The borehole erosion test

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ABSTRACT: Soil erosion is a major problem in civil engineering. It is involved in bridge scour, meander migration, levee and dam overtopping, internal erosion of earth dams, surface erosion of embankments, and cliff erosion. The best way to predict the erodibility of a soil is to measure it directly on a site specific basis by testing samples in the laboratory or by in-situ testing in the field. The borehole erosion test or BET is a new in-situ soil erosion test proposed to measure the erosion of the walls of a borehole while wet rotary drilling takes place. The increase in diameter of the borehole as a function of time and for a given flow velocity in the borehole is measured with borehole calipers. The result is a profile of soil erodibility as a function of depth. Tests in clay and in sand conducted at the National Geotechnical Experimentation Sites at Texas A&M University are presented.

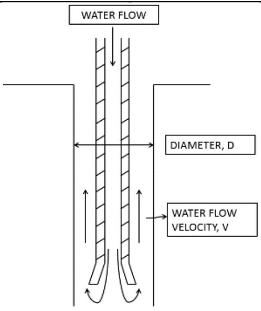
1 INTRODUCTION

Soil erosion is a major problem in civil engineering. It is involved in bridge scour, meander migration, levee and dam overtopping, internal erosion of earth dams, surface erosion of embankments, and cliff erosion. The erodibility of a soil or rock is defined here as the relationship between the erosion rate of the soil surface and the water velocity v or interface hydraulic shear stress τ. This relationship is called the erosion function and serves as the fundamental constitutive law for soil erosion problems much like the stress strain curve is the fundamental constitutive law for deformation problems. The best way to predict the erodibility of a soil is to measure it directly on a site specific basis by testing samples in the laboratory or by in-situ testing in the field. Many tests have been proposed over the last 25 years starting with laboratory tests and more recently with in-situ tests. The borehole erosion test or BET is a new in-situ erosion test which only makes use of existing equipment and gives a profile of the soil erodibility vs. depth. It consists of drilling a borehole by the wet rotary method while measuring the increase in diameter of the hole as a function of depth and as a function of time. In this article, the new borehole erosion test concept is explained, the equipment is described, the test procedure is outlined, and the results of BETs conducted at the clay and at the sand site of the National Geotechnical Experimentation Sites at Texas A&M University are presented and discussed.

2 BOREHOLE EROSION TEST CONCEPT AND PROCEDURE

The Borehole Erosion Test (BET, Fig. 1) consists of drilling a hole approximately 100mm in diameter and to a depth covering the zone of interest for the erosion problem at hand. For a scour hole around a bridge pier this may be estimated as a conservative depth equal to 3 times the width of the bridge pier. Once the hole is drilled, the rods and rill bit are removed and a borehole caliper is lowered to the bottom of the hole. The diameter of the borehole is logged as the borehole caliper is pulled out of the hole to obtain the zero reading borehole diameter profile. Once the caliper is out of the borehole, the rods and drill bit are re-inserted to the bottom of the borehole. Water is circulated at a chosen velocity down the rods and up the annulus between the rods and the wall of the borehole. This erodes the wall of the soil borehole if the water velocity is larger than the critical velocity. After a set time (say 10 minutes), the flow of water is stopped and the drill bit and rods are removed from the hole.

Borehole Erosion Test	Erosion function of soil



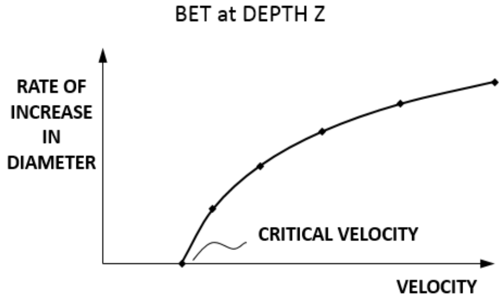


Figure 1. Borehole Erosion Test concept (Briaud, 2014).

The diameter of the borehole is logged again with the same borehole caliper. The increase in radius which occurred during the flow divided by the flow duration is the erosion rate associated with the flow velocity. It gives one point on the erosion function. Note that in this case the BET gives a complete profile of erosion rate where the erodibility of all soil layers within the depth of the borehole are evaluated in one single test. The caliper is removed from the borehole and the rods and bit are reinserted. A higher velocity is chosen and the flow is maintained during a set time (say 10 minutes) to repeat the process. Velocity after velocity, the erosion function of all soil layers within the borehole depth including the critical velocity profile are obtained.

3 BET EQUIPMENT

One of the advantages of the BET is that it only requires the use of commonly available equipment. Indeed, it requires a commonly used drilling rig for wet rotary boring, and a commonly used borehole caliper. The borehole caliper can be a mechanical caliper with radial arms which extend horizontally in a cone shape (Fig. 2) or optical calipers which use sound waves to scan the distance from the instrument to the borehole wall. The water circulation part of the BET relies on the pump from the rig, an in line flow meter and a stop watch (Fig. 3).

4 BET FIELD TESTS AND SOILS

A series of BET tests were undertaken at the National Geotechnical Experimentation Sites at Texas A&M University (NGES-TAMU). There is a clay site (NGES-TAMU Clay) and a sand site (NGES-TAMU Sand). The clay at the NGES-TAMU is a very stiff clay with an average shear strength of 110 kPa within the top 4 m. It is overconsolidated by desiccation and of relatively high plasticity because it was deposited in a very low energy environment through a series of geologic transgressions and regressions of the Gulf of Mexico over Texas. Additional properties are shown in Fig. 4. The sand at the sand site is medium dense sand with an average SPT blow count equal to 15 bpf within the top 4 m. It was deposited by an ancient meander of the Brazos River and contains a significant amount of fine grained soils. Additional properties are shown in Fig. 5.

Calibrating the 3 arms caliper	Inserting the caliper in the open borehole
	

Figure 2. Borehole caliper for BET.

5 BET TEST RESULTS

The results of the BET tests at the clay site are shown in Fig. 6. The initial borehole was completed with an 89 mm three wing bit to a depth of 3.35 m. After removing the drilling tool and rods the caliper was inserted and gave the zero diameter reading profile (C-0 on Fig. 6). The average initial diameter drilled with the 89 mmm bit was about 95 mm. This enlargement is likely due to the circulation of the drilling mud during the drilling process. Then the caliper was removed and the drilling rods were reinserted.

Flow meter	Flow out of the borehole in the mud pit
	

Figure 3. Flow meter and flow.

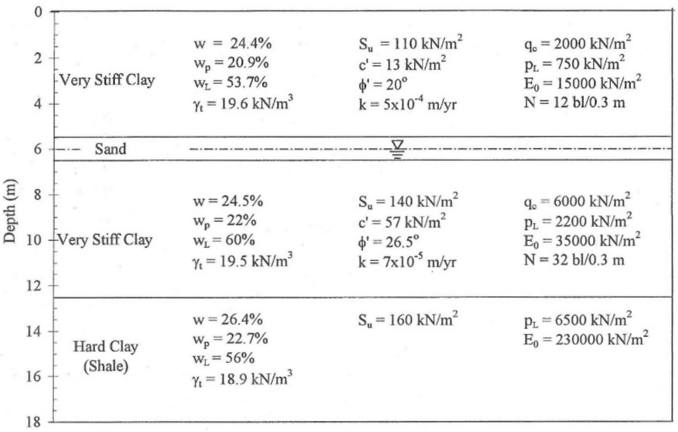


Figure 4. Summary of soil properties at the clay site

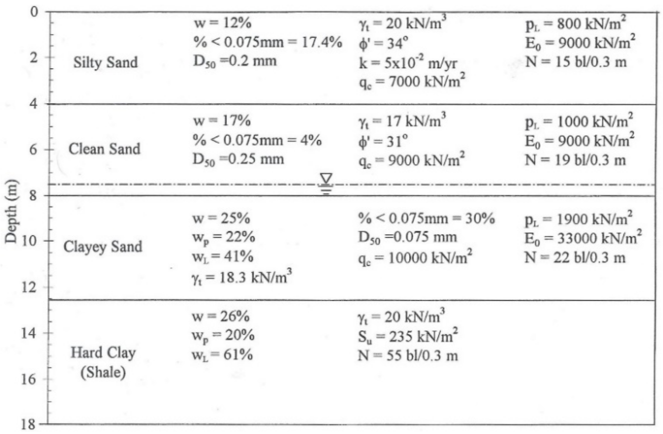


Figure 5. Summary of soil properties at the sand site

The drilling mud was circulated with a flow measured by an in line flowmeter as being 0.00142 m3/s. This test is called C-1 in Fig. 6. The velocity was calculated by using the equation:

$$Q = vA \tag{1}$$

Where Q is the flow, v is the velocity, and A is the cross section area between the outside of the rods measured on site and the borehole walls as given by the caliper. The velocity during test C-1 was 0.4 m/s which was maintained for 10 minutes. As can be seen during those 10 minutes of flow at 0.4 m/s, the borehole diameter increased from about 95 mm to about 99 mm as measured by the mechanical caliper. The corresponding average erosion rate calculated as increase in radius divided by the time of flow is 12 mm/hr. This rate indicates a soil with medium to high erodibility according to Briaud (2013) classification chart. This seems reasonable for this fissured and blocky clay. The rate of 12 mm/hr combined with the flow velocity of 0.4 m/s, gives a first point on the erosion function curve (Briaud, 2013). A second BET was conducted in the same hole by reinserting the rods and increasing the flow velocity to 1.36 m/s and maintaining it for 10 minutes. Table 1 gives the flow rates, velocities, and time of application of each velocity for the tests in clay and in sand.

Table 1. Flow, velocity, and time for the BETs at the clay and sand national TAMU sites.

Clay Site

Flow (m^3/s)	Velocity (m/s)	Duration (min)
0.00142	0.40	10
0.00562	1.36	10
0.00568	1.19	10

Sand Site

Flow (m^3/s)	Velocity (m/s)	Duration (min)
0.00172	0.50	10
0.00513	1.49	10

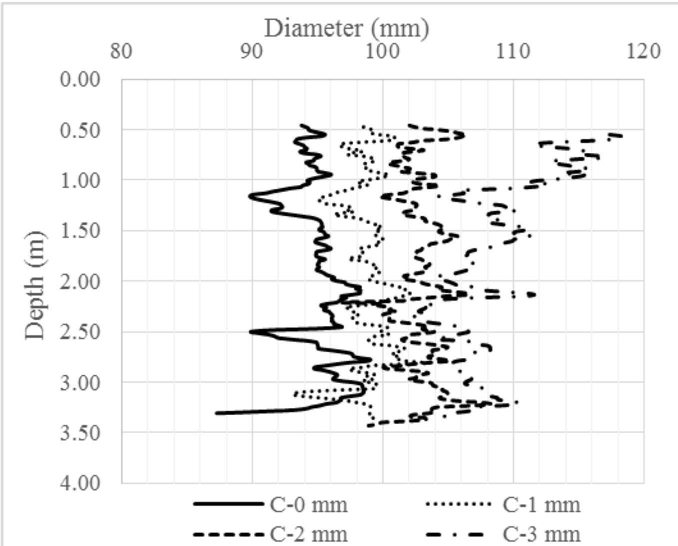


Figure 6. BET results of a test in clay.

The results of the BETs at the sand site are shown in Fig. 7. They indicate that the sand eroded quite a bit less than the clay which is counter intuitive. Samples were taken at both sites and it was found that the sand was cemented because the BET borehole had been situated next to a retaining wall subjected to intense grouting.

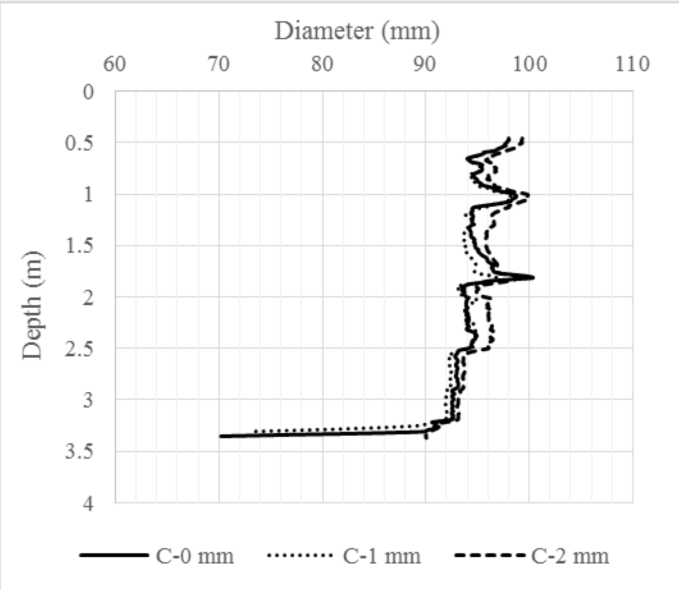


Figure 7. BET results of a test in sand.

6 CONCLUSIONS

A new in situ erosion test called the borehole erosion test or BET is proposed. It consist of circulating water in an open borehole using conventional drilling equipment and a set of calipers. The flow duration for each velocity is suggested to be 10 minutes. The lateral increase in diameter is recorded after each 10 minute flow period and a corresponding erosion rate is obtained as the increase in radius divided by the time of flow application. By repeating the BET for different velocities, the erosion function is obtained point by point. Early tests are very encouraging.

The BET test has several advantages

- It does not require that any special equipment be built and as such anyone can carry the test.
- It is quite rapid compared to most laboratory tests.
- Each test gives the erosion function for all layers traversed since a complete borehole diameter profile is obtained from the calipers. This would require many tests on many samples if laboratory tests were to be conducted.
- It has two component tests: the lateral erosion test associated with the increase in diameter of the borehole or LBET and the bottom erosion test associated with the increase in depth below the bottom of the drilling rods during the flow or BBET. The BBET is much like an in situ jet erosion test. Only the LBET results are presented here.

The BET also has some limitations

- If the borehole collapses, it will give erroneous readings leading to a false increase in erosion rate. Proper drilling mud should be used to limit this possibility.
- The cross section of the borehole may not perfectly circular; this could lead to some error in the readings if the three arms of the caliper are not going into the hole lined up as in the previous profile measurement.
- The penetration of the caliper arms into the walls of the borehole may not always be the same. There is a need to have soft springs on the arms and larger areas at the tip to minimize the pressure on the wall of the borehole.
- The circulating fluid may not be the same as the one circulating during the scour process or the meander migration process or other erosion process. This is a limitation of all erosion tests.

One issue is important in the preparation of a BET as follows. It is important to select the diameter of the drilling bit to ensure that the desired velocity range will be reached considering the capacity of the pump on the drilling rig and the outer diameter of the drilling rods. The work is continuing by performing parallel laboratory erosion tests with the EFA, HET, and JET and associated numerical simulations.

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