DEVELOPMENT OF A TEST METHOD TO IDENTIFY EROSION CHARACTERISTICS

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ABSTRACT

Erosion of the sub-base material in concrete pavements leads to a loss in slab support and thus cracking of the concrete slab itself. This occurrence is indicated when pumping occurs at the joints in the concrete slab and needs to be predicted in the design stage. Current test methods used to evaluate erosion and durability properties, such as the wet and dry durability test takes weeks to conclude and are highly influenced by human factors. This paper describes the design and construction of a Rotational Shear Device (RSD) that can be used to identify erosion characteristics of sub base materials. Results from a series of tests are presented that indicate a potential benefit in the characterisation of erosion properties of sub base materials.

1 INTRODUCTION

When considering the design of a rigid pavement, erosion under a concrete slab and material resilience to erosion can be difficult to predict. Currently the wet and dry durability test, TMH1 (1986) Method A19, is used to determine the weathering and wearing that material can withstand. However, this method has flaws that researchers and engineers generally perceive as troublesome:

- Results are only available after 8 weeks due to the extended curing and testing period required.
- The human factor influencing the amount of pressure that is applied to the brush differs from material tester to material tester. This is cause for concern as one sample tested by two different material testers will potentially have two different results.

The concept of the Rotational Shear Device (RSD), which accurately predicts material erosion within a short testing time, was first reported by Moore & Masch (1962). The RSD exerts a shear force on a soil sample that is caused by water around the sample – simulating what happens in practice under a rigid pavement. The sample is placed in a cylindrical container which is then filled with water. The cylinder is rotated at a high speed, but the sample is prevented from rotating. This allows for a shear force to be exerted onto the soil sample.

Figure 1 shows a schematic layout of the RSD as used by Van Wijk (1985). Van Wijk tested samples 102 mm in diameter, 117 mm in height and limited the maximum aggregate size in the samples to 9.5 mm. Samples were tested at rotational speeds of between 300 and 3000 revolutions per minute (rpm). The angular spacing between the sample and the inside of the container varied between 9.5, 13 and 16 mm. Shear stress applied to the sample was measured at less than 35 Pa.

Ras (2004 and 2006) commissioned a RSD similar to the one used by Van Wijk (1985). Different rotational speeds were also investigated, but limited the maximum speed to 1700 rpm due to limitations of the particular experimental setup. Shear stresses up to 15 Pa were measured (Ras, 2004) It was noted that the shear stress seemed to be a function of rotational speed, with little influence caused by sample roughness. In a subsequent study (Ras, 2006) much lower shear stresses (less than 0.2 Pa) were measured. In all the tests performed the rotational speeds, and time of testing, were varied during the testing of a particular sample. A test protocol proposed included testing at 1 750 rpm for 90 minutes.

Currently the focus is on standardising the test method to produce a test that could practically be implemented in the industry, and which designers can use to predict a material’s ability to withstand erosion. This paper describes the design and commissioning of a robust RSD to characterise the durability properties of a material. The refinement of a test protocol is described, and initial test results confirming the appropriateness of the test are provided.

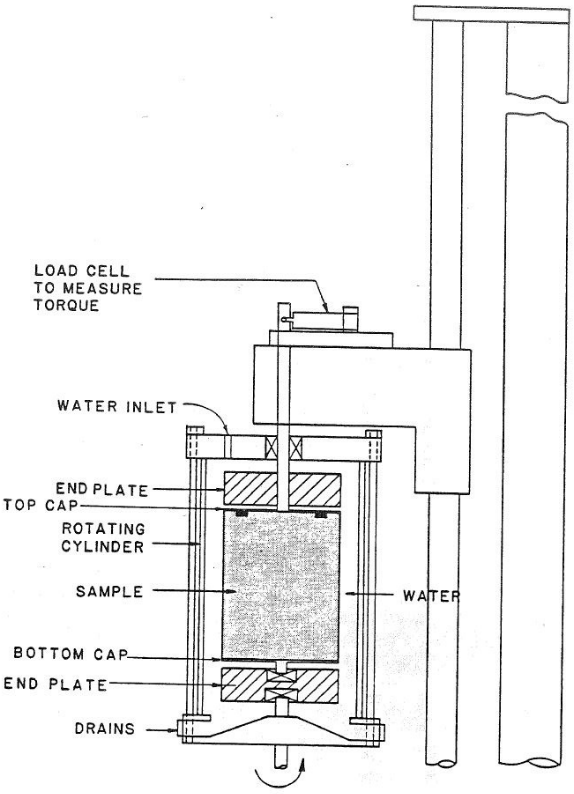

Figure 1: The concept of a Rotational Shear Device (Van Wijk, 1985)

2 DESIGN AND CONSTRUCTION OF THE RSD

The current RSD design, shown in Figure 2 was mainly based on the design by Ras (2004). A compacted sample of 101 mm in diameter and 117 mm in height was used in conjunction with a 9.5 mm annular spacing between the sample and the inner shell of the container. Improvements incorporated in the new RSD include the following:

- The drains from the bottom disk were removed as leakages were experienced at high rotational speeds and the eroded material clogged the drains.
- A three-phase motor was fitted to the RSD to improve speed control which can be electronically regulated by an inverter.
- In order to increase the rotational speed of the RSD, a pulley system was introduced allowing the system to produce rotational speeds of up to 3 000 rpm. However, a speed of 1 500 rpm was chosen to ensure a safe and comfortable working environment.
- A stabilising arm was added as a support structure to prevent the spinning container from becoming unstable at higher rotational speeds.
- A thrust bearing was fitted at the top axle to provide an axial force to prevent the sample from slipping. A thrust bearing was chosen as it exerts a negligible torque reaction onto the sample. Previously a spring was used between the top cap and disk. The spring itself added additional torque onto the axle as it connected the top disk and top cap, resisting the differential movement.
- Instead of using a system of strain gauges, a torque transducer was installed to measure the torque on the axle which can be related to the shear force on the sample. The torque transducer can measure a torque range between 0 and 1.2 N.m.
- A computer controlled data acquisition system was added to not only allow the precise control of the testing speed, but also capture time, speed and torque data at a frequency of up to 49 KHz.
- A screen was mounted around the RSD to improve safety.

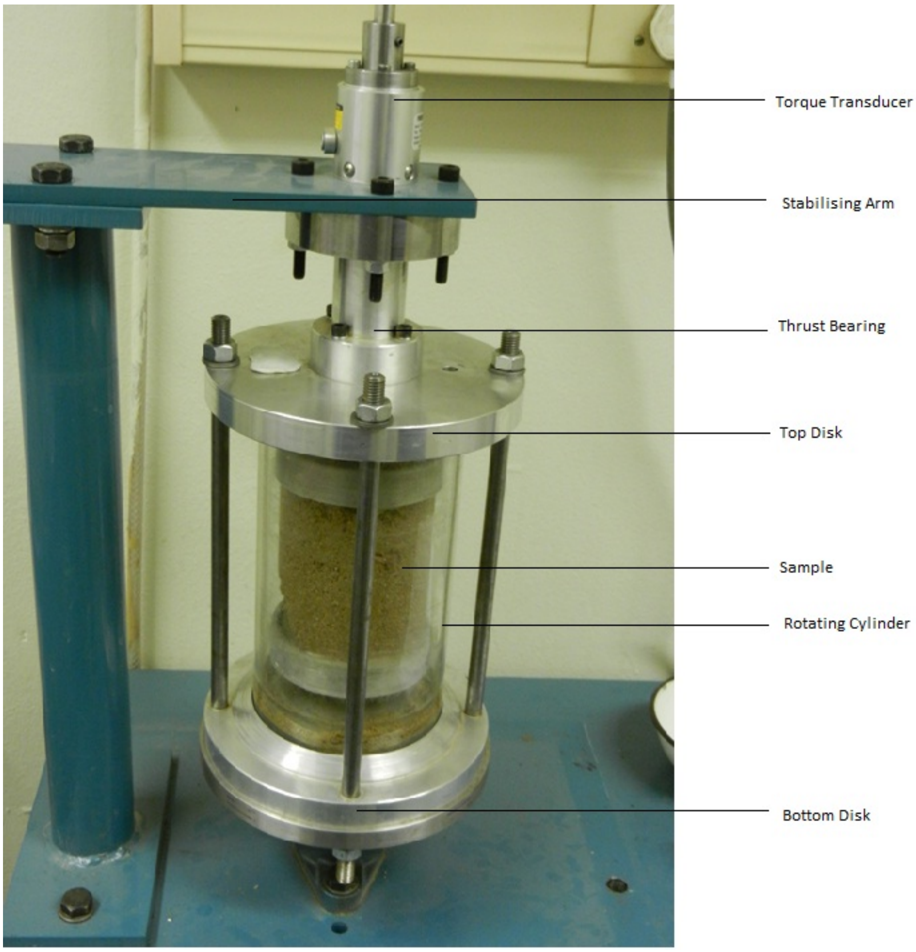

Figure 2: Constructed RSD indicating sample, the clamping fixture and torque measurement device

3 TORQUE MEASUREMENTS

During the initial commissioning of the device a series of torque measurements were performed on a variety of samples with different roughness properties. Figure 3 depicts the measured torque applied to a soil sample at different rotational speeds. For this experiment the tests were run twice, once with the container filled with water and once without water. This made it possible to determine the torque that was created by the friction of the machine and that could be deducted from the measured torque with the container filled with water, thus producing the absolute torque that is exerted on the sample from the water.

The measured data was scattered with values that vary quite significantly. The graph in Figure 3 represents an average of all tests performed at the respective rotational speeds. Unfortunately the variance in the measured values produces a standard deviation that is greater than the difference between the measured values, which led to the conclusion that the data is unreliable. A rotational speed of 1500 rpm was then chosen for the remainder of the research.

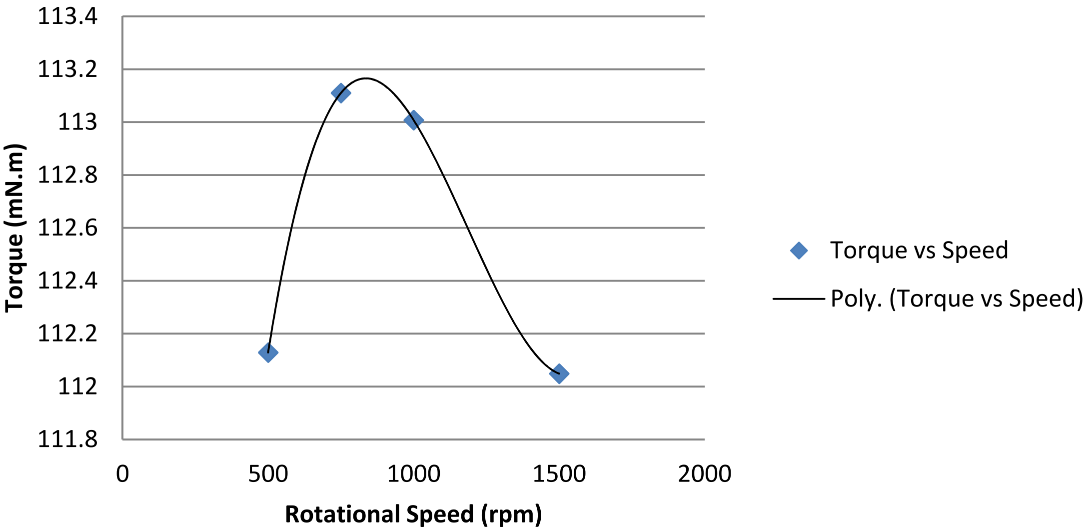

Figure 3: Graph depicting torque against speed

4 SAMPLE PREPARATION

The following sample preparation technique was adopted for RSD testing:

- Determine the Maximum Dry Density (MDD) and the Optimum Moisture Content (OMC) as per TMH 1(1986), Method A7;
- Compact the material passing the 6.5 mm sieve in a 101 mm diameter split mould by using the 4.536 kg Hammer, a drop height of 457.2 mm and applying 55 Blows to each of 3 soil layers;
- Confirm the compaction effort for verification;
- Seal in a plastic bag to be used for the rapid curing process as in TMH 1, method A13T;
- Remove the sample from the plastic bag and soak in water for one hour, and
- Air-dry the sample before commencing with testing.

For the purpose of the series of commissioning testing that are described in the following sections, a large sample of crusher dust material was collected, tested for standard TR14 (1985) classification and stored. Typical properties of the material are summarized in Table 1.

Table 1: Properties of material used during commissioning testing

Description	UCS (kPa)			MDD
% MDD	90	93	95	
3% CEM32.5 N	988	1242	1447	2112 kg/m^3 @ 6.8% optimum moisture
4% CEM32.5 N	1673	1961	2180	

5 COMMISSIONING TESTING

In an effort to select an appropriate testing time, a series of tests were performed on samples with a C3 classification (TRH14, 1985) and the testing time varied (at 1 500 rpm). Figure 4 shows the relationship between mass loss measured and testing time. The relationship is as expected: higher mass loss with an increase of time or a larger number of rotations. The selection of a standard testing time was based on the following:

- Mass loss of more than 10% could possibly cause material particles that have already been removed from the sample to significantly aid in the erosion process and influence the result.
- Variability in the data might complicate the differentiation between materials at shorter testing times (less than 1 hour)
- The shortest possible testing time should be selected to enable testing of a set of samples to be concluded in the shortest time possible.

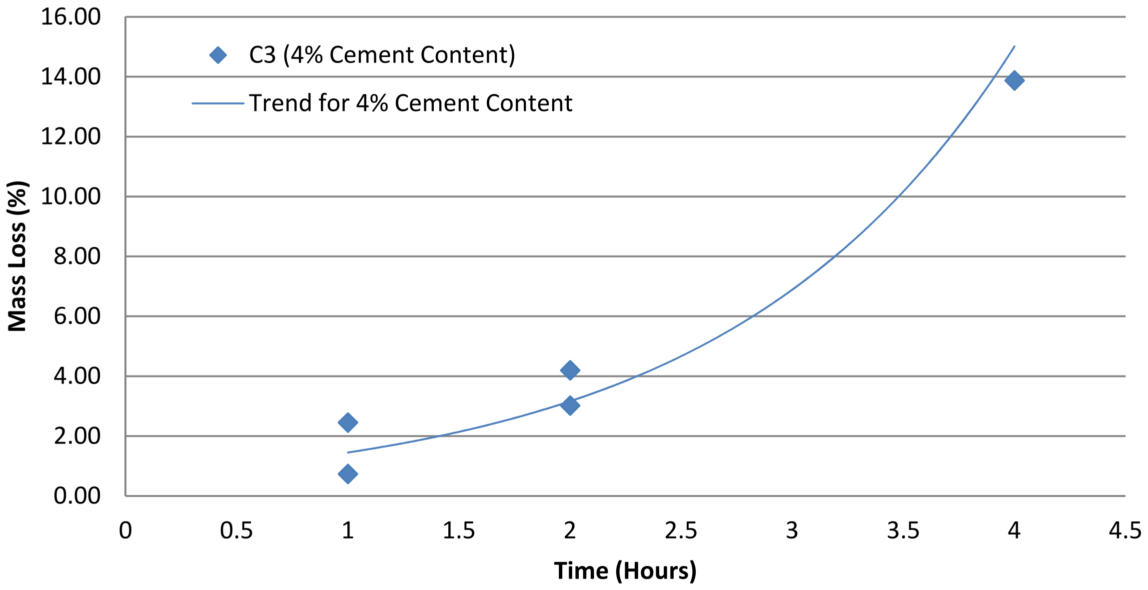

Figure 4: % Mass loss depicted over time for a C3 quality material

Considering the above, a testing time of 2 hours was selected and a number of tests repeated on 3% (C4 quality) and 5% (C2 quality) cement content material to confirm the limits of mass loss measured. Table 2 summarises the results and indicates an inconsistent result with higher mass loss, measured for the higher cement content material and a high variability in the results.

Table 2: Statistical analysis of results for 3% and 5% cement tested at 1 500 rpm for 2 hours

Material	Number of samples	% mass loss		
		Average	Standard dev.	Variance
3% CEM	4	1.51	0.49	0.32
5% CEM	4	1.61	1.57	0.98

In an effort to reduce the variability, the process of handling the samples and setting up the RSD for testing were reviewed. The following measures were included in the sample preparation protocol:

- The addition of a Silicone cap on the top of the sample to prevent edge breakage when the sample is being inserted into the RSD, and
- Light brushing of the sample with a soft bristle brush to ensure no loose particles are left on the sample from handling before the test commences.

Testing of the 3% and 5% samples were repeated and the results summarised in Table 3. The improvement to the sample preparation procedure resulted in an acceptable answer with higher mass loss measured at lower cement contents. However, the variation in the data still seems high, though only 3 samples could be tested at the time.

Table 3: Statistical analysis of results for repeat tests on 3% and 5% cement samples

Material	Number of samples	% mass loss		
		Average	Standard dev.	Variance
3% CEM	3	1.09	0.39	0.35
5% CEM	3	0.22	0.17	0.75

6 CONCLUSION

Although current research is still in progress to further refine the RSD test method, significant progress has been made in standardising a test protocol. The test apparatus has been improved on and can now handle testing on a commercial scale. Standard settings for rotational speed and testing time have also been fixed to 1 500 rpm and 2 hours. The sample preparation protocol has also been refined.

Future work includes the establishment of an acceptable sample size (number of tests required) as well as the testing of a wider scope of material before an alternative to the Wet & Dry Durability Test can be fully endorsed.

7 REFERENCES

Moore, W.L, 1962. “Experiments of the Scour Resistance of Cohesive Sediments”. Journal of Geophysical Research, Vol. 67, No. 4, April 1962.

Ras, E, 2004. “The development of a Rotational Shear Device to evaluate the erodibility of stabilised subbases”. Undergraduate Research Report, University of Pretoria.

Ras, E, 2006. “The development of a Rotational Shear Device for evaluating erodibility of stabilised subbases.” MEng Dissertation, University of Pretoria.

Technical Methods for Highways, 1991. TMH 1 Standard Methods of Testing Road Construction Materials. Pretoria.

Technical Recommendations for Highways, 1985. TRH 14 Guidelines for Road Construction Materials. Pretoria.

Van Wijk, A.J, 1985. “Rigid pavement pumping: (1) Subbase erosion and (2) economic modeling”. PhD Thesis, Purdue University, United States of America.