DRAFT

Durability Testing of LCB and CTB Materials Supplied by Caltrans

Technical Memorandum prepared for the California Department of Transportation

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ABSTRACT

Carbonation of cement-stabilized layers under concrete pavements in California was investigated as a potential reason for faulting of these pavements. In discussions with personnel from the Pavement Research Center, it was mentioned that a layer of loose material is often observed between the concrete slab and the supporting cement stabilized layer. Samples of materials commonly used under concrete slabs were sent to South Africa for durability testing using South African test methods. These test methods were primarily developed at the CSIR, Transportek, for the purpose of durability assessment of stabilized materials.

The materials supplied by Caltrans consisted of samples of two aggregates used to make cement treated base (CTB) and lean concrete base (LCB). The aggregate sources for these materials were, named *Mission Valley* and *Lake Herman*. Details of gradings, water content, and cement content were provided with the samples. These materials were tested for durability using the Initial Consumption of Cement test (ICC), the mechanical and hand wet/dry brushing test, the erosion test, and the uncarbonated and carbonated unconfined compressive strength test (UCS). The test results were evaluated according to South African experience using these techniques and South African standards. Two compaction energy levels were also used to determine whether the density to which the materials were compacted had an effect on durability.

Most of the specimens passed the test criteria at both compaction energy levels, suggesting that the amounts of cement used are excessive and may be reduced, thus creating the potential for cost saving in terms of cement costs. However, the erosion test indicated that at the lower compaction energy, the CTB materials are probably erodible under concrete slabs. This tendency toward erosion may be overcome by compacting the materials to higher densities.

It is recommended that the in-service materials be compacted to higher densities and that further testing be done to determine the appropriate cement contents. The cement contents used here were those specified by Caltrans.

A further recommendation is that site investigations be undertaken to enhance the knowledge gained from laboratory testing as the effects of other factors affecting layer performance such as drainage, poor compaction, material deficiencies, etc., can only be observed in-situ.

The possibility of mechanical crushing of the cement-stabilized layer should also be investigated.

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1.0 INTRODUCTION

Transportek prepared a synthesis report on stabilization technology in South Africa for the University of California Pavement Research Center during the period January to June 2001. This report covered aspects such as material tests and specifications, the mechanical properties of the stabilized material, and the behavior and performance of the stabilized material under laboratory and full-scale testing conditions. A presentation was given to the staff of the Pavement Research Center and Caltrans in June 2001 based on the contents of the report.

During the presentation, one of the aspects of cement stabilization that immediately drew reaction was carbonation. In discussions during the meeting it was speculated that carbonation might be a contributing factor to step-faulting on concrete pavements. Following the presentation, a project needs list was developed by the Pavement Research Center and Dynatest. One of the items on the list was a comparison between the durability of cement treated bases (CTB) and lean concrete bases (LCB) using the test methods currently used in South Africa for testing the durability of cement-treated road building materials.

Subsequently two materials were supplied to Transportek by Caltrans for durability testing according to South African standards.

This report outlines an investigation into the durability aspects of the two materials when stabilized according to Caltrans specifications and then tested using South African durability test methods. These test methods were developed in South Africa (predominantly at Transportek) to evaluate stabilized materials used in southern Africa. It was anticipated that they would be suitable for testing California materials.

1.1 Problem Statement

Some of the more common problems that were evident in the California concrete roads included:

- Pumping of fines from the supporting layers under the concrete pavements;
- Transverse, corner, and longitudinal cracking of the concrete slabs;
- Diminished riding quality as a result of faulting.

1.2 Durability of Stabilized Layers

In the case of concrete, durability is defined as the ability of concrete to retain its strength, impermeability, dimensional stability and appearance over a prolonged period of service under the conditions for which it was designed.(*1*) For cemented bases, durability also includes resistance to moisture absorption, strength reduction, and wetting and drying.(*2*) It is suggested that the durability of stabilized materials for roads can be similarly defined with the omission of "appearance" (this ignores the problem of cracking).

In South Africa, road layers stabilized with pozzolanic stabilizers such as cement, lime, slagment, etc., have sometimes failed due to durability problems. These durability problems were mostly caused by the ingress of water and/or air into the layer.

2.0 BACKGROUND TO THE SOUTH AFRICAN EXPERIENCE REGARDING DURABILITY PROBLEMS WITH STABILIZED MATERIALS

Flexible pavements with stabilized layers are a popular construction method in many areas of South Africa. For example, more than 80 percent of the pavements in Gauteng and surrounding provinces are constructed using this type of construction. This method of construction has also proved to be cost effective: materials that would otherwise be unsuitable have provided good performance when stabilized. The value of stabilized subbases is also recognized in that it provides firm support to the upper pavement layers facilitating their proper compaction and overall structural contribution. Most pavements incorporating layers stabilized with lime, cement, slagment, or combinations of these have performed satisfactorily over the years. However, a number of failures associated with pozzolanic stabilized road construction materials have occurred in the past.

The distress or failures of pavements containing cement-treated layers in southern Africa have in many instances been attributed to unsatisfactory durability of the stabilized layers. This led to various investigations and research projects by Transportek into the testing of stabilized materials with the aim of minimizing stabilization failures. It was found that the cause of failure was in many cases carbonation of the stabilizer, which led to weakening or loss of the bond between aggregate particles thereby reducing the layer structural capacity and often resulting in shear failures. Carbonation of lime, cement, or other pozzolanic stabilizers occurs when these materials come into contact with the carbon dioxide. Small quantities of this gas are found in the atmosphere and in soils where it is produced by decaying organic matter (e.g., tree trunks, grass, insects, etc.).

2.1 Carbonation Process (*3*)

Lime, and to a lesser extent Portland cement, are unstable under normal environmental conditions and carbonate readily under the right conditions. For example, lime ($Ca(OH)^2$) is only stable at a partial pressure of CO_2 (P_{CO_2}) of less than 3×10^{-4} atmospheres. Under normal conditions such as atmospheric air (P_{CO_2} of 3×10^{-4} atmospheres, or 0.03 percent by volume), $CaCO_3$ is the stable phase. The same would apply to cement, although some of the compounds are stable at somewhat lower pH and therefore higher P_{CO2} of up to about 10^{-9} atmospheres. It is well accepted in concrete technology that complete carbonation of Portland cement is chemically possible even at a low concentration of carbon dioxide in the atmosphere. Very broadly, the reactions involve a reversal of those that took place during their manufacture. For example, lime simply reverts to the limestone from which it was made:

$Ca(OH)_2$	+	CO_2	=	$CaCO_3$	+	H_2O
Slaked lime		Carbon dioxide	=	Limestone		Water

Cement similarly reverts to the original components from which it was made or similar combinations:

$CaOSiO_2H$	+	$CaOAl_2O_3H_2O$	+	CO_2	=	$CaCO_3$	+	SiO_2	+	Al_2O_3	+	H_2O
Hydrated lime or Cement reaction products						Limestone		Silica		Alumina		Water

2.2 Erosion

Another cause of failure was identified as the erosion of materials in stabilized pavement layers. This was particularly evident during Heavy Vehicle Simulator (HVS) testing of asphalt base pavements where certain stabilized subbases were found to erode and fine materials pumped to the surface through cracks.(*4*)

The erosion of pavement layers may be defined as the wearing down of the material from the interface of the layers due to hydraulic and/or mechanical action under traffic loading and is always associated with excessive pore water pressure within pavement layers or between layer interfaces and with erodible materials.(*5*)

Erosion involves two processes: production of loose material and movement of this material. Depending on the pavement characteristics, these processes occur in different ways and lead to different results. These differences need to be identified so they may be reflected in the failure criteria developed for the erosion test (ET).

2.2.1 Erosion Failure in Flexible Pavements

In thin flexible pavements consisting of a surfacing and supporting layers, such as those built in South Africa, the traffic load is carried by the supporting layers and not the surfacing layer. The surfacing has a relatively low permeability and acts as a seal to prevent the ingress of water into the supporting layers. The base may be constructed from a stabilized granular or asphalt material. The subbase is normally constructed from stabilized materials or natural gravels.

The local deflection of a flexible pavement surface caused by traffic loading sets up high local contact stresses between the asperities of aggregates of different layers. These high contact stresses can potentially disturb particle cementation and lead to crushing or compressive failure of the aggregates producing “free fines” on weakly stabilized layers. Water infiltrates the pavement either through the pavement shoulders, surface cracks, or ground water. With traffic loading, high pore water pressures build up in the pavement layers, shifting the loose particles, potentially reducing densities, and thus creating voids. These voids are subsequently filled by the surrounding material. This redistribution of material may lead to surface deformation if the void occurs in supporting layers, or potholes and cracking if it occurs near the road surface. Once the cracks form, the ingress of water and air into the pavement layers increases and accelerates the erosion process. The erosion is further accelerated as carbon dioxide also infiltrates the layer causing carbonation of the stabilizer, which further weakens bonding between particles.

Stabilized subbase layers are prone to cracking under traffic due to excessive stabilizer, which causes shrinkage cracking. This post-cracked phase can be designed for (*6*) and can even add substantially to the life of the pavement. Should this cracking be severe, however, or if fatigue cracks are open to the surface, water and air containing carbon dioxide may enter the pavement facilitating the erosion process. The water removes any loose material around the cracked blocks and weakens the layer, whereas the carbon dioxide carbonates the stabilizer. The blocks then begin to rock back and forth under traffic loading, crushing aggregates and producing fines, which are removed from the pavement under pumping. This process has been defined as follows:

> "Pavement pumping is the rapid release of a pressurised soil and water composition from a relatively high to a relatively low pressure potential, whereby subsurface material may be redistributed multi-directionally. Normally, the pressure is released vertically through pavement joints, cracks and edges."(*7*)

Once water has entered the pavement, the erodibility of the materials used will determine the ability of the road to withstand deterioration. Erosion tests assist in identifying erodible materials so that they may be avoided or correctly modified.

2.2.2 Erosion Failure in Rigid Pavements

It was also found that the failures occurring in concrete pavements were mainly a result of failures in the supporting stabilized layer.(*5*) This was mostly caused by vehicle loads deflecting and rocking the concrete slabs and causing the movement of water in the layer below. This water entered the layer through cracks or joints in the concrete slab. The fine material in the layer is displaced with the water movement to other areas under the slab and through joints and cracks, which leads to pumping of the fines and erosion of the layer, resulting in the development of voids under the concrete slab with a consequent reduction in uniform support provided by the subbase. This often led to failure of the concrete as cracking or movement of the joints resulted. Stabilized materials that are prone to carbonation will exacerbate erosion when used under concrete pavements as the bonds formed by the stabilizer are weakened, allowing the fines particles to be easily loosened by water movement.

In concrete pavements, most of the traffic loading is carried by the concrete slab and little stress is transferred to the subgrade. Unlike a flexible pavement, a rigid pavement is not subject to local deflections due to loading. Instead, slab sections deflect. Water infiltrates the pavement through joints or edges where it accumulates under the slab. As traffic loading deflects the approach slab, the accumulated water is pushed at high velocity towards the departure slab. The departure slab is then deflected very rapidly by the wheel load and the water is pushed back under the approach slab. The high water velocities induce high shear stresses on the support surface layers redistributing material. This causes movement of material from under the departure slab to under the approach slab (Figure 1), as well as potential formation of voids and a loss of slab support leading to corner cracking of the slabs (Figure 2).

2.3 Modification and Cementation (*8*)

Modification and cementation are terms used to describe the degree of treatment given to a stabilized material.

Modification is considered to have taken place when the addition of stabilizer is only required to change the plasticity of a material without a significant increase in tensile or compressive strength. In this case, addition of stabilizer results in agglomeration of the clay particles but does not form a cemented matrix. Typically 2 to 3 percent stabilizer (normally lime) is added to a clayey material to achieve this.

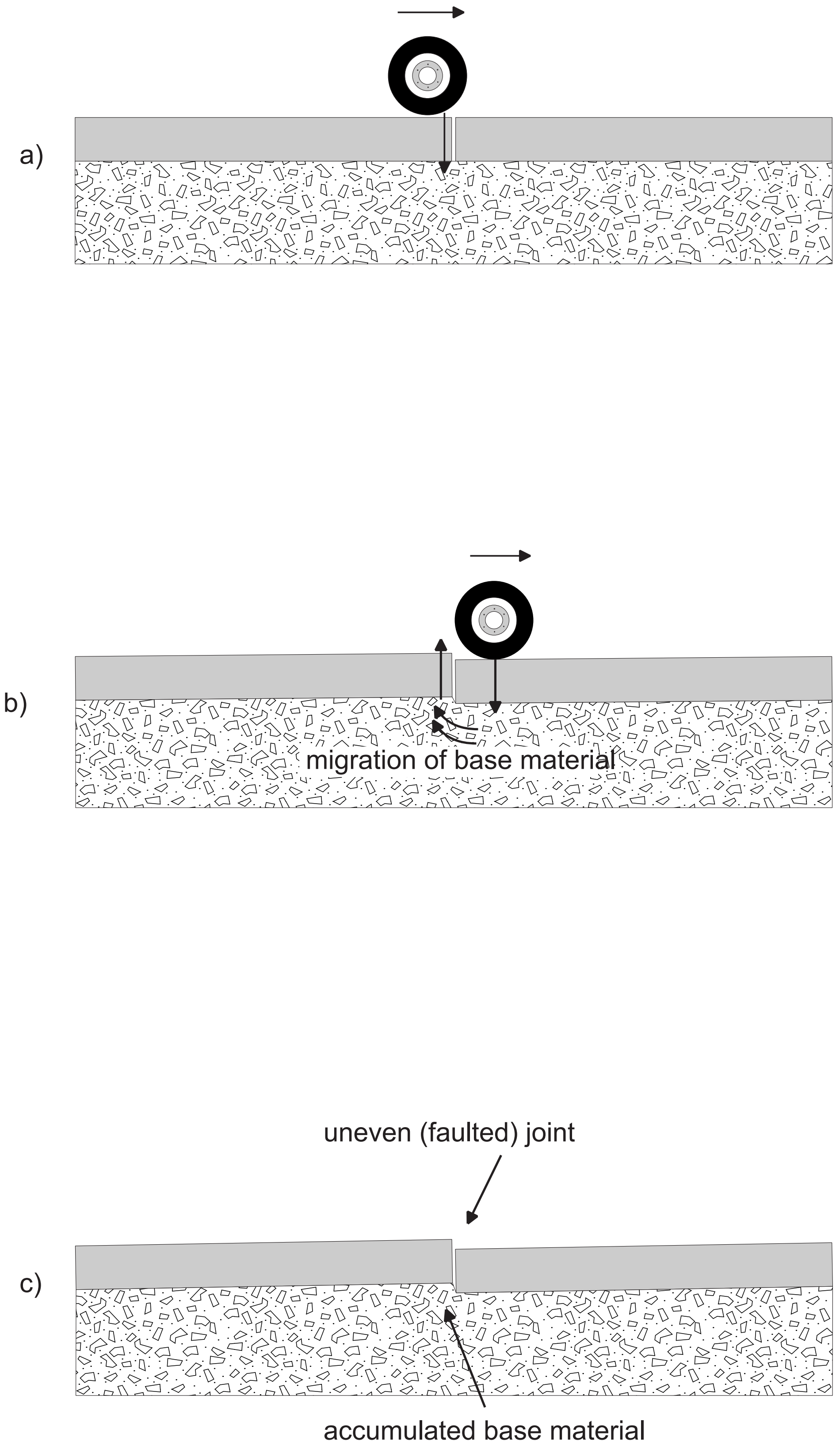

Figure 1. The mechanism of base migration an faulting under a concrete slab.

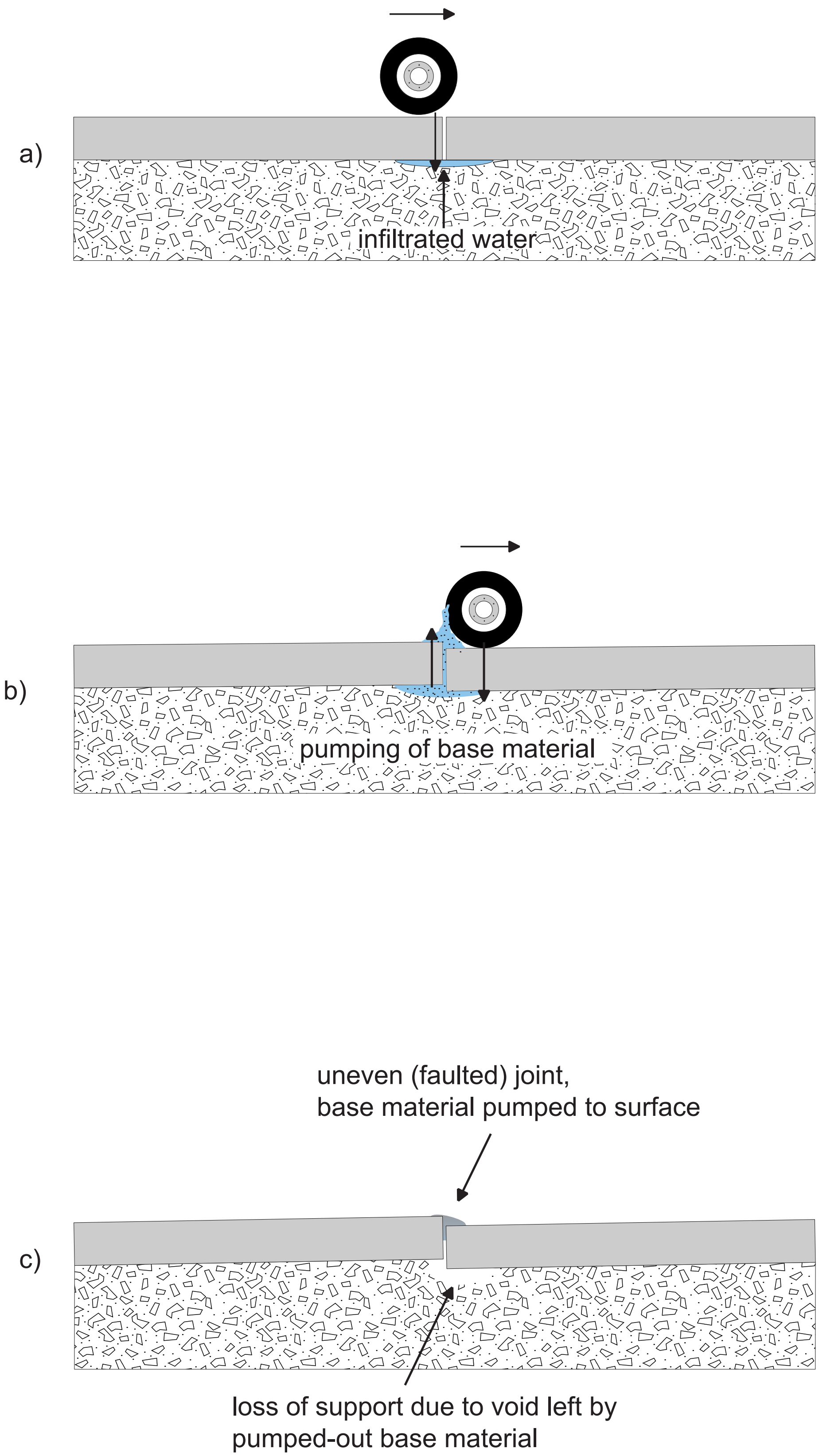

Figure 2. The mechanism of pumping, void formation, and faulting under a concrete slab.

Cementation occurs when the conditions are favorable for the development of cementing products (usually calcium silicate hydrates) to significantly increase the compressive and tensile strength of the material. Normally a quantity of 3 to 4 percent stabilizer (usually cement) is added to materials to bring about cementation.

Thus, in the case of modification for which only a small quantity of stabilizer is added, the material is particularly susceptible to carbonation and deterioration through repeated wetting and drying. In many cases, the initial consumption of lime or cement (ICL or ICC) has not been satisfied and whilst the properties of the soil may have improved at the time of testing, exposure to carbonation and/or wetting and drying will result in the agglomeration of the clay and reversion to the original soil characteristics. The subsequent impact and breakdown under traffic releases the clay minerals causing an increase in plasticity in the material, a reduction in bearing capacity, and eventual premature failure of the pavement.

Experience has shown that the plasticity is permanently reduced only if sufficient stabilizer is added to maintain the pH above 12.0 so that cementation occurs and is maintained. Sufficient stabilizer must be added to satisfy the initial consumption of lime or cement and maintain the pH at suitably high level for the design life of the structure to ensure that long-term cementation occurs.

There was therefore a need to test stabilized materials for carbonation potential and susceptibility to erosion in the laboratory so that failures caused by carbonation and erosion could be avoided when road layers were stabilized. In the past, requirements and specifications for materials treated with pozzolanic stabilizers in South Africa were based almost entirely on strength requirements after 7-day curing, with little attention being paid to the long-term durability of the material. Research has shown little correlation between durability and strength and has identified the ability of a stabilized material to lose strength under certain environmental conditions, namely wetting/drying and carbonation.(*8*) It is important that this strength reduction, in terms of the residual unconfined compressive strength, is not such that the structural capacity of the layer becomes inadequate for the applied loads.

It was found that the methods used to test and evaluate stabilized materials were somewhat problematic and not suitable to test the durability of stabilized layers in terms of carbonation and erosion potential.(*8*) These test methods would have to be modified or improved. Research was undertaken to improve the existing test methods such as the wet/dry brush test, which was known to give an indication of the durability of materials treated with pozzolanic stabilizers, and to develop test methods to determine the erodibility and carbonation potentials of stabilized materials. This effort resulted in the development of the mechanical brush test, the erosion test, and the carbonated Unconfined Compressive Strength test (RUCS) and subsequent test specification limits.

2.4 Development of Test Methods

The following aspects were identified as those for which certain criteria needed to be satisfied to ensure adequate long-term performance of stabilized layers (*8*):

- Appropriate stabilizer content to maintain the required pH, so that the cementation reaction can proceed normally;
- Suitable durability test that would identify the potential of a stabilized material to degrade in the presence of adverse conditions such as cyclical wetting and drying and/or carbonation;

- Minimum residual UCS value, which will ensure adequate structural capacity under the most severe environmental conditions likely to be encountered in service; and
- Method for determining the susceptibility of a stabilized to erode and pump under trafficking.

2.4.1 The Mechanical Brush Test

The commonly used test method for determining durability of stabilized materials was the wet/dry brush test (hand brush) developed by the Portland Cement Association and specified by AASHTO (*9*) and ASTM (*10*) and is incorporated in the South African testing manual, Technical Methods for Highways, number 1 (TMH 1) (*11*). The South African experience showed that several problems existed with the method (*12*):

- The precision limits (repeatability and reproducibility) of the test were poor, mainly due to the susceptibility of the brushing technique to operator variability. Also, there were various brushing techniques used by different laboratories, further adding to the poor reproducibility.
- The test specifies that the samples be compacted to Proctor density in 102-mm diameter molds and it was felt that compaction to Modified AASHTO density in the larger 152-mm molds would be more appropriate as it would be easier to compact materials with a coarser grading, especially base course. Also, the loss of a single large piece of coarse aggregate would not affect the total percentage loss as much as it did in the case of the smaller diameter specimen, as its mass would be a smaller percentage of the total mass.

- The compaction of road layers in South Africa is normally controlled from the results of a Modified AASHTO laboratory compaction test [TMH 1, method A7 (*11*)], in terms of maximum dry density (MDD) and optimum moisture content (OMC), which gives a higher MDD and lower OMC than the proctor compaction specified for the test. Thus, the higher compactive effort, in practice, was likely to give a stronger and more durable material than that obtained using the prescribed method.

It was evident that some form of wetting and drying test was required to assess a likely performance of a material in these conditions. The options considered were to modify the existing test method or to develop a new method. As the basis of a wet/dry brushing test was available and it had been successfully used in some regions to predict the performance of certain materials, it was deemed feasible to improve the existing test rather than to develop a completely new method from scratch. It was therefore decided to modify the existing method in such a way that the concerns listed above would be addressed.

After experimenting with several mechanical brushing techniques, in order to eliminate operator susceptibility, a mechanical brushing apparatus was devised that would brush the specimens using a consistent effort.(*12*) The larger Modified AASHTO specimens (152 mm diameter) were used in the test, but it was also possible to test the smaller Proctor specimens, if required. Apart from the brushing method and compaction in larger molds at a higher density the rest of the test method remained essentially unchanged. The brushing apparatus is shown in Figure 3. The full test method is included in Appendix A.

Performance-related results available for the mechanical brushing test at the time and correlations to convert the limits based on hand brushing and Proctor compaction enabled tentative limits to be developed for the mechanized test (*8*):

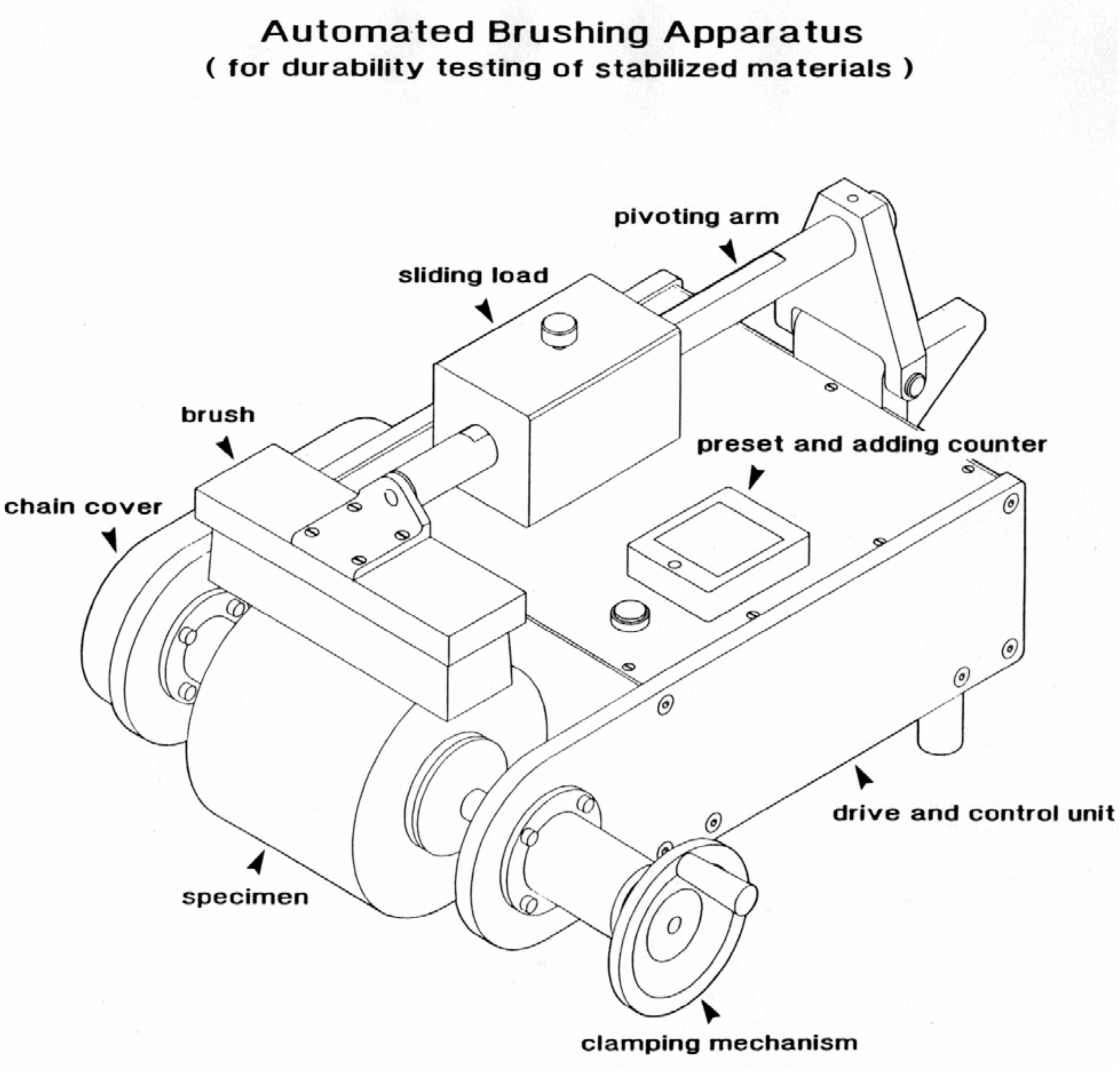

Figure 3. The mechanical brushing apparatus.

Stabilized materials under concrete pavements	< 5% loss
Stabilized base	< 8% loss
Stabilized subbase	< 13% loss

These are different from the original limits given for the hand brush test and Proctor compaction by the Portland Cement Institute,(*13*) which were:

For AASHTO soil groups A-1, A-2-4, A-2-5 and A3 (granular and sandy, low plasticity material	14%
For AASHTO soil groups A-2-6, A-2-7, A-4 and A-5 (granular and sandy, higher plasticiy material)	10%
For AASHTO soil groups A-6 and A-7 (silts and clays)	7%

Note that the limits derived for the new mechanical brush test are more appropriately based on the use of the materials rather than the material type.

2.4.2 The Erosion Test

Traditionally, erosion tests were developed to evaluate the erosion resistance of materials for canals, earth dams, and soil slopes. These tests were also used to evaluate pavement materials used in rigid pavements. Many of these tests were found to be unsuitable for the identification of erosion susceptibility of stabilized materials for use in pavement layers.(*7*)

In view of the limitations and disadvantages of the existing test methods relative to the observations and findings during HVS testing of flexible pavements, a new method was required that would achieve the following:

- Provide an objective erodibility test that simulates flexible pavement behavior in the wet state as observed during HVS testing;
- Incorporate the aggregate-to-aggregate contact stresses, which may contribute to surface crushing (compression stress) to produce erodible fines;
- Provide a relatively quick assessment of the potential erodibility of materials to be used in stabilized layers;
- Have a simple and easy method of measuring erosion. Weight loss measurements are fraught with inconsistencies, particularly if specimens are tested wet. Therefore, a linear measurement of the depth of erosion was preferred.

An erosion test was developed during the late 1980's to satisfy the above criteria. The test simulates the grinding action of pavement layers in the presence of water pressure and gives a good indication of the tendency of particles to erode (become loose) and pump. A schematic diagram of the erosion test is shown in Figure 4. The full test method included in Appendix A.

Specimens for the erosion test are compacted in beam molds (75 × 75 × 450 mm) in three layers. Each layer is compacted with 56 blows of a standard Modified AASHTO hammer, after which the protruding material is pressed flush with the mold surface using a compression apparatus to attain the density previously calculated. Different compaction efforts may be used to attain desired densities. The specimens are cured for a period of 28 days at room temperature in sealed chambers, after which they are submersed in water for 24 hours and then tested using the Erosion machine to determine their Erosion Index (L). The Erosion Index is the measurement of the average depth of erosion in millimeters averaged from 15 measurements on each erosion specimen after 5000 load repetitions in the test device.

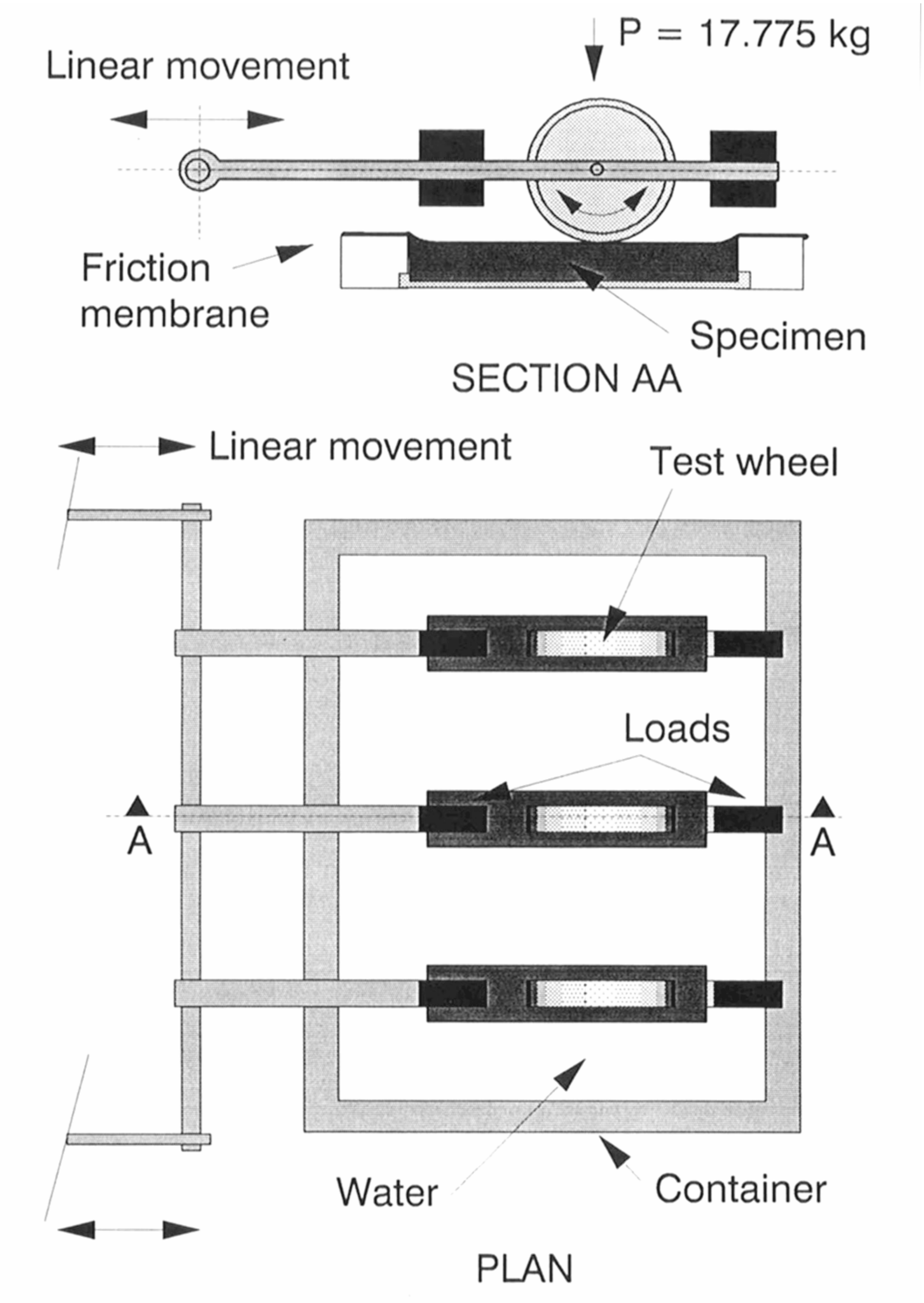

Figure 4. Schematic diagram of the erosion testing device.

The specimens are tested submerged and covered with a membrane on which a wheel loaded with 17.775 kg travels backwards and forwards (see Figure 4) simulating traffic action. The underside of the membrane, which rests on the specimens, is coated with an abrasive powder to promote abrasion.

The laboratory test results were correlated with extensive full-scale field testing with the HVS on different asphalt base pavement structures and failure criteria for the test method developed.

The failure criteria for the erosion test for materials used in flexible pavements specified in Gass, Ventura, and de Beer (*5*) is given in Table 1. The traffic classification, on which the criteria is based, is given in TRH4 (1985) (*14*) (figures available when the test was developed). Revised figures given in the later version of TRH4 (1996), (*15*) are also shown. The classification of the traffic class given in Table 1 is shown in Table 2. Note that no criteria were developed for cemented bases under rigid pavements.

2.4.3 The Residual Unconfined Compressive Strength (RUCS) Test

Stabilized materials that satisfy the 7-day cured unconfined compressive strength (UCS) requirements may not always satisfy the requirements if they are subjected to wetting and drying and/or carbonation in the field. Therefore, rather than base the strength criteria on the 7-day UCS, it is recommended that a residual UCS (RUCS) be considered to ensure that even if the material is subjected to wetting and drying or carbonation in service, it will retain sufficient structural integrity to satisfy the original design requirements in terms of UCS.(*8*)

Table 1 **Failure Criteria for C3/C4 materials in Flexible Pavements (*5*)**

Layer	Traffic Class TRH4 (1985)	Traffic Class TRH4 (1996)	Erosion Index (L) (mm)
Bases	E0 – E4	ES0.1 – ES30	≤ 1
Sub-bases	E0 – E2	ES0.1 – ES3	≤ 5
Sub-bases	E3 – E4	ES10 – ES30	≤ 3

Table 2 **Classification of Traffic for Structural Design Purposes**

Specification	Traffic Class	Pavement Design Bearing Capacity (million 80-kN axles/lane)	Volume and Type of Traffic
TRH 4 (1996)	ES0.1	0.003 – 0.01	Very lightly trafficked roads; very few heavy vehicles.
	ES3	1 – 3	Medium volume of traffic; few heavy vehicles.
	ES10	3 – 10	High volumes of traffic and/or many heavy vehicles.
	ES 30	10 – 30	Very high volume of traffic and/or a high proportion of fully laden heavy vehicles.
TRH 4 (1985)	E0	< 0.2	Very lightly trafficked roads; very few heavy vehicles.
	E2	0.8 – 3	Medium volume of traffic; few heavy vehicles.
	E3	3 – 12	High volumes of traffic and/or many heavy vehicles.
	E4	12 – 50	Very high volume of traffic and/or a high proportion of fully laden heavy vehicles.

The RUCS test is usually carried out on cylindrical specimens compacted at typically 100 percent or 97 percent Modified AASHTO, but any compaction method or compaction energy may be used to suit requirements. After 7-day curing, the compacted specimen is placed under vacuum in a vacuum dessicator or other appropriate vessel, which is then filled with carbon dioxide and afterwards with water. Specimens are placed in a water bath and allowed to soak for 4 hours after which they are crushed in a concrete press until failure and the load at failure recorded.

The stabilizer content of any material or project was determined in such a way that the minimum design UCS after 7 days curing was satisfied. The recommended minimum and maximum limits for the UCS of cemented materials given in TRH 14 (*16*) is shown in Table 3.

Table 3 Recommended UCS Strengths for Stabilized Materials

Material Classification	**Unconfined Compressive Strength (UCS) (MPa)**			
	100 % Modified AASHTO Compaction		**97 % Modified AASHTO Compaction**	
	Maximum	**Minimum**	**Maximum**	**Minimum**
C1	12	6	8	4
C2	6	3	4	2
C3	3	1.5	2	1
C4	1.5	0.75	1	0.5

According to TRH 4, C1 materials are not generally used due to the excessive shrinkage and cracking experienced, and C2 materials are only used when a non-pumping, erosion resistant layer is required, such as that under a concrete pavement.(*15*) In general, the limits used for stabilized base and subbase layers are those for C3 and C4 materials.

It was recommended that the UCS strengths given in Table 3 be attained after specimens were subjected to the RUCS test (carbonated and vacuum saturated) to ensure that even if the material is subjected to wetting and drying or carbonation in service it will retain sufficient structural integrity to satisfy the original requirement in terms of UCS strength.(*8*)

2.4.4 Initial Consumption of Lime or Cement Test

The use of lime or cement treated materials in the construction of road layers was and is common practice in southern Africa, as is discussed previously. Some of these roads failed in spite of the fact that the materials used fulfilled all the material requirements at that time. It was found that one of the reasons for this was that the lime demand of the material had not been satisfied, as determined by the test method developed by Eades and Grimm.(*17*) It was also established that all natural materials have, to a greater or lesser extent, a demand for lime (*3*) and it is important that this demand be quantified when stabilization of a material is being considered. Weathered, clayey materials tend to have a greater lime demand than fresh materials.

Consider the case where 3 percent cement stabilizer is added to a soil with an initial consumption of lime (ICL) of 5 percent. The lime demand of the soil is the primary reaction and is responsible for the consumption of a portion of lime [$Ca(OH)_2$] released during the setting and hardening process of cement. In such a scenario, the ICL could seriously interfere with the gain in strength since only the lime that is left after the lime demand of the soil has been satisfied is available for the binding and hardening process. The determination of the lime demand of stabilized road construction materials is thus considered of extreme importance, especially where carbonation is likely to occur.

The method developed by Eades and Grimm is essentially the measurement of the pH of a soil stabilized with various percentages of lime. The quantity of lime necessary to maintain a pH of 12.4 in a lime-soil-water mix after 1 hour is considered to be the ICL of the material. The word "lime" may be substituted by cement, or any other pozzolanic stabilizer, as they all behave in a similar manner. This test was initially performed on the –0.425mm (–#40) fraction of the material, but was later modified by Klauss (*18*) to test construction material as a whole (crushed to pass a 19-mm sieve) as it was assumed that this would be a better indication of the lime demand of the material as a whole. As was stated earlier, for adequate stabilization using pozzolanic stabilizers, sufficient stabilizer should be added to ensure an excess after the reactions are complete, i.e., the initial consumption of lime or initial consumption of cement (ICL or ICC) of the soil should be satisfied and an excess provided.

A stabilizer content of ICL or ICC plus an additional 1 percent is recommended.(*3*)

3.0 MATERIALS TESTED

Two aggregate materials were supplied by Caltrans for durability testing using South African standards. Information on the grading composition of the aggregate materials and the percentage of cement and water to be added was also supplied. The sources for the aggregate materials were named *Mission Valley* and *Lake Herman-Madison sand*. Testing of a cement-treated base (CTB) containing 5 percent cement and a lean concrete base (LCB) containing 8 percent cement was required for both materials. The cement for treating the materials was also supplied by Caltrans (Type 2 cement modified ASTM C-150).

Mission Valley CTB (MV CTB) and LCB (MV LCB) samples were supplied mixed in the correct proportions, whereas for the Lake Herman-Madison sand samples, various fractions of the materials were supplied in separate buckets and the LCB (LH LCB) and CTB (LH CTB) mixes had to be constituted according to the information supplied, as shown in Table 4. The gradings of all the materials tested are depicted graphically in Figures 5 and 6.

Table 4 Composition of Lake Herman/Madison sand CTB and LCB

Layer type	Aggregate type/water	Percentage of mix (%)
Cement treated base	Lake Herman aggregate	84
	Madison concrete sand	16
	Water	5.6
Lean concrete base	Lake Herman Aggregate	49
	Madison concrete sand	51
	Water	8.2

4.0 LABORATORY TESTING

The materials were tested for durability according to the methods specified in Section 2.2 of this report. In addition to durability testing, standard classification testing such as grading analysis, Atterberg Limits, linear shrinkage, etc., were also performed.

4.1 Compaction

Compaction of soils may be defined as the process whereby soil particles are packed more closely together by the expulsion of air surrounding these particles. Compaction is usually performed by mechanical means.

The materials were tested at both Standard Proctor and Modified AASHTO compaction efforts to illustrate the increase in durability of the material when compacted at higher density.

Modified AASHTO compaction is done in 152.4-mm (6-in.) diameter molds into which material is compacted in five layers with each layer receiving 55 evenly distributed blows of a 4.536 kg (10-lb.) tamper, dropping 457.2 mm (18-in.). The density of the specimens so obtained is designated as 100 percent Modified AASHTO density. Standard Proctor compaction in a 152.4-mm (6-in.) diameter mold is achieved by compacting the specimens in three layers using a smaller hammer weighing 2.495 kg (5.5 lb.), the number of blows is 55 and the drop is 304.8 mm (12 in.). The density obtained using this compaction is normally 92 to 95 percent of that

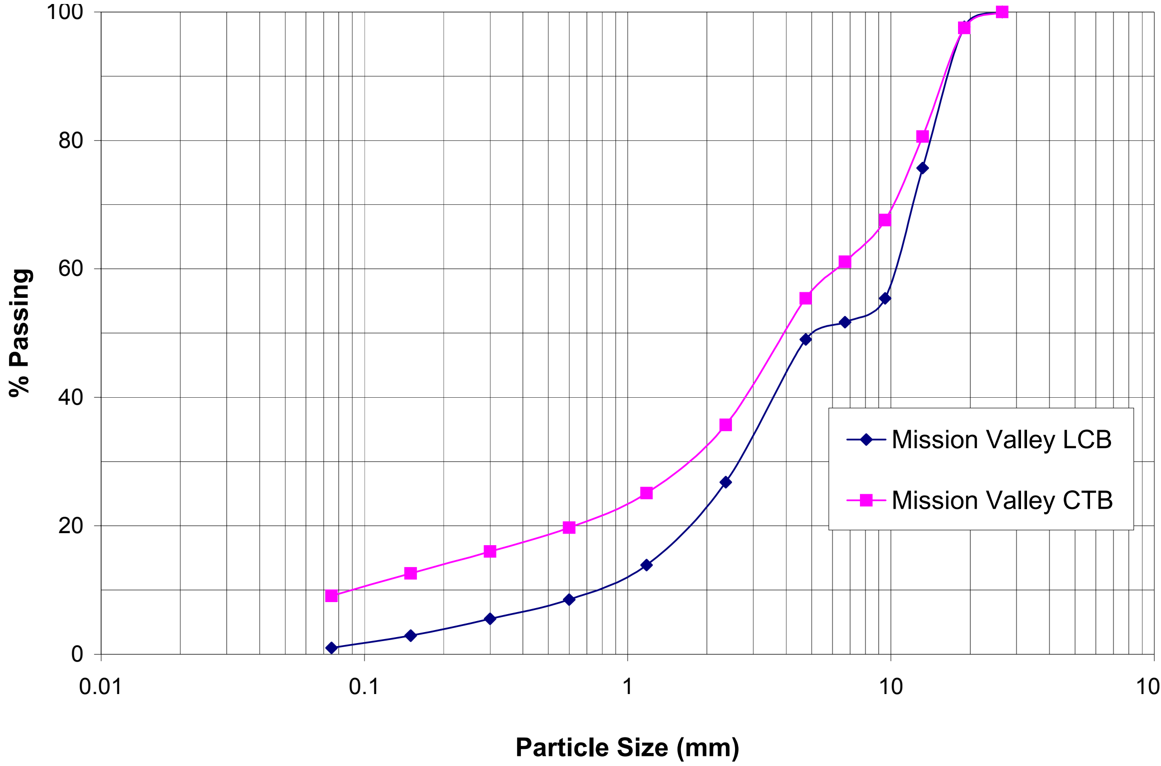

Figure 5. Grading Curves for the Mission Valley samples.

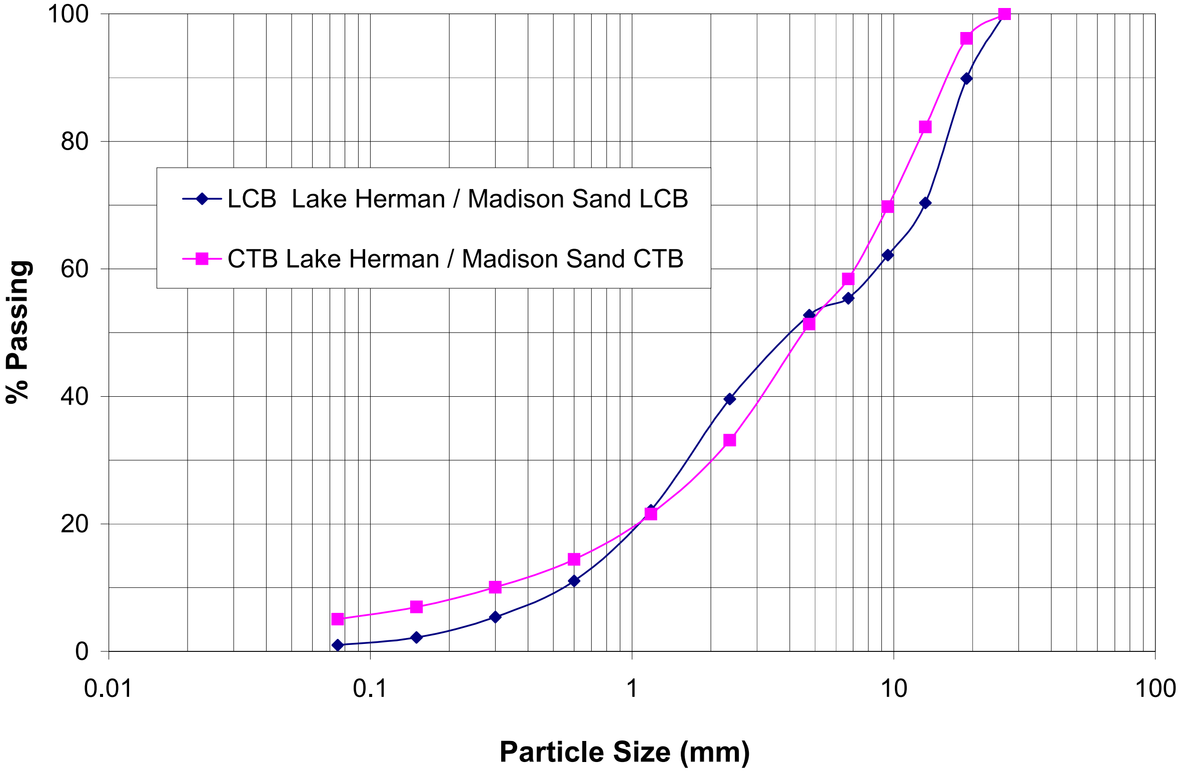

Figure 6. Grading Curves for the Lake Herman samples.

obtained using Modified AASHTO compaction. The total energy imparted to the sample is approximately 5.6 kJ for Modified AASHTO compaction, whereas for Standard Proctor the energy is of the order of 1.2 kJ.

For comparisons to be made between the original hand brushed test method and the mechanical brushing method, some samples were compacted in the 101.2-mm (4-in.) diameter molds at standard Proctor effort. Standard Proctor compaction in this smaller mold is attained by compacting the material into the mold in 3 layers, each layer receiving 22 blows of the smaller hammer described above.

For erosion and durability problems to occur in pavement layers, the ingress of water and air is necessary. Therefore, the more permeable the layer, the more susceptible it will be to both erosion and durability. Materials compacted to higher densities have fewer voids and are therefore less susceptible to the ingress of water and air. In addition, higher density compaction provides better particle interlock, which leads to materials with better shear strength. However, higher compactive efforts may lead to breakdown of coarse aggregates if they are soft or perhaps weathered, which may result in fines being generated. Excessive fines may be detrimental to the compaction process resulting in lower densities and, in some instances, higher plasticity in situations in which the fines generated by compaction are from weathered materials containing clays.

4.2 Initial Consumption of Cement (ICC) Test Results

The initial consumption of cement (ICC) for the Mission Valley CTB and LCB specimens satisfied the specification that the percentage of cement added should be equal to the ICC plus 1 percent. According to the test specifications, the cement added to the CTB and LCB materials should at least be 2.0 and 2.5 percent respectively, whereas the actual quantities added were 5 and 8 percent.

Similarly the Lake Herman / Madison sand materials required the addition of 3 percent cement to satisfy the test requirements, which was below the actual amounts added.

4.3 Brush Test Results

The test results for mechanical and hand brushed specimens of the two materials are shown in Table 5 and graphically depicted in Figure 7. Because of the limited amounts of material available, testing had to be limited to two and in some cases one specimen per combination of variables.

4.3.1 Mission Valley specimens

For the Modified AASHTO compaction effort, the material losses for the machined brushed were very low for both 5 and 8 percent cement contents. There was also no significant difference between the results at the two cement contents. The percentage loss for the CTB specimens was 0.5 percent; that of the LCB 0.6 was percent. The hand brushed specimens lost twice as much material (1 and 1.2 percent for the CTB and LCB specimens, respectively), but this is still considered a small amount. Figure 8 shows hand brushed specimens for both CTB and LCB Mission Valley materials.

Table 5 Mechanical and Hand Brush Test Results

Compaction	**Mold Size**	**Brush Type**	**Mass Loss (%)**			
			Mission Valley CTB (5% cement)	**Mission Valley LCB (8% cement)**	**Lake Herman CTB (5% cement)**	**Lake Herman LCB (8% cement)**
Modified AASHTO	Modified AASHTO	Mechanical	0.5	0.6	1.2	0.8
		Hand	1.0	1.2	3.6	1.6
Standard Proctor	Standard Proctor	Mechanical	0.7	0.8	4.5	1.2
		Hand	2.8	2.0	41.0	2.9

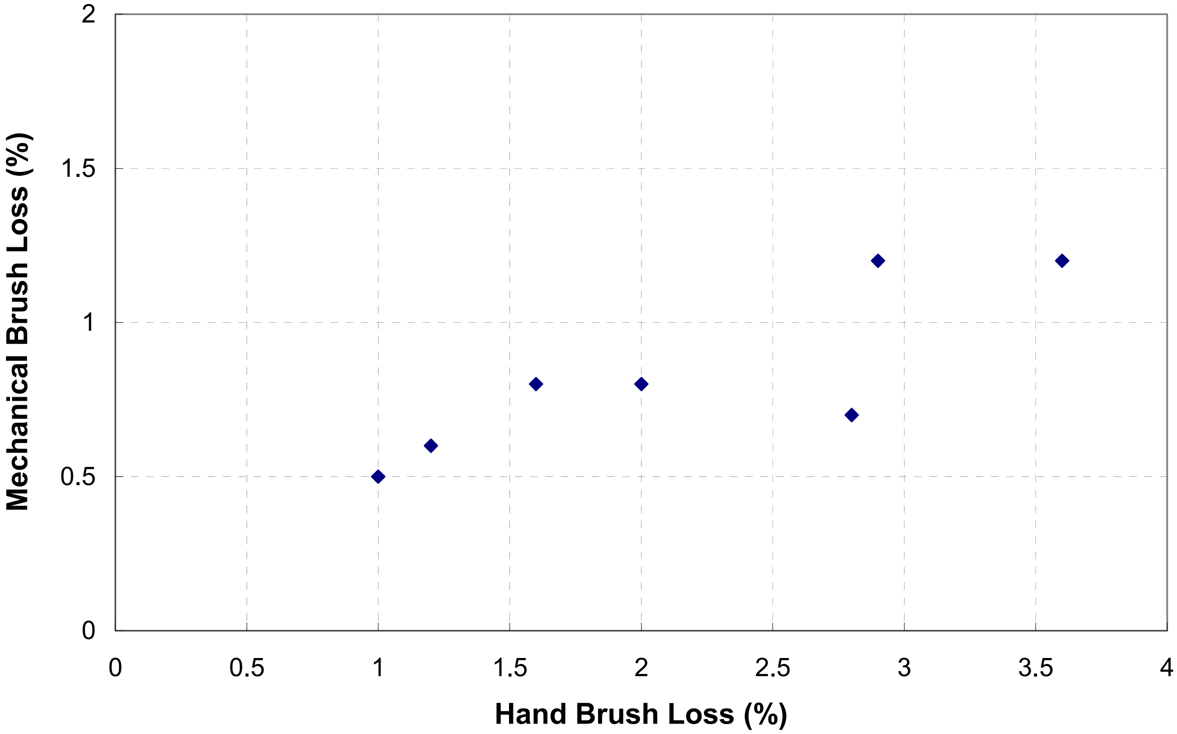

Figure 7. Comparison between hand and mechanical brushing.

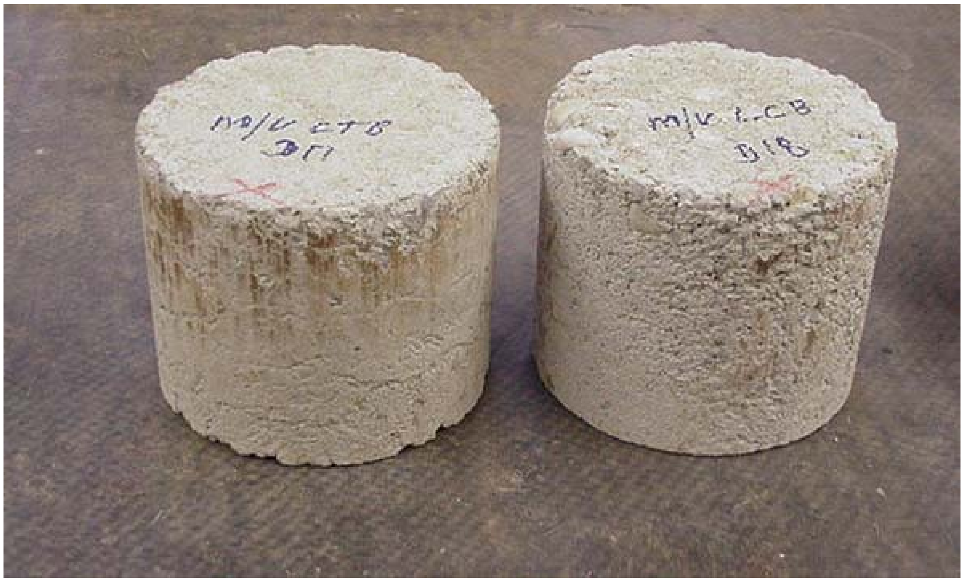

Figure 8. Machine brushed specimens of Mission Valley CTB (left) and LCB (right) materials compacted at Modified AASHTO effort.

The losses for the hand brushed specimens, although double that of the machine brushed specimens, were still very small and again there was no significant difference between the materials at the two cement concentrations.

The specimens for mechanical and hand brushing compacted at Standard Proctor effort in the smaller molds (101.2-mm diameter) lost more material on brushing than did the Modified AASHTO specimens, as was expected. At the lower density, the specimens are less resistant to the brushing action and also, the contact stresses caused by the brush on the smaller diameter specimens are higher. Another reason for the increased loss of material in the smaller specimens is that the loss of large aggregate particles represents a higher percentage loss of the total specimen mass. The mass of the Standard Proctor specimens was typically 2 kg, whereas that of the Modified AASHTO specimens was in the order of 5 kg. However, the Proctor mechanical brushing losses were only slightly higher than the losses experienced by the mechanically brushed specimen compacted at Modified AASHTO effort in the larger diameter molds, whereas the material loss for Proctor hand brushed specimens were markedly higher than for the Modified AASHTO specimens.

It was expected that the Mission Valley CTB material would lose significantly more material than the Mission Valley LCB (as was the case with the Lake Herman specimens). However, three of the four results reported in Table 5 for the Mission Valley material show the opposite of this expected trend. The LCB material has a coarser grading and would therefore have been more susceptible to brushing as the brush tends to pluck the large aggregate from the soil matrix and also, the loss of a few pieces of large aggregate will make a larger percentage difference to the overall loss than the loss of fine materials. Yet another probable cause was that the large aggregate in the LCB material was rounded river gravel, whereas in the CTB material the large aggregate was partly crushed river gravel. It is assumed that the rounded particles (smooth surfaces) do not bind as well with the rest of the mix when cemented and therefore more material would be lost with the brushing action.

At both Modified AASHTO and Standard Proctor compaction efforts, the specimens tested were acceptable in terms of the test specifications, where the most stringent requirement for mechanical brushed specimens compacted at Modified AASHTO effort is a loss of less than 5 percent for a stabilized base layer under a concrete pavement and a loss of less than 7 percent for A-6/A-7 materials when hand brushed and compacted at Standard Proctor effort in the smaller molds.

4.3.2 Lake Herman / Madison Sand Specimens

The LCB treated with the higher percentage of cement proved to be more resistant to both the mechanical and hand brushing than the CTB with the lower cement content, as was be expected. The machine brushed specimens again lost less material than the hand brushed specimens. The loss for the CTB and LCB mechanically brushed specimens compacted at Modified AASHTO effort was 1.2 and 0.8 percent respectively, whereas these figures for the hand brushed specimens were 3.6 and 1.6 percent (Figure 9). The percentage loss figures for the specimens compacted at standard Proctor effort and mechanically brushed were 4.5 and 1.2 for the CTB and LCB specimens. The corresponding losses for the hand brushed specimens were 41 and 2.9 percent (the figure of 41 percent seems extremely high when compared to the other test results and therefore this test should be repeated). However, lack of sufficient quantities of material did not permit replication of that specimen.

The specimens once again had acceptable durability in terms of the test specification limits, with exception of the hand brushed specimen compacted at Standard Proctor effort.

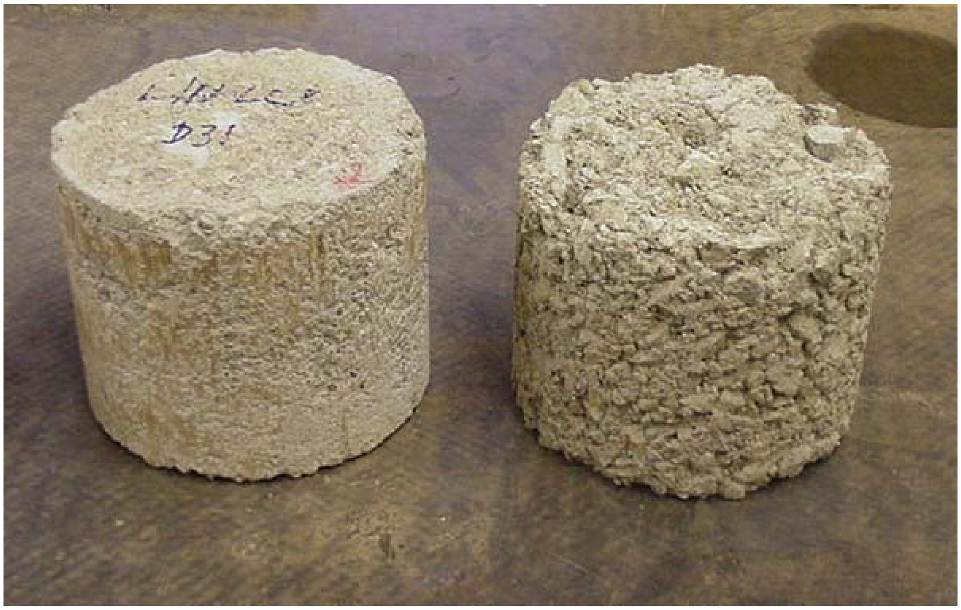

Figure 9. Hand brushed Lake Herman LCB (left) and CTB (right) specimens compacted at Modified AASHTO effort.

4.4 Erosion Test Results

The erosion test results are shown in Table 6.

Table 6 Erosion Test Results

Sample	Modified AASHTO Compaction		Standard Proctor Compaction	
	EL (mm)	Density (kg/m^3)	EL (mm)	Density (kg/m^3)
Mission Valley CTB	0.49	2293	1.47	2201
Mission Valley LCB	0.29	2283	0.35	2123
Lake Herman CTB	0.53	2248	1.90	2091
Lake Herman LCB	0.22	2267	0.45	2108

EL = Erosion Index

4.4.1 Mission Valley specimens

The CTB materials with the lower cement content proved more erodible than the LCB materials, for specimens compacted at both Modified AASHTO and Standard Proctor efforts, as was to be expected. The brushing is considered to be a plucking action (tensile force) whereas the erosion wheels exert a downward force on the specimens, which is probably why aggregate shape (rounded particles) in the LCB mix had no significant effect on the test results, compared to the brush test.

For specimens compacted at Modified AASHTO effort, the Erosion Index (L) for the CTB was 0.49 mm and that of the LCB 0.29 mm, which is less than the limit of 1 mm prescribed for the most demanding traffic loading for the base layer of roads with a very high volume of traffic and/or a high proportion of fully laden heavy vehicles. The specimens compacted at the lower Standard Proctor energy had higher erosion values, as was expected. The CTB material gave an Erosion Index value of L = 1.47 mm and therefore was no longer considered suitable for base layers (see Table 1), but may still be used as a subbase material for the most highly trafficked roads. The value of compacting materials to higher densities and thus creating a more durable mix is again highlighted by these results.

4.4.2 Lake Herman / Madison Sand

The erosion indices for the Lake Herman / Madison sand specimens were similar to those of the Mission Valley specimens. The erosion Index for the CTB material was 0.53 mm and that of the LCB 0.22 mm for specimens compacted at Modified AASHTO effort. At Standard Proctor compaction, these values were 1.9 mm and 0.45 mm, respectively.

At the higher compaction effort, these materials would be suitable for use in any base or subbase layer, whereas when compacted at the lower energy, the CTB material is not recommended for bases but only subbases.

4.4.3 General

The Erosion test results therefore indicate that both cement content and compaction energy affect the durability of the materials in terms of erodibility. The higher the cement content, the less erodible the specimens. Likewise, the higher the compaction energy, the less erodible the specimens. It is interesting to note that both Mission Valley and Lake Herman CTB specimens with the lower cement contents increased in erodibility by approximately 3 times when compacted at the lower Standard Proctor effort, whereas this increase was not as pronounced at the higher cement contents. This suggests that at the lower contents the level of compaction is very important for erosion resistance characteristics.

Figure 10 shows specimens of the Mission Valley and Lake Herman CTB materials compacted at Modified AASHTO and Standard Proctor compaction efforts, after erosion testing. These were the materials with highest erosion index values when compacted at Standard Proctor effort. Note the loss of fines between the coarse aggregates of the materials compacted at Standard Proctor compaction.

4.5 UCS and Residual UCS Test Results

The Unconfined Compressive Strength (UCS) test results for both materials after standard and carbonated conditioning are shown in Table 7.

Table 7 Unconfined Compressive Strength (UCS) Values for Uncarbonated and Carbonated Specimens

Compaction Effort	Condition	Mission Valley			Lake Herman		
		Density values (kg/m^3)	UCS Values (kPa)		Density values (kg/m^3)	UCS Values (kPa)	
			CTB	LCB		CTB	LCB
Modified AASHTO	Uncarbonated	2292	8512		2238	11707	
	Carbonated	2294	9594		2248	11075	
	Uncarbonated	2288		18503	2254		12336
	Carbonated	2313		19189	2261		14254
Standard Proctor	Uncarbonated	2231	11513		2210	12481	
	Carbonated	2223	10143		2205	10750	
	Uncarbonated	2192		16862	2249		14419
	Carbonated	2204		14803	2218		12500

Mission Valley CTB Standard Proctor Compaction
Lake Herman CTB Standard Proctor Compaction
Mission Valley CTB Modified AASHTO Compaction
Lake Herman CTB Modified AASHTO Compaction

Figure 10. Mission Valley and Lake Herman CTB specimens after erosion testing.

It was assumed that the uncarbonated specimens would have higher strengths than the carbonated specimens. Whereas this was the case for all the tests done at the Standard Proctor compaction, the strength remained the same or increased slightly after carbonation of the Modified AASHTO compacted samples. The only exception was the Lake Herman CTB specimen compacted at Modified AASHTO effort, which had a carbonated strength of 11075 kPa compared to an uncarbonated strength of 11787 kPa. The strength differences between uncarbonated and carbonated specimens were very small. The largest difference was observed with Lake Herman LCB specimens at both Standard Proctor and Modified AASHTO compaction efforts. The Lake Herman LCB specimens had differences of 15.4 and 15.5 percent for uncarbonated and carbonated specimens, respectively.

There was no trend observed in UCS values of the specimens between the compaction efforts, whereas one would have expected higher UCS values for Modified AASHTO specimens because of their higher densities. In some instances, the specimens compacted using the Standard Proctor method were stronger than those compacted using the Modified AASHTO method (i.e., Mission Valley CTB uncarbonated, Lake Herman CTB uncarbonated, Lake Herman LCB uncarbonated) whereas in some cases, Modified AASHTO compacted specimens were stronger than those compacted at Standard Proctor (Mission Valley LCB uncarbonated, Mission Valley LCB carbonated, Lake Herman CTB carbonated, Lake Hermand LCB carbonated).

The densities achieved for specimens compacted at Standard Proctor were not much lower than those of the specimens compacted at the higher Modified AASHTO effort. Generally, the densities obtained using the lower compaction effort are in the vicinity of 92 to 95 percent of the densities obtained using the higher compaction energy. However, this finding is dependent on the material characteristics and type. In this study, the lowest density obtained compacting with Standard Proctor effort was that of the Mission Valley LCB specimen, which was 96 percent of the density of the specimen compacted at the Modified AASHTO density. The Standard Proctor densities were 97, 98, and 99 percent of the Modified AASHTO densities for the Mission Valley CTB, Lake Herman CTB and Lake Herman LCB, respectively.

In terms of strength of the carbonated materials, the Proctor specimens behaved in the expected manner. The uncarbonated specimens gave higher UCS values than did the carbonated specimens. This observation suggests that at lower densities, the infiltration of the CO_2 into the compacted materials is higher, resulting in higher carbonation levels and reduced strength.

The CTB specimens were in all cases weaker than the LCB specimens for both Standard Proctor and Modified AASHTO compaction efforts, as was expected because of the higher cement contents of the LCB specimens.

Due to the quantities of materials supplied it was not possible to do repeat testing on the materials.

According to South African standards, the UCS values obtained for both carbonated and uncarbonated specimens and at the both compaction levels exceed the minimum requirement for a C1 material, which is 6,000 kPa (see Table 3). C1 materials are the strongest in terms of UCS strength recommended by the specifications.(*15*) Therefore, these materials can be used in any base or subbase layers, including a subbase under a concrete pavement. However, some of the specimens had UCS values that exceeded the maximum suggested value of 12,000 kPa at 100 percent Modified AASHTO density, and therefore excessive shrinkage and cracking may result. Even under a concrete slab, this shrinkage and cracking may be a cause for failures as movement or rocking may occur, and water and air containing CO_2 may infiltrate into the cracks causing weaknesses in the layer.

According to the South African experience, it may be beneficial to reduce the cement contents resulting in lower material strengths, thereby reducing shrinkage cracking and layer costs. However, for most Caltrans rigid pavements, the use of thick concrete layers and bond breaker between the cemented base and Portland cement concrete should minimize the impact of shrinkage cracking in the LCB on the pavement performance. On the other hand, Caltrans flexible pavements with CTB underneath the asphalt concrete have exhibited reflection cracking of shrinkage cracks, such as on I-15 near Baker.(*19*)

5.0 SUMMARY OF TEST RESULTS, CONCLUSIONS, AND RECOMMENDATIONS

5.1 Initial Consumption of Cement (ICC)

The initial consumption of cement (ICC) for the Mission Valley CTB and LCB specimens satisfied the South African specification that the percentage of cement added should be equal to the ICC plus 1 percent. According to the test specifications, the cement added to the CTB and LCB materials should at least be 2.0 and 2.5 percent respectively, whereas the actual quantities added were 5 and 8 percent.

Similarly the Lake Herman / Madison sand materials required the addition of 3 percent cement to satisfy the test requirements, which was below the actual amounts added.

In terms of the ICC test requirements, it would thus be possible to reduce the quantities of cement added, which would reduce the construction costs. This result is primarily applicable to CTB and LCB for flexible pavements, and is not recommended for rigid pavements.

5.2 Hand and Mechanical Brushing

Specimens of the two materials were compacted at both Modified AASHTO and Standard Proctor compaction efforts and tested by hand brushing and by mechanical means.

As expected, the hand brushed specimens lost more material than the mechanically brushed specimens. The mass losses of the Mission Valley specimens were similar for both the CTB and LCB materials, where it was expected that at the higher cement content LCB specimens would be more resistant to brushing. The large aggregates in the LCB material, however, were rounded river gravel, which probably did not bond well with the rest of the mix because of the round smooth surfaces. At both the Modified AASHTO and Standard Proctor compaction efforts, the specimens tested were acceptable in terms of the test specifications, where the most stringent requirement for mechanical brushed specimens is a loss of less than 5 percent for a stabilized base layer under a concrete pavement and a loss of less than 7 percent for A-6/A-7 materials when hand brushed.

The Lake Herman / Madison sand LCB treated with the higher percentage of cement proved to be more resistant to both the mechanical and hand brushing than the CTB with the lower cement content, as was expected. The machine brushed specimens lost less material than the hand brushed specimens.

These specimens had acceptable durability in terms of the test specification limits, with the exception of the hand brushed specimens compacted at Standard Proctor effort, which had a mass loss of 41 percent. This loss is considered excessive and is probably a testing anomaly rather than a true reflection of performance.

The most stringent requirement according to South African specifications for mass loss for mechanically brushed specimens compacted at Modified AASHTO effort is a loss of less than 5 percent for a stabilized base layer under a concrete pavement and a loss of less than 7 percent for A-6/A-7 materials when compacted at Standard Proctor effort and hand brushed. With exception of the Lake Herman CTB hand brushed specimens, all specimens of both materials compacted at both Standard Proctor and Modified AASHTO efforts, at both cement contents, hand or mechanically brushed, were acceptable in terms of the South African and California specifications. This suggests that the cement content may be reduced, especially where 8 percent is used, without adversely affecting the durability of the materials in terms of brushing resistance. This also suggests that LCB is only somewhat better than CTB in terms of durability. This result should be checked by coring field pavements with LCB that have been in place 10 to 20 years.

5.3 Erosion Testing

The CTB materials with the lower cement content proved more erodible than the LCB materials for specimens compacted at both Modified AASHTO and Standard Proctor efforts, as was to be expected. Both the Mission Valley and Lake Herman / Madison sand specimens compacted at Modified AASHTO effort exceeded the test requirements for the most demanding traffic loading, for which an erosion index (L) of ≤ 1 mm is specified. At Standard Proctor compaction, the CTB materials were no longer considered suitable for base layers, including the subbase layer under concrete slabs. LCB materials with the higher cement content were still considered acceptable for use as base layers. <u>It is probable that erosion failures will occur should the materials with the lower cement contents be used as a supporting layer under concrete slabs.</u>

5.4 Unconfined Compressive Strength (UCS) Testing

According to South African standards, the UCS values obtained for both carbonated and uncarbonated specimens and at the both compaction levels exceed the minimum requirement for a C1 material, which is 6,000 kPa (see Table 3). C1 materials are the strongest in terms of UCS strength recommended by the specifications.(*15*) These materials can therefore be used in any base or subbase layers, including a subbase under a concrete pavement. However, UCS values of some of the specimens exceed the maximum suggested value of 12,000 kPa at 100 percent Modified AASHTO density and therefore excessive shrinkage and cracking may result. Even under a concrete slab, this may be a cause for failures as movement or rocking may occur and water and air containing CO_2 may infiltrate into the cracks, causing weaknesses in the layer. The UCS results also suggest that some reduction in cement content could be made without sacrificing the required strength in terms of the South African specifications, although not as low as the cement contents or specification of CTB.

Some of the observed failures of cement-stabilized layers in California rigid pavements may also be related to the mechanical crushing of the layer. It is recommended that a stress analysis be performed to apply the crushing criteria developed by de Beer. No additional testing will be required to apply these criteria.

6.0 RECOMMENDATIONS

The following recommendations are made based on the results and conclusions of this report:

Flexible Pavements

Field survey. It is recommended that a field survey of flexible pavements be performed with Lean Concrete Base (LCB) and Cement Treated Base (CTB) base layers. It is recommended that this field survey determine:

a. Typical distresses, in particular the extent to which shrinkage cracking has reflected up from the LCB or CTB layer through the asphalt concrete.
b. The durability of these materials under the various mix designs and compaction levels, and under the various climates and traffic levels. Durability should be determined through observation of pumping, and some coring on each project. The results of the recently completed test section evaluation by a recent Caltrans research contract (*20*) or should be reviewed for any LCB/CTB sections as a start.

Required compaction. It is recommended that the required compaction for CTB be increased from 95 percent to either 98 or 100 percent, relative to California Test Method 312 for Class A CTB (inactive test) if this material is still being used. This will increase durability without increasing the risk of shrinkage.

Flexible Pavement Design. If the recommended field survey shows that the reflection of shrinkage cracks from the cemented base up through the asphalt concrete is a likely and difficult to rehabilitate distress, it is recommended that the use of Lean Concrete Base (LCB) be eliminated for use directly beneath the asphalt concrete surface in flexible pavements.

Test standards.

a. It is recommended that use of the initial cement/lime consumption (ICC/ICL) test for determining the cement content of cemented base materials be considered.

b. It is also recommended that use of the Residual Unconfined Compressive Strength (RUCS) test for durability of cemented base materials be considered.

c. If use of LCB and Class A CTB is continued, it is recommended that the risk of shrinkage cracking be reduced by consideration of a maximum unconfined copmressive strength (UCS) specification as used in South African specifications, or by use of a shrinkage test.

Rigid Pavements.

Field survey. It is recommended that a field survey be performed of rigid pavements with Lean Concrete Base (LCB) base layers. It is recommended that this field study evaluated the durability of these bases under the various mix designs and under various climates and traffic levels. Durability should primarily be evaluated through coring to evaluate disintegration and condition survey to evaluate faulting for comparison with pavements with Class A CTB. The results of the recent Caltrans research contract work (*20*) should be reviewed for any LCB sections as a start. The test sections used by Caltrans to make the decision to change from CTB to LCB in the early 1990's (*21*) should be reviewed in light of the recent extensive use of dowels in rigid pavements which, reduces deflections at corners and joints.

Durability under Rigid Pavements. If durability of LCB under rigid pavement is found to be an issue in the recommended field survey, it is recommended that use of the Residual Unconfined Compressive Strength (RUCS) test be considered.

Shrinkage Cracking. If durability problems associated with shrinkage cracking are found for LCB, it is recommended that consideration be given to a maximum UCS test strength or a shrinkage test.

Abrasion. If mechanical abrasion durability is an issue, it is recommended that adoption of a mechanical abrasion test be considered, although the risk of abrasion durability problems should be greatly reduced by the use of dowels.

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APPENDIX A: TEST METHODS

TEST METHOD NO. CA 34-83(1984)

SOUTH AFRICAN COUNCIL FOR SCIENTIFIC AND INDUSTRIAL RESEARCH
NATIONAL INSTITUTE FOR TRANSPORT AND ROAD RESEARCH
ROADS BRANCH
SOIL ENGINEERING GROUP

DESCRIPTION: DETERMINATION OF THE INITIAL CONSUMPTION OF LIME IN SOIL (GRAVEL ICL TEST PROCEDURE)

1. DEFINITION

The test is known as "gravel ICL" and deviates from the original (soil fines; Eades and Grim, 1966, and corrected soil fines, Clauss and Loudon, 1971) ICL by:

(a) testing construction material as a whole (crushed to pass a 19 mm sieve) in place of the -0,425 mm fraction only;

(b) using a 200 g sample in place of 20 g; and

(c) reducing the water content to just above saturation moisture content (pore moisture) and so dispensing with the necessity of a correction factor for lime water saturation.

2. OBJECTIVE

The objective of the gravel ICL test is the control of the pH in lime and cement stabilized soil in order to allow the possible formation of cement minerals, CSH in particular.

3. EQUIPMENT

Balance (accuracy : 0,1 g)
pH meter (accuracy : 0,02 units)
5 plastic beakers (150 mℓ, tall)
Spatula or pallet knife
Soft tissues
Glass beaker (200 mℓ)
Distilled water
Calcium hydroxide and/or lime to be used
Jet bottle (for cleaning electrode)
Sample splitter (25 mm and 5 mm approx. are sufficient in general)
Drying oven (105 - 110 °C)
Thermometer (accuracy 0,5 °C)

4. PREPARATION OF SOIL SAMPLES

(a) The test is carried out on 2 kg of material finer than 19 mm. Any oversize material is crushed to pass 19 mm as described in TMH1, Method A7, Section 3.1.

(b) Oven dry sample at 105 - 110 °C.

(c) The sample is further reduced to 200 g quantities by means of sample splitters and placed into 150 mℓ (or larger) plastic containers.

5. TESTING PROCEDURE

(a) Since most materials require between 2 and 5 per cent lime, it is advisable to set up six beakers with lime percentages of 1, 2, 3, 4, 5 and 6 of the dry soil mass, i.e. 200 g soil + 2, 4, 6, 8, 10 and 12 g of $Ca(OH)_2$. This will ensure, in most cases, that the percentage of lime required can be determined in one hour. Weigh the lime to the nearest 0,1 g and add it to the soil. Mix soil and dry lime.

(b) Slightly over-saturate samples with distilled water. The material shall be judged over-saturated when the pores of the material are water filled and free water can be observed on the surface of the mix. The surface particles need not be submerged completely.

(c) Mix the soil-lime and water until there is no evidence of dry material on the bottom. Mix for a minimum time of 30 seconds.

(d) Mix for 30 seconds every 10 minutes.

(e) After one hour, measure the pH by inserting the pH electrode gently into a hole made in the material with the spatula to a depth of about 20 - 30 mm and gently covering this part of the electrode with the material. Tap the beaker gently for contact between electrode and material.

(f) Record the pH of each of the soil/lime-water mixtures. The lowest percentage lime from which on the pH remains constant is the saturation lime content of this particular gravel.

6. RECORDING OF RESULTS

The results are recorded to the nearest 0,5 per cent lime required to produce the max. pH in the soil/water/lime mixture as indicated by the pH of the mix. Since the pH depends on the temperature (Figure 1), this must also be recorded.

7. PREPARATION OF pH METER

The calibration procedure of the manufacturer must be strictly followed. The temperature-asymmetry- and slope adjustment are of particular importance. The electrode efficiency must be assured.

8. TECHNICAL TERMS

CLC - The cement reaction lime content is the quantity of lime ($Ca(OH)_2$) which produces a pH in a soil-lime-water mixture after 1 h at which cement minerals, CSH in particular, may form if they can form. This pH is possibly > 11,0.

CEMENT REACTION pH is the pH of a soil-lime-water mix at which cement minerals, CSH in particular, may form (possibly pH > 11,0).

ICL - The initial consumption of lime of a soil is the quantity of lime ($Ca(OH)_2$) necessary to maintain a lime created pH of 12,4 in a lime-soil-water mix at 25 °C after 1 h.

LIME SATURATION is achieved by a quantity of lime which produces a pH not increasing further if more lime is added.

MAXIMUM pH - see saturation pH.

SATURATION LIME CONTENT - see lime saturation.

SATURATION pH is a pH not increasing further if more lime is added.

9. REFERENCES

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EADES, J L and GRIM, R E A quick test to determine lime requirements for lime stabilization. Highway Research Board, HR-Record No 139, Washington, 1966, pp 61-72.

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TEST METHOD No CA 15

THE WET-DRY DURABILITY TEST FOR CEMENT-TREATED MATERIALS USING THE MECHANICAL BRUSHING MACHINE

1. SCOPE

This method covers the procedure for determining the soil-cement losses obtained by repeated wetting, drying and machine brushing of hardened soil-cement specimens (see 5.4).

2. APPARATUS

2.1 A moisture curing room capable of maintaining a relative humidity of 95 to 100 per cent and a temperature of 22 to 25°C or suitable plastic bags to hold specimens and carriers in an airtight condition in a water bath as described in 2.2 below.

2.2 A suitable water bath with thermostatic control capable of maintaining a temperature of 22 to 25°C.

2.3 A balance to weigh up to 2 kg, accurate to 0,5 g.

2.4 A drying oven capable of maintaining temperatures of 71 ± 3°C and 110 ± 5°C.

2.5 A brushing apparatus of the type shown in Fig. 1 and complying with the following:

(a) Capable of rigidly holding a moulded Proctor (101,6 mm in diameter) or MOD AASHTO (152,4 mm in diameter) specimen and rotating it, under the prescribed load, at the rate of 60 ± 5 revolutions per minute around its longitudinal axis.

Automated Brushing Apparatus

(for durability testing of stabilized materials)

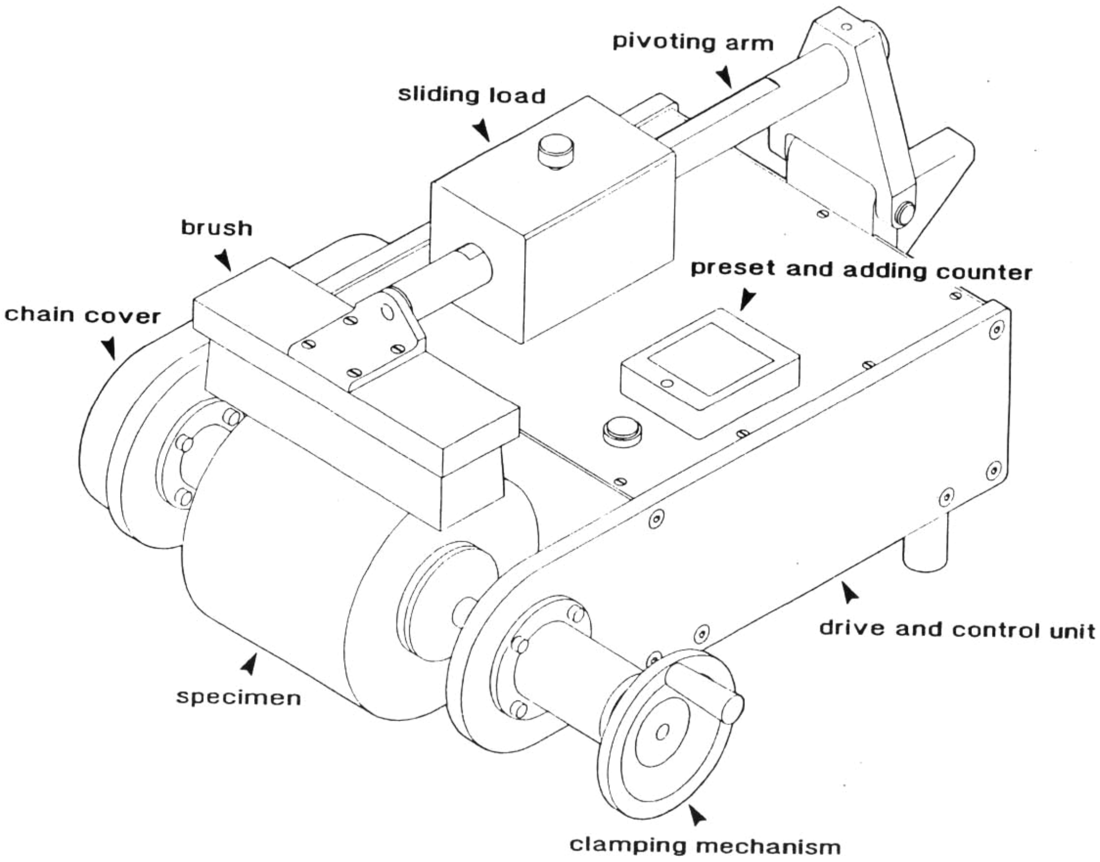


FIGURE 1

(b) Incorporating an electronic device for setting and controlling the number of revolutions.

(c) Having a wire brush that can be brought into contact with the specimen and loaded with 2,25 kg ± 0,05 kg. The brush shall be made of 40 mm x 1,8 mm x 0,5 mm spring steel bristles randomly assembled in 180 groups of 6 bristles and mounted on a 200 mm x 60 mm wooden block.

3. METHOD

3.1 Preparation of specimens

Prepare specimens in accordance with the procedure described in the Appendix to this method.

3.2 Curing of specimens

Cure the specimens for seven days at a relative humidity of 95 to 100 per cent and a temperature of 22 to 25°C in a suitable curing room or in plastic bags and a suitable water bath.

3.3 Wetting, drying and brushing

After seven days, remove the specimens from the curing room or plastic bags and submerge them in water at room temperature for a period of five hours.

Remove the specimens from the water and place them in an oven at 71°C for 42 hours.

Remove the specimens from the oven. Clamp the specimens securely between the pads of the brush machine specimen holder.

Lower the brush onto the specimen and switch on the machine, (brush load = 2,25 kg ± 0,05 kg; revolutions = 50).

The procedure described so far in this section constitutes one cycle (48 hours) of the wet-dry durability test. The specimens are again submerged in water and the procedure repeated for 12 cycles (see 5.2).

3.4 Determination of soil-cement losses

After 12 cycles, dry the specimens to constant mass at 110°C and weigh to determine the oven-dry mass of the specimens. The data collected will permit the calculation of the soil-cement losses of the specimens after the prescribed 12-cycle test.

4. CALCULATIONS

4.1 Calculate the soil-cement loss of the specimens as a percentage of the original oven-dry mass (as determined after moulding - see appendix) of the specimens as follows:

$$L = \frac{W - M}{W} \times 100$$

where

L = soil-cement loss (%)

W = original calculated oven-dry mass (g) (calculated according to 3,5 in the Appendix to the method).

M = final oven-dry mass (g).

4.2 The percentage loss shall be calculated to the nearest 0,1 per cent, and shall be reported to the nearest 0,1 per cent. These results are required for designing a mix and are reported graphically against cement content.

5. NOTES

5.1 Mass determination of the specimens before and after brushing are usually made at the end of each cycle during research or special investigations.

5.2 If is is not possible to run the cycles continuously because of Sundays or holidays or for any reason, the specimens should be held in the oven during the lay-over period.

5.3 The test was originally developed to determine the wet-dry durability of cement-treated material. It can, however, be used with equal success on material trested with other chemical stabilizers, for example lime, or mixes of lime and milled blastfurnace slag, or cement and milled blastfurnace slag.

Normally these stabilizing agents take more than seven days to produce strengths equivalent to that of cement. To obtain significant results it will therefore be necessary for each case first to determine the curing time that gives equivalent strengths, and then to adjust the curing time given in 3.2 accordingly.

REFERENCES

ASTM Designation D558-57 (AASHTO Designation T134-61)
ASTM Designation D559-57 (AASHTO Designation T135-57)

APPENDIX TO METHOD CA 15

PROCEDURE FOR THE MAKING OF SPECIMENS OF SOIL-CEMENT FOR THE WET-DRY DURABILITY TEST

1. APPARATUS

1.1 Proctor compaction

1.1.1 Compaction moulds 101,6 ± 0,5 mm in diameter and 116,4 ± 0,5 mm high with detachable collar and base plate with a hole 7 mm deep and 6 mm in diameter at its centre. If the non-split type mould similar to Fig A19/2 of TMH 1 is used, a suitable extruder will also be required to extrude the specimens from the moulds.

1.1.2 A 2,495 kg tamper with a 50,8 mm diameter face and a sheath to give a 304,8 mm drop.

1.1.3 to 1.1.17
As for Method A7, Subsections 2.3 to 2.17.

1.1.18 Filter paper, 100 mm rounds.

1.1.19 to 1.1.23
As for Method A7, Subsections 2.19 to 2.23.

1.1.24 Suitable carrier plates to hold specimens.

1.1.25 A cap made to the dimensions shown in Fig. 2, to fit over the tops of the moulds for the purpose of centering the specimens. (The dimensions given in Fig. 2 are only approximate measurements as these will vary according to the wall thicknesses of the various mould types.)

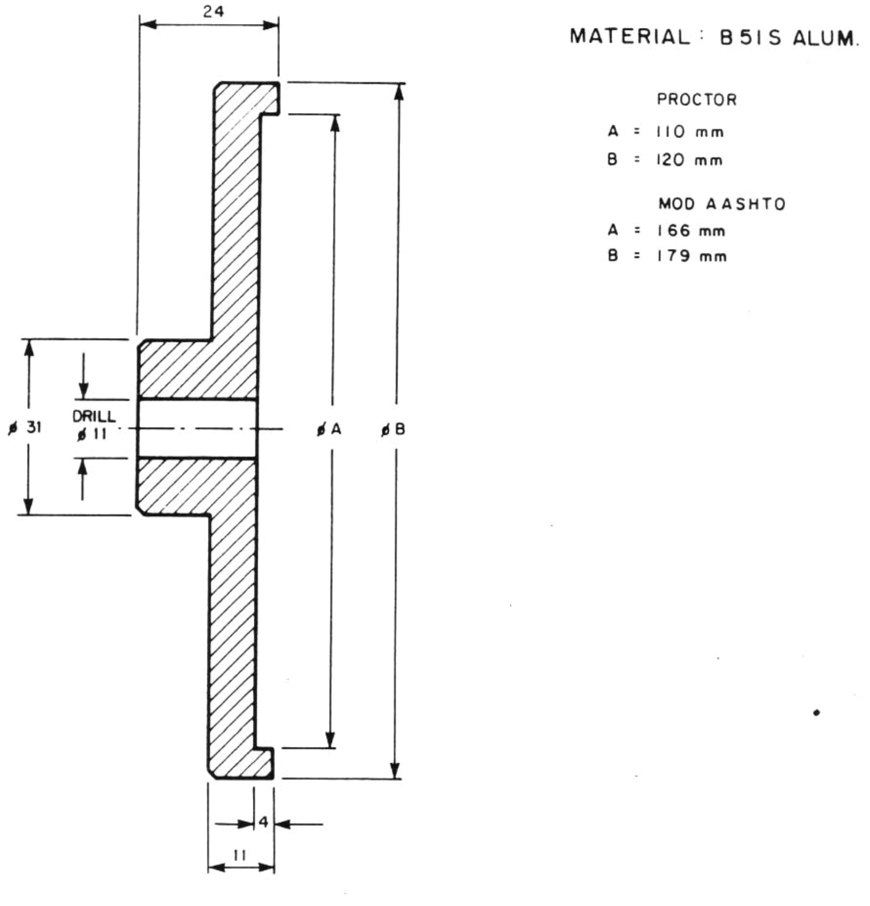

24
MATERIAL : B51S ALUM.
PROCTOR
A = 110 mm
B = 120 mm
MOD AASHTO
A = 166 mm
B = 179 mm
ø 31
DRILL
ø 11
ø A
ø B
4
11

FIGURE 2

1.1.26 A stud 11 mm in diameter to fit into the base-plate and a punch 70 mm long of the same diameter.

1.1.27 A small mallet or hammer.

1.2 Mod AASHTO compaction

1.2.1 Compaction moulds 152,4 ± 0,5 mm in diameter, 152,4 ± 1 mm high, with detachable collar and base plate and a 25,4 ± 1 mm thick spacer plate with a hole 7 mm deep and 6 mm in diameter at its centre. If the non-split type mould similar to Fig. A7/1 in TMH 1 is used, a suitable extruder will also be required to extrude the specimens from the moulds.

1.2.2 A 4,536 kg ± 20 g tamper with a 50,8 ± 1 mm diameter face and with a sheath to give a 457,2 ± 2 mm drop.

1.2.3 to 1.2.23
As for Method A7, Subsections 2.3 to 2.23.

1.2.24 Suitable carrier plates to hold specimens.

1.2.25 to 1.2.27
As for Proctor compaction.

2. PROCEDURE

2.1 Preparation

Prepare and quarter out five lots of about 3 kg each for Proctor compaction and 6,5 kg for Mod AASHTO compaction, as described in Method A7, Subsection 3.1.

2.2 Determination of hygroscopic moisture content

Two representative samples are now taken from the remaining material and placed in suitable containers to determine the moisture content. The sample should be between 500 and 1 000 g. The more coarsely graded the material, the larger the samples. The samples are weighed immediately, to 0,1 g, and dried to constant mass in an oven at 105 to 110°C. The average moisture content is determined to the nearest 0,1 per cent. Immediately after the moisture content samples have been taken the remaining material is transferred to airtight tins.

2.3 Determination of optimum moisture content (OMC) and maximum dry density (MDD) of stabilized material

Weigh out 4 per cent cement by mass of the air-dried raw material for each of the five lots as prepared in 2.1 above. Determine the OMC and MDD as follows:

2.3.1 Mixing

The cement should be admixed with the raw material immediately prior to the admixing of water. The procedure for the mixing in of water is described in Method A7, Subsection 3.2.

2.3.2 Preparation of the mould

As in Method A7, Subsection 3.3, except that the filter paper is used on the base plate.

2.3.3 Compaction

(a) Proctor. The moist material is now compacted in the mould, with the collar attached, in three equal layers, so as to give a total compacted depth of about 130 mm. Scarify the top of the first and second layers with a chisel or other tool to remove smooth compaction planes before placing and compacting the succeeding layer. Each layer is compacted with 25 blows from the tamper, uniformly distributed over its surface. When the tamper is raised, the operator should ensure that the sheath is resting on the soil and that the tamper is right at the top of the sheath before the tamper is dropped. The fall of the tamper should be perfectly free. The operator should also ensure that the tamping face of the tamper is kept clean and that a cake of material is not formed on the face.

(b) Mod AASHTO. The moist material is compacted into the mould in five equal layers, so as to give a total compacted depth of about 140 mm. Scarify the top of the layers with a chisel or other tool to remove smooth compaction planes before placing and compacting the succeeding layer. Each layer is compacted with 55 blows from the tamper. The blows must be distributed over the whole layer in five cycles of 11 blows each. In each cycle eight blows are applied to the outside circumference and three blows round the centre. When the tamper is raised the operator should ensure that the sheath is resting on the soil and that the tamper is right at the top of the sheath before the tamper is dropped. The fall of the tamper should be perfectly free. The operator should also ensure that the tamping face of the tamper is kept clean and that a cake of material is not formed on the face.

The compaction should be carried out on a firm base such as a concrete block weighing at least 100 kg with the base plate bolted onto it.

2.3.4 Determination of the moisture content

As described in Method A7, Subsection 3.5.

2.3.5 Removal of excess material

As described in Method A7, Subsection 3.6.

2.3.6 Weighing of mould

As described in Method A7, Subsection 3.7.

2.3.7 Establishing of additional points for the moisture-density relationship curve

As described in Method A7, Subsection 3.8.

2.3.8 Calculations

As described in Method A7, Subsection 4.

2.4 Making of specimens for the wet-dry durability test

Using the remaining air-dry material in the airtight tins (see 2.2) quarter out five similar lots of material of approximately 6 kg (oven-dry) each for Proctor compaction and 13 kg for Mod AASHTO compaction. For convenience, the mass of the five lots can be made the same by adding or scooping out some of the material so as to bring the mass of each lot to 6 kg oven-dry raw material (calculate the mass of air-dry material required for each lot by taking into account the moisture content of the air-dry material as determined on the samples in 2.2). Select five different cement contents at which the specimens for wet-dry durability tests are to be made. These are usually in increments of one percentage points, e.g. 4, 5, 6, 7 and 8 per cent by mass of the total oven-dry raw material (4 per cent means four parts cement to 100 parts oven-dry raw material).

Calculate and weigh out the five quantities of cement required for the above lots of raw material.

Calculate and measure out the required quantity of water to bring each lot to OMC. The quantity of water required is the difference between the quantity of water present in the air-dry material (as determined in 2.2) and the quantity of water required to obtain the OMC as determined in 2.3 above. Mix in cement and water and compact two specimens from each lot as described above.

Weigh the mould with the compacted specimens. Fit the cap described in Section 1.25 over the top of the mould and punch a hole approximately 10 mm deep into the centre of the specimen using the punch and hammer. Remove the specimens from the moulds either by dismantling the split moulds or, if the moulds are not of the split type, by extruding the specimens with the extrusion jack (see 4.2). The specimens are now placed on the carrier plates and are ready for curing.

3. CALCULATIONS

3.1 Moisture content (%)

$$d = \frac{a - b}{b - c} \times 100$$

where

d = moisture content expressed as a percentage of the dry material
a = mass of container and wet material (g)
b = mass of container and dry material (g)
c = mass of container only (g)

3.2 Mass of the air-dry material if the moisture content and mass of the oven-dry material are known:

$$M = \frac{W(100 + d)}{100}$$

where

W = mass of oven-dry material (g)
M = mass of air-dry material (g)
d = moisture content of air-dry material expressed as a percentage of oven-dry material.

3.3 Quantity of cement to be added for specimens

$$C = \frac{YW}{100}$$

where

C = mass of cement required (g)
Y = percentage of cement required
W = mass of oven-dry material (g).

3.4 Quantity of water to be admixed with the material for specimens

$$V = \frac{Q(P + C)}{100} - (M - P)$$

where

V = volume of water (ml)

Q = optimum moisture content

P = mass of material (oven-dry) to be used (g)

C = mass of cement to be added (g)

M = mass of material (air-dry) (g).

3.5 Oven-dry mass of specimens if the moisture content and the mass of the wet specimens are known

$$W = \frac{M - C}{100 + D} \times 100$$

where

W = oven-dry mass of specimen (g)

M = mass of mould and wet specimen (g)

C = mass of mould (g)

D = moisture content of wet specimen expressed as a percentage of oven-dry material.

3.6 Percentage of cement by volume

$$v = \frac{A.m}{B(100 + A)} \times 100$$

where

v = % cement by volume of the total stabilized material

A = % cement by mass of the total raw material (as obtained from graph of cement content against % loss after 12 cycles)

m = maximum dry density (kg/m^3) as determined in Subsection 2.3

B = density of cement (kg/m^3).

3.7 Accuracy of calculations

3.7.1 Moisture content: to the nearest 0,1 per cent.

3.7.2 Mass of oven-dry material if the moisture content and mass of air-dry material are known: to the nearest 1 g.

3.7.3 Quantity of cement to be added for specimens to the nearest 1 g.

3.7.4 Quantity of water to be admixed to the material for specimens: to the nearest 1 ml.

3.7.5 Oven-dry mass of specimens if the moisture content and the mass of the wet specimens are known: to the nearest 1 g.

3.7.6 Cement content: to the nearest 0,1 per cent (for volume as well as mass).

4. NOTES

4.1 In cases where the material contains soft and friable aggregate which will break up during compaction, e.g. certain types of ferricrete, calcrete, soft sandstone, etc. such aggregate should be disintegrated. In borderline cases, the operator should use his discretion, in regard to the extent to which particles should be disintegrated as well.

4.2 With certain materials lacking cohesion it may be necessary to leave the samples in their moulds for 24 hours to develop some strength before the moulds are removed. If this is necessary, the specimens in the moulds should be kept in the curing room or covered with damp hessian for 24 hours.

4.3 The procedure using Proctor compactive effort is intended only for finer materials with a low percentage of material greater than 4,75 mm. It is not possible to make satisfactory specimens of material with a high coarse aggregate content, such as crushed stone base-course material, owing to the low compaction effort and the size of the mould. Assessment of materials with high coarse aggregate contents should be done using Mod AASHTO moulds and compactive effort as described in Method A7 of TMH 1.

The determination of the residual, vacuum-carbonated unconfined compressive strength of stabilised soils, gravels and sands

Method A14 in TMH 1 is followed in full other than section 3.2 which is modified as described below. The method for vacuum-carbonation is adapted from the original CADS test proposed by De Wet and Taute (1985).

3.2 Curing of specimens

Cure the specimens for 7 days at a relative humidity of 95 - 100 per cent and a temperature of 22 - 25 °C in a suitable curing room or in plastic bags and a suitable water bath.

After 7 days remove the specimens from the curing room or plastic bags and seal in a vacuum dessicator or other appropriate vessel with free access to a source of carbon dioxide. Apply a vacuum of 80 kPa to the chamber for 10 minutes.

Close the valve through which the vacuum was applied and connect the CO_2 cylinder to either this or another valve if available on the chamber.

Open the CO_2 valve and slowly let CO_2 into the chamber until it is filled with CO_2. Close the valve and leave for 10 minutes.

Repeat the evacuation and carbonation procedures twice more and then evacuate once more.

Connect a hose from a bath of water to the valve and open the valve slowly to allow the vacuum to suck water into the chamber to saturate the specimen.

When the chamber is full, release the vacuum pump and open the chamber to remove the specimen(s) and conduct unconfined compressive strength test(s) according to 3.3.

DETERMINATION OF THE EROSION INDEX OF CEMENTITIOUS MATERIALS

CONTENTS

A.1 SCOPE

This method describes the procedures for determining the Erosion Index, L, of cementitious materials using the Erosion Test device in which water saturated beams of cementitious materials are tested under repetitive loading. This is known as the Erosion Test Method.

A.2 APPARATUS

A.2.1 Apparatus for soil preparation

A.2.1.1 Sieve 19 mm
A.2.1.2 Riffler with 25mm spacings, 800 mm long
A.2.1.3 Plastic bags (460 mm x 300 mm)
A.2.1.4 Plastic bags (900 mm x 550 mm)
A.2.1.5 Oven (0-200 C)
A.2.1.6 Aggregate crusher (to reduce aggregate to minus 19 mm)
A.2.1.7 Basins (400 mm x 125 mm deep)
A.2.1.8 Balance (0 - 10 kg)
A.2.1.9 Shovel

A.2.2 Apparatus for mixing of materials

A.2.2.1 History sheet (see Figure A1)
A.2.2.2 Basin (400 mm x 125 mm deep)
A.2.2.3 Scoop
A.2.2.4 Flask (500 ml)
A.2.2.5 Distilled water (+- 500 ml per specimen)
A.2.2.6 Balance (0 - 10 kg)
A.2.2.7 Plastic bags (460 mm x 300 mm)

A.2.3 Apparatus for production of specimens

A.2.3.1 Static loading facility (+- 275 kN) with minimum bottom plate dimensions of 200 mm x 500 mm

A.2.3.2 Compaction mould (see Photo Plates A1 and A2)

(i) Two side plates

(ii) Two end plates

(iii) Top and bottom plate

(iv) Four (4) high tensile steel rods 510 mm long with threaded ends, M17.

(v) Four (4) steel M17 nuts and washers

(vi) Metal bar (449.5 mm x 74.5 mm x 85 mm)

(vii) Two handling rods (120 mm x 5 mm diameter)

(viii) Metal spacer strips:

   (a) Two of 520 mm x 25 mm x 20 mm
   (b) Two of 520 mm x 25 mm x 10 mm
   (c) Two of 520 mm x 25 mm x 5 mm

(ix) Mould extension (see Photo Plate A3)

(x) Fibre based phenolic resin base plate (448.5 mm x 25.4mm x 74.5)

(xi) Four (4) rubber spacers (40 mm x 25 mm x 35 mm)

A.2.3.3 Vernier caliper (0 - 150 mm, in mm)

A.2.4 <u>Apparatus for accelerated curing</u>

A.2.4.1 Stainless steel container (460 mm x 80 mm x 120 mm)
A.2.4.2 Container cover with silicone rubber seal
A.2.4.3 Four (4) M5 wing nuts

A.2.5 <u>Apparatus for cutting specimen</u>

A.2.5.1 Water cooled diamond saw cutting facility

A.2.6 <u>Apparatus for mounting of specimen</u>

A.2.6.1 Stainless steel mounting tray (300 mm x 95 mm x 27 mm deep)
A.2.6.2 Tray extensions (75 mm high)
A.2.6.3 Two (2) clamps
A.2.6.4 Tray extension supports
A.2.6.5 Flask (2000 ml)
A.2.6.6 Spatula
A.2.6.7 Gypsum (Calcium sulphate, CaS0 1/2 H 0) approximately 1.25 kg for each specimen
A.2.6.8 Waterproof marking pen

A.2.7 Apparatus for Unconfined Compressive Strength (UCS)

A.2.7.1 Loading facility as in A.2.3.1

A.2.7.2 Vernier caliper (0 - 150 mm)

A.2.7.3 Test result form as in TMH1, method A14, form A14/1 (See also figure A5)

A.2.8 Apparatus for erosion testing

A.2.8.1 Erosion test device (see Photo Plate A4)
A.2.8.2 Neoprene rubber membrane (520 mm x 445 x 3 mm thick) (See Photo Plate A5)
A.2.8.3 Membrane retaining frame (see Photo Plate A4)

A.2.8.4 Six (six) stainless steel specimen tray clamps (flat plate 45 mm x 30 mm x 5 mm with 10.5 mm diameter hole at centre)

A.2.8.5 Four (4) clamps
A.2.8.6 Friction pads (one for each specimen)
A.2.8.7 Six (6) M10 stainless steel Allen screws 25 mm x 40 mm
A.2.8.8 M10 Allen key wrench

A.2.8.9 Three (3) spacers (perspex sheets 30 mm x 95 mm x 25 mm thick)

A.2.9 Apparatus for preparation of friction pads

A.2.9.1 Norton P80 Tuffback Durite wet of dry abrasive paper (280 mm x 230 mm)

A.2.9.2 Silicon Carbide Crystolon grit (crystals), 1 mm (16 mesh) (+- 30 grams for each friction pad of size 75 mm x 220 mm)

A.2.9.3 Pliobond (500 ml)
A.2.9.4 Acetone (500 ml)
A.2.9.5 Glass beaker (80 ml)
A.2.9.6 Glass beaker (400 ml)
A.2.9.7 Paint brush (25 mm)
A.2.9.8 Plastic bags (250 mm x 200 mm)
A.2.9.9. Clipboard and waste paper (300 mm x 250 mm)
A.3.0.0 Stanley trimmer knife
A.3.0.1 Stainless steel mounting tray (as in 2.6.1)
A.3.0.2 Steel rule (400 mm)
A.3.0.3 Scale (0 - 1 kg)

A.3 APPARATUS FOR MEASUREMENT OF DEPTH OF EROSION

A.3.1 Measuring jig (see Photo Plate A10 later on)
A.3.2 Vernier caliper (0 - 150 mm)
A.3.3 Erosion Test sheet (see Figure A3)
A.3.4 Balance (0 - 10 kg)
A.3.5 Phenolthalene (500 ml)
A.3.6 HCL (5N diluted, 500 ml)

A.4 METHOD FOR PREPARATION OF EROSION SPECIMENS

A.4.1 Soil preparation

Air dried material is treated in accordance with TMH1 method A7 to establish maximum dry density and optimum moisture content.

A.4.2 Mixing

A.4.2.1 The required mass of raw material (- 19 mm) as calculated from example shown in Section A.6 is placed in a large basin (400 mm x 125 mm deep)

A.4.2.2 Stablising material is added and thoroughly mixed with the dry raw material

A.4.2.3 The calculated quantity of distilled water is added while mixing thoroughly

A.4.2.4 The required mass of wet mixture is weighed out into a plastic bag, (mass of bag added) sealed, and left for 30 minutes

A.4.2.5 Material is remixed by manipulation, in situ, in the sealed bag

A.4.3 Compaction mould preparation

A.4.3.1 Semi-floating mould preparation:

(i) The clean mould is assembled and placed over the bottom plate which, with the use of four rubber spacers (each spacer 40 x 25 x 35 mm high compresses approximately by 16 mm at 2 kN load) placed between the mould and bottom plate at the four corners, allows the male portion of the bottom plate to enter the mould by +- 5 mm. See Photo Plate A6.

(ii) A 25.4 mm thick fabric-based fenolic resin specimen support plate (448.5 mm x 75 mm x 25.4 mm), mass previously recorded, is placed on top of the bottom plate to facilitate specimen handling on completion. Support plates are numbered and are used to identify specimens until they are mounted in trays. The numbered trays will then serve this function.

(iii) The inner surfaces of the mould and top and bottom plates are sprayed with a release agent (WD40). Excess release agent is mopped up with paper towelling. A mould extension is placed on top of the mould to facilitate placement of material.

A.4.3.2 Dynamic plus static mould preparation

Rubber spacers are not used. Preparation is identical to semi-floating in all other respects.

A.4.4 Compaction of the specimens

A.4.4.1 Static compaction

(1) The predetermined (as in Section A.6) mass of mixed material from the plastic bag is poured and spread evenly into the mould to fill it. If necessary, tamp the material with a spatula or use metal bar (449.5 x 74.5 x 85 mm) to settle it below the level of the extension. See Photo Plate A2 (b). Remove the extension from the mould.

(ii) Two metal spacer strips (as in Section A.2.3.2(viii)) 1 x 20 mm and 1 x 10 mm thick (total of 30 mm either side) are placed on top of the mould. The top plate is then positioned with the male portion entering the mould.

(iii) The mould assembly is positioned in the centre of the loading facility and the metal bar (as in Section 2.3.1 (vi)) placed on top to distribute the load to be applied.

A load of 20 kN is applied and released, then the 20 mm thick spacers between the mould and top plate are removed. A load of 90 kN is applied and released. The remaining metal and rubber spacers are removed. The mould should now be hanging on the specimen, supported only through friction between the specimen and the mould. The load is reapplied up to a maximum of 275 kN and cycled five times to attain maximum density. The mould is then removed and dismantled in Section A.4.5 (removal of specimen)

NOTE: It is unlikely that MDD (Max. Dry Density) will be attained by this compaction effort which is found to be less than the MDD attained by the AASHTO method (from which the required mass of material is calculated) However, should 100% MDD be attainable 25 mm thick spacers to compensate for the 25.4 mm thickness of the specimen support plate will need to be introduced to prevent the specimen being compressed to less than 75 mm thickness, i.e. more than 100% MDD (modified AASHTO)

A.4.4.2 Dynamic compaction (MOD. AASHTO)

After mixing, the required mass of material for the specimen is equally divided by mass into three separate plastic bags.

The compaction mould extension is marked at 14 positions 30 mm apart. See also Photo Plate A3 (a).

Using a MOD. AASHTO hammer, the specimen is compacted in three layers as follows:

(i) Material from one bag is evenly spread into the mould plus extension which is standing on a concrete floor.

(ii) The hammer is positioned at the first reference point against one side of the mould and allowed to fall freely from its maximum height. It is then moved to the next adjacent reference point. This process is repeated for all points (total 14) along this one side and is repeated along the opposite side.

Total blows on this first layer are now 28. A repeat on this layer is now done to give a total of 56 blows on this first layer.

(iii) The second and third layers are similarly treated. The mould extension is now removed, and the top plate placed on the mould with the male portion entering the mould. Spacers (1 x 20 and 1 x 5 mm thick) are placed between the mould and top plate.

(iv) The metal bar as in Section A.2.3.1 is placed on top and the whole unit positioned in the static loading facility and a maximum load of 275 kN is applied and cycled five times to obtain maximum density and an even surface on the specimen.

A.4.5 Removal and curing of specimen

For static compaction (A.4.4.1)

A.4.5.1 Support the compaction mould by introducing spacers between the mould and bottom plate. This is to prevent the sides of the mould from slipping down and possibly damaging the specimen when dismantling.

For dynamic compaction (A.4.4.2) no spacers are required.

A.4.5.2 The top plate is removed and mould dismantled by removing retaining bolts and tapping the end plates outwards. (The side plates of the mould must be held in position as they tend to separate from the specimen of their own accord when the end plates come free.) Remove side plates.

A.4.5.3 The exposed specimen resting on the support plate is removed as a unit and massed. The previously recorded mass of the support plate is subtracted and specimen mass and a mean of three measurements for length, width and height are recorded on specimen history sheet.

A.4.5.4 For normal curing, the specimen (still resting on support plate) is placed in the humidity room and protected by plastic sheeting placed over it.

A.4.5.5 For accelerated curing, the specimen (still resting on support plate) plus excess water (approximately 70 ml) is sealed in the stainless steel container as in Section A.2.4.1 (460 mm x 80 mm x 120 mm internal diameter) and placed in an oven at 70 - 75°C for a period of seven days.

See Photo Plate A7. All details of storage, date made, etc. are recorded on the specimen history sheet (see Figure A.1)

A.4.6 Erosion testing procedure

A.4.6.1 Preparation of test specimen (third point loading and/ erosion or UCS)

After the curing, as described in the previous section, the beam specimens (450 mm x 75 mm x 75 mm) are removed and allowed to cool slowly for approximately two to three hours.

If third point loading tests (Otte, 1972, 1978) are also to be done, the beam specimens (450 mm x 75 mm x 75 mm) are used for this purpose.

After the third point loading test, the larger piece of specimen is used for erosion testing. The smaller piece is cut into 75 mm cubes for soaked Unconfined Compressive Strength (UCS) testing. If only erosion testing is to be done, two equidistant pieces (leaving 270 mm centre portion for erosion specimen) are cut from the ends of the beam specimens and are used for UCS testing. See Photo Plates A8.

A.4.6.2 Moulding of erosion specimen with gypsum ($CaSO_4 1/2\ H_2O$)

Mix sufficient gypsum and water to ensure a creamy pourable mix (approximately 1.25 kg per specimen). Pour the mixture into a specimen tray plus extension and place the specimen equidistantly within the tray with the top of manufactured specimen uppermost. There should be sufficient mix so that the specimen will displace the mix to fully fill the tray and extension. If necessary, add extra mixture with a spatula to accomplish this. After the gypsum has set, remove the extensions and clean gypsum from sides of tray. Write the specimen number at the left-hand corner of any long side of tray using waterproof permanent ink. Submerge specimens in water and enter details (where stored, date mounted, etc.) on relevant specimen history sheet (see figure A1)

A.4.6.3 Preparation of the surface of erosion specimens

(i) Owing to the possible effects of carbonation (Netterberg, 1984) on the surface of the specimens (just prior to testing), the specimens are cut to the wanted thickness so as to remove the carbonated layer. Specimens may be cut to a thickness of 75 mm, 50 mm or 27 mm (measured from bottom of tray)

(ii) The specimens are cut with a diamond saw blade and water so that the cut surface is parallel to the bottom of the tray in which it is mounted. (See Photo Plate A9 (b))

NOTE: The particular field of interest being investigated will determine the cutting thickness, for example, if the surface of an in situ stabilised layer is carbonated, a block of cemented material is removed from the road and cut to produce erosion specimens of the required thickness leaving the carbonated surface intact so that the effects of carbonation on erosion can be studied.

(iii) Wash the surface of the specimens under running water to remove loose particles, then immerse in water until no further gain in mass is recorded (soaked) (typically overnight)

(iv) Remove excess water with a moist cloth and weigh the specimens.

(v) Test with phenolthalien and HCL reaction. (Carbonation Test, Netterberg, 1984)

(vi) Place erosion specimen in measuring jig, see Photo Plate A10 (use specimen number on tray as a reference point for subsequent measurements) and take the measurements at the preselected positions on the jig, using a Vernier Caliper.

Record all data on Erosion Test Sheet. (See Figure A.3)

A.4.6.6 Preparation of Erosion Test device

(i) Place three erosion specimens in erosion Test device, again using the specimen number as a reference point to ensure that specimens are always placed in the same relative position in the Erosion Test device.

NOTE: If specimens are cut to less than 75 mm, spacers under the specimen tray must be introduced so as to maintain a total height of approximately 75 mm

(ii) Tighten specimen tray retaining clamps.

(iii) Position neoprene rubber membrane and ensure that it is always used in the same relative position for the duration of the test.

(Ensure that friction pads are on the underside of the membrane). See also Photo Plate A5

(iv) Position retaining frame over the membrane and clamp at the four corners.

(v) Fill the test tray with water until it overflows at the elevated vents. Maintain a head of water by means of a tube connected to the water tap and placed in one of the vents.

(vi) Lower the three tracking (loading) wheels on to the membrane, set the counter at zero and start the Erosion Test device.

(vii) At the required number of erosion repetitions (Counter x 2) remove the erosion specimens and repeat from Section A.4.6.3 (iii) to (vi) without the need for soaking, leaving loose aggregate (4.75 mm) on the surface of the specimen.

NOTE: The required number of erosion repetitions to determine the Erosion Index, L, is 5 000. The Erosion Index, L, is defined as the average depth of erosion after 5 000 erosion load repetitions in the Erosion Test device, measured from 15 positions on the erosion specimen, using the measuring jig and Vernier caliper. For research purposes, the depth of erosion may be determined, if needed, after every 500 repetitions in order to obtain the rate of erosion in mm per erosion repetition.

A.5 PRODUCTION OF FRICTION PADS

In this section, the production of the friction pad used in the Erosion Test device, is described. The necessary apparatus for this production is listed in Section A.2.9

In this case the production of 30 friction pads is described, but the quantities listed can easily be adjusted for the production of different quantities of friction pads.

(1) Number ten sheets of Norton P80 Tuffback wet or dry abrasive paper (Item A.2.9.1 in Section A.2.9) from 1 to 10 and record the mass of each sheet.

(ii) Place piece of scrap paper in clipboard and clamp a sheet of abrasive paper by its very edge with the abrasive surface uppermost.

(iii) Pour entire 500 ml of pliobond into a plastic bag and tie up the open end with a rubber band to completely seal the bag. Invert the bag and cut off one corner to make a small aperture. Stand in a suitable container to keep upright and prevent leaking.

(iv) Pour approximately 200 ml acetone into the 400 ml beaker and stand the brush therein.

(v) Place clipboard on a balance, note mass, and from the plastic bag squeeze approximately 23 grams of pliobond on to the abrasive paper. Using the paintbrush, quickly spread evenly over the entire surface and, replace brush in beaker with acetone.

(vi) Without delay, dump an excess of Crystolon crystals (Item A.2.9.2) on to the prepared surface, and using the specimen tray (Item A.2.6.1.), firmly bed the grit on to the prepared surface.

(vii) Remove the scrap paper, together with the abrasive paper and excess grit, and place to one side. Repeat the process, making a total of four. The first one should now be dry enough to recover the excess of grit by tipping it on its side. This excess (loose) grit is added to the supply to be used in making further pads.

When number five is made, recover grit from number two etc. On completion of the ten pads, they are left for 24 hours to cure.

(viii) Each pad is now firmly rubbed with the palm of the hand to dislodge any loose particles. A distinct difference between a loose or firm surface can be felt. Shake the pad to remove the loose grit and record the mass of the coated pad.

(ix) Subtract the uncoated mass from the coated mass to establish the mass of the grit retained. Should this be greater than 145 g, rub the coated surface with a rubber pad to reduce the grit mass to 145 g, if possible.

(x) Place 30 ml pliobond and 30 ml acetone into the 80 ml beaker to dilute the pliobond. Use the paintbrush for mixing. Pour 50 ml of the mixture on to the pad and with the paintbrush distribute the mixture to evenly cover the surface. Should it be necessary, use part of or all of the remaining 10 ml mix. Place the pad aside and make a new mix in the same proportions, e.g. if only 50 ml was used, fill to 35 ml mark with pliobond and to 60 ml mark with acetone, i.e. 25 ml pliobond and 25 ml acetone added to the 10 ml remainder. After treating all ten pads, cure them in the sun for two hours and then in an oven at 70°C for one hour.

(xi) Mark off the pads in 70 mm widths across the 230 mm width of pad and score heavily from the underside with the steel rule and Stanley knife. The individual widths can now be pulled apart to form three pads of 70 mm x 280 mm. The mass of each pad should be 55 g, plus or minus 5 g (50 g - 60 g).

A.6 CALCULATIONS

A.6.1 Determination of the wet mass required for a target relatively modified AASHTO density.

(i) List of symbols:

MDD = Maximum dry density of stabilized material (modified AASHTO compaction)

OMC = Optimum moisture content of stabilized material (TMH1 method A14)

C = Percentage stabilizer required according to TMH1 method A14 or based on experience, durability requirements or economical factors

V = Volume of specimen = 450 mm x 75 mm x 75 mm

M1 = Mass of dry raw material, at density k(%) in grams

M2 = Mass of dry raw material plus excess dry raw material, in grams

M3 = Mass of dry raw material (M2), plus mass of stabilizer total, in grams

M4 = Mass of total wet mix, in grams

k = Percentage relative density (AASHTO) (%)

M5 = Mass of wet mix required at k density, in grams

(ii) Formulae:

M1 = $\frac{MDD \times V \times k \times 1000}{(1 + C/100)}$ A.1
M2 = M1 + 200 ...
(Excess of 200 g dry raw material) A.2
M3 = $M2\ (1 + C/100)$...................... A.3
M4 = $M3\ (1 + OMC/100)$.................... A.4
M5 = $k(MDD \times (100 + OMC) \times V)) \times 10$........ A.5

A.6.2 Example calculation

Calculate the mass of materials required for an erosion specimen comprising soil and four per cent cement, where

MDD = 2025 kg/m^3
OMC = 9.2 per cent
C = 4 per cent
k = 95/100 (95% Mod.AASHTO required density)

(i) Mass of dry raw material, in situ compaction; 95% Mod. AASHTO, M1

$$= \frac{\text{MDD} \times V \times k \times 100}{(1 + C/100)}$$

$$= \frac{2025 \times 0.450 \times (0.075)^2 \times 0.95 \times 1000}{(1 + 4/100)}$$

$= 4682$ grams

(ii) Add 200 grams for excess: $M2 = M1 + 200$
$= 4682 + 200$
$= 4882$ grams

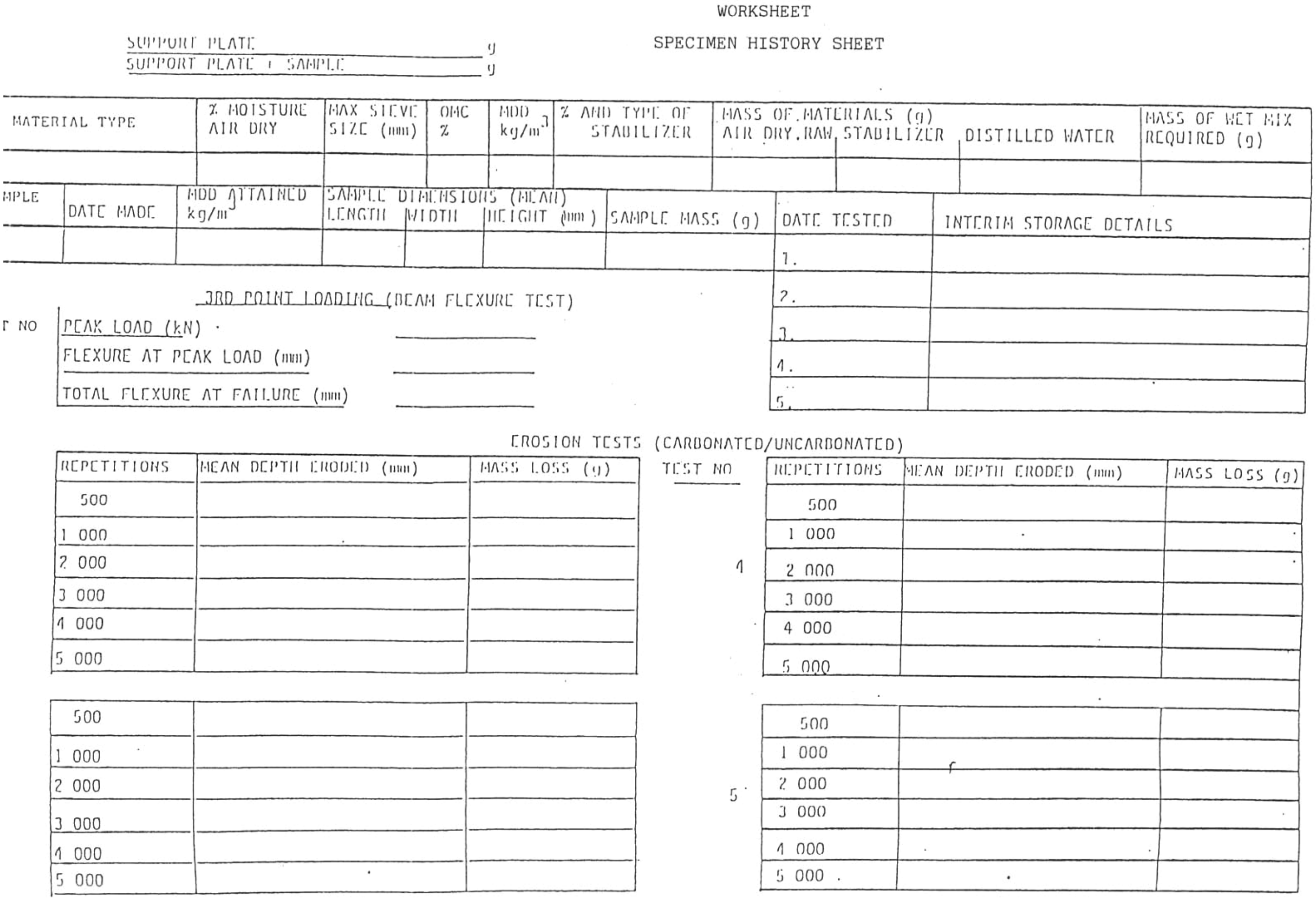
(iii) Add mass of 4 per cent cement: $M3 = M2\ (1 + C/100)$
$= 4882\ (1 + 4/100)$
$= 5077$ grams

(iv) Add mass of OMC: $M4 = M3\ (1 + \text{OMC}/100)$
$= 5077\ (1 + 9.2/100)$
$= 5544$ grams

(v) Mass of wet mix required:

$M5 = k\ (\text{MDD} \times (100 + \text{OMC}) \times V) \times 10$
$M5 = 0.95\ (2025 \times (100 + 9.2) \times 0.450 \times (0.075)^2)) \times 10$
$M5 = 5317$ grams

In order to obtain an erosion specimen at a target density of 95 per cent of modified AASHTO and 4% cement, 5317 grams of wet mix (soil, cement and water) must be compacted in a beam specimen of the dimension 450 mm x 75 mm x 75 mm, using dynamic or static, or both methods of compaction.



WORKSHEET

SPECIMEN HISTORY SHEET

SUPPORT PLATE ________________ g
SUPPORT PLATE + SAMPLE ________________ g

MATERIAL TYPE	% MOISTURE AIR DRY	MAX SIEVE SIZE (mm)	OMC %	MDD kg/m^3	% AND TYPE OF STABILIZER	MASS OF MATERIALS (g) AIR DRY, RAW	STABILIZER	DISTILLED WATER	MASS OF WET MIX REQUIRED (g)

MPLE	DATE MADE	MDD ATTAINED kg/m^3	SAMPLE DIMENSIONS (MEAN) LENGTH	WIDTH	HEIGHT (mm)	SAMPLE MASS (g)	DATE TESTED	INTERIM STORAGE DETAILS
							1.	
							2.	
							3.	
							4.	
							5.	

3RD POINT LOADING (BEAM FLEXURE TEST)

T NO

PEAK LOAD (kN) __________
FLEXURE AT PEAK LOAD (mm) __________
TOTAL FLEXURE AT FAILURE (mm) __________

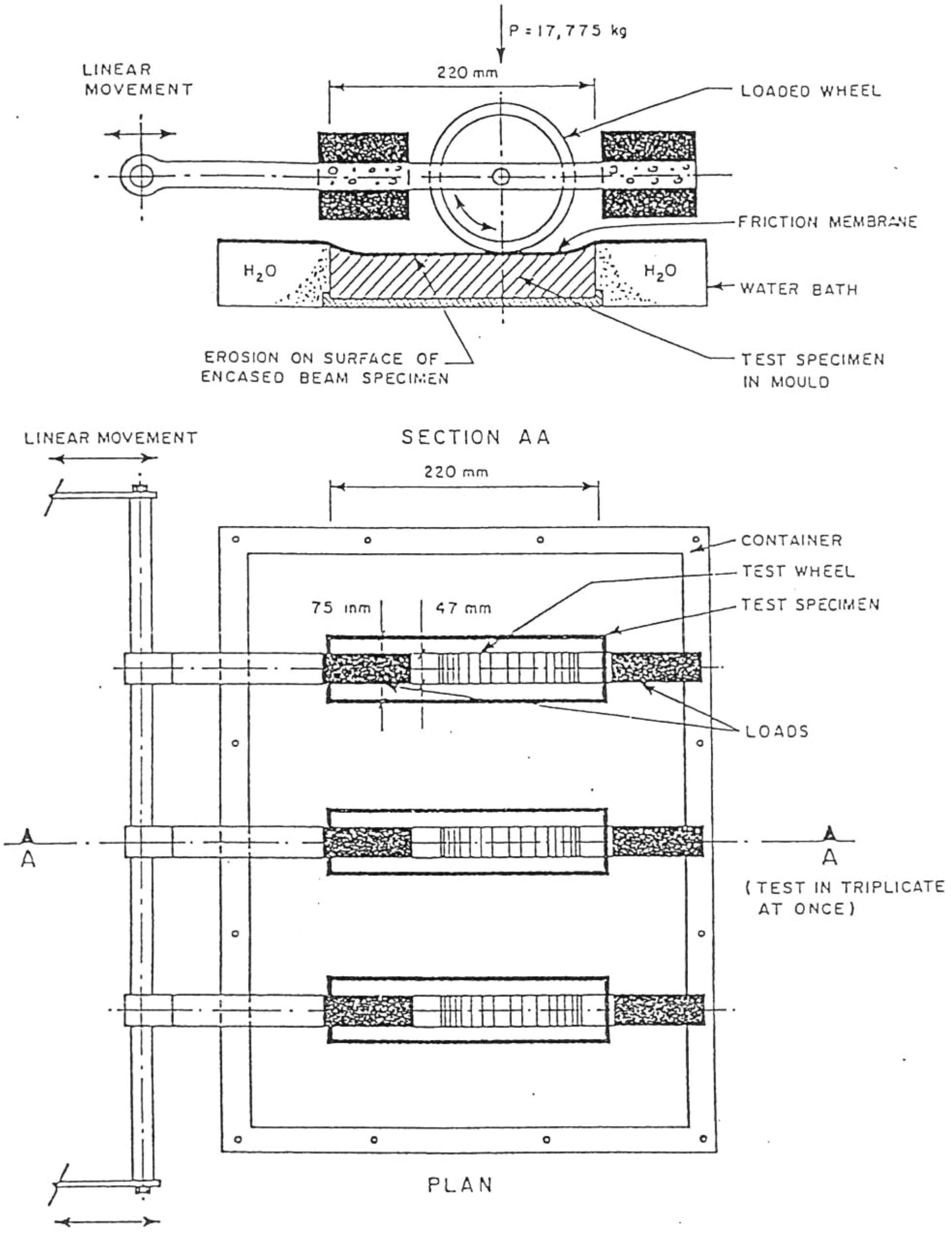
EROSION TESTS (CARBONATED/UNCARBONATED)

REPETITIONS	MEAN DEPTH ERODED (mm)	MASS LOSS (g)
500		
1 000		
2 000		
3 000		
4 000		
5 000		

500		
1 000		
2 000		
3 000		
4 000		
5 000		

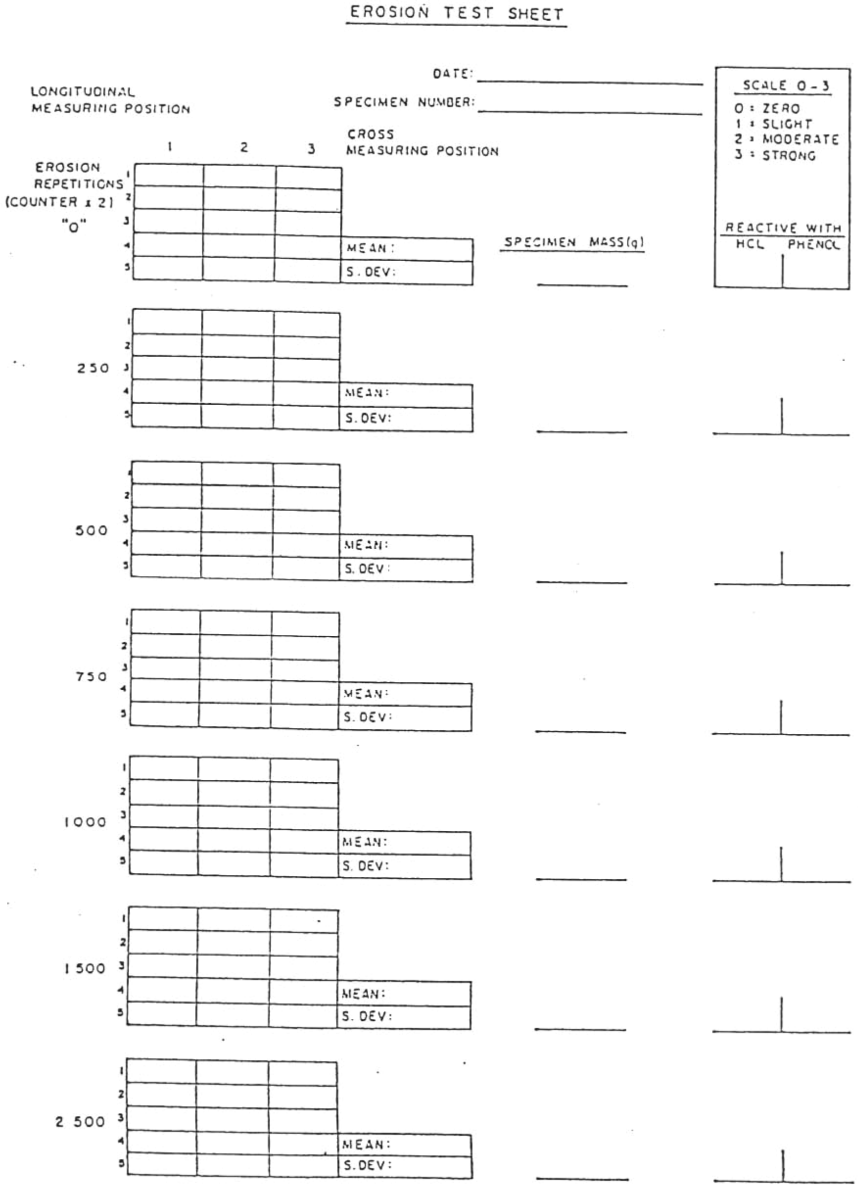
TEST NO	REPETITIONS	MEAN DEPTH ERODED (mm)	MASS LOSS (g)
	500		
	1 000		
4	2 000		
	3 000		
	4 000		
	5 000		
	500		
	1 000		
5	2 000		
	3 000		
	4 000		
	5 000		

Figure A.1



SCHEMATIC DIAGRAM OF THE EROSION TEST DEVICE (ET)

Figure A.2



EROSION TEST SHEET

DATE: ____________

SPECIMEN NUMBER: ____________

LONGITUDINAL MEASURING POSITION

CROSS MEASURING POSITION

SCALE 0 - 3
0 = ZERO
1 = SLIGHT
2 = MODERATE
3 = STRONG

EROSION REPETITIONS (COUNTER x 2)		1	2	3		SPECIMEN MASS(g)	REACTIVE WITH HCL	REACTIVE WITH PHENOL
"0"	1							
	2							
	3							
	4				MEAN:			
	5				S. DEV:			
250	1							
	2							
	3							
	4				MEAN:			
	5				S. DEV:			
500	1							
	2							
	3							
	4				MEAN:			
	5				S. DEV:			
750	1							
	2							
	3							
	4				MEAN:			
	5				S. DEV:			
1000	1							
	2							
	3							
	4				MEAN:			
	5				S. DEV:			
1 500	1							
	2							
	3							
	4				MEAN:			
	5				S. DEV:			
2 500	1							
	2							
	3							
	4				MEAN:			
	5				S. DEV:			

DATA SHEET FOR EROSION TEST RESULTS

Figure A.3

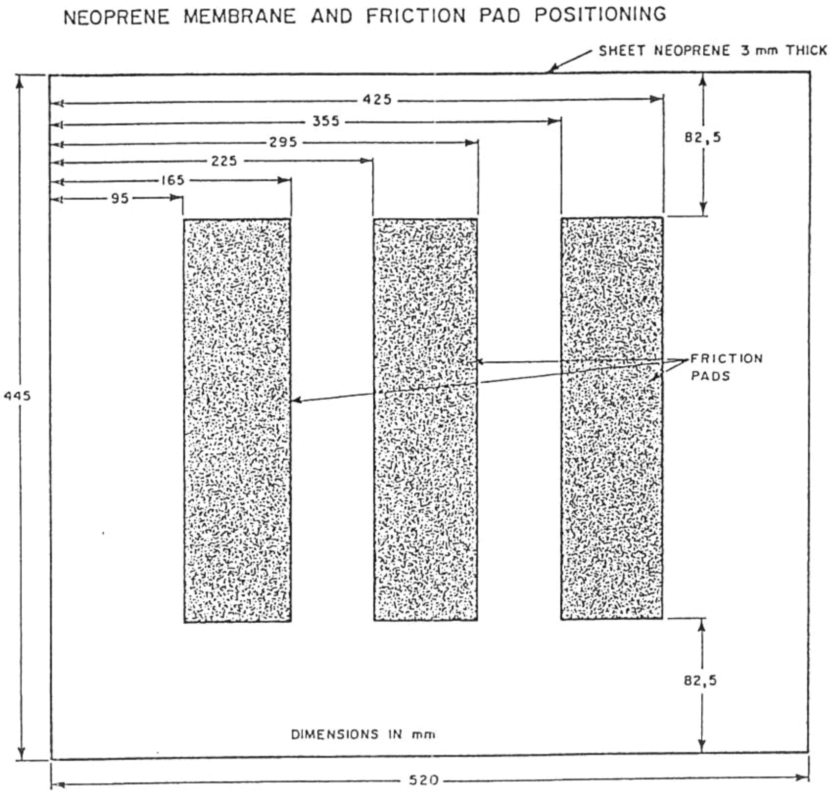
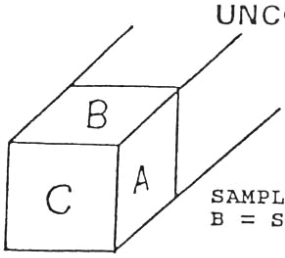

NEOPRENE MEMBRANE AND FRICTION PAD POSITIONING
SHEET NEOPRENE 3 mm THICK
425
355
295
225
165
95
82,5
FRICTION PADS
445
82,5
DIMENSIONS IN mm
520

Figure A.4

UNCONFINED COMPRESSIVE STRENGTH
WORKSHEET



SAMPLE AS MADE
B = SURFACE

________________________ DATE: ________________

P

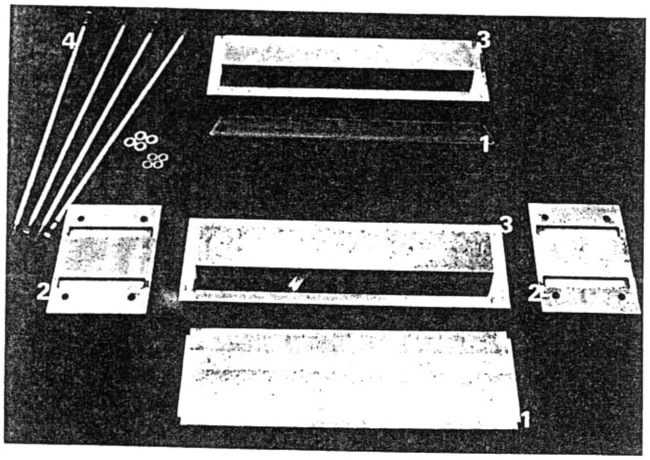
SAMPLE NUMBER		A	B	C	NEWTONS	MPa	REMARKS
	1						
	2						
	1						
	2						
	1						
	2						

	1						
	2						
	1						
	2						
	1						
	2						

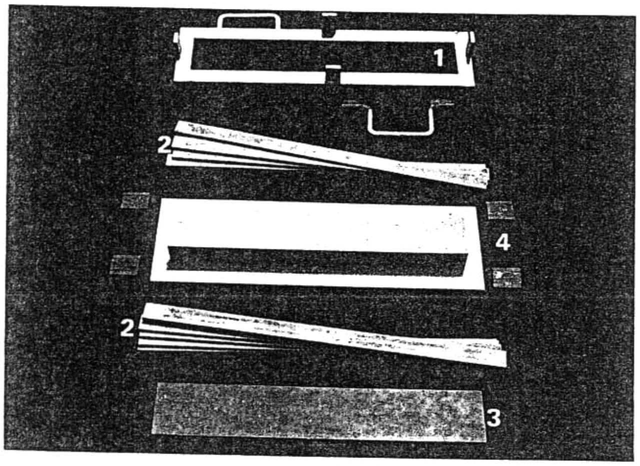
	1						
	2						
	1						
	2						
	1						
	2						

Figure A.5

A.8 PHOTO PLATES OF EROSION TEST DEVICE AND ACCESORIES

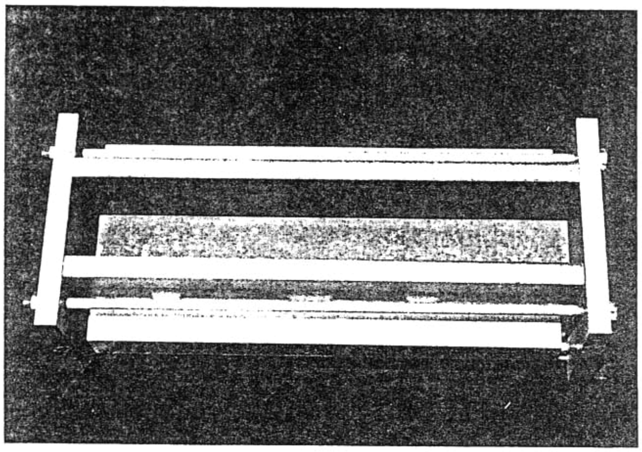


(a) Layout of the compaction mould: two side plates (1); two end plates (2); top and bottom plate (3); high tensile steel rods (4)

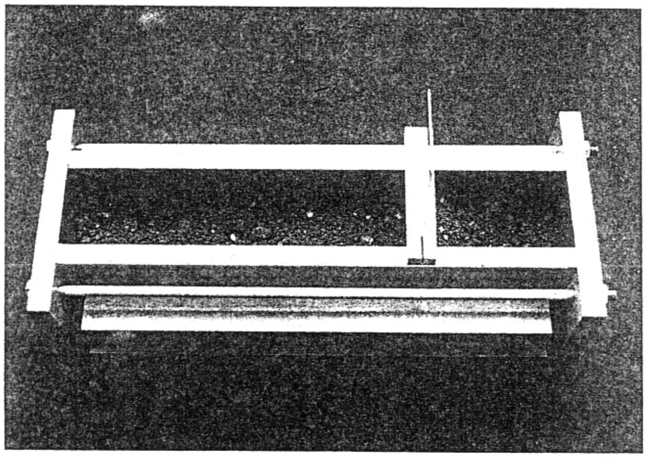


(b) Layout of the extention (1); metal space bars (2); phenol resin base plate (3) and rubber blocks (4) to be used in conjunction with the compaction mould in (a).

PLATE A1: COMPACTION MOULD AND ACCESSORIES.

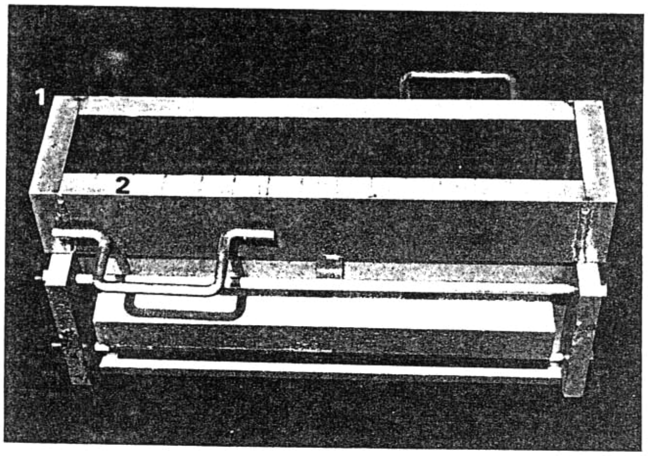


(a) Compaction mould with base plate in position.

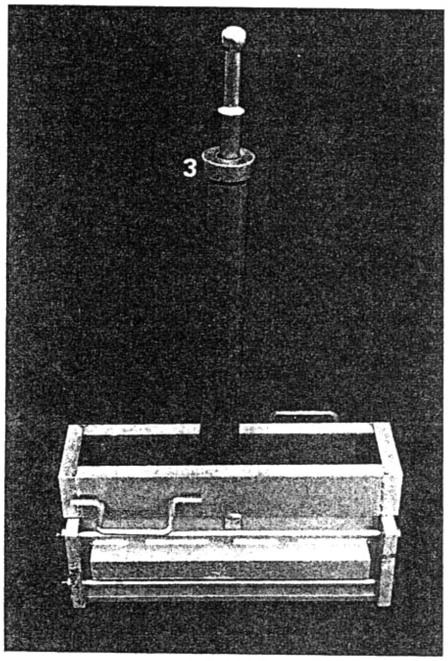


(b) Compaction mould with loose cementitious soil and spatula.

PLATE A2: ASSEMBLED COMPACTION MOULD.

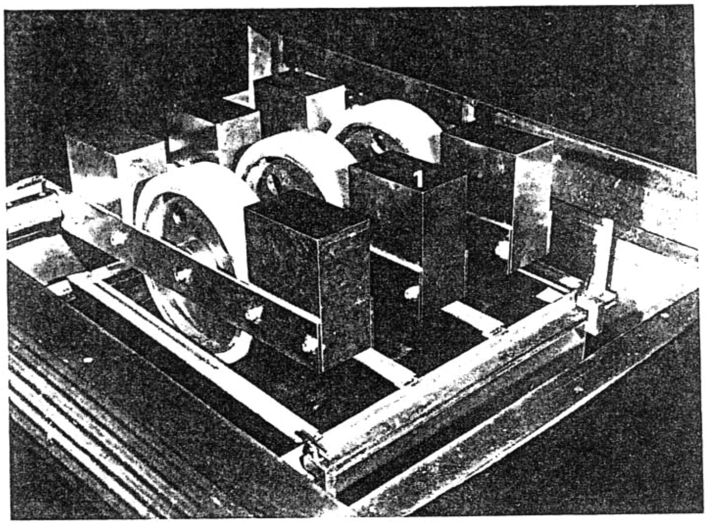


(a) Compaction Mould with extention (1) needed for dynamic compaction at predetermined positions for compaction hammer, (2) on the extention.

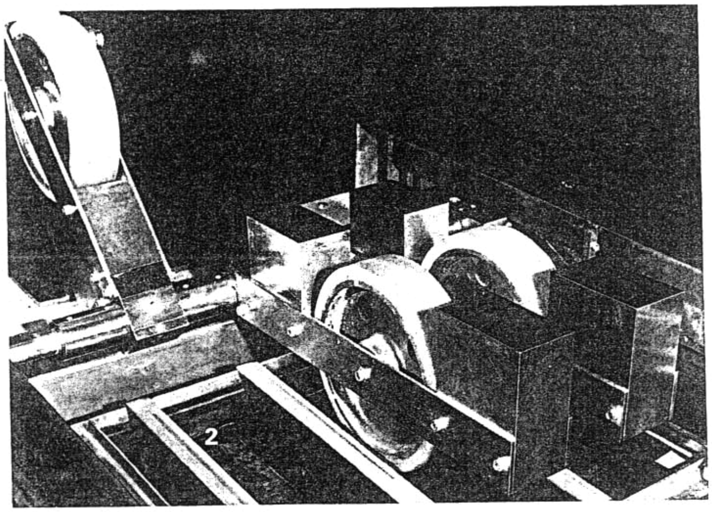


(b) Dynamic compaction using a Modified AASHTO hammer (3).

PLATE A3: COMPACTION MOULD WITH EXTENTION AND MODIFIED AASHTO HAMMER.

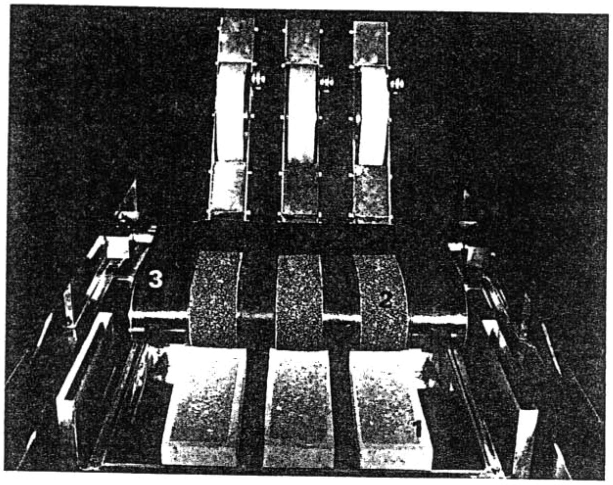


(a) Erosion Test device – with the three lineary driven loaded wheels (1) in position.

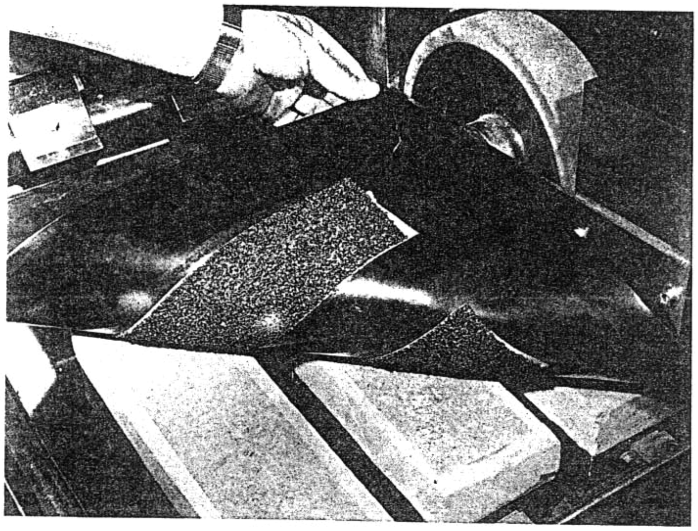


(b) Erosion Test device. Note the black neoprene flexible membrane (2) under the wheels.

PLATE A4: EROSION TEST DEVICE.

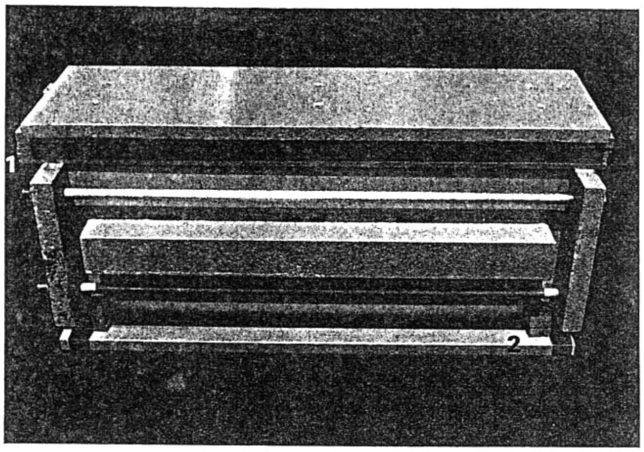


(a) Erosion Test device with three prepared specimens (1) in test position. Note also the friction pads (2) glued onto the black flexible neoprene membrane (3).

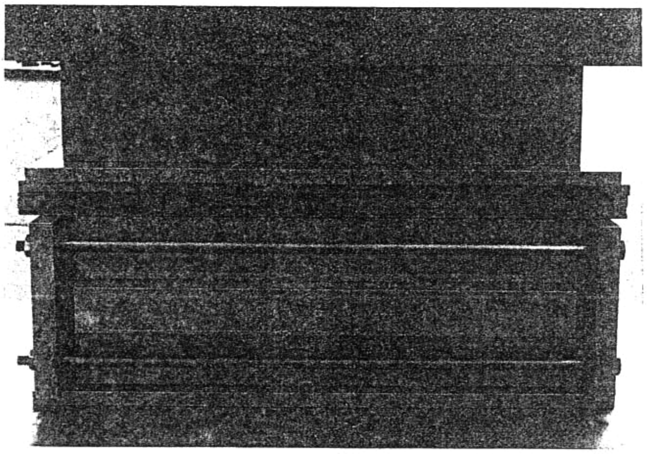


(b) Close view of the friction pads. (Two wheels are in the unload position.)

PLATE A5: FRICTION PAD WITHIN THE EROSION TEST DEVICE.

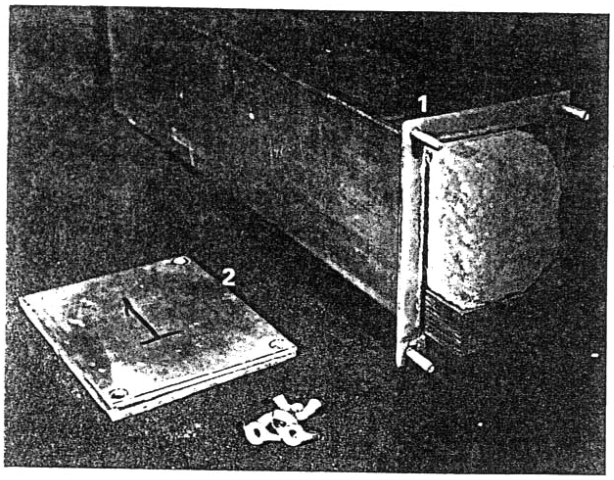


(a) Compaction mould with metal bars (1) and rubber blocks (2) used during static compaction.

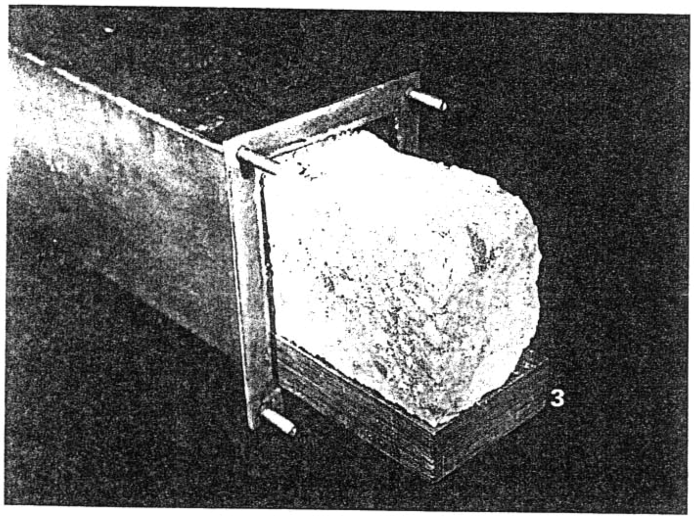


(b) Setup for static compaction in loading facility.

PLATE A6: STATIC COMPACTION OF EROSION BEAM SPECIMEN.

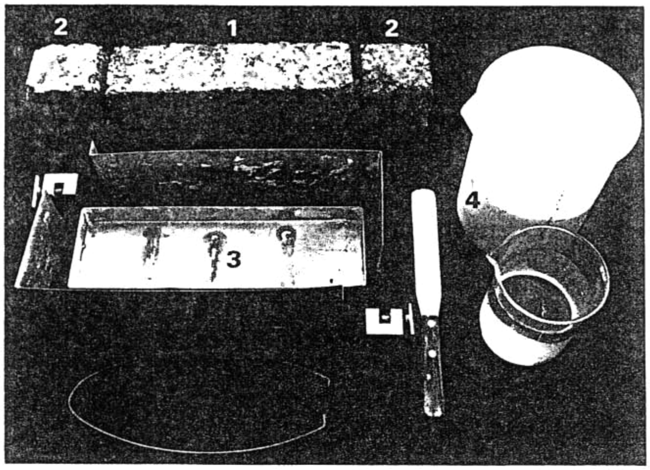


(a) Curing chamber (1) with air tight seal cap (2).

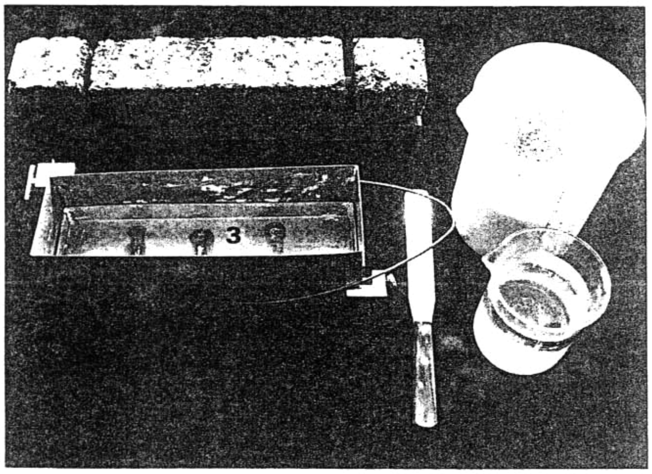


(b) Specimen on fabric based phenol resin base plate (3) in the curing chamber.

PLATE A7: CURING CHAMBER FOR CURING OF THE EROSION SPECIMEN.

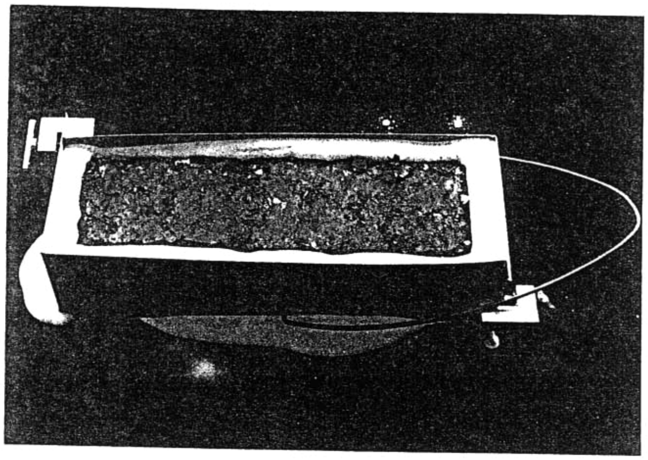


(a) Erosion specimen (1); two UCS specimens (2) and the apparatus for moulding the specimen with gypsum (3).

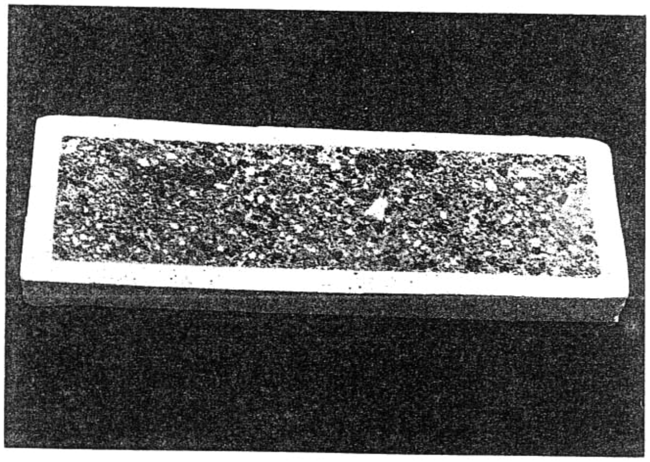


(b) Assembled moulding apparatus (3).

PLATE A8: MOULDING OF EROSION SPECIMEN WITH GYPSUM.

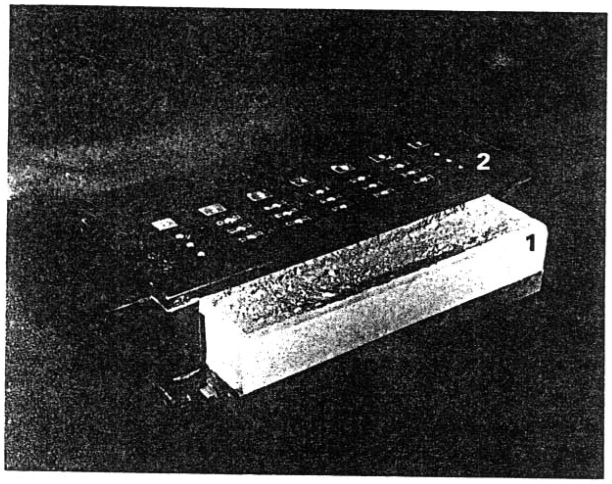


(a) Moulded erosion specimen.

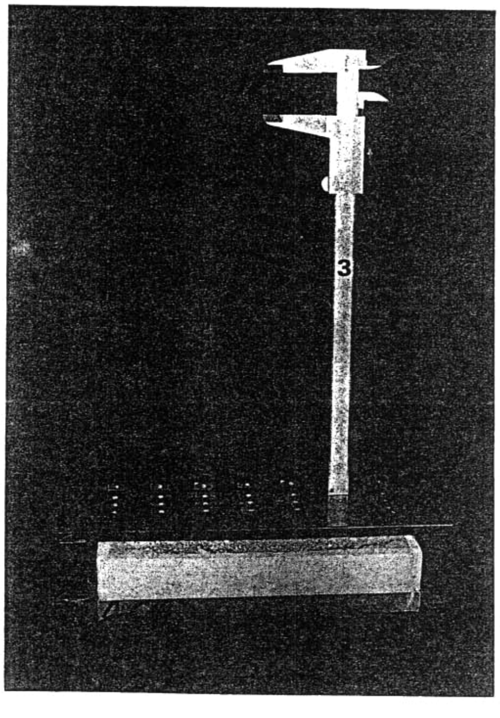


(b) Saw cut prepared erosion specimen ready for erosion testing.

PLATE A9: MOULDED AND SAW CUT PREPARED EROSION SPECIMEN.

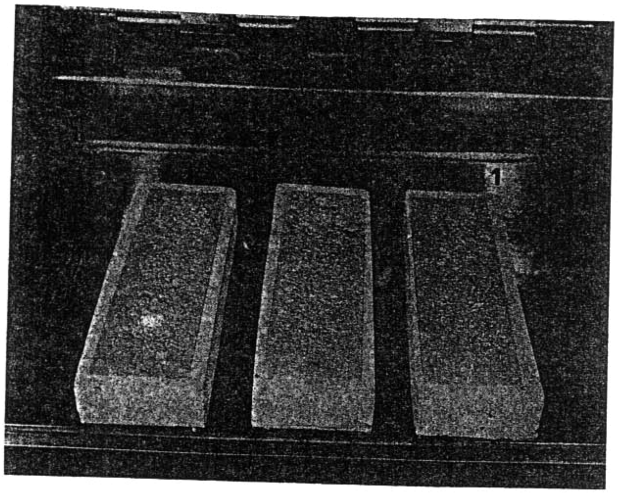


(a) Erosion specimen (1) in the meauring jig (2) in order to measure the depth of erosion on the surface of the specimen.

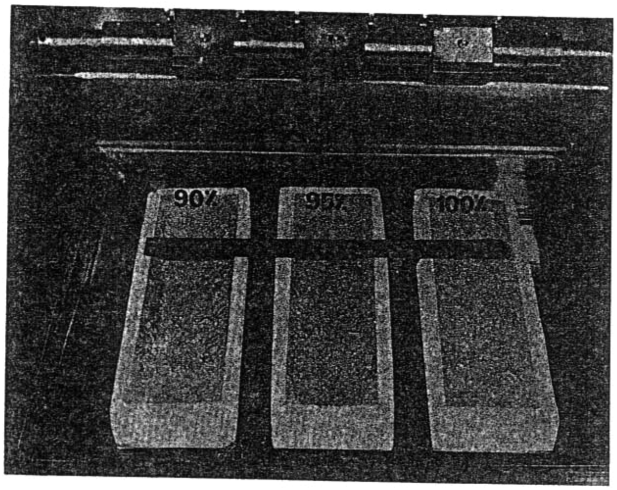


(b) Vernier caliper (3) for measuring the depth of erosion on the fifteen (15) fixed positions on the erosion specimen.

PLATE A10: MEASUREMENT OF THE DEPTH OF EROSION.



(a) Three erosion specimens in position in the water bath (1) (without water) of the Erosion Test device, before testing.



(b) Three erosion specimens after testing. The three specimens were compacted at different relative modified AASHTO compaction densities ie 90%, 95% and 100%. Note the difference in depth of erosion on the surface of these specimens.

PLATE A11: EROSION TEST SPECIMENS IN EROSION TEST DEVICE BEFORE AND AFTER TESTING.