Development of IMPACT35
- 3D Model -

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References


Hydrodynamic Characteristics
Cylinder: X (COM), B (COV)
Triple Coordinate Transform

- Earth-fixed coordinate (E-coordinate)

- Cylinder’s main-axis following coordinate (M-coordinate)

- Hydrodynamic force following coordinate (F-coordinate).
\[ \mathbf{j}_M = \mathbf{k} \times \mathbf{i}_M, \quad \mathbf{k}_M = \mathbf{i}_M \times \mathbf{j}_M \]
E-Coordinate, $F_E(O, i, j, k)$

- COM Position: $X = xi + yj + zk$

- Translation velocity:

  \[ \frac{dX}{dt} = V, \quad V = (u, v, w) \]
Transform Between E- and M-Coordinate Systems

\[ E_M \mathbf{R}(\psi_2, \psi_3) \equiv \begin{bmatrix} r_{11} & r_{12} & r_{13} \\ r_{21} & r_{22} & r_{23} \\ r_{31} & r_{32} & r_{33} \end{bmatrix} \]

\[
= \begin{bmatrix} \cos \psi_3 & -\sin \psi_3 & 0 \\ \sin \psi_3 & \cos \psi_3 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \cos \psi_2 & 0 & \sin \psi_2 \\ 0 & 1 & 0 \\ -\sin \psi_2 & 0 & \cos \psi_2 \end{bmatrix},
\]
F-Coordinate System
E- and F-Coordinate Transform

\[
i_F = i_M = \begin{bmatrix} r_{11} \\ r_{21} \\ r_{31} \end{bmatrix}, \quad j_F = \frac{\mathbf{V}_2}{|\mathbf{V}_2|}, \quad k_F = i_F \times j_F.
\]

\[
^E_F \mathbf{R}(\psi_2, \psi_3, \phi_{MF}) = \begin{bmatrix} r_{11} & r_{12} & r_{13} \\ r_{21} & r_{22} & r_{23} \\ r_{31} & r_{32} & r_{33} \end{bmatrix},
\]
Momentum Equation in E-Coordinate System

\[
\frac{d}{dt} \begin{bmatrix} u \\ v \\ w \end{bmatrix} = -\begin{bmatrix} 0 \\ 0 \\ (1 - \rho_w / \bar{\rho}) g \end{bmatrix} + \frac{1}{\rho\Pi} \begin{bmatrix} F_x \\ F_y \\ F_z \end{bmatrix},
\]
Moment of Momentum Equation in M-Coordinate System

\[ J \cdot \frac{d\omega}{dt} = M_b + M_h, \]
M-Coordinate

The moment of gyration tensor for the axially Symmetric cylinder is a diagonal matrix

\[
\mathbf{J} = \begin{bmatrix}
J_1 & 0 & 0 \\
0 & J_2 & 0 \\
0 & 0 & J_3
\end{bmatrix},
\]
Moment of Momentum Equations

\[ \frac{d\omega_1}{dt} = -a_1\omega_1, \]

\[ \frac{d}{dt} \begin{bmatrix} \omega_2 \\ \omega_3 \end{bmatrix} = -B \cdot \begin{bmatrix} \omega_2 \\ \omega_3 \end{bmatrix} + a_2, \]
F-Coordinate

Hydrodynamic forces (drag and lift) are easily calculated.

\[ M_{y1} = -C_{m1} \omega_1 i_F, \quad C_{m1} \equiv \pi \mu L d^2. \]
Interfacial Penetration Modeling
M-Coordinate System
Equivalent Cylinder
Penetration into Sediment
Experiments

- Mine Drop Experiment (MIDEX, 1/20th Scale)
  - June 2001 (NPS Swimming Pool)

- Mine Impact Burial Experiment (MIBEX, Near Full Scale)
  - May 23, 2000 (Monterey Bay, Sand Bottom)
MIDEX

• Cylinder Parameters:

  1. Density Ratio (1.68, 1.70, 1.88)
  2. Center of Mass Position.
  3. L/D ratio.

• Drop Parameters:

  1. Drop Angles: 15°, 30°, 45°, 60°, 75°.
  2. Release Velocity $V_{\text{init}}$
Injector

Light Sensor

To Universal Counter

Drop Angle Control Device

Shapes:
Length: 15, 12, 9 cm
Diameter: 4 cm
Coordinate System

- X
- Y
- Z

Mine Injector

Camera (4' Above Deck)

Camera (4' Above Deck)
Center of Mass

MODEL # 1
L=15.1359 cm  D=4 cm  m=2.7 cm
Weight=322.5 g  Volume=190.2028 cm³  Density=1.6956 g/cm³
H:  10.360  8.052  5.725 cm
h:  -1.462  0.866  3.193 cm
M:  0.000  18.468  36.935 mm

MODEL # 2
L=12.0726 cm  D=4 cm  m=1.7 cm
Weight=254.2 g  Volume=151.709 cm³  Density=1.6756 g/cm³
H:  8.450  6.609  4.768 cm
h:  -1.564  0.277  2.119 cm
M:  0.000  12.145  24.290 mm

MODEL # 3
L=9.1199 cm  D=4 cm  m=1.47 cm
Weight=215.3 g  Volume=114.6037 cm³  Density=1.8786 g/cm³
H:  6.662  5.592  4.521 cm
h:  -1.368  -0.297  0.774 cm
M:  0.000  6.847  13.694 mm

Defined COM position as:
2 or -2: Farthest from volumetric center
1 or -1
0: Coincides with volumetric center
Data Analysis

1. Video converted to digital format.
2. Digital video from each camera analyzed frame by frame (30Hz) using video editing program.
3. Mine’s top and bottom position determined using background x-z and y-z grids. Positions manually entered into MATLAB for storage and later processing.
4. Analyzed 2-D data to obtain mine’s x,y and z center positions, attitude (angle with respect to z axis) and u,v, and w components.
Sources of Error

1. Grid plane behind mine trajectory plane. Results in mine appearing larger than normal.
2. Position data affected by parallax distortion and binocular disparity.
3. Air cavity affects on mine motion not considered in calculations.
4. Camera plane not parallel to x-y plane due to pool slope.
Model-Data Comparison
Model-Data Comparison
Gravity Cores During MIBEX (5/21/2000)
Model-Data Comparison

![Graph showing model data comparison](image)
Conclusions

• Triple coordinate transform is an effective method to predict 3D movement of cylinder in air, water, and sediment columns.

• Momentum equation (E-coordinate)

• Moment of momentum equation (M-coordinate)

• Hydrodynamic forces and torques (F-coordinate)
Future Work

• (1) Extensive Model Verification
  • NRL (Dr. Phil Valent)
  • JHU-APL (Drs. Alan Brandt, Sarah Rennie)
  • FWG (Dr. Thomas Wever)

• (2) Extension the IMPACT35 for Cylindrical Mines to Naval Operational Mines
  • Korean Mines, Bowen Mines, Psi Mines
  • KW36, KW52, KWDST, KWGE, KWIT
  • Mark36N, Mark52 …