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A New Proposed Test Method for Shear Strength of Lean and Normal Strength Concrete

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Abstract: It is important to fully understand the characteristics and physical properties of concrete in order to predict the response of concrete structures. Compressive strength is used as a reference of the overall quality of concrete. However, compressive strength is not the only characteristic influencing the behaviour of concrete structures and, in particular, gravity concrete dams where the determination of shear strength capacity, as well, is imperative. This can be obtained using either lab-cast cylinders or drilled cores or sawn blocks from a test section. This paper describes the set up of a newly proposed test for shear strength of lean and normal strength roller compacted concrete (RCC), and compares the results of this test with the standard direct shear test (ASTM D 5607). The study included the effects of compressive strength level, diameter of specimen and moisture content on the results of both tests, and the relation between them. The investigation showed a direct relationship between level of strength and the differences in shear strengths measured by the two methods. The standard ASTM method showed higher strengths in most of the cases. For the effect of specimen diameter, it was found that lowest results were recorded when the largest diameter is used (150 mm). On the other hand, dry samples tested with the new method showed 26 to 42 % higher shear strength values when compared to saturated surface dry samples. In addition, the paper presents the relation between the shear strength measured by the proposed method, compressive strength and splitting tensile strength of normal strength RCC (20 to 50 MPa). Linear relationships with high correlation factors were achieved. The proposed alternative method is thought to be easier to carry out than the standard direct shear box method, and thus to obtain more accurate shear strength results.

1. INTRODUCTION

Shear strength of concrete is of prime importance in case of water retaining structures and roller compacted concrete (RCC), especially for the bond between layers of this type of concrete. Compressive strength of concrete is usually considered as an indicator of the overall strength of concrete, but it is not the only property influencing the behaviour of concrete. The determination of tensile and shear strength capacities is imperative as well.

Direct shear testing can be performed in accordance to ASTM D 5607, Direct Shear Strength Test of Rock Specimens Under Constant Normal Stress. This test procedure requires the use of a special testing frame and pouring an encapsulating material around the specimen. As a minimum, three test specimens should be tested at three different unconfined pressures for each parent RCC or joint condition to adequately develop the Mohr circle, which is used to determine cohesion and internal friction angle. The shear strength per unit area is expressed by the common Coulomb's equation.

[1] $\tau_v = \sigma \tan \Phi + C$

Where τ_v is the shear strength (resistance to sliding per unit area), σ is the applied normal stress, and Φ and C are the friction angle and the cohesion respectively(strength parameters).

Two reference sources, Hansen and Reinhardt (1991) and Schrader (1999) describe an alternative indirect shear strength testing method that involves drilling core samples at multiple angles and then testing the samples in a compression machine. This method is mainly intended for testing RCC lift joints and uses angled drilling to minimize the damage of the lift joints as well as to improve sample recovery. If this method is used, the test section should be adequately sized to account for the lateral distance of the angled drilling, Schrader (1999) and Kline (2003).

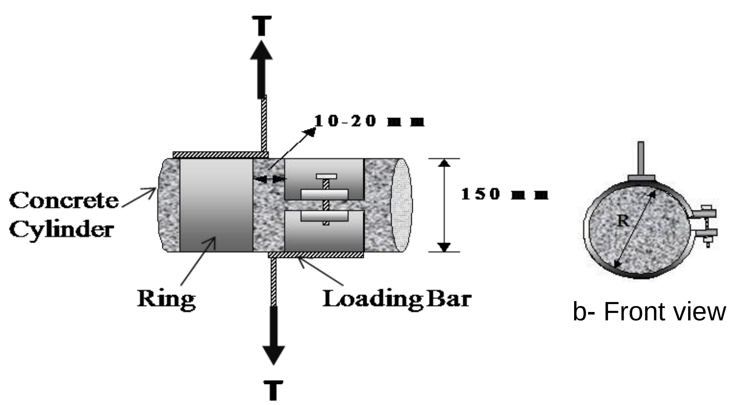
Saw cut block samples can be tested in-situ or at the laboratory. Previous in-situ tests have used hydraulic jacks to create the shear force and heavy equipment wheel loads to simulate the normal force. Obtaining the shear strength of RCC and other types of concrete using the available direct or indirect methods are usually difficult to carry out.

This paper discusses laboratory test results and the relationship between compressive strength and indirect tensile strength versus direct shear strength tested with a newly proposed set-up, and the effects of specimen dimensions and moisture conditions. Two classes of RCC are investigated, lean RCC (less than 20 MPa) which is used in constructing dams, and normal strength RCC (20 to 50 MPa) used in pavements.

2. SET-UP OF THE PROPOSED ALTERNATIVE SHEAR TEST

A new alternative method was developed for testing concrete cylindrical samples for obtaining shear strength which may be considered as a direct shear test. The test is performed mainly on RCC samples, but it can be carried out on other types of concrete as well.

The RCC cylinder specimen (with varied diameters) is rounded by two steel rings having enough thickness to avoid any distortion or deformation under the load. The rings have to be clamped with 10 to 20 mm gap between them. Two bars facing each other welded on the rings were used to apply the tensile load to the specimen. These bars were fitted firmly by the grips of a universal tensile testing machine used for standard tensile test of reinforcing steel bars. No sliding was noticed during the tests. The load direction was perpendicular to the center line of the concrete specimen. The direct shear test equipment setup is shown in Figure 1.



b- Front view

a- Side view

Figure 1: Direct shear test equipment and set-up

The tension load is applied gradually without shocking or bending until a peak shear force is reached for different test specimens ending by the cleavage of the cylinder specimen at the gap between the rings. This test was carried out under constant rate of tensile load of 0.2 to 2.7 KN/s, depending on specimen diameter. The maximum load at the moment when the specimen starts to crack is recorded ,and divided by the cross sectional area. Figure 2 shows the shear failure mode of the specimen after testing, Mansour (2009).

To verify the validity of the new alternative method, different ring diameters and moisture conditions were tested. In addition, concrete samples with different compressive strength levels were evaluated. The obtained results were compared with the ASTM shear strength test traditionally applied for rock specimens.

Figure 2: Typical Failure Pattern After Testing

3. EXPERIMENTAL PROGRAM

3.1 Materials

3.1.1 Cement

ASTM Type I normal Portland cement was used. The physical and mechanical properties and chemical composition met the requirements of the relevant Libyan and ASTM specifications.

3.1.2 Aggregates

The coarse aggregates used in mixes were crushed basalt with maximum nominal sizes of 14 and 20 mm mixed as 1 : 1. The fine aggregates composed of 60 % crushed quarry sand mixed with 40 % natural sand. Fine aggregates mixture has 2.36 mm maximum size, and composed 35 % of total aggregates in the concrete mix. The specific gravity and absorption values of the coarse aggregate mixture were 2.63 and 1.67 % respectively, and for fine aggregate mixture they were 2.66 and 0.69 % respectively. The gradings of all aggregate types comply with the requirements of ASTM C 33.

3.1.3 Mixing Water

The usual requirements for water quality in concrete were adopted. It was free from excessive amounts of alkalis, acids, organic materials that might adversely affect concrete properties.

3.1.4 Admixtures

A high-range water reducing superplasticizer was used to increase workability of RCC under reduced water content. It is a ready-to-use, chloride free, liquid admixture that meets ASTM C 494 requirements for types A and F admixtures. In addition, retarders and air entraining admixtures are commonly used for this type of concrete.

3.2 Preparation of Specimens

Un-joined RCC Concrete specimens were prepared in the laboratory using 150 mm diameter by 150 mm height cylinders. In addition, specimens with 54 and 100 mm diameters were casted and tested also with l/d ratio of 1:2 and 1:1.5 respectively. However, l/d values found to be irrelevant as long as the height of the specimen is adequate for fixing the test rings. The cylindrical specimens were compacted using a vibrating hammer following the soil approach method. Cylindrical specimens were casted in two layers or lifts of 150 mm thickness and were cured in water until testing time, Mansour (2009), Barony and Sifaw (2002).

4. RESULTS AND DISCUSSIONS

4.1 Lean Concrete

Various compressive strength levels could be reached using variable cement contents. Strengths of lean RCC ranged from 3.70 to 18.00 MPa, with cement contents from 100 to 250 kg/m^3. Comparing the results of the proposed shear strength test with the ASTM D 5607 test results, along with investigating the effects of sample diameter and moisture condition on the results are discussed briefly in the following sections.

4.1.1 Proposed test vs. ASTM test

The proposed shear test results on 54 mm diameter samples, which can be considered as a direct shear strength are plotted in Figure 3 against the correspondent shear strength obtained by the ASTM D 5607 test. Each data point represents the average of three cylinders, and the data was found statistically representative.

It can be noticed from this figure that the proposed test method showed always lower results (15 ~ 25 % less) except for very low strength mixes (less than 5 MPa). The difference between the results increases gradually with the increase in strength levels. On the other hand, both tests showed strong linear relationships with compressive strength. Proposed direct shear strength results ranged from 24 to 32 % of the correspondent compressive strength values. This range was 25 to 36 % in the case of ASTM test.

The higher results obtained by the standard test method may be attributed to the loading condition in this test, where a vertical normal load is applied on the specimen in addition to the horizontal shear force. This normal force is expected to impose higher stresses on the concrete specimen when compared to the new set-up which includes direct shear force only.

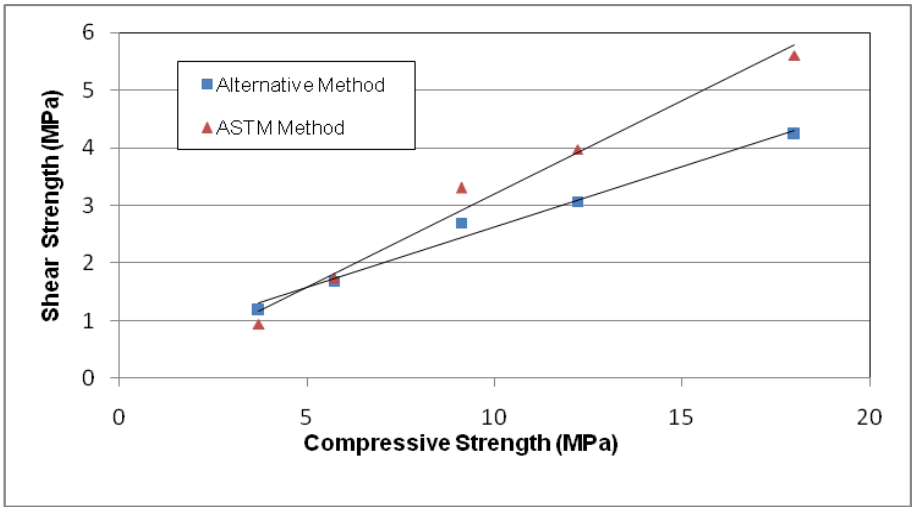


Figure 3: New Alternative Method vs. ASTM D 5607 Method

4.1.2 Effect of sample diameter

For the aim of verifying the application of the new alternative method, samples made of the same mixes but with different diameters were evaluated to investigate the size effect. Figure 4 represents the obtained results. Shear strengths of samples with 54 and 100 mm diameters were almost identical, where increasing the diameter to 150 mm results in a drop in shear strength especially at higher compressive strength levels. The difference in shear strength reaches about 25 % at 18 MPa compressive strength level. This behavior may be related to the size effect where the relative restraining effect of test rings is higher in smaller diameters. Again, for all diameters, strong linear relationships have been found.

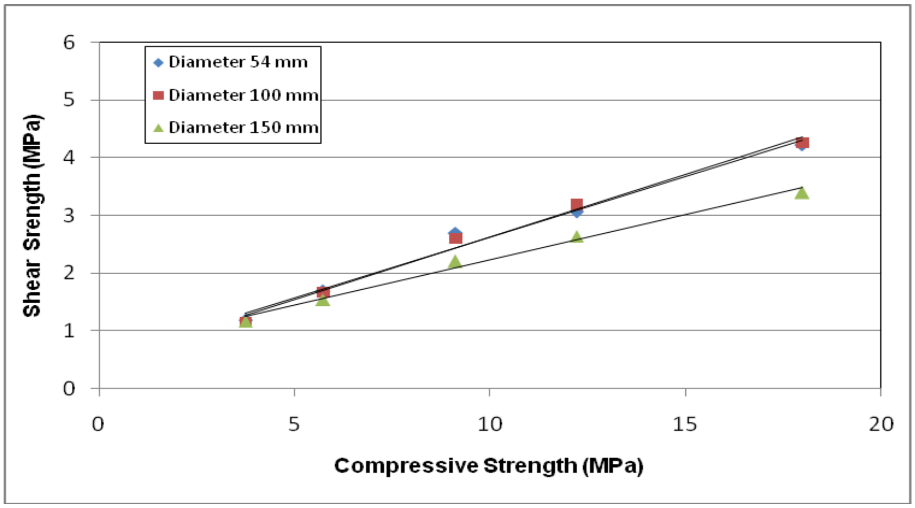


Figure 4: Effect of Sample Diameter on Shear Strength Measured by the alternative Test Method

4.1.3 Moisture conditions effect on shear strength

To study the possible effects of moisture conditions on the results of the new proposed method, oven dry and saturated surface dry (SSD) samples made of the same mixes of lean RCC with different strength levels were tested. The results are shown in Figure 5. It can be seen clearly that dry samples showed 26 to 42 % higher shear strength results when compared to SSD samples. The higher is the strength level, the higher is the difference percentage in results. This behavior is believed to be related to the effect of internal pore water pressure, and it is consistent with a previous work which found that the strength of air-dried cores is on average 14 % larger than the strength of cores soaked in water, Bartlett and MacGregor (1994).

4.2 Normal Strength RCC

For normal strength RCC (20 to 50 MPa), the investigation focused on studying the relations between the results of direct shear strength measured by the new test method and both of compressive and splitting tensile strengths. All samples were 150 mm diameter. Figures 6 and 7 illustrate the direct proportion relationships between direct shear strength (f_{sh}), compressive strength (f_c) and splitting strength (f_{sp}) respectively. Studying the results led to that (f_{sh}/f_c) ranged from 0.09 to 0.14, while (f_{sh}/f_{sp}) varied from 1.05 to 1.29. Generally, these values decrease with the increase of strength level.

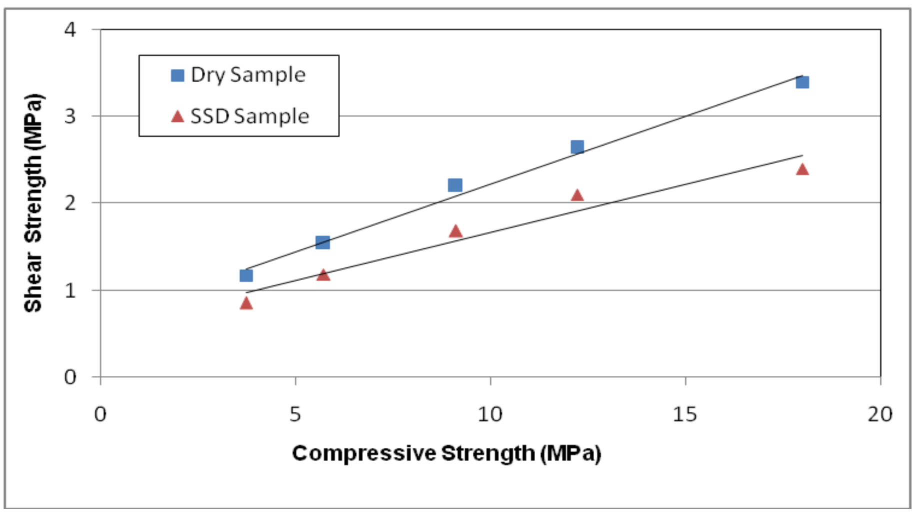


Figure 5: Effect of Moisture Conditions on Shear Strength of lean RCC

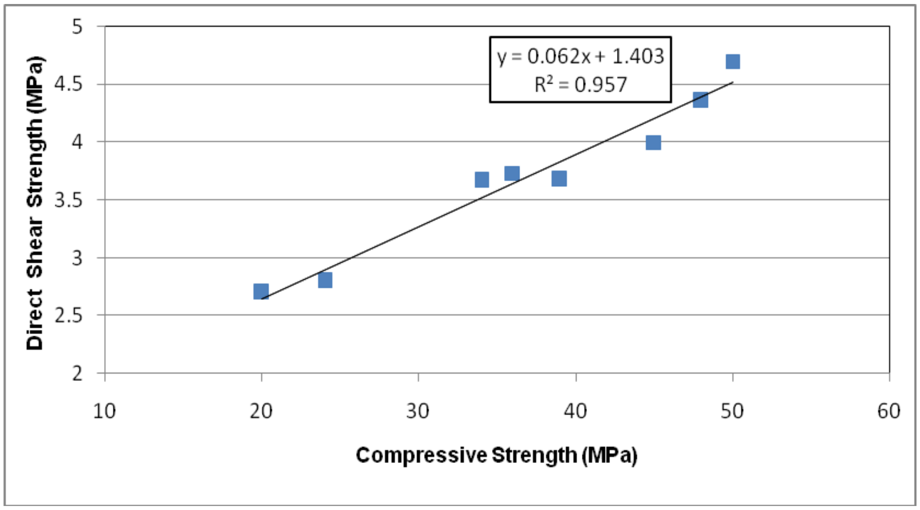


Figure 6: Correlation between Shear and Compressive Strengths of Normal Strength RCC

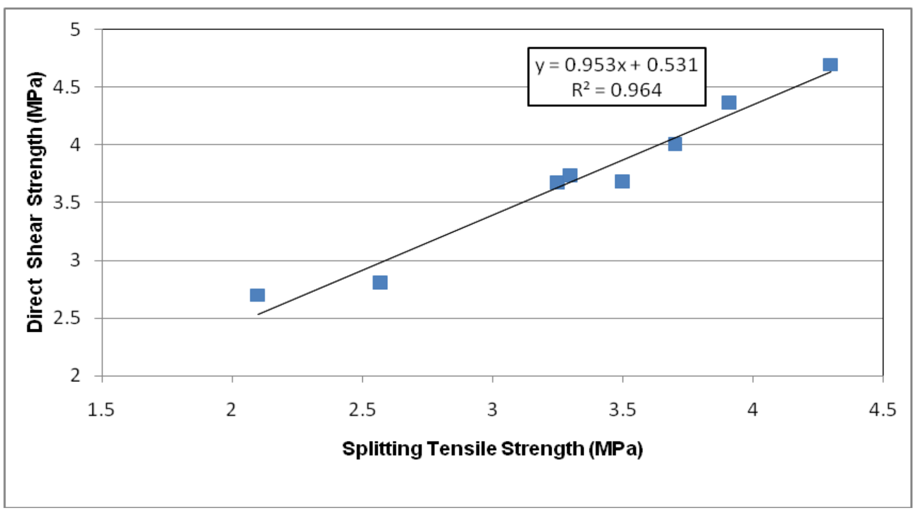


Figure 7: Correlating Shear and Splitting Tensile Strengths of Normal Strength RCC

5. CONCLUSIONS

- The alternative method of testing shear strength of lean and normal strength roller compacted concrete was carried out successfully, and it proved to be easier to handle and less time consuming comparing to the standard ASTM test of rock specimens, and thus it may lead to more accurate and reliable shear strength results.

- When expressed as a percentage of compressive strength, the results show that the percentage of shear strength measured by the proposed test ranged from 8.9 to 13.5 % in the case of normal strength RCC, and from 19 to 31 % in the case of lean RCC.

- The new method gives 15 to 25 % smaller values of shear strength when compared to the standard ASTM D 5607 method.
- Increased sample diameter for higher than 100 mm will result in decreasing shear strength results.
- Shear strength of dry samples is 26 to 42 % higher than that of saturated surface dry samples.
- Strong linear relationships have been achieved between all the investigated parameters. This can be considered as a strong indication of the adequacy and reliability of using the proposed test method for strength predictions. However, more research work need to be carried out in this regard to verify this paper's preliminary findings.

6. RECOMMENDATIONS

In spite of the promising performance and results of the newly proposed shear strength test, and the high correlation factors between the studied parameters, this method requires a more extended research to confirm it as a reliable method for testing shear strength of different types of concrete, with emphasis on roller compacted concrete.

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