SECONDARY AND FEEDER ROAD DEVELOPMENT PROGRAMME FOR ZIMBABWE

Part 3, Literature Study

MATERIAL: LABORATORY AND IN-SITU TESTING

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PREFACE

The Government of Zimbabwe through the Ministry of Transport (MoT) and in co-operation with the District Development Fund has decided to implement a Secondary and Feeder Road Programme. A fact-finding mission by SIDA in late 1985 concluded that a sector support programme for transport in Zimbabwe could be an effective means of channelling Swedish aid. It was proposed that a large proportion of the support should go to secondary and feeder roads.

A joint mission with representatives from ILC, SweRoad, SGI and VTI, financed by SIDA, visited Zimbabwe in May/June 1986 to formulate a programme which could contribute to the development of roads in the communal areas through possible external aid inputs by SIDA.

The programme was to include a selection of pilot projects, a tentative work programme, and a definition of test activities of standards and methods for the planning, construction, and maintenance of secondary and feeder roads.

As a complement to the programme, a study of available literature related to the construction and maintenance of roads in developing countries was also carried out. This is an offprint of the literature review on materials testing, both laboratory and in-situ testing methods.

Linköping, September 1986
In general, there are only small problems with the roadbed when constructing roads in Zimbabwe. Therefore, ground investigations are seldom done except in bridge foundations and in cases of problematic soils. Soil investigations in connection with road-building are principally a matter of determining compaction characteristics and of checking the degree of compaction. This appears for example from the kind of soil parameters most commonly determined in the MoT's laboratories.

In this chapter a brief description is made of how the most common soil parameters are determined in Zimbabwe. In some cases other types of test procedures are described which could be used instead or as a complement.

**Visual inspection of soil**

In all types of soil denomination and testing a proper visual inspection is of great importance. Through this, information is obtained about the soil type. It also serves as a check that the determined parameter correspond with the correct soil sample. In Zimbabwe the following assessments are made in the visual inspection. (Example from MoT's formula for sieving analyses).

1. **SOIL CLASSIFICATION**
2. **GEOLOGICAL ORIGIN**
3. **COLOUR (dry state)**: white, cream, fawn, yellow, orange, red, brown, grey, black
4. **ORGANIC CONTENT**: high, low, nil
5. **MICA CONTENT**: high, low, nil
6. **HARDNESS OF AGGREGATE**: sound, fractured, hard, soft
7. **SHAPE OF AGGREGATE**: rounded, irregular, flaky, angular, elongated
8. **SURFACE TEXTURE OF AGGREGATE**: glassy, smooth, granular, rough, honeycombed
If all the above mentioned assessment are made correctly, this will give a good indication of the soil type and its properties /26/, /27/, /28/.

**Moisture content**

The moisture content can be defined as the mass of water which can be removed from the soil by heating at 105°C, expressed as a percentage of the dry mass. Measurement of moisture content, both in the natural state and under certain defined test conditions, is indispensable for determining soil characteristics. The standard test method used in most countries is oven-drying at 105°C /29/, /30/, /31/. In Zimbabwe, however, drying is sometimes done by heating the soil on an electric plate or paraffin stove. This may, under certain conditions, result in the soil being heated far over 105°C. If this occurs, some adsorption-water will also evaporate and the result will be misleading. This can partially be avoided by using the sand bath method.

*Figure 10  Determination of moisture content.*
The sand bath method is intended as a site test for moisture content, where a drying oven is not available, or as a rapid method for granular soils. The only difference with this method compared to heating on a stove or plate is that a sand bath, consisting of at least 25 mm sand is placed between the sample container and the heating source. In this way the heat is spread more evenly. The sand bath method should, however, not be used for soils containing gypsum, calcareous matter or organic matter /29/, /30/.

It is often prescribed in standards that the sample should be dried before different kinds of test procedures are carried out. This is often done to determine the dry weight of the sample. The most common ways to do this are air drying where the soil is exposed to a warm dry atmosphere, or oven drying at 105°C. However, the drying of a soil sample may create larger attraction between particles, which may lead to them appearing to be aggregate instead of as individual particles. This will may lead to incorrect determinations of different soil parameters.

**Liquid limit**

The definition of liquid limit is the moisture content at which soil passes from the plastic to the liquid state, as determined by the liquid limit test /29/, /30/, /32/. Today, the percussion liquid limit (Casagrande method) is the only used method in Zimbabwe. Another way of determining this limit is with the fall-cone method, which is recommended in several countries. There are some advantages in using the fall-cone. This method is for example faster than the Casagrande method and the values seem to be more reliable according to a study made at the Swedish Geotechnical Institute /32/. Furthermore, the fall-cone equipment can be used to determine the shear strength and the sensitivity of cohesive soils. Research projects that are still in progress in e.g. France, UK, Sweden and the USA show that even the plastic limit can be determined with the fall-cone method /33/. In the USSR a standard has already been worked out and is in practice.
Plastic limit

Plastic limit is defined as the moisture content at which a soil passes from the plastic to the solid state, and becomes too dry to be in a plastic condition, as determined by the plastic limit test. The test can be carried out only on soils with some cohesion, on the fraction passing a 425 µm sieve. The test procedure is almost the same all over the world and the result is much more dependent on the operator than on e.g. different kinds of underlayers etc. As mentioned above, the fall-cone method may probably soon be a new standard method for determining the plastic limit /30/, /32/, /34/.

Figure 11 Determination of plastic limit
Consistency, liquidity and plasticity index

These indexes are defined in the same way everywhere and should therefore give the same values wherever they are determined. They may, however, vary depending on how the consistency limits are determined (e.g. Casagrande or fall-cone method etc) /29/, /30/, /32/.

Particle size distribution

The object of a particle size analysis is to group the conglomeration of discrete particles of various shapes and sizes, which a soil naturally consists of, into separate ranges of sizes, and so determine the relative proportions, by dry weight, of each size range. This is done by two separate and quite different procedures. For the coarse fractions (e.g. sand, gravel) the proportions are determined from the sizes of square openings in sieves, i.e. sieving analysis. The determination of fine soil particles (i.e. silt and clay) are obtained from a sedimentation analysis. In a sedimentation analysis, the particle sizes are calculated with the help of Stokes' law from the rate of sedimentation. In this calculation the grains are assumed to be spherical. The results therefore give the equivalent diameter. It must be remembered that the silt and clay particles are far from spherical. However, the absolute magnitude of particle size is of less importance than the distribution of sizes as determined by a recognized standard procedure, and this is the sense in which particle size analysis is applied to soils. The result of a particle size analysis is usually presented graphically showing the percentages finer than any given size, plotted against the particle size on a logarithmic scale /30/, /35/.

Applications of particle size analysis in road-building are, for example, selection of fill materials, sub-base materials, drainage filters, groundwater drainage, chemical injection and stabilization and compaction.

Even though, or maybe due to the fact that sieving and sedimentation analyses are quite common methods all over the world, there are varying test standards. The sieve sizes and the number of sieves, for example, often vary between countries. This can partially be explained by the fact
that the limits of fractions vary from country to country. Another thing one must remember is that the test methods have sometimes had to be modified to suit local conditions and soil types.

The Zimbabwean standards for particle size distribution analysis, mentioned in Manual Part N Materials Testing /29/, correspond, with only slight modifications, to A.S.T.M. and B.S. The sieving test procedure corresponds to A.S.T.M. D 422, while the sieve sizes correspond to B.S. The sedimentation analysis corresponds fairly well to A.S.T.M. E 100.

The standard sieve sizes in Zimbabwe are as follows (in mm): 37.5, 26.5, 19.0, 9.5, 4.75, 2.36, 1.18, 0.600, 0.300, 0.150, 0.075. There are also some larger sieve sizes which are used when determining coarse fractions (i.e. gravel and cobble). These are (in mm): 250, 150, 75 and 53.

Figure 12  Sieving analysis.

The 250 mm and 37.5 mm sieves are used when determining the Reject Index (R.I). This index is commonly used to describe the quantity of coarse fractions in a soil sample. The R.I is defined as the mass of gravel
smaller than 250 mm retained on a 37.5 mm sieve, expressed as a percentage of the total mass of the sample smaller than 250 mm /29/.

The RI is often used instead of sieving the coarser fractions, which otherwise requires very large quantities of material for a representative result to be obtained. This depends on the fact that the result from a sieving analysis is completely based upon the total size of the sample. If the size of the sample is too small, the inclusion or exclusion of only a few large particles can influence the whole particle size analysis considerably. A guide to the minimum quantity of material to be taken for sieve analysis appears from Table 6 /30/.

**Table 6** Minimum quantities for particle size tests.

<table>
<thead>
<tr>
<th>Maximum size of material present in substantial proportion retained on BS sieve (mm)</th>
<th>Minimum mass of sample to be taken for sieving</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pass 2 mm or smaller</td>
<td>100 g</td>
<td>Based on BS 1377:1975, Section 1.5.4.2 (5)</td>
</tr>
<tr>
<td>63</td>
<td>200 g</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>500 g</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>1 kg</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>2 kg</td>
<td></td>
</tr>
<tr>
<td>28</td>
<td>6 kg</td>
<td></td>
</tr>
<tr>
<td>37.5</td>
<td>15 kg</td>
<td></td>
</tr>
<tr>
<td>50</td>
<td>35 kg</td>
<td></td>
</tr>
<tr>
<td>63</td>
<td>50 kg</td>
<td></td>
</tr>
<tr>
<td>75</td>
<td>70 kg</td>
<td></td>
</tr>
<tr>
<td>100</td>
<td>150 kg</td>
<td>Author's suggestion</td>
</tr>
<tr>
<td>150</td>
<td>500 kg</td>
<td></td>
</tr>
<tr>
<td>200</td>
<td>1000 kg</td>
<td></td>
</tr>
</tbody>
</table>

If a soil contains fine material, even in small quantities, it is necessary to carry out a wet sieving procedure in order to measure the proportion of fine material present, before the dry sieving analysis is performed. If clay is present, or if there is evidence of particles sticking together, the material should be immersed in a suitable dispersant solution before the wet sieving. The most common standard sieve size for wet sieving is 75 µm, but 63 µm sieves are also used.

A source of error in all sieving analysis is if the soil particles easily break and crush. If so, one must be careful especially during the sieve
shaking operation, and the time for this may have to be decreased compared to the standard. This is of special importance when a mechanical sieve shaker is used. Easily eroded particles will also lead to problems during a dispersing procedure. Soils containing particles originating from mudstone, dolomite, limestone, mica, etc and/or pedogenic rocks such as silcrete, calcrete, laterite and ferricrete are examples of materials which may easily be eroded and therefore problematic.

In a sedimentation test, a suspension of a known mass of fine soil particles (usually <2 mm) is made up in a known volume of water. The particles are then allowed to settle under gravity. From certain measurements, made at given intervals of time, the distribution of particle sizes can be assessed. These measurements can be carried out by different methods, pipette, hydrometer or the so-called suspended-body method, etc. The hydrometer method is neither the most correct nor the fastest, but still the most common method, used all over the world.

In Zimbabwe sedimentation analysis is rarely performed, even if there is a standard for hydrometer analysis mentioned in Part N. This is unsatisfactory as, for example, one problem with gravel roads is dust emission which is partially due to whether the fine material consists of clay or silt. Another example is compaction characteristics where the silt or clay content is of importance. The sedimentation analysis consequently gives important information about the soil and its behaviour.

A significant source of error in particle size distribution tests, especially sedimentations analysis, is whether the particles are sufficiently dispersed and separated before the test procedure. To achieve this, a dispersing agent is used with a soil suspension in water. There are numerous substances that have been tested as dispersing agents.
Some examples are:

- Ammonia solutions
- Tannic acid
- Sodium polyphosphate
- Starch
- Sodium hexametaphosphate
- Trisodium phosphate
- Sodium oxalate
- Tetrasodium phosphate
- Sodium hydroxide
- etc.

For most purposes it has been found that sodium hexametaphosphate is one of the most suitable and convenient dispersants. However, this dispersant is probably not the most suitable for lateritic soils. For these types of soils, trisodium phosphate or tetrasodium phosphate is suggested /30/.

Density and compaction characteristics

The main purpose with compaction in road-building is usually to avoid future settlement. Whenever soil is placed as fill, it is nearly always necessary to compact it to a dense state, so as to obtain satisfactory engineering properties, which would not be achieved with loosely-placed material. Compaction on site is usually effected by mechanical means such as rolling, ramming or vibrating. Control of the degree of compaction is necessary to achieve a satisfactory result at reasonable cost. Determination of compaction characteristics and packing degree can be done in many ways and with different kinds of methods. A great number of both in-situ and laboratory testing methods are used. The choice between different methods is often a matter of the kind of local construction and testing equipment normally used, and also which procedures the constructor/engineer are familiar with. The type of material used in the construction is another significant factor when choosing test method. In many cases a combination between two or more testing methods may give the best results. For these reasons, it is more or less impossible to give proposals about which testing and control methods that are in general, most advantageous /30/, /36/, /37/, /38/.

It is difficult to use conventional soil classification systems to determine the most suitable compaction method and type of compaction equipment.
One important reason is that the consistency limits are not directly related to the compactability. Brems and Forssblad have therefore proposed a classification system to be used with reference to compaction, Table 7 /36/.

**Table 7** Soil classification system with reference to compaction.

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>I</strong></td>
<td>Rock fill and granular soils with large stones and boulders:¹</td>
<td></td>
</tr>
<tr>
<td><strong>II</strong></td>
<td>Sand and gravel:¹</td>
<td></td>
</tr>
<tr>
<td></td>
<td>a Well-graded</td>
<td></td>
</tr>
<tr>
<td></td>
<td>b Uniformly graded</td>
<td></td>
</tr>
<tr>
<td><strong>III</strong></td>
<td>Silt, silty soils, etc.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>a Silty sand, silty gravel, moraines</td>
<td></td>
</tr>
<tr>
<td></td>
<td>b Silt and sandy silt, clayey sand, clayey gravel</td>
<td></td>
</tr>
<tr>
<td><strong>IV</strong></td>
<td>Clay</td>
<td></td>
</tr>
<tr>
<td></td>
<td>a Clay with low or medium strength:²</td>
<td></td>
</tr>
<tr>
<td></td>
<td>b Clay with high strength:³</td>
<td></td>
</tr>
</tbody>
</table>

¹ With less than 5 to 10% of material smaller than 0.06 mm
² Unconfined compressive strength ≤ 0.2 MPa
³ Unconfined compressive strength > 0.2 MPa

According to this system, the gradation of the soils in Groups I, II and III is determined. For Group IV the unconfined compressive strength has to be measured at the water content which will be applicable during compaction. Group I and II are non-cohesive and free-draining soils and relatively easy to compact. Group III and IV have a certain content of fines and the degree of compaction is highly dependent on the water content. If a high degree of compaction is required for the latter two groups, the water content should not differ considerably from the optimum water content. To compact clays at water contents below or around the optimum, compactors generating high static or dynamic contact pressure are required to overcome the shear resistance. It is also
necessary to work with a limited layer thickness. The suitable compaction method should be determined by the strength of the soil, which indicates the compactability better than consistency tests /36/.

Both in-situ and laboratory compaction tests furnish the following basic data for soils:

- The relationship between dry density and moisture content for a given degree of compactive effort.
- The moisture content for the most efficient compaction, i.e. at which the maximum dry density is achieved under that compactive effort.
- The value of the maximum dry density so achieved.

There is, as mentioned, a large number of test methods for determining compaction characteristics and achieved packing degree. For example, soil properties such as different kinds of density determinations, (e.g. bulk, dry, limiting and maximum dry densities, etc) and moisture content are useful. They can be determined both in-situ with e.g. nuclear methods (also called moisture-density gauges) such as Troxler, and with standardized laboratory methods. Other parameters of interest in compaction are consistency limits and particle size distribution which are determined in laboratories.

One of the most well known laboratory method to determine the optimum water content and the corresponding maximum dry density is the Proctor test. It is based on a manually operated rammer which is used to compact a soil in three layers in a mould. The Proctor compaction test (in principal standard AASHO) has also been modified (Modified Proctor ~ modified AASHO) to meet increased demands on compaction standards. The compaction energy in the modified method is about 4.5 times larger than in the Standard Proctor test /30/, /37/. 
Due to the larger compaction energy in the Modified Proctor test, the maximum dry density is 5 to 10% higher than that obtained in the Standard Proctor test. The difference is about 5% for granular materials and about 10% or more for cohesive soils. The optimum water content is normally 3 to 8% lower at Modified Proctor compared with Standard Proctor. Also here the differences are larger for cohesive than for granular soils.

A source of error concerning laboratory compaction tests is that the soil material may be more disintegrated and crushed than during field compaction. This can partially be avoided by using a new sample in each individual test instead of the normal procedure, where the same sample is repeatedly used after a successive addition of water.
A number of standardized laboratory compaction tests are shown in table 8/36/.

Table 8  Laboratory compaction tests.

<table>
<thead>
<tr>
<th>Standard</th>
<th>Modified</th>
<th>Bureau of</th>
<th>British Standard</th>
<th>German Standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>AASHO (T99)</td>
<td>AASHO (T180)</td>
<td>Reclamation, USA</td>
<td>BS 1377</td>
<td>DIn 18127</td>
</tr>
<tr>
<td>ASTM D 698</td>
<td>ASTM D 1557</td>
<td>USA</td>
<td>USA</td>
<td></td>
</tr>
</tbody>
</table>

| Mould Diameter mm | 102 | 102 | 108 | 152 | 105 | 105 | 100 | 100 |
| Height mm | 116 | 116 | 152 | 114 | 115.5 | 115.5 | 120 | 120 |
| Volume cm³ | 944 | 944 | 1416 | 2082 | 1000 | 1000 | 342 | 342 |
| Rammer Weight kg | 2.49 | 4.54 | 7.49 | 4.54 | 2.50 | 4.50 | 2.50 | 4.50 |
| Drop height mm | 305 | 457 | 457 | 457 | 300 | 450 | 300 | 450 |
| Diameter mm | 51 | 51 | 51 | 51 | 50 | 50 | 50 | 50 |
| Layer Number | 3 | 5 | 3 | 5 | 3 | 5 | 3 | 5 |
| Material Maximum particle size mm | A: 4.75 | A: 4.75 | A: 4.75 | 4.75 | 19.1 | 19.1 | 20 | 20 |
| Compaction effort Blows per layer | 25 | 25 | 25 | 55 | 25 | 25 | 25 | 25 |
| Energy Nm/m³ | 5.9 × 10⁵ | 2.7 × 10⁵ | 5.9 × 10⁵ | 2.7 × 10⁵ | 5.5 × 10⁵ | 2.5 × 10⁶ | 5.9 × 10⁵ | 2.6 × 10⁶ |

1) Variants with larger moulds also exist, e.g. ASTM Method B and D with 152 mm mould.

There are also different laboratory vibration methods to achieve compaction. For example, the U.S. Bureau of Reclamation has developed a compaction method for cohesionless soils based on vibration of saturated samples. The method is widely used and standardized (ASTM D 2049). Another vibration method is Dynapac (Apparatus typ TE 10), which is approved as a Swedish standard method. A similar method has been developed in Britain and adapted as B.S. (1377, Test 14)/36/.

The vibration methods have several advantages compared to other
laboratory compaction tests. They can more easily be adapted to larger test moulds which also means that larger particle sizes can be tested. They are also faster.

The California Bearing Ratio test (CBR) is probably the most used method all over the world for the design of flexible pavements. It is also a very well known and frequently used method in Zimbabwe, which means that a lot of experience about the method and its results already exist. The CBR test can be carried out in a laboratory or as an in-situ test /29/, /30/, /39/, /40/.

The Texas Triaxial test is a commonly used method in Africa to determine the quality of materials which may be used in e.g. base construction /41/. The procedure for determining the Texas triaxial class is given in Standards Association Central Africa, CAS A 43 Part 2 (1974).

Figure 14 Equipment for Texas triaxial test, Central lab, MoT.
In-situ methods for control of compaction degree may be divided into three main groups as follows.

A. Loading tests
   
   e.g. Plate Load test
   Static Loading Bearing test
   Pressuremeter test
   Screw Plate test

B. Relative methods
   
   e.g. Volumeter test
   Comprimeter test
   Weight Sounding test
   Dynamic Cone Penetrometer test
   Cone Penetration test
   Standard Penetration test
   Ram Sounding test

D. Dynamic methods
   
   e.g. Falling Weight test
   Compactometer test

In general, loading tests are accurate methods for determination of compaction degree, but they are also expensive and therefore not so common in connection with road-building. Nevertheless, the State Loading Bearing test is used, e.g. in Europe, as a compaction test in highway construction. Normally a loading plate with a diameter of 300 mm is used, from which the deformation modulus is calculated. This modulus or an elastic modulus are in principle better indications of the strength of a base, subbase or subgrade than different kinds of density tests. This is because for coarse materials such as rockfill and gravel, there is a good relationship between the modulus of elasticity and density. A source of error with this method is, however, that the measurements are done on the top layers which sometimes have a lower degree of compaction which results in low values, even if the material below the top layer is well compacted /36/.
There are a number of methods which are based on the volumeter method such as the Sand-Replacement method, the Oil-Replacement method, the Water-Balloon method and Tube sampling etc. In Zimbabwe the Sand-Replacement method is commonly used. It may be described as follows. A hole is excavated by hand in the compacted fill. The weight and water content of the excavated material is carefully determined. The volume of the hole is measured by filling with calibrated dry sand from a special cone cylinder. With knowledge of the material weight and the volume of the hole, the dry density of the compacted fill can be calculated /29/, /30/, /36/.

Figure 15  The Sand-Replacement Method
The Oil-Replacement method and the Water-Balloon method are carried out in much the same way as the Sand-Replacement method, except that oil or a water-balloon respectively are used for the volume determination.

Tube sampling is used to determine the compaction degree on fine-grained soils, especially clays. This method is standardized both as ASTM method (2037) and as BS (1377, Test 15D) [36].

The Comprimeter test has been developed in Norway. The method is based on the fact that the soil loosens up in a compacted zone when a pole is driven into the soil. The volume of the heave is measured with a liquid, enclosed in a rubber-membrane, which is placed on the ground.

The weight sounding test is the most common sounding method in Scandinavia. It is a cheap method, the equipment is simple and easy to handle. The test can be performed either by hand or mechanically. However, there is a disadvantage when checking compaction with all kinds of methods based on sounding. That is because the value for the upper 150-300 mm of the material can not be determined due to
disturbance effects during penetration /42/.

The portable Dynamic Cone Penetrometer test (DCP) consist basically of a hammer sliding on a rod which strikes an anvil forcing a steel cone to penetrate the soil. The advantages of this method are that it is easy to handle, cheap, light and that the achieved values are calibrated to the CBR which means that CBR values in the range of 1-50 can be directly determined with the DCP /43/, /44/.

The Cone Penetration test (CPT) is a very sophisticated method and still under an intensive development process. The CPT has a lot of advantages such as the giving of continuous information from the top layers down to the bottom. The results are also reproducible as the effects of the human factor are minimized. The method also gives results that are immediately readable in the field. One kind of CPT-system has been developed by Geotech AB. It is based on acoustically transferred signals between the surface and the probing point. No cable is needed and the system is therefore probably one of the best. However, all CPT-methods are very expensive and demand great knowledge and experience /42/, /45/, /46/.

The Standard Penetration test (SPT) is the most commonly used sounding method worldwide. The SPT method is a combination of dynamic sounding and probing. This method is not one of the best for determining compaction, but must be mentioned due as it is very well known and there is a great deal of experience in how to interpret the results obtained /42/.

The Ram Sounding test is usually performed to determine the relative consistency of coarse soils. In such cases it has been proved that this method is preferable to e.g. Weight Sounding or Cone Penetration methods. However, in fine graded soils the Ram Sounding method may occasionally give higher values than the actual compression and strength properties of the soil.

The Static-Dynamic Probing test, developed at the Swedish Geotechnical Institute (SGI), combines the high penetrability of the dynamic probing device and the sensitivity of the cone penetrometer. The test is
performed as a normal dynamic probing test to a certain depth. At this depth a static test is performed with a constant rate of penetration. This method is suitable when it is important to obtain more detailed information about the soil characteristics of dense soils where CPT can not be performed, e.g. in soils containing boulders and stones.

Another method, also developed at SGI, is Dynamic Probing with a Slip Coupling test. This method is performed in the normal manner to the level at which the skin friction is to be measured. When this depth is reached, the rods are withdrawn 0.2 m. Thereafter, the number of blows required to drive the rods into contact with the point is recorded, which then gives the skin friction resistance. The point resistance is determined as the difference between the total and the skin friction resistance.

The Falling Weight test is based on measurements of the weight retardation during the course of the blow.

The Compactometer test is a relatively new method. It is based on an accelerometer mounted on a vibratory roller. The measurements are performed continuously during the movement of the roller, and the compactometer gives values of the dynamic qualities of soils /36/.

The compaction degree can also be estimated with a surface level control, which is carried out with a levelling instrument. Before and after a number of passes with any kind of compactor, one measures the level of the fill. This method is especially relevant for rock fills.

The Benkelman Beam is used to measure the deflection of a pavement under a heavy wheel load. A relative measure of the modulus of elasticity of the pavement is obtained.

Finally, it may be pointed out that one way of dealing with compaction problems and control is to utilize experience, i.e. knowledge about the grain-size and water content will, with a certain compactive effect, give a certain packing degree. This is a common way in e.g. Sweden, to solve compaction problems.
Some examples of laboratory and in-situ test methods have been described above. However, these are only some of the methods which can be used. More or less all soil parameters will, in fact, give information, in one way or another, about soil compaction characteristics.


43 van VUUREN, D J. Rapid determination of CBR with the portable dynamic cone penetrometer. Rhodesian Engineer, September 1969.


