |
| AVERAGELY BALANCED | : | $1200 < A \leq 3000$ |
| POORLY BALANCED | : | $A > 3000$ |

These limits are illustrated in Figure 6, where they have been superimposed on the previous DCP data from Figure 5. Figure 6, with these limits, but without the DCP data, represents the pavement **strength-balance or DCP classification sheet**. By means of this approach, nine **distinct pavement strength-balance or DCP categories** are defined. These categories are summarized in Table 1.

* Although the classification system is based on the parameter B, the corresponding limits in the BN-values of the SPBCs are also given.

TABLE 1 DEFINITION OF THE NINE DIFFERENT PAVEMENT STRENGTH-BALANCE CATEGORIES

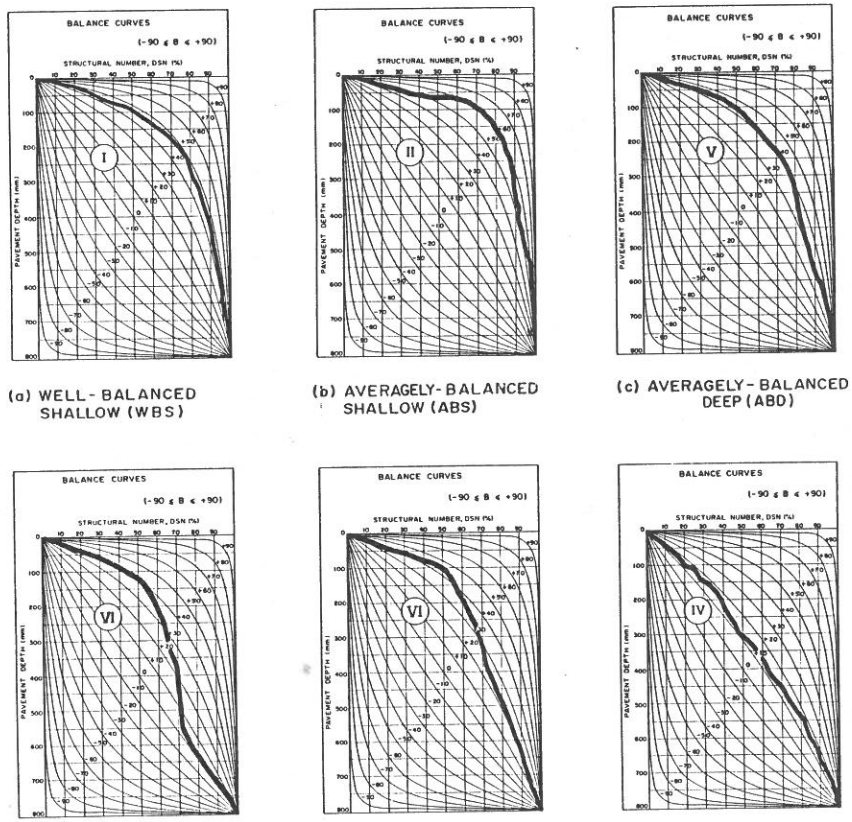
| LIMITS FOR PARAMETERS B AND A | | | DESCRIPTION OF CATEGORY |
|---|---|---|---|
| B≥40 | 0≤A≤1200; | (I) | WELL-BALANCED SHALLOW STRUCTURE (WBS) |
| B≥40; | 1200<A≤3000; | (II) | AVERAGELY BALANCED SHALLOW STRUCTURE (ABS) |
| B≥40; | A>3000; | (III) | POORLY BALANCED SHALLOW STRUCTURE (PBS) |
| 0≤B<40; | 0≤A≤1200; | (IV) | WELL-BALANCED DEEP STRUCTURE (WBD) |
| 0≤B<40; | 1200<A≤3000; | (V) | AVERAGELY BALANCED DEEP STRUCTURE (ABD) |
| 0≤B<40; | A>3000; | (VI) | POORLY BALANCED DEEP STRUCTURE (PBD) |
| B<0; | 0≤A≤1200; | (VII) | WELL-BALANCED INVERTED STRUCTURE (WBI) |
| B<0; | 1200<A≤3000; | (VIII) | AVERAGELY BALANCED INVERTED STRUCTURE (ABI) |
| B<0; | A>3000; | (IX) | POORLY BALANCED INVERTED STRUCTURE (PBI) |

In Figures 7(a) and 7(b), various examples of the different categories are shown. These figures should be read together with Table 1. In Figure 8, the examples illustrated in Figures 7(a) and 7(b) are indicated on the DCP classification sheet.

INFERENCES FROM THE DCP DATA IN TERMS OF BALANCE

With the **pavement strength-balance classification system** defined, it is also possible to locate **deviations** in the **balance** of the pavement structure. This is accomplished by studying the balance curve of the data in relation to the "best fit" SPBC for the same data. In Figure 9 an example of DCP data and the related SPBC, B = 43, is illustrated. The figure shows deviations of parameter A between the data and the related SPBC at depths of approximately 80 mm and 210 mm. There are discontinuities in the pavement structure at these depths. Normally this occurs when a relatively strong layer overlies a relatively weak layer, or vice versa.



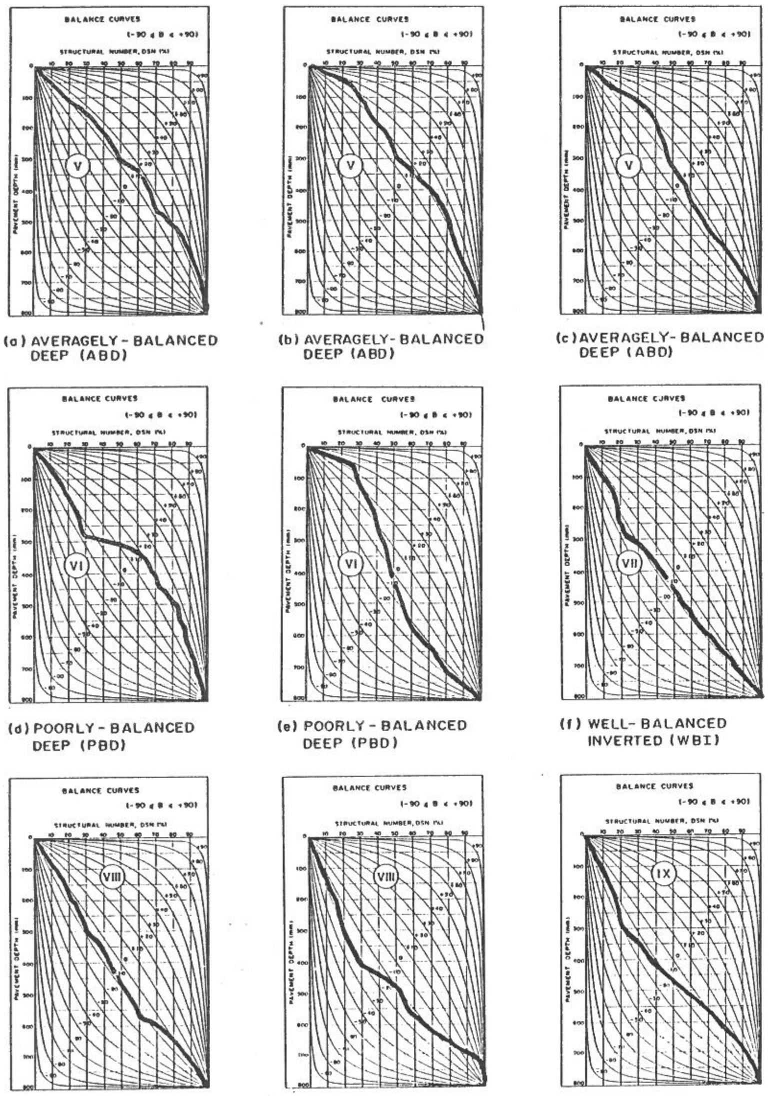



(a) WELL-BALANCED SHALLOW (WBS)
(b) AVERAGELY-BALANCED SHALLOW (ABS)
(c) AVERAGELY-BALANCED DEEP (ABD)
(d) POORLY-BALANCED DEEP (PBD)
(e) POORLY-BALANCED DEEP (PBD)
(f) WELL-BALANCED DEEP (WBD)

(I) : DCP CATEGORY (See Table I and Figure 6)

**FIGURE 7(a)**

EXAMPLES OF DIFFERENT DCP CATEGORIES




(a) AVERAGELY-BALANCED DEEP (ABD)

(b) AVERAGELY-BALANCED DEEP (ABD)

(c) AVERAGELY-BALANCED DEEP (ABD)

(d) POORLY-BALANCED DEEP (PBD)

(e) POORLY-BALANCED DEEP (PBD)

(f) WELL-BALANCED INVERTED (WBI)

(g) AVERAGELY-BALANCED INVERTED (ABI)

(h) AVERAGELY-BALANCED INVERTED (ABI)

(i) POORLY-BALANCED INVERTED (PBI)

(V) : DCP CATEGORY (See Table I and Figure 6)

FIGURE 7(b)

EXAMPLES OF DIFFERENT DCP CATEGORIES



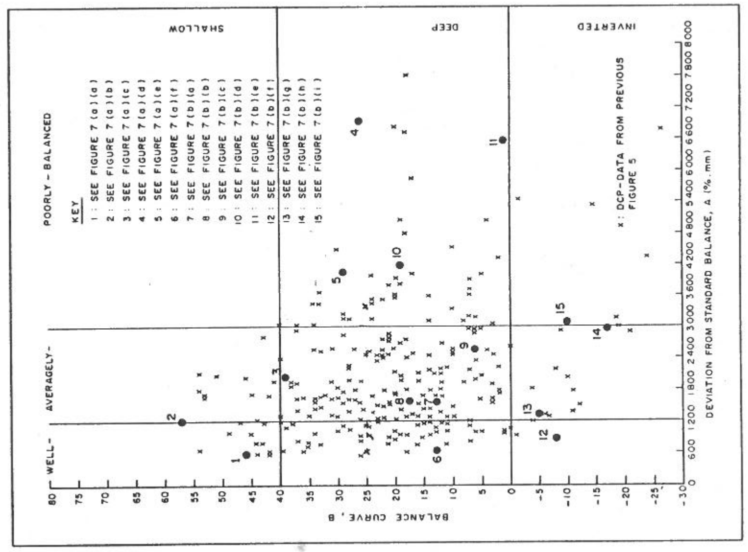



FIGURE 8

EXAMPLES OF THE DIFFERENT DCP-CATEGORIES ON THE DCP-CLASSIFICATION SHEET

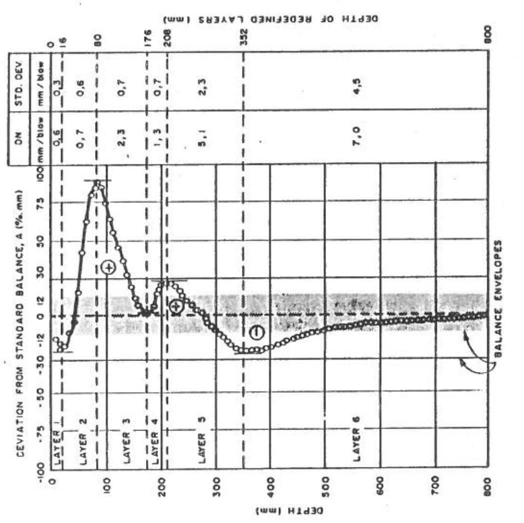



FIGURE 10

*NORMALIZED CURVE OF THE DEVIATION (A) VS PAVEMENT DEPTH OF DCP-DATA FROM THE STANDARD PAVEMENT BALANCE CURVE, B=43*

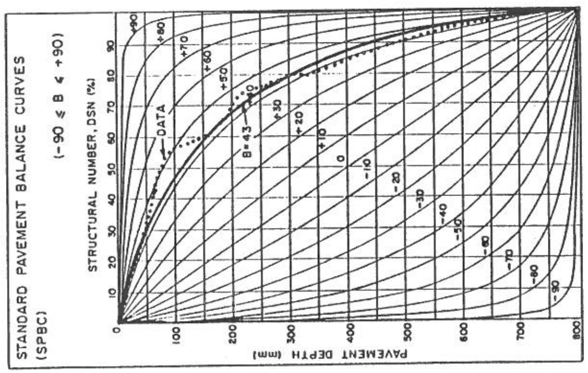



FIGURE 9

*EXAMPLE OF DCP-DATA AROUND THE STANDARD PAVEMENT BALANCE CURVE, B=43, FROM WHICH NORMALIZED CURVES OF THE DEVIATION ARE DRAWN*





In order to distinguish more accurately between the layer interfaces, i.e. where these discontinuities occur within the pavement structure, a **normalized curve** of the deviations, $A_i$, at different depths in the pavement is compiled. The normalized curve for the DCP data of Figure 9, is illustrated in Figure 10. The figure shows that the deviations, $A_i$, vary with pavement depth, and can be either positive, zero or negative. Further, maximum and minimum values for parameter $A_i$ reflect discontinuities within the pavement structure. The interfaces of the different in situ layers in the pavement structure are therefore defined by the depths where these maximum and minimum values for parameter $A_i$ occur. By means of this approach, new layer thicknesses are defined on the basis of the relative strength of the in situ layers.

This is very useful in the evaluation of pavement structures, as the in situ pavement structure (layers) in the field is seldom the structure (layers) as designed, or what one assumes will exist in the field. Also indicated in the figure are the average penetration rates, DN, in mm per blow, for the different layers. The "strength" of the layers are described by their DN values. Inspection of the normalized curve in Figure 10 reveals that an increasing and then decreasing A, with depth, reflects a relatively strong layer (relatively low DN) upon a relatively weaker layer (relatively high DN), and vice versa. In Figure 11, various examples of normalized deviation curves on Road 2212 at Bultfontein (Tvl), are illustrated. From this figure the variations in composition of the "same" pavement, as measured with the DCP, are obvious. This is very important information, not only for the analysis of basic pavement behaviour, but also for pavement rehabilitation design.

## DCP COMPUTER PROGRAMS

Two DCP computer programs to evaluate the DCP data have been developed at the NITRR [12]. The names of these programs are **DCPB** and **AVEB** and they can be run on IBM compatible personal computers.

The program **DCPB** is used to evaluate DCP data measured at a single position, while program **AVEB** is used to evaluate the average of up to 50 individual DCP measuring positions.

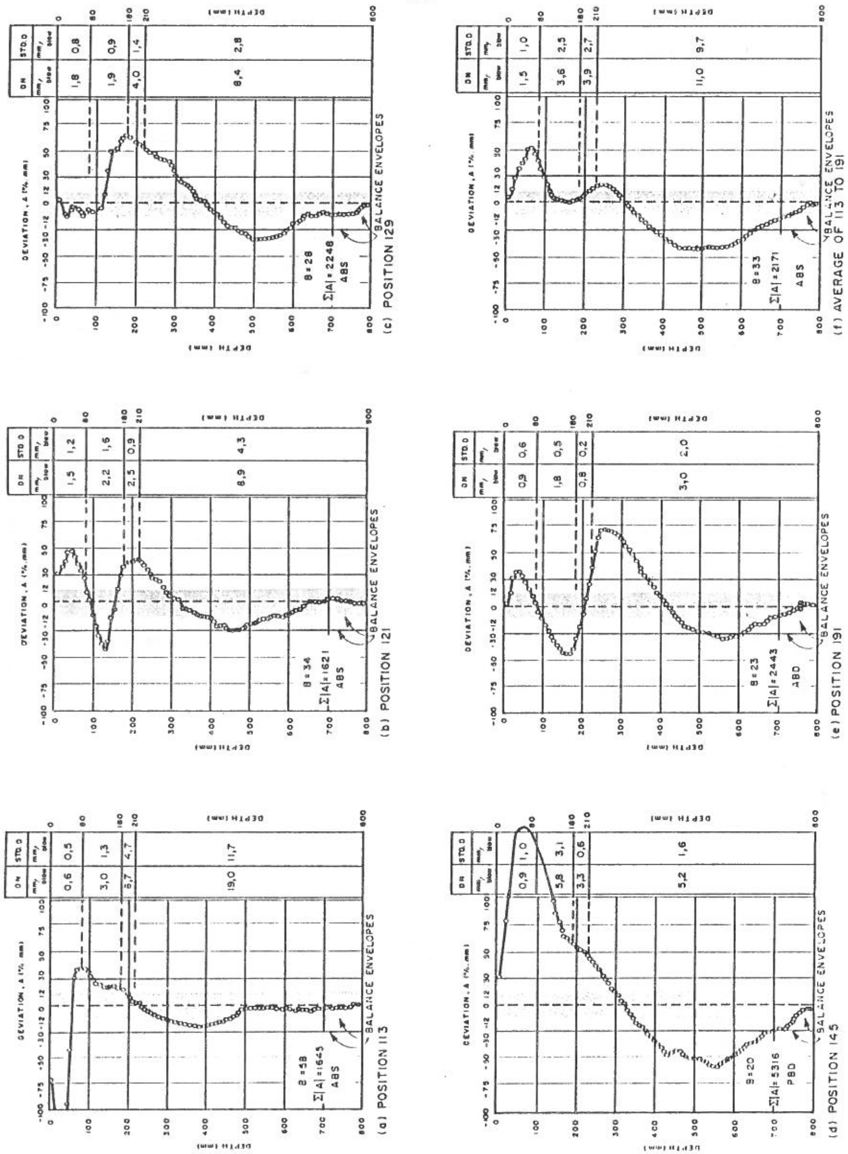


FIGURE 11 VARIOUS EXAMPLES OF NORMALIZED DEVIATION CURVES ON ROAD 2212 AT km 12,65 (BULTFONTEIN, TVL)



Both programs calculate average penetration rates through the pavement for the different layers, including certain percentile values, depending on the category of the road under consideration.

The **pavement strength-balance classification** is done automatically, as is an evaluation of the **state of balance** including the **redefinition** of the thicknesses of the layers based on in situ measured strength.

## SUMMARY AND CONCLUSIONS

In this paper a **universal classification system**, based on the concept of **strength-balance of pavements**, is described. The **strength-balance** of the pavement is calculated by means of the data obtained with the **Dynamic Cone Penetrometer (DCP)**.

This **classification** is based on two unique parameters, B and A. **Parameter B** defines the **Standard Pavement Balance Curve** (SPBC) of the data, and **parameter A** describes the **state of balance** of the same data. The DCP data are classified into one of **nine possible pavement strength-balance categories**.

With this data the pavement can be classified as either a **shallow, deep or inverted pavement structure**, which can be either **well-balanced, averagely balanced or poorly balanced**.

Further, the pavement can be divided into different layers, based upon the **in situ measured strength**, by using the variation in the deviation (parameter A) of the Standard Pavement Balance Curve (SPBC), with depth. These newly defined layer interfaces correspond to discontinuities within the in situ pavement structure and are **essential** in defining the pavement structure with regard to the **analysis and understanding** of **basic pavement behaviour**.

Two **DCP computer programs** have been developed to **analyse** and **classify** the DCP data in terms of the concept of **pavement balance**. Based on the relative DCP strength of the individual pavement layers, the failure mechanisms such as permanent deformation and fatigue cracking of pavements may also be explained.

It is the opinion that this method of classification, will be of great assistance in particular to unexperienced users of the DCP instrument as a pavement design and evaluation tool. It is further envisage that this universal method of classifying DCP data and hence flexible pavements, will contribute largely towards a sound basis of comparison between different pavements and different failure mechanisms of pavements in general.

Finally, the implementation of the pavement strength-balance classification system will improve current methods for designing new pavements and rehabilitating existing pavements, particularly in the developing countries in southern Africa where the existing road network needs to be extended or rehabilitated.

## ACKNOWLEDGEMENTS

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