HYPERCONCENTRATED FLOW CLASSIFICATION, RHEOLOGY AND STRUCTURAL DESIGN

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Objective

Provide guidelines for designing mitigation countermeasures based on the type of hyperconcentrated flow
Rheology of Hyperconcentrated Sediment Flows

Total shear stress:

$$\tau = \tau_y + \tau_v + \tau_t + \tau_d$$

- Yield stress
- Viscous stress
- Turbulent stress
- Dispersive stress
Quadratic rheological equation
(O’Brien and Julien, 1985)

\[ \tau = \tau_y + \eta \frac{du}{dy} + \zeta \left( \frac{du}{dy} \right)^2 \]

- **Yield stress**: \( \tau_y = \tau_c + \tau_{mc} \)
- **Viscous stress**: \( \eta \frac{du}{dy} \)
- **Turbulent stress**: \( \zeta \left( \frac{du}{dy} \right)^2 \)
- **Dispersive stress**: \( \zeta = \rho_m l_m^2 + a_i \rho_s \lambda^2 d_s^2 \)
Dimensionless quadratic rheological model
(Julien and Lan, 1991)

\[ \tau^* = 1 + (1 + T_d^*) a_i D_v^* \]

\[ \tau^* = \frac{\tau - \tau_y}{\eta \frac{du}{dy}} \]

\[ T_d^* = \frac{\rho_m l_m^2}{a_i \rho_s \lambda^2 d_s^2} \]

\[ D_v^* = \frac{\rho_s \lambda^2 d_s^2}{\eta} \left( \frac{du}{dy} \right) \]

Low \( \tau^* \)
Viscous Flow

High \( T_d^* \)
Turbulent Flow

High \( D_v^* \)
Dispersive Flow
Dimensionless quadratic rheological model

![Graph showing the relationship between dimensionless shear stress and dimensionless dispersive-viscous ratio. The graph includes data points from Govier et al. (1957), Bagnold (1954), and Savage and McKeown (1983).]
Flow Classification

Viscous $\rightarrow$ Mudflow
$D_v^* < 30$

Turbulent $\rightarrow$ Mud Flood
$D_v^* > 400$ and $T_d^* > 1$

Dispersive $\rightarrow$ Debris Flow
$D_v^* > 400$ and $T_d^* < 1$
Mudflow

- High viscosity and yield stress
- High concentration of silts and clays
- $45\% < C_v < 55\%$
- Low velocity
- Low Froude Number
- No abrasion
- Large flow depths
- High pressure
Mud Flood

- Turbulent
- Non-cohesive particles
- Cv as high as 40%
- High velocity
- High Froude Number
- Abrasive
Debris Flow

- Dispersive
- Large clastic particles
- Non cohesive
- Low viscosity
- High velocity
- Destructive impact force

Images showing debris flow at 6 sec and 7 sec.
Countermeasures

Mudflow Features:
- High viscosity and yield stress
- High concentration of silt and clay
- $45\% < \text{Cv} < 55\%$
- Low Froude Number
- No abrasion

Effective Solution → Store, Deflect, Spread
- Storage basins
- Deflection walls
Storage Basin
Countermeasures

Mud Flood Features:
- Turbulent
- Non cohesive particles
- $C_v$ as high as 40%
- High Froude Number
- Abrasive

Effective Solution ➔ Convey
- Straight channels
- Lined canals, berm and levee channels
- Drop structures, energy dissipators
Lined canal with drop structures
Countermeasures

Debris Flow Features:
- Dispersive
- Large clastic particles
- Low viscosity
- Large velocity
- High impact

Effective Solution  Retain large clasts
                   Drain fluid matrix

- Concrete Sabo dams
- Steel frames and debris rakes
Sabo Dam Construction
Sabo Dam and Steel Frames
Debris Rakes
Conclusions

- Quadratic rheological model describes continuum of hyperconcentrated flow behavior

- Mudflows exhibit high yield and viscous stresses
- Mud floods have dominant turbulent stress
- Debris flows have dominant dispersive stress
Conclusions

• Mitigation structures for mudflows
  » Detention basins
  » Deflection walls

• Mitigation structures for mud floods
  » Straight channels
  » Lined canals, berm and levee channels
  » Drop structures, energy dissipators

• Mitigation structures for debris flows
  » Concrete Sabo dams
  » Steel frames and debris rakes