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# Effect of moisture content in soil on mass flow during landslides

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***Abstract***— ***Landslide constitute a major natural hazard, which causes considerable loss of life and damage to human settlements, communication routes, cultivation and forest lands. Landslide involves mass movement such as rock fall, mudflows or debris flows. Excessive rainfalls are a major cause for such mass movements. However, landslide can also be triggered by seismic events and human activities. Shear viscosity of soil play a major role in the governing flow behavior and failure in soil. Knowledge of shear viscosity is important to understand the post failure flow properties in landslide. In a developing country like India, the susceptibility of slopes to failure has not been well mapped and prediction and early warning systems for disaster are not in place. There are some mitigation methods such as geometric method in which geometry of general slope is engineered, hydrological method in which soil moisture is controlled, chemical and mechanical method where shear strength of the soil is improved or piles or reinforced ground to counteract destabilizing forces. The present study focuses on water content due to excessive rains on shear viscosity of the soil. This in turn will affect the stability of foundations of many a structures. Tests were done using fall cone apparatus. The fall cone apparatus used in experimental study was connected to potentiometer and high speed data logger to record continuous data. Tests were conducted on clay sample thoroughly mixed with water and then kept overnight to ensure proper mixing. Cone was permitted to fall freely and time-penetration data recorded by logger is used to calculate viscosity. Obtained values of viscosity were observed decreasing with increase in liquidity index.***

***Keywords—Clay, Fall cone, Mass flow, Moisture content, Viscosity***

## I. INTRODUCTION

damage to life and property. Parameters like topography of area, rainfall intensity, and duration can affect on the phenomenon of mass flow. Ering and Babu (2016) performed back analysis using probabilistic method on rainfall induced landslide of Malin region. Also concluded that rainfall intensity and duration can affect on stability of slope. Fan et al. (2016) adapted Perla model to calculate hazard of debris flow run out including viscosity parameter for rainfall induced debris flow assessment.

Behavior of soil is considered as one of the important factor in such events. Soil is classified in four states according to moisture content as; solid state, semi-solid state, plastic and liquid state. Soil changes its characteristics in each of this state. When soil exceeds liquid limit it starts moving as liquid. This phase of soil is considered as viscous liquid phase. Viscosity explains the general behavior as it controls flow velocity. When viscosity value is low that time flow velocity is high.

Asch et al. (2007) considered viscosity parameter to predict field velocities using strain controlled test in ring shear apparatus and compared with viscosities obtained from back analyses. Lee and Widjaja (2013) conducted flow box test on Maokong soil sample to determine viscosity. It was concluded that viscosity changes when it comes closer to liquid limit and it triggers the flow. Soil shows the tendency to move as it comes in contact with water. Widjaja and Pratama (2015) conducted test on kaolin and Parakan Muncang soils to determine viscosity using flume channel instrument. Also notated that it is difficult to obtain viscosity value near liquid limit with conventional viscometer. This study follows the method given by Mahajan and Budhu (2009) in which instrumented fall cone penetrometer was used to determine viscosity close to liquid limit.

## II. Materials and Experimental Setup

In the present study, Marine clay was used collected from Mumbai coast. This soil had liquid limit (LL) of 75.92% and plastic limit (PL) of 31.74%. The specific gravity of clay was 2.82 and it comes under CH group. This soil has 8.2 pH values. Maximum dry density of 1.42 Mg/m³ at corresponding optimum moisture content of 22%.

A fall cone apparatus (BS 1377, British standard Institution, 1990) with 30º smooth cone was used in this study. Its dial gauge was replaced by potentiometer (LVDT) and connected to high speed data logger as previously done by Budhu (2009). Figure 1 shows the experimental set up. The total mass of cone assembly with cone, shaft and LVDT was 0.89N.

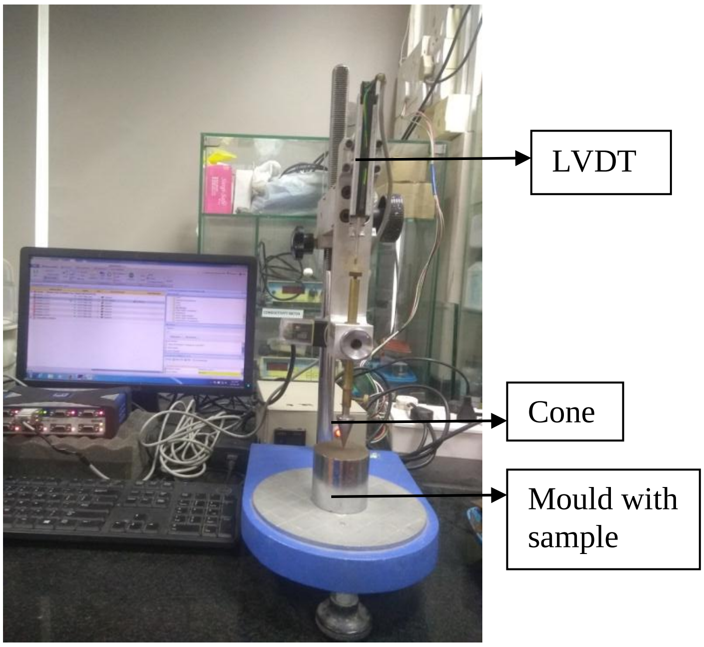


Fig. 1 fall cone apparatus connected to LVDT

To prepare the specimen 150g soil passing through 425μ IS sieve was used. Water was added step by step in small amount to get paste of require water content with uniform consistency. Then soil was kept in air-tight container for 24 hours to ensure uniform moisture distribution. Wet soil paste then poured in mould by tamping to remove the interrupted air. Surface was leveled using spatula. Then cone was fixed such that its tip just touches the surface of sample. It was allowed to fall freely for 5s. Automatic timer provides accuracy and avoids manual errors. Depth of penetration of cone was noted and small amount of specimen taken for moisture content determination. The total depth at which cone penetrates in sample is final depth of penetration. Moisture content was determined by oven dry method. Viscosity at different liquid index was calculated using procedure given by Budhu (2009).

## III. Results and discussion

Table 1 shows one of the trial result obtained by fall cone penetration which represents all the tests. Shear viscosity was determined using the equation proposed by Budhu (2009)

$$\mu = 2.94KW\sqrt{h_f}\,((\frac{0.67}{h_{eq}}) - (\frac{1}{h_f}))^2 \qquad (1)$$

where μ is the shear viscosity, $h_f$ is the final depth of penetration, $h_{eq}$ is equilibrium depth of penetration at which velocity reaches to its maximum as shown in fig. 3, K is modified cone factor (Koumoto and Houlsby, 2001) and W is weight of cone assembly.

**Table: 1** Results obtained from fall cone test

| Sr. No | $h_f$ mm | heq mm | Water Content % | LI | Weight N | $\tau_{cs}$ (kPa) | τ (kPa) | Ÿ / s | μ (pa s) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 12.82 | 4.5 | 66.8 | 0.79 | 0.89 | 7.20 | 26.13 | 3.00 | 1980 |
| 2 | 14.62 | 5.75 | 68.52 | 0.83 | 0.89 | 5.54 | 16.00 | 2.81 | 974 |
| 3 | 16.04 | 7 | 73.7 | 0.94 | 0.89 | 4.60 | 10.80 | 2.68 | 491 |
| 4 | 18.98 | 7.9 | 77.2 | 1.02 | 0.89 | 3.29 | 8.48 | 2.47 | 495 |
| 5 | 20.85 | 9.04 | 78.27 | 1.05 | 0.89 | 2.72 | 6.48 | 2.35 | 344 |
| 6 | 21.87 | 9.59 | 80.01 | 1.08 | 0.89 | 2.47 | 5.75 | 2.30 | 300 |
| 7 | 24.2 | 10.5 | 83.81 | 1.17 | 0.89 | 2.02 | 4.80 | 2.19 | 274 |

Figure 2 shows the variation of the penetration depth of the cone with time. Penetration depth versus time is plotted (Test 1 as representative of all tests) using the data obtained by logger. Cone penetrates due to its weight, it stops penetrating after reaching final depth and shows constant displacement.

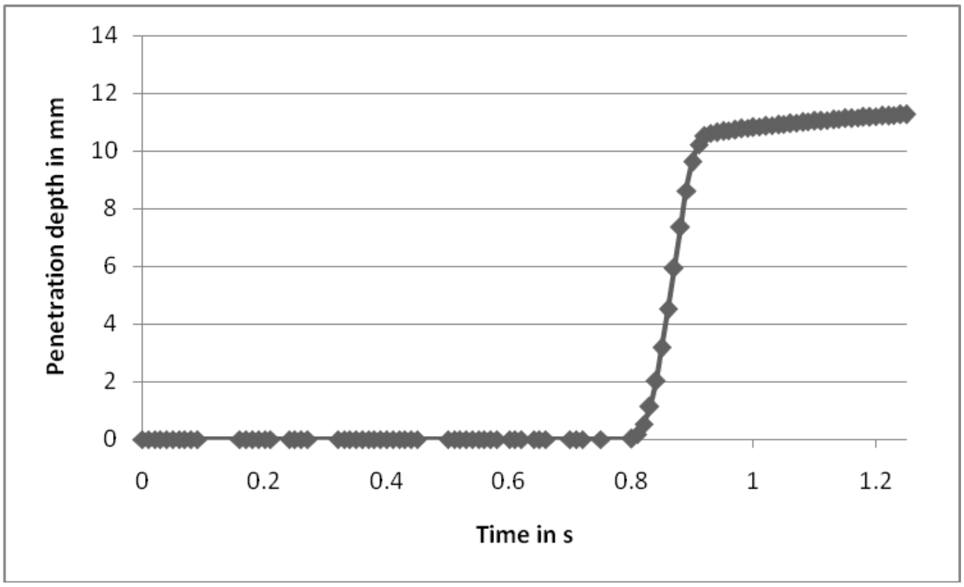


Fig. 2 Time penetration data obtained by data logger

Figure 3 shows plot of velocity versus penetration depth. Velocity is obtained by differentiating polynomial. When velocity of cone increases up to its maximum value at equilibrium depth and starts decreasing. In this case equilibrium height of 4.50mm obtained at maximum cone velocity of 142.65mm/s.

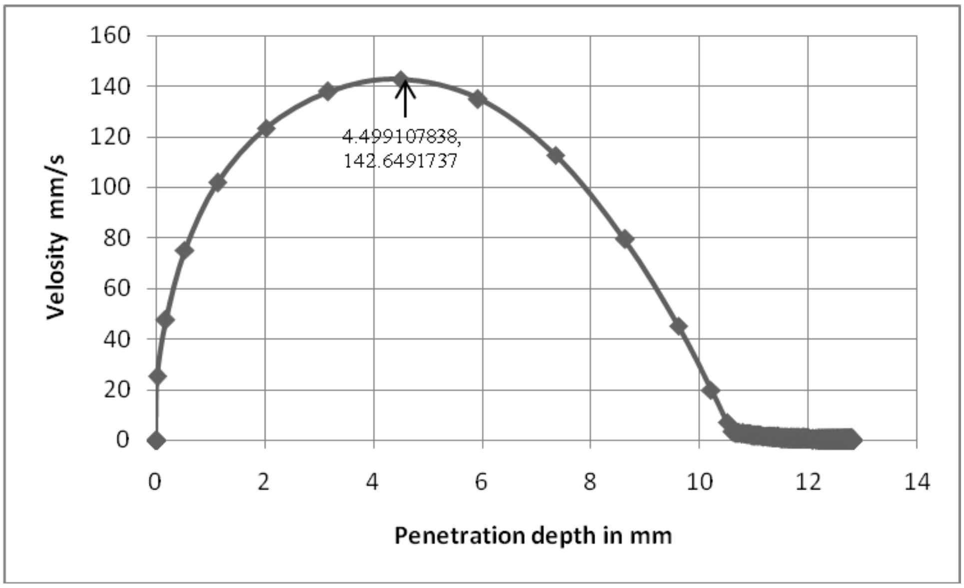


Fig. 3 Velocity versus penetration plot

Plot shows relationship between liquidity index and shear viscosity. Shear viscosity decrease exponentially with increase in liquidity index. As liquidity index passes one it enters viscous liquid state with increase in water content. After rainfall saturation of soil layer will occurs and reduces the viscosity. Decrease in viscosity reduces the friction between particle and some time it may lead to flow of soil mass during landslide.

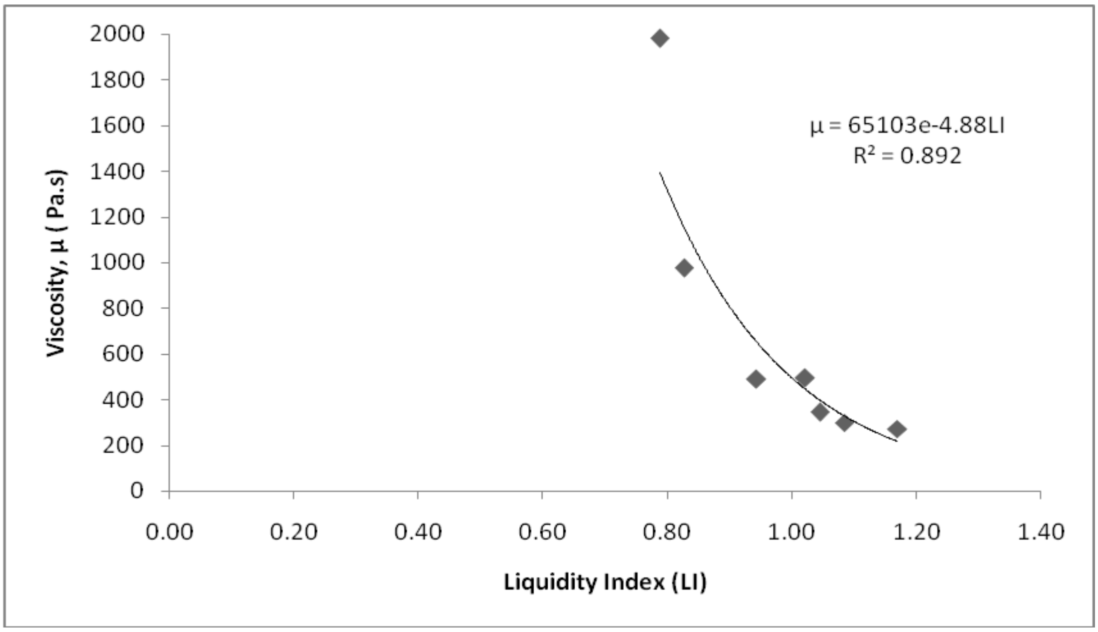


Fig. 4 Relationship between shear viscosity and liquidity index for marine clay

## IV. CONCLUSIONS

In this study fall cone shown reliable to estimate viscosity at low liquidity index. Simple fall cone test can be used to determine viscosity at LI less than 1.5. Conventional viscometer cannot gives viscosity near plastic limit. Viscosity deceases exponentially with increase in liquidity index. It shows characteristic of flow as increase in water content results in decreased viscosity. According to this rheological concept, soil starts flowing when water content increases more than liquid limit. So that viscous parameter can help to determine flow characteristics in early warning and mitigation for rainfall induced mass flow during landslides. It can be used in prior investigation of area where such events are counted very frequently, so that proper stabilization technique can be adopted as precautionary measure.

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