10th CONFERENCE ON ASPHALT PAVEMENTS FOR SOUTHERN AFRICA

PRACTICAL GUIDELINES USED TO ASSIST WITH THE ACCURATE CHARACTERISATION AND MODELLING OF PAVEMENT MATERIALS AND LAYERS

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Abstract

The South African Mechanistic Design Method (SAMDM) has been used extensively in South Africa the past four decades and established itself as an excellent tool to calculate the bearing strength or functional remaining life of pavement layers during rehabilitation. However, some designers in the industry experience problems with the method (both in correctly using, modelling and interpreting it) and hence find it difficult to use the method and/or models to simulate the distress road conditions and functional pavement life accurately. Due to the relative complexity involve as well as the various inputs required to "model" your pavement structures accurately during the SAMDM process, it is important that the designer at least use input data that represents the in-situ properties of the pavement structure and its associated material properties accurately.

1. INTRODUCTION

The South African Mechanistic Design Method (SAMDM) has been used extensively in South Africa the past four decades and established itself as an excellent tool to calculate the bearing strength or functional remaining life of pavement layers during rehabilitation. However, some designers in the industry experience problems with the method (both in correctly using, modelling and/or interpreting it) and hence find it difficult to use the method and/or models to simulate the distress road conditions and functional pavement life accurately. Due to the relative complexity involve as well as the various inputs required to "model" your pavement structures accurately during the SAMDM process, it is important that the designer at least use input data that represents the pavement structure and its associated material properties accurately.

In general, for a practitioner or designer to model a pavement structure to be used in the SAMDM, the following methodology / process, inter alias, can be followed:

(i) Collection of all available data (e.g. the preliminary investigation and initial assessment which inter alias may include gathering of available information on as-built data, pavement structural data, geometry, geology, DCP testing, traffic data, rut depth measurements, riding quality, deflection bowl measurements etc.),
(ii) Identification of uniform sections using a holistic approach which inter alias includes the use of deflection measurements etc.,
(iii) Characterisation of pavement layers and modelling of pavement structures. After the identification of the uniform (pavement) sections, additional testing and analysis are required in order to develop a mechanistic or pavement model for each uniform section for a typical pavement structure representing such a uniform section,

(iv) Prediction and calculation of the associated stresses and strains,
(v) Calculation of the structural or bearing capacity ("functional life") of the different pavement layers for the proposed pavement model.

For the purpose of this paper, we will only deal with certain aspects related to points (i) and (iii) above in which guidelines will be provided for the practitioner on how to use field performance data to assist in validating input parameters in the characterisation and modelling of the pavement materials and layers.

One of the most important aspects in the development of a mechanistic model for different pavement structures is to characterise the pavement structure and its material properties so that it can be used as input parameters in the SAMDM for evaluation purposes. Each model derived at, in general, will comprise of the following input parameters: layer thicknesses, layer type, Effective elastic properties, and Poisson's ratio.

Next will be the back-calculation of the Effective Elastic E-moduli using the following input data:

- contact tyre pressure and standard design axle load,
- number of wheels and position,
- material properties including the estimated effective elastic moduli (elastic stiffness),
- Poisson's ratio of each layer,
- number of pavement layers and the layer thicknesses thereof, and
- measured deflections and deflection basin parameters etc.

The characterisation or classification of the pavement structure (layer thickness and type, number of layers, material properties) during the modelling process are very important input parameters and hence great care needs to be taken to use and interpret these input parameters correctly. Part of the problem in characterising and interpreting the material properties results of the different pavement structure layers is to take into account the effect of stabilisation of layers, in-situ moisture and density of the different pavement layers / materials etc.

This paper gives practical guidelines (a rudimentary approach), assisting in the process to use and interpret material property results (in-situ field performance data) as input parameters into the SAMDM to validate and develop a more accurate pavement model using inter alias the following:

- test pit data (which includes the classification of materials according to the TRH 14),
- ensure that the material properties of old stabilised layers are incorporated into your pavement model analysis,
- using DCP data to characterise and classify pavement layer materials and validate pavement thicknesses, and
- consider the influence of in-situ moisture content and density of materials on a rudimentary basis.

Experience using these practical guidelines or techniques has resulted in the modelling of pavement structures within the SAMDM which in effect simulate the distress road conditions and functional pavement life more accurately.

2. BACKGROUND

Using the methodology, mentioned above, to model a pavement for mechanistic design purposes (see points (i) to (v) under introduction), there are several aspects that needs to be considered. If during one of these processes problems are experience on how to use or interpret the data or information, or if input field data are not used in the correct way, it is sad to say but the engineer / practitioner will be in trouble even before an analysis has started. Thus, the SAMDM will then only become a big black box that can produce any answer that is required by the practitioner by fiddling with certain input parameters. As we all are aware, it is very important that adequate data needs to be gathered and correctly processed from the word go. For example, in order to have a good statistical set of data to work from and determine uniform sections, an adequate amount of deflection data sets is needed. Research and statistics already available proofed that if for example data points measured at every 100m compare to data every 5 to 6m along a section of road, you can already build an error of ±20-30% into your data. Therefore, the data started off with, is not necessarily representative of what will be actually measured on the road. Thus modelling a representative pavement model for the various uniform sections will become troublesome. The problem in practice is this : First, the perception exists that it is expensive if more tests are to be done – which is not really true because you pay for what you get or what you measure for. Second, engineers / practitioners needs to put more pressure on their clients to allow for more testing to be done – if you build an error of ±20-30% into your data even before any analysis have been done, it will eventually costs the client much more for the rehabilitation actions required due to data that have such a large margin of error. Engineers / practitioners need to be become more equipped with the statistical side that is required to obtain the correct data during the modelling and analysis phases of a rehabilitation design. Various research, papers and studies have already addressed this issue and will not be discuss in this paper.

Another important aspect is that a model is to be created which represents the current or existing pavement structures in the field (the existing in-situ condition properties or field performance data). Although it is very important to test your materials in the laboratory, characterise and classify the materials accordingly and get all the properties thereof using standard laboratory testing, of equal importance are the behaviour of these materials in the field and the influence of the various climatic and environmental conditions on the design input parameters. Also important is the influence of each layer on the other (on top and/or bottom). Although the different pavement layers act separately, they also act as one and the behaviour and changes that one layer may experience, will directly influence the other layers. For example, if layers experience a sudden ingress of water, and become saturated, these layers may decompact/de-densify and thus influence the surrounding layers. Also, the shear properties of such a wet or saturated layer will be totally different than when in a dry state. Currently it is very difficult to simulate these actions in a laboratory. Therefore, one needs to look holistically in constructing your pavement models and use as much as possible in-situ measured field performance data during the design process.

Jooste (2004) in his paper “A re-evaluation of some aspects of the Mechanistic Empirical (ME) Design Approach” inter alias came to the following conclusion: “The two examples presented in this paper illustrated the sensitivity of the ME design method to material properties. It also showed how the ME design method could become a source of confusion or contention, and could easily lead to an incorrect assessment of a pavement’s structural capacity.” He concluded that by changing any minor input into the SAMDM programme, major changes occur in the calculation process and that the programme is very sensitive to changes in material properties. He also stated that in order to improve the decision making process, the material classification input needs to be simplified. Although Jooste (2004) made an important assessment on how sensitive the SAMDM is for material classification input as well as a more simplified material classification, it is important also to realise that the influence of such changes are less likely to be a problem during the design phase since all the input parameters in the field can be measured and thus be interpreted correctly if adequate information is available and if modelled correctly using the input data. For example, if a Norite crushed stone is used as a base course, the in-situ density, moisture, material properties, stiffness for such a material would have been already build into the deflections measured on the road and subsequently into the Effective Elastic Moduli for the material which will then subsequently determine the stresses and strains for this specific material. If a Quartzite crushed stone is used instead of the Norite crushed stone for the same section, the same above would have been applied and hence due to the different material type properties of the two materials you will have different in-situ or field performance specifics that you will get from such a pavement base course etc. By using data statistically correct and modelling your pavements according to all data available and according to the existing field performance of the input data (in-situ measurements), the chances are good that the model will reflect the correct material and pavement properties, the past history of the pavement and subsequently its functional pavement life.

It is very important to take rut depth measurements at the same position that the deflections have been taken for various reasons, an exercise which is omitted by many practitioners today, when modelling pavement. If practitioners do not utilise rut depth measurements when constructing their pavement models for mechanistic design purposes, it will be very difficult if not almost impossible to model a pavement correctly. Hence, it will become extremely difficult to obtain results from your model that explain exactly what is currently happening on your roads and why. Indirectly, permanent deformation in the form of rut depth is an important output parameter of a mechanistic model and one of the criteria to determine “end of optimal pavement life or functionality”. Current research done by various researchers for the South African National Roads Agency Ltd (SANRAL) on this matter will provide some new insight into this matter and new mathematical models and/or transfer functions may be adapted for future use into the SAMDM.

Although much more can be said, it needs to be stressed that during the process to model a pavement for mechanistic analysis purposes, it is of the utmost importance to ensure that the input data and/or parameters are accurate, represent in-situ or field conditions and validate the relationship of the model with the data obtained from the field.

3. CHARACTERISATION AND “RE-CLASSIFICATION” OF PAVEMENT STRUCTURES AND MATERIAL PROPERTIES

As already stated, the characterisation of the pavement structure (layer thickness and type, number of layers, material properties, in-situ properties) during the modelling process are very important input parameters and great care needs to be taken to use and interpret these input parameters correctly. Part of the problem in the characterisation and interpretation of the material property results of the different pavement structure layers, is to take into account the effect of stabilisation of layers, in-situ moisture and density of the different pavement layers / materials. Thus taking into consideration how the materials or layers perform in-situ and how to incorporate these in-situ performances into you pavement model or analysis.

The following aspects will be addressed in order to give some guidance on how to accurately characterise the pavement layers and material properties and on how to incorporate this into the design. It will also give practical guidelines on how to interpret the input data and material property results (in-situ properties / field performance data) in order to validate and develop a more accurate pavement model:

- test pit data (which includes the classification of materials according to the TRH 14),
- ensure that the material properties of old stabilised layers are incorporated into your pavement model analysis,
- using DCP data to characterise and classify pavement layer materials and validate pavement thicknesses, and
- consider the influence of in-situ moisture content and density of materials on a rudimentary basis.

3.1 Test pit data and standard laboratory testing

After collection of all relevant data and information during the preliminary investigation/initial assessment and uniform sections have been identified (see paper by Jordaan and deBruin, 2003), the next important aspect in the modelling process is to identify suitable positions to conduct the test holes/ pits. This is one of the most important aspects during the modelling process since the data obtained from these test pits will be used as the input parameters when modelling a representative pavement structure for each uniform section thus forming the “cornerstones” of the pavement model. The position of such test hole / pit representing a uniform section needs to be considered carefully and is necessary to develop a mechanistic or pavement model for each uniform section identified. The total number of test pits that need be taken for each uniform section will ultimately depend on the total length of the uniform section, the budget available, the geology of the area etc. and it maybe required that more than one or two test pits are identified. However, this decision will be taking only after looking at all the data holistically and it will be section or site specific. Crucial, in deciding where the test pit will be positioned is to first statistically determine, for example, what the 90th percentile value for your deflection bowl measurements will be (if road is for example classified as a Category B road according to the TRH12, 2006) for each uniform section as well as the position thereof taking into consideration the traffic, geology, as-built data, deflection data, rut depth data and Dynamic Cone Penetrometer (DCP) data etc. The test holes need to be taken at the exact positions where, for example, the deflection bowl measurements along the uniform section are represented by the calculated 90th percentile deflection bowl measurement for that specific section. By doing this, the position where the test hole will be place will represent typical material properties for the representative 90th percentile deflection bowl measurement for that uniform section. If more than one position has been identified along the uniform section then one needs to look where one of these sections have a more uniform distribution of 90th percentile deflection measurements similar to the representative 90th percentile measurement determined for the uniform section and then to position your test pit there.

Now that we have establish the test pit position, let’s look at what standard laboratory testing needs to be done in order to start characterise the pavement model or structure.

The following standard laboratory tests have been identified for each pavement layer at each test pit in order to characterise the material properties for the different layers:

Table 1: Standard laboratory tests used in characterising and classifying materials

Density	Mod. AASHTO	Maximum dry density (kg / m^3)
		Optimum Moisture Content (OMC) (%)
		Water absorption
California Bearing Ratio (CBR) Analysis	Swell (%)	
	Relative Density (%)	90%, 93%, 95%, 98% & 100%
Grading or sieve analysis	Grading Modulus (GM)	Max. particle size (mm)
	Particle size distribution	Percentage passing the 0.075mm
Atterberg Limits	Liquid Limit (LL)	Plasticity Index (PI)
	Plastic Limit (PL)	Linear shrinkage (LS) (Bar)
Aggregate Crushing Value (ACV)		
No. of Fractured Faces		

By using the above standard laboratory tests the material properties obtained from the test pits can now be used to classify and characterise the different pavement layers using the TRH14 (1987) specifications and the Colto (1998) specifications.

The following additional advanced laboratory testing is also available. These testing consist of static - and dynamic tri-axial testing to determine the following mechanical properties of the material:

- Resilient modulus of the material,
- Shear strength of the material, and
- Permanent deformation (plastic strain) characteristics of the material.

Unfortunately due to costs constraints as well as interpretation of these results into a mechanistic design method, they are specialised tests that are seldom used by practitioners and are mainly used for research purposes. With the Revision of the South African Pavement Design Method (SAPDM) currently undertaken by SANRAL, more of these tests may be required in future for characterisation and design purposes as input into the SAPDM.

3.2 Incorporating the effect of old stabilised layers acting as Equivalent Granular (EG) layers into the model

The state of different pavement structures change with time due to the weathering, breaking down of the different pavement layers (i.e. stabilised layers breaking down to an equivalent granular layer) etc. It follows that the state of materials under investigation may differ significantly from the as-built state. It is therefore important to conduct a sufficient number of test holes to get a meaningful and representative indication of the layer thicknesses (important input in the mechanistic model), the quality of the material and their properties. The characterisation and classification of the different pavement layer's are done using results obtained from test holes in combination with as-built data.

The TRH 14 (1987) classification of the various pavement layers shown in Table 2 and Table 2.1 (see note (A)) is based on the California Bearing Ratio (CBR) at mod. AASHTO density, Grading Modulus (GM), sieve distribution, maximum stone size, Plasticity Index (PI), Linear Shrinkage (LS) and Liquid Limit (LL) etc. derived from standard laboratory testing at the relevant density, as specified in the TRH 14 (1987).

The aim of the test pit investigation is also to determine if the different layers were stabilised during construction. **Phenolphthalein** as well as **HCL** testing are used for this purpose. If, for example, a layer is stabilised with cement the HCL will react as whitish foam on the layer while with a lime stabilisation the material will react with the Phenolthalein and become pinkish. The more the layer is stabilised the heavier the reaction will be and the darker the colouring will be. Once these tests have been done and stabilisation during construction is confirmed, the material classification may be adjusted or "re-classified" as an interim. Stabilised layers will eventually break down to an Equivalent Granular (EG) material of a quality better than the original material, e.g. a G5 layer that was stabilised as a C4 layer will break down as an EG4 layer and will be analysed accordingly. Thus, becoming an equivalent G4 granular material with material properties better than that of a G5 material. This is a very important finding from the test pits and the effect of the stabilisation may be confirmed with DCP tests results. To be discussed later as well. This is also important in the final classification and or characterisation of the material that will be used as input into the SAMDM and ultimately in determining the structural capacity. For example, in Table 2 and Table 2.2 it can be seen that the subbase (which was stabilised) is classified as a G5 material using the TRH14 (1987) classification system. Taking into consideration that the layers was stabilised and the fact that the material has become one class better than the original material, the subbase material is now "re-classified" as an EG4 (an equivalent G4 layer) (see note (B) Table 2.2). This is an interim re-classification and will be further validated by assessing the in-situ density as well as the in-situ DCP test results.

3.3 Incorporating the effect of Relative Density (RD), in-situ density and in-situ moisture

3.3.1 Relative Density

As stated above, the TRH14 classification is derived by material properties for the different layers and for most of the time the one most important test result used during the classification process is the CBR at mod. AASHTO – which in lay-man's term is the shear strength property of a material measured at OMC. Taking this into consideration, it is also important to see at which density in the field the material or layer is now operating- thus to assess the relative density (RD) (in-situ) or compaction of a material (see Table 2.3 – note (C)). The in-situ density or relative compaction of the material in the field also gives important information on the behaviour of the pavement layer or material. For example, although a material may test as a G5 material in the laboratory (e.g. subbase material), due to various reasons, it could behave as a G4 or a G6 material within the pavement structure. This may be due to relatively high or low densities, stabilisation, de-compacted layer, moisture etc. within the pavement structure. For the purpose of this exercise the in-situ field densities were taken and the different material re-classified according to the relative density of the material in the field. As can be seen in Table 2.3 (note C) – the subbase is "re-classified" as a G3/G4 material.

Table 2: Example of standard laboratory test results for typical test pit

REHABILITATION OF ROAD SECTION 1 - BETWEEN KM 42.6 TO KM 51.0 - KM 49.50 N LOWT – TP9 - SOIL MECHANICAL PROPERTIES					
LABORATORY NUMBER	A660	A661	A662	A663	A664
LAYER	Base course	Upper Subbase	Lower Subbase	Selected Subgrade	Subgrade
DEPTH	25-230	230-400	400-610	610-800	800-1000
THICKNESS(mm)	205	170	210	190	200
DESCRIPTION	Light reddish brown and grey Quartzite	Dark brown dense weathered Dolerite - stabilised	Dark brown dense weathered Dolerite - stabilised	Dark olive brown loose sandy Silt and weathered Sandstone	Dark olive brown loose sandy Silt and weathered Sandstone with Shale
Moisture condition when sample	Slightly moist	Slightly moist	Slightly moist	Moist	Moist
Indication of Stabilisation of layers					
Phenol & HCL Testing	Yes	Yes	Yes	Yes	Yes
Stabilised		X	X		
Lightly stabilised					
No trace or indication of stabilisation	X			X	X
GRADING ANALYSIS - % PASSING SIEVES (TMH1 1986 : METHOD A1(a) & A5)					
Passing 53. 00 mm		100	83		92
37. 50 mm	100	92	82		92
26. 50 mm	93	91	78		91
19. 00 mm	83	89	74	100	89
13. 20 mm	70	80	69	99	86
9. 50 mm					
4. 75 mm	48	60	57	96	77
2. 00 mm	33	44	45	91	68
0. 425 mm	20	19	23	84	59
0. 075 mm	9	9	11	50	9
GRADING MODULUS	2.38	2.28	2.21	0.75	1.64
ATTERBERG LIMITS ANALYSIS (TMH 1 1986 : METHOD A2 & A3 ; TMH 1 1979 : METHOD A4)					
LIQUID LIMIT	0	0	27	22	21
PLASTICITY INDEX	SP	NP	5	6	9
LINEAR SHRINKAGE (LS)	0.5	0.0	2.5	3.5	4.5
IN-SITU MOISTURE CONTENT (FIELD)	2.1	10.4	13.7	18.5	14.8

Table 2: Example of standard laboratory test results for typical test pit (Continue)

CALIFORNIA BEARING RATIO ANALYSIS (TMH 1 1986 : METHOD A7 & A8)					
MAXIMUM DRY DENSITY (Kg/m3)	2255	2072	2102	1994	2034
OPTIMUM MOISTURE CONTENT (%) (OMC)	7.7	13.1	12.2	10.8	12.6
PERCENT COMPACTION / FIELD DENSITY	101.1	98.9	90.9	86.3	86.5
CBR @ 90% Mod AASHTO	17	14	26	8	4
CBR @ 93% Mod AASHTO	31	31	31	11	5
CBR @ 95% Mod AASHTO	47	45	34	14	6
CBR @ 98% Mod AASHTO	127	58	40	22	11
CBR @ 100% Mod AASHTO	247	68	46	34	17
Swell (max)	0.0	0.1	0.1	0.1	0.2

Table 2.1: Classification of pavement layers / materials using TRH14 (1987) and COLTO (1998) (A)

	Classification (Using CBR)	G1/G2/G3/G4	G5	G6	G8	G10
	Classification (Using GM)	G1-G4	G1-G4	G1-G4	G7	G5
	Classification (Using PI)	G1	G1	G2-G4	G2-G4	G5
	Classification (Using LL)	G1-G4	G1-G4	G5	G1-G4	G1-G4
	Classification (Using LS)	G1-G4	G1-G4	G1-G4	G1-G4	G1-G4
A	**TRH14 / COLTO Classification**	**G2**	**G5**	**G6**	**G8**	**G10**

Table 2.2: Classification of pavement layers /materials using the effect of stabilisation (B)

B	**Re- Class. - Provision for Stabilised layers**	**G2**	**EG4**	**EG5**	**G8**	**G10**

EG : Equivalent Granular Layer - Traces of stabilisation - break down as better quality material

Table 2.3: Classification of pavement layers / materials using the relative density (C)

C	**Re- Class. - Relative Density**	**G2**	**G3/G4**	**G6/G7 /G8**	**G8-G10**	**G8-G10**

3.3.2 In-situ field density and in-situ moisture content

The TRH 14 (1987) classification of the various pavement layers shown in Table 2 and Table 2.1 (see note (A)) is based on the California Bearing Ratio (CBR) at mod. AASHTO density (soaked), Grading Modulus (GM), sieve distribution, maximum stone size, Plasticity Index (PI), Linear Shrinkage (LS) and Liquid Limit (LL) etc. It sometimes does happen that a material may be tested for e.g. a G5 material according to its CBR at mod. AASHTO but all of a sudden the material become a G6 material or borderline material G5/G6 material because it does not meet the criteria or specification for the GM or PI of the material. Thus with one and/or two parameters being in the higher quality range of a G5 material. Taking the above into consideration, measured CBR values determined in the laboratory through standard testing are done at mod. AASHTO densities and are carried out on soaked samples. We all know that the material in the field may be in a dry, moderate or a wet state and thus a soaked mod. AASHTO CBR value does not represent the material and its behaviour in the field. If a pavement layer was stabilised during construction and after the additional in-situ field testing (e.g. Phenolphthalein, HCL etc.) proofed it to be, the next most crucial and if not the most important field test results that are required for modelling purposes is the in-situ or field density and in-situ or field moisture content measurements for each and every pavement layer.

Emery (1992) did some excellent research work by determining criteria on how to take the calculated laboratory soaked CBR (CBRs) and using different material properties to derive at a representative unsoaked CBR (CBRu) or in-situ field CBR (see Table 2.4).

Table 2.4: Classification of pavement layers / materials using Emery's (1992) in-situ density and in-situ moisture (soaked (D) & unsoaked (E) CBR)

	Optimum Moisture Content (OMC) (%)	7.7	13.1	12.2	10.8	12.6
	Linear Shrinkage (LS)	0.5	0.0	2.5	3.5	4.5
	Percentage passing the 0.425mm sieve (P425)	20.0	19.0	23.0	84.0	59.0
	Im (Thornthwaite's Moisture Index)	-20	-20	-20	-20	-20
	K	1	0	0	0	0
	CBRs - Soaked CBR (s) @ in-situ density	**300.0**	**62.5**	**27.5**	**6.5**	**3.0**
	FMC - Field moisture content	**2.1**	**10.4**	**13.7**	**18.5**	**14.8**
	CBRu -Unsoaked (u) CBR at in-situ moisture & @ in-situ density	**567.2**	**137.8**	**61.0**	**14.3**	**20.6**
	Ecbr - E calculated from E/DN and CBR/DN relationship using CBRu	**1464**	**449**	**227**	**68**	**91**
	EMC1 - Expected equilibrium moisture content using Im, LS and P425	**3.68**	**7.93**	**8.14**	**9.14**	**10.21**
	EMC2 - Expected equilibrium moisture content without using OMC	2.73	4.41	5.60	8.54	8.56
	EMC3 - Expected equilibrium moisture content without using LS and P425	4.94	13.10	11.96	10.18	12.46
D	**Revised Class. - In-situ Density & Moisture Classification (CBRs)**	G1/G2/G3 /G4	G5	G6	G9	G10
E	**Revised Class. - In-situ Density & Moisture Classification (CBRu)**	**G1/G2/G3 /G4**	**G1/G2/G3 /G4**	**G5**	**G7**	**G7**

The representative calculated soaked CBR value (CBRs) calculated in the laboratory at different densities are now used and a new soaked CBR value (CBRs) is determined for the pavement layer using the measured in-situ (field) density of that particular layer by interpolation. Thus, a soaked CBR value is calculated that will represent the soaked CBR at the density that has been measured in the field. After this, a new unsoaked CBR (CBRu) value can be derived at using the soaked CBR (CBRs) at and the in-situ / field moisture content and the OMC of the material (see Table 2.4).

The following Equation (1)(Eq.1) can be used to calculate an unsoaked CBR that represents the in-situ or field moisture content (Emery, 1992):

$$CBRu = 59.13 \times e^{(-1.33 \times FMC / OMC)} \times CBRs^{0.46} \quad \text{(Eq.1)}$$

Where	CBRu	-	Unsoaked CBR at in-situ moisture (FMC) and at in-situ density
	CBRs	-	Soaked CBR at in-situ density
	FMC	-	Field Moisture Content or in-situ moisture content
	OMC	-	Optimum Moisture Content

CBRu is therefore the CBR at in-situ density (field density) and at in-situ moisture content (field moisture). The conversion models to obtain CBRu from CBRs are only applicable up to a maximum CBRs of 80. The results obtained from the above exercise were used as an input for classification and for analysis purposes (see Table 2.4 – note (D) and (E)).

The following Equations 2 to 4 (Eq. 2-4) for the Equilibrium Moisture Content (EMC) developed by Emery (1992) are also used with great success in the characterisation and classification of the materials:

$$EMC1 = 0.59\,(OMC) + 0.033\,(LS)\,(P425)^{0.7} + 3.72\,(\log_e(100 + Im)) - 1.2\,(K) - 16 \quad \text{(Eq.2)}$$

$$EMC2 = 0.053\,(LS)\,(P425)^{0.7} + 4.75\,(\log_e(100 + Im)) - 1.9\,(K) - 16.4 \quad \text{(Eq.3)}$$

$$EMC3 = 1.27\,(OMC) + 2.73\,(\log_e(100 + Im)) - 1.3\,(K) - 15.5 \quad \text{(Eq.4)}$$

Where	K	-	1 for base and 0 for subbase and subgrade
	OMC	-	Optimum Moisture Content @ mod. AASHTO
	P425	-	Percentage Passing 0.425mm sieve
	LS	-	Linear Shrinkage LL - Liquid Limit
	Im	-	Thornthwaithe’s moisture index
	EMC1	-	Expected equilibrium moisture content using Im, LS and P425
	EMC2	-	Expected equilibrium moisture content without using OMC
	EMC3	-	Expected equilibrium moisture content without using LS & P425

Moist climates have positive values of Thornthwaite's Moisture Index (Im) and dry climates have negative values. Climatic types can also be classified in terms of the moisture index

(Im) (Table 2.5). In Figure 1: below the Revised Thornthwaite's Moisture Index (Im) Map is given.

The Equivalent Moisture Content (EMC) is used to describe the moisture content in die field in the different layers after about two to three years after construction. The two most important variables affecting the EMC are the material type and its properties and the climate as can be seen in the above equations. Results from these equations can also be used to get a better understanding of the materials used in the different layers as well as at what moisture regime it operates. By carefully studying these values, valuable input can be obtained and used as input into the SAMDM.

For e.g. if the measured FMC of some of the pavement layers are considerably higher than the EMC it may indicate that moisture problems exist on these sections (with associated reduction in pavement life). Relative high FMC compared to the measured EMC found near or at an existing cuttings, may just illustrate that urgent attention needs to be given to subsoil drainage conditions along the entire length of these sections.

Table 2.5: Definitions of climatic types (Leyland and Paige-Green, 2010)

Climatic type	Moisture index (Im)
A Perhumid	≥ 100
B1-4 Humid	20 to 100
C2 Moist sub humid	0 to 20
C3 Dry sub humid	-20 to 0
D Semiarid	-40 to -20
E Arid	-60 to -40

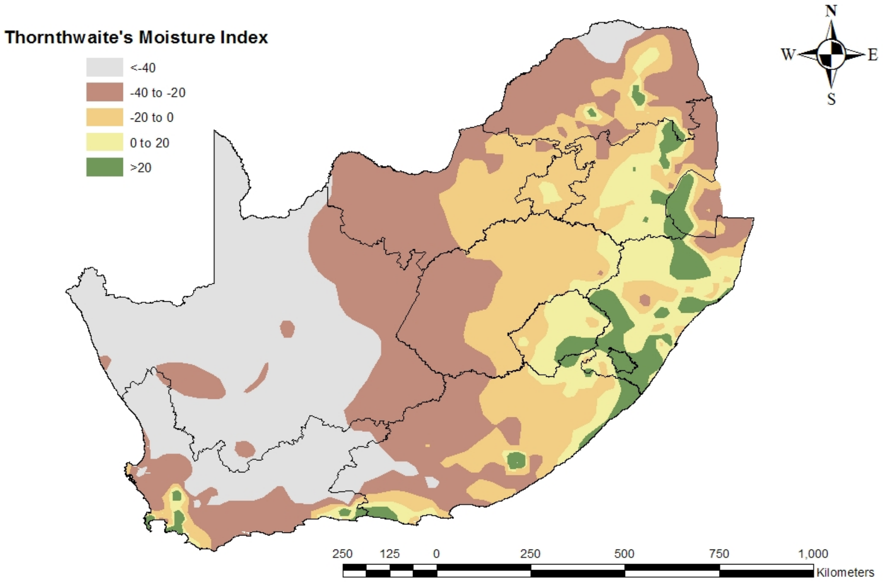


Figure 1: Revised Thornthwaite's Moisture Index (Im) (revised Thornthwaite's Im, Leyland and Paige-Green, 2010)

By using Equation (1) (which now incorporate the CBRs (using in-situ / field density), the OMC as well as the in-situ / field moisture content) and calculating the CBRu for the different layers, it is now possible to "re-classify" the material of the different pavement layers (see Table 2.4 – note (D) and (E)) according to these criteria and specifications. The subbase layer is now "re-classified" as a G5 material and a G1-G4 material using the newly derived CBRs and CBRu respectively.

3.4 Dynamic Cone Penetrometer (DCP) data

In South Africa, the measurement of the in-situ shear strength of the pavement layers using a DCP is well established (Kleyn et al, 1987), (Kleyn, 1984), (Kleyn and Savage, 1982), (DOT, 1997). The DCP is used to measure the rate of penetration (DN) through the various components (layers) of the pavement structure. The penetration is a function of the in-situ shear strength of the material and the profile in depth thereof gives an indication of the effective in-situ properties of the materials in all the pavement layers up to a depth of penetration (800 mm is recommended). The California Bearing Capacity (CBR) test, which is a standard laboratory test, also gives an indication of the shear strength of the material but has the typical limitation of all similar laboratory tests, such as unnatural conditions, which makes it difficult and time consuming to obtain the in-situ prevailing pavement condition. Although in principle the DCP and CBR both measure the shear strength of the material, the DCP has the advantage that it is non-destructive, easy to transport and use and allows for the detailed in-situ evaluation and analysis of pavement structures and their different layers (Kleyn et al, 1987), (Kleyn, 1984), (Kleyn and Savage, 1982). Good correlations were found and documented between the DCP measurements and the well-known CBR of granular materials and the Unconfined Compressive Strength (UCS) of cemented materials (Paige-Green et al, 1999), Kleyn (1984), (Kleyn and Savage, 1982), (DOT, 1997). The DCP test results, together with test pits, are also used to determine the thicknesses of the different layers, which have similar shear properties. The different layer thicknesses are of utmost importance in the design approach and required as input into the SAMDM.

For the purpose to fully utilise the benefits that are available in doing DCP testing, it is recommended that DCP tests are done at frequent intervals along the entire section of road (at least @ 50 to 100m intervals depending on the total length of the uniform section) in the same direction that the deflection measurements had been taken as well as at all the test pits. During this exercise data are not only used to obtain a meaningful indication of the layer thicknesses, but also to assist in determining the in-situ material quality, properties and uniformity of the pavement structure. Thus ultimately assist with the in-situ classification of the materials.

According to sound pavement engineering, the results of geotechnical/material tests or in this case the DCP data should be combined and statistically processed to obtain reliable design data. The results are shown in Figures 2 and 3 respectively. First for the combined DCP test taken at the position where the test pits was made and secondly the combined DCP test results taken along the uniform section of length. The DCP tests are also used to obtain the in-situ CBR of the materials in all the pavement layers. Research done by Paige Green et al (1999), provides an estimate of an effective G-classification by using a CBR/DN relationship (see Table 2.6) This relationship for the prediction of unsoaked CBR (DCP) from soaked CBR, under current compaction and moisture conditions appears to provide considerable better predictive capabilities and a more realistic relationship based on field experience.

Table 2.6: Relationship between percentile in-situ CBR/DN and effective G-classification (Paige-Green et al, 1999)

CBR (from DCP)	DN value (mm/blow)	Classification
100	3.0	G4
80	3.6	G5
50	5.2	G6
25	9.0	G7
15	13.5	G8
10	18.0	G9
8	22.0	G10

These relationships are used as guidance on determining what the G-classification of materials is by using DCP test results. Various projects undertaken have shown that these relationships are more accurate than the existing ones used in the field and in most cases validate the field data for modelling purposes.

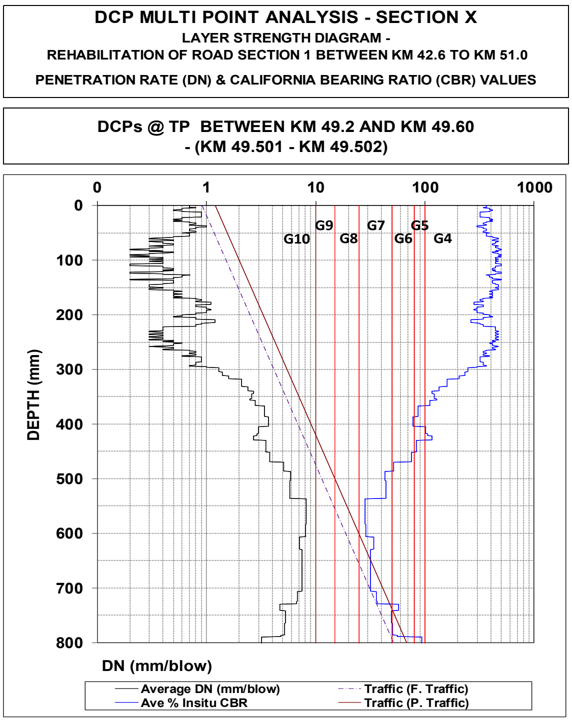


Figure 2: Combined DCP @ test pit

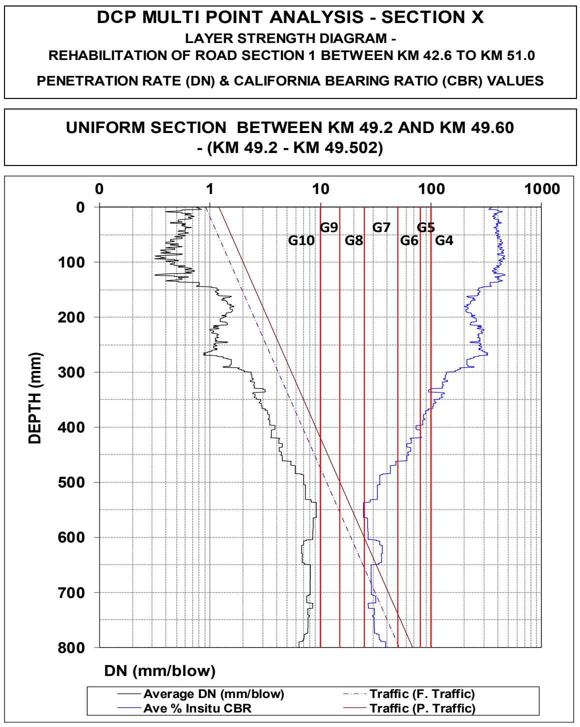


Figure 3: Combined DCP - uniform section

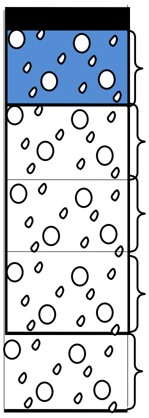
In Table 2.7, the DCP test results as determine for the Test Pit (TP)(see F) as well as the DCPs used in the Uniform Sections (US)(see G) are used to "re-classify" the materials according to their in-situ shear properties which also include the influence of density and moisture within the different pavement layers. It is important to see how these DCP data has also proof the accuracy of the stabilised layers and confirm the quality and material properties to be used in the final model (see Figures 2 and 3).

Table 2.7: Classification of pavement layers / materials using DCPs taken @ Test Pit (F) and using the DCP taken over the uniform section (G)

F	Re- Classification - DCPs @ Test Pit	>>G4	G3/G4 (<<G5)	G6 / G7	G7	Not available
G	Re- Classification - DCP for Uniform Sections	>>G4	G3/G4 (<G5)	(<G6) G7	G7	Not available

Taking all the so called "re-classified" materials in the different pavement layers into consideration and again looking at all the data and information available holistically, it is now possible to "re-classify" the different materials in the different pavement layers by taking the in-situ measured properties into consideration. In Table 2.8 the final "re-classified" materials are given and will be used in the modelling and final analysis. Various projects have been tested in practice using these techniques or processes with great success and hence assist in a better understanding of the behaviour of the pavement layers as it is in the field.

Table 2.8 : Re-classification of pavement layers / materials to be used into the SAMDM model taking into consideration input from (A) to (G)



TRH14 (A)	STAB. (B)	RD. (C)	CBRs (D)	CBRu (E)	DCP TP (F)	DCP US (G)	FINAL (A)-(G)
G2	G2	G2	G1-G4	G1-G4	>>G4	>>G4	G2
G5	EG4	G3/G4	G5	G1-G4	G3/G4	G3/G4	EG3/EG4
G6	EG5	G6-G8	G6	G5	G6-G7	G6-G7	EG5/EG6
G8	G8	G8-G10	G9	G5	G7	G7	G7/G8
G10	G10	G8-G10	G9	G7	N/A	N/A	G10

4. SUMMARY & RECOMMENDATION

As can be seen from the test pit and material test results available, the standard laboratory test results (soaked CBR etc.), do not necessarily represent what the in-situ performance of the different materials are. By using the TRH 14 (1987) material classification for the different materials, the in-situ behaviour of the different pavement layers / materials is not necessarily explained or validated. This paper briefly showed that by using the standard laboratory test results together with in-situ test results, a better characterisation / classification of the different materials can be obtained and better models of what actually happen in the field can be modelled. By using the different techniques in validating the input data through various processes, pavement models are constructed that represent the current material behaviour in the field (in-situ) and thus assist in a more accurate characterisation or classification of the materials in the field. This will ultimately lead to a more accurate calculation of the structural capacity of the pavement layers and subsequently lead to more accurate designs and hence a cost saving to the client.

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