STEADY-FLOW OF A NON-HOMOGENEOUS BINGHAM MATERIAL OVER A WEDGE

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Summary A model for describing steady flow of a cementitious target over a wedge shaped penetrator is proposed. The target medium is described by a rate dependent constitutive equation that accounts for combined effects of strain rateand compaction on yielding. The influence of characteristics of the penetrator/target interface, impact velocity, target mechanical properties and nose geometry on the resistance to penetration is investigated.

Kinetic energy penetration phenomena are of interest in a variety of applications ranging from terminal ballistics to protection of spacecraft due to meteoroid impact, containment of high mass or high velocity debris due to accidents or high rate energy release, design of hardened protective facilities, erosion and fracture of solids due to impact, *etc*. The occurrence of multiple phenomena in the impacted material such as localization, plasticity, slip dependent friction, anisotropic damage, fragmentation pushes the limits of existing modeling and computational capabilities for description of the target response.

In this paper, a model for describing the flow of a cementitious material over a penetrator is proposed. The cementitious medium is described by a non-homogeneous Bingham with locked hydrostat (see [1],[2]). The rationale for adopting such a model is that it can account for both rate dependency and compaction effects on yielding, which are key properties of concrete or any other geologic material. The projectile is wedge-shaped

The extent of the domain affected by the impact event is considered to be 2 (F+1) R, where R is the shank radius, and F is an integer number estimated from tests. In the domain D_o, in front of the projectile, and in the domain D_f behind it, the target medium is moving as a rigid body with the striking velocity V, while in domain D_{visco} the material undergoes viscoplastic deformation. To reduce the complexity of the problem, we further suppose that in the viscoplastic domain D_{visco}, the flow lines are centered at a certain pole O.

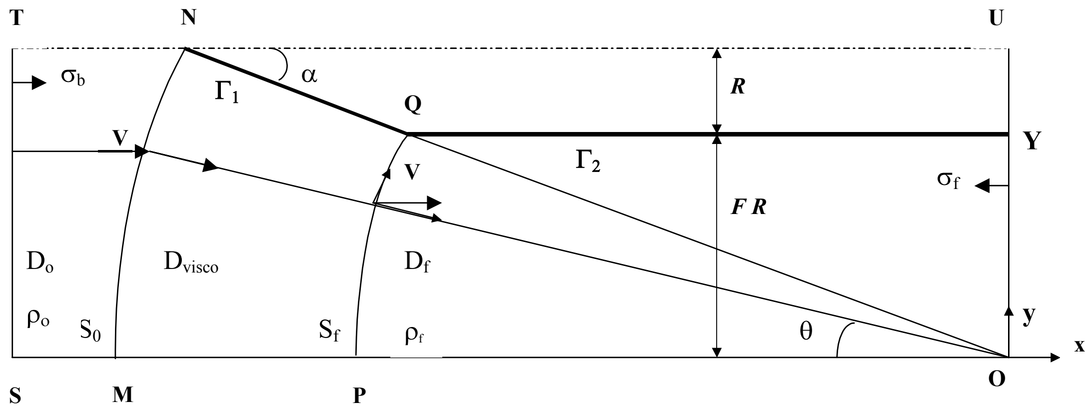

Figure 1: Schematic of the flow

The viscoplastic domain D_{visco} is bounded by the nose surface, Γ_1, MP, and the two surfaces S_0 and S_f. We assume that there exist velocity discontinuities tangent to the surfaces S_0 and S_f while the components of velocity normal to these surfaces are continuous. It follows that in the viscoplastic domain D_{visco}, the only non-zero velocity component is the radial component. From the continuity equation in D_{visco}, we obtain that the density in the viscoplastic domain is directly proportional to the inverse of the radius. Using the work-hardening law in conjunction with the radial compaction law for the material, the stress distribution in the viscoplastic domain is calculated. It is assumed that Coulomb friction law applies along the surface area of contact between the nose of the rigid projectile and the target. Along the surface area of contact between the compacted target material and the shank a slip-dependent friction law is considered. The resistance to penetration is calculated using the theorem of power expanded. Based on this analysis optimization of the wedge angle is performed. To illustrate the predictive capabilities of the model, its application to mortar is presented. The data available on mortar consists of laboratory quasi-static unconfined and confined compression tests for confining pressures in the range 50- 450 MPa under a strain rate of 10^{-6}/s and both confined and unconfined Split-Hopkinson bar data at strain rates of 60/s to 160/s. The theoretical resistance to penetration σ_b normalized by the locking pressure p^* as a function of the projectile semi-angle α for different striking velocities V is shown in Figure 2. For any given impact velocity, the minimum of each of the resistance to penetration vs. semi-angle curves corresponds to an optimum semi-angle nose. The plot of the optimal nose half-angles vs. the corresponding impact velocities is presented in Figure 3. Analysis of the effect of interface conditions shows that for the same impact velocity, at lower friction on the nose, the optimum nose angle is smaller. As expected, for the same impact velocity, at lower friction between the nose and target, a sharper nose projectile encounters less resistance to penetration.

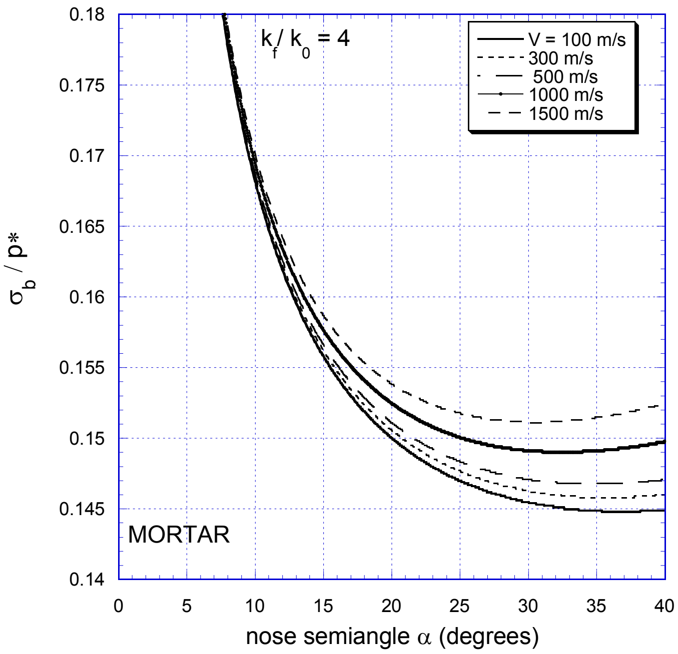

Figure 2: Resistance to penetration σ_b normalized by the locking pressure p^* for different striking velocities.

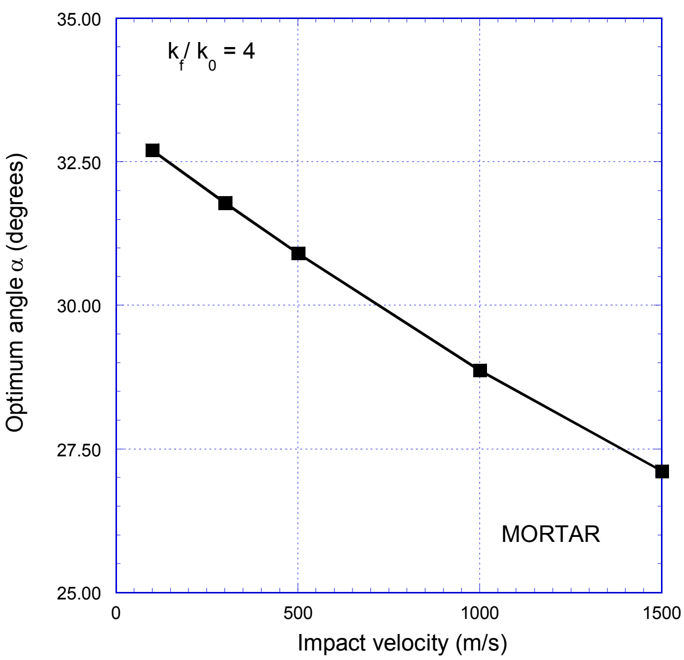

Figure 3: Optimum projectile semi-angle vs. impact velocity.

References

[1] Cazacu, O. and Cristescu, N. D. *Italian Geotechnical Journal*, **34**, (3), 44-54, 2000.

[2] Cristescu, N. D., Cazacu, O.,and Cristescu, C. A Model for Landslides, *Canadian Geotechnical Journal*, **39**, 924-937, 2002.