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An Experimental Investigation on the Amount of Drag Force of Sand on a Cone Moving at Low Uniform Speed

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Abstract**—**The amount of resistance of a particular medium like soil to the moving objects is the interest of many areas in science. These include soil mechanics, geotechnical engineering, powder mechanics etc. Knowledge of drag force is also used for estimating the amount of momentum of fired objects like bullets. This paper focuses on measurement of drag force of sand on a cone when it moves at a low constant speed. A 30-degree apex angle cone has been used for this purpose. The study consisted of both loose and dense conditions of the soil. The applied speed has been in the range of 0.1 to 10 mm/min. The results indicate that the required force is basically independent of the cone speed; but, it is very dependent on the material densification and confining stress.

Keywords**—**Drag force, sand, moving speed, friction angle, densification, confining stress.

I. INTRODUCTION

DRAG forces are created when objects move relative to fluids or gases [1]. Based on the Stoke's and other laws; the amount of this force may depend on the first or higher powers of moving speed in subsonic; sonic or supersonic conditions [1], [2]. Measurement of drag force has been a way for obtaining properties of these media, as viscosity [1]. Particulate media like sand also flow when they reach their yield state [2]. They also exert drag forces on the objects moving in them [3]-[16]. It would then be a good idea to measure the drag force on the objects moving in these media for the purpose of estimating their frictional properties as friction angle ¤. Drag force in very viscous fluids is not expected to depend on a power of velocity more than one when the speed is low [1]. This is also what is expected in soils. Due to high friction in soil; it is believed that the flow would be very subsonic at low speeds. Some earlier indirect studies in other ranges on artificial materials like glass beads and spheres indicated that speed does not have any effect [3], [6], [14]. Therefore, it has been the aim of this study to investigate the effect of speed on the drag force a real granular material like sand exerts on a typical object like cone. Also; in contrast to other studies; this effect has been studied under the application of extra confining pressure. Both loose and dense conditions of the sand are studied for this purpose.

II. TEST MATERIAL

Experiments were performed on a typical relatively angular grained sand gradation curve of which is given in Fig. 1. It is classified as a poorly graded sand (SP), based on the unified classification of soils. The measured angle of repose of the sand was 37.5 degrees. The maximum and minimum densities of sand in dry state were found using the procedures given by ASTM. These values have been 17.6 and 14.5 kN/m^3, respectively.

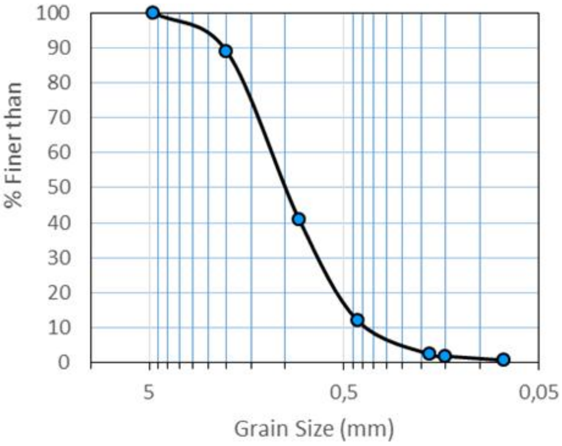

Fig. 1 Grain size distribution curve of the sand

III. TEST EQUIPMENT AND PROCEDURE

Experiments are performed using a relatively hard wooden cone having an apex angle of 30 degrees. The height and base diameter of the cone are 90 and 54.3 mm, respectively. The soil container used for the experiments is cylindrical. The diameter and height of the container are about 300 mm. The container is placed on the center of loading machine pedestal. The first layer of soil is then poured in and leveled in a thickness of about 70 mm. The cone is attached to a thin, relatively inextensible, but flexible cord from its tip and hanged from the tension loading ring. The loading machine is then adjusted so that the cone sits very gently on the already placed layer of sand from its base at the middle of cylinder. The sand is poured and compacted over the cone until its apex is buried. The third layer of soil is then placed from this level to near the top of the container. If the experiment is to be

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performed at dense state; proper compaction and densification should be given to each layer. The surface of soil in the container is then leveled. A round wooden platen having a radial groove for passage of the cord is then placed on top, and the 250 N surcharge weights are applied (Fig. 2). This was to induce a confining pressure in the soil.

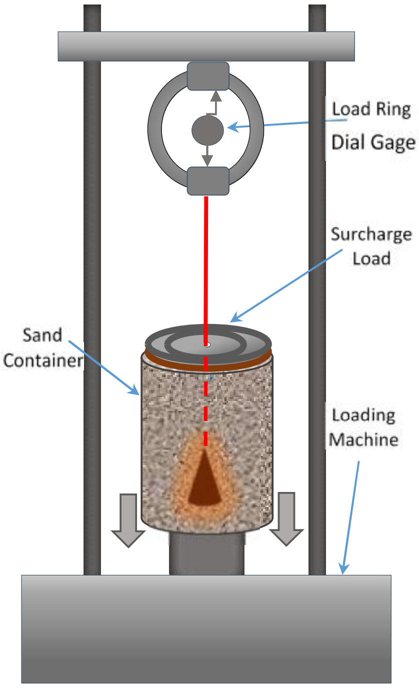

Fig. 2 Schematic diagram of the experimental setup

The machine speed is then set to the desired speed. By starting the machine; the soil container placed on the pedestal is brought down while the cone attached and hanged to the cord in its middle remains stationary. The downward movement of soil exerts a drag force on the cone, amount of which is recorded by the loading ring attached to the cord. The amount of force relative to any displacement is plotted to give a force-displacement curve. Experiments are performed at speeds in the range of 0.1 to 10 mm/min to see the effect of speed on the results. This is the rage in which the speed of usual soil shear tests fall. They are also performed both on loose and dense states of sand to see the effect of relative density on the results. Loose states are provided by just pouring the sand from funnel into the container. The dense state is obtained by tamping on a plate placed on each layer as well as giving vibration under a small load. Knowing the weight of soil in the container; the relative density for each experiment is obtained by measuring the volume the sand occupies. Pilot tests indicated the development of two types of mechanism: 1. Surface mechanism 2. Deep mechanism. The first one develops when the surcharge is small and the cone is near to the surface of the soil. The force vs. displacement graph keeps decreasing after an initial peak. The second one is when the cone is deep and the surcharge is not little. The force-displacement graph shows a relatively constant force after a peak. The drag force vs. displacement curves for these mechanisms are shown in Fig. 3. A transition between these two mechanisms is also possible. Our study in this work is only based on the deep mechanism.

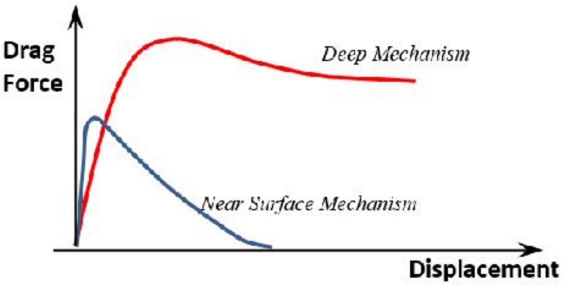

Fig. 3 Comparison between the force-displacement curves for near surface and deep mechanisms

IV. Experiment Results

Experiments consist of tests at different speeds in both loose and dense sand. Fig. 4 shows some of the force-displacement graphs for movement of the cone in loose sand at different speeds.

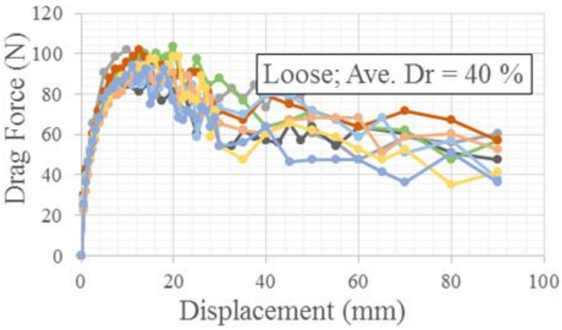

Fig. 4 Force-displacement curves for tests on loose sand with the average relative density of 40%

Fig. 4 indicates that the force decreases to a relatively constant value after a peak. In all of these tests; the sand is carefully poured into the container to avoid densification. The procedure for preparation of the samples for these tests is the same. This is to keep the effect of variation in density minimal. Despite of this; there are differences in relative densities causing some scatter in force-displacement curves. The average relative density D_r for tests on loose sand is about 40%. All of these tests are performed under the same surcharge load, 250 N. Therefore; if the minor effects due to differences in densities are ignored; the differences in load-displacement curves should be attributed to the differences in the moving speed. Comparison shows no significant difference between the curves. Fig. 5 shows similar data for some tests performed on dense sand. Attempt is made to densify the samples with similar procedure. This is to exclude the effect of density on the results. Nevertheless; there are some differences in initial densities causing some scatter in force-displacement curves. The average relative density D_r for tests on dense samples is about 82%. Again, all of the tests are performed under the same surcharge load, i.e.; 250 N.

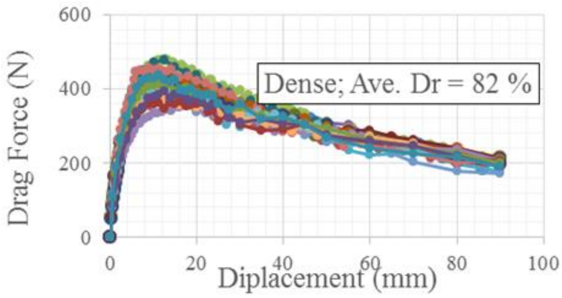

Fig. 5 Force-displacement curves for tests on dense sand with the average relative density of 82%

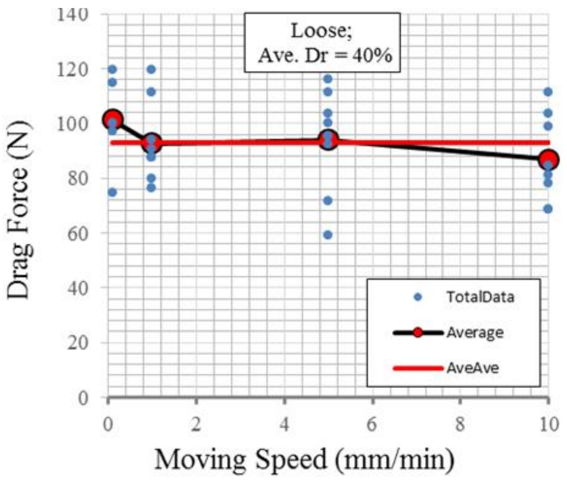

Fig. 6 Variation of maximum of drag force with moving speed in experiments on loose sand

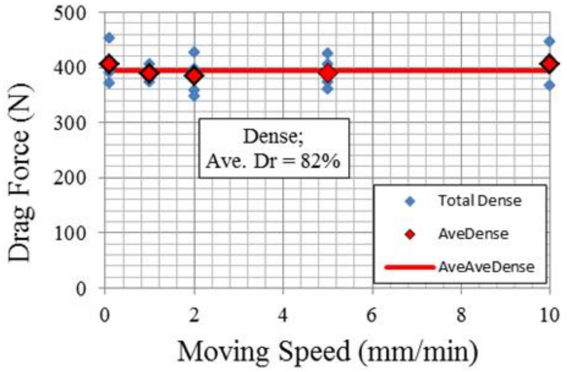

Fig. 7 Variation of maximum of drag force with moving speed in experiments on dense sand

Comparison of the load-displacement curves in Fig. 5 indicates that despite of minor differences in densities; the peak values are more or less the same. It can be concluded that in the range of speed applied, the drag force is independent of movement speed. This holds for both dense and loose conditions of the sand. Small variations can only be attributed to small differences in relative densities in each case which is usual in experimental works.

Effect of speed is realized well if the peak values of the force-displacement graphs are plotted vs. the applied speed. Fig. 6 depicts the peak values of drag force exerted on the cone versus speed for experiments on loose sand. The range of speed applied is 0.1 to 100 mm/min. The average relative density is 40%. The average of the peak values at each speed is also plotted by red circular markers in the figure. The solid red line indicates the average line through these average values. The result clearly indicates that the peak and residual forces are not affected by the cone speed. The average value of peak drag force for the loose sand under 250 N has been about 93 N. Fig. 7 shows similar data for dense sand with an average relative density of 82%. Although the same cone has been used in these tests; the drag force in dense sand has been substantially higher (393 N). Here again; the peak value of force shows to be basically independent of the movement speed.

V. CONCLUSION

Experimental studies of this research indicate that in the range of usual speeds considered for shear tests in soils; the speed of the test does not affect the drag force of sand on the cone. This was shown to hold both for loose and dense conditions of the sand. This indicates that in the range of speeds as low as 0.1 to 10 mm/min; the generated drag force is not of the type produced in viscous fluids. It is rather of frictional type which does not depend on speed. The developed friction in soil depends on the confining pressure induced by surcharge load as well as the densification given to the material. It is also concluded that the measurement of drag force in such a simple test shown here, suffices in giving an estimate of shear strength of the soil at any state of densification and confining pressure.

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