MODULE – 7
Dynamic Soil-Structure Interaction
Dynamic Earth Pressures on Retaining Walls

- Design of retaining wall under seismic condition is very important in earthquake prone areas to reduce the devastating effect of earthquake.
- Evaluation of earth pressure under seismic condition is important.
- Several methods are available to compute dynamic earth pressures viz.
  (1) Force-based analysis
  (2) Displacement-based analysis.

Force-Based Analysis

- **Pseudo-static method**
  - Limit Analysis [Soubra (2000) etc.]
  - Method of Characteristics [Kumar (2001) etc.]
  - Finite Element method [Richards et al. (1999) etc.]

- **Pseudo-dynamic method**

- **Dynamic analysis using MSD model**
Displacement-Based Analysis

Richards and Elms (1979),
Prakash (1981),
Nadim and Whitman (1983)
Choudhury and Chatterjee (2007)
etc.

Pseudo-Static Analysis

Failure surface and the forces considered by
Mononobe-Okabe (1926, 1929)
Dynamic Earth Pressures As Per Seismic Codes

**IS 1893: 1984, Part 3 (Bridges and Retaining Walls)**
- Using pseudo-static approach to evaluate stability of retaining walls.
- Compute seismic earth pressure using Mononobe-Okabe equations.
- Dynamic increment of earth pressure will act at mid height of the wall.
- Effect of dry, partially submerged and saturated backfill is considered.
- Range of permissible displacement is not specified.

Dynamic Earth Pressures As Per Seismic Codes

**As per Eurocode 8**
- Based on pseudo-static analysis.
- Compute seismic earth pressure using Richards and Elms model.
- Permissible displacement for sliding and rocking movement of the wall are considered.
- Included non-linear behaviour in base soil and backfill.
- The point of application of the dynamic earth pressure increment is at mid-height of the wall.
- Hydrodynamic forces @0.4H from base of the wall for saturated layer is assumed to act.
Dynamic Analysis using MSD Model


Basic SDOF Mass-Spring-Dashpot (MSD) Model by Scott (1973)
Dynamic Analysis using MSD Model

\[ m \ddot{x} + C_{xbs} \dot{x} + K_{xbs} x = m \ddot{x}_g \]

\[ |Q_b| = K_{xbs} \dot{x} + C_{xbs} \dot{x} \]

\[ k = m (\pi^2 / 4H^2)(G/\rho) \]

[Veletsos and Younan (1994)]

SOIL DYNAMICS

Dynamic Analysis using MSD Model

2 – DOF MSD Model considered for Retaining Wall by Choudhury and Chatterjee (2006)

**Dynamic Analysis using MSD Model**

Free Body Diagrams of Mass (a) $M_1$ and (b) $M_2$

[Choudhury and Chatterjee (2006)]

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**Mononobe-Okabe Method (1926, 1929)**

\[
P_{ae,pe} = \frac{1}{2} \gamma H^2 (1 - k_v) K_{ae,pe}
\]

\[
K_{ae,pe} = \frac{\cos^2(\phi + \beta - \theta)}{\cos \theta \cos^2 \beta \cos(\delta \pm \beta + \theta) \left[1 - \left(\frac{\sin(\phi + \delta) \sin(\phi + i - \theta)}{\cos(\delta + \beta + \theta) \cos(i - \beta)}\right)^{0.5}\right]^2}
\]

\[
\theta = \tan^{-1} \left[\frac{k_h}{1 - k_v}\right]
\]
Model considered by Choudhury and Nimbalkar (2006) for active earth pressure

\[ a_h(z, t) = a_h \sin \left[ \omega \left\{ t - \frac{(H - z)}{V_s} \right\} \right] \]

\[ a_v(z, t) = a_v \sin \left[ \omega \left\{ t - \frac{(H - z)}{V_p} \right\} \right] \]

where \( \omega \) = angular frequency; \( t \) = time elapsed;
\( V_s \) = shear wave velocity; \( V_p \) = primary wave velocity

\[ Q_h(t) = \int_0^H m(z)a_h(z, t)dz \]

\[ Q_v(t) = \int_0^H m(z)a_v(z, t)dz \]

The total (static plus dynamic) active thrust is given by,

\[ P_{ae}(t) = \frac{W\sin(\alpha - \phi) + Q_h(t)\cos(\alpha - \phi) - Q_v(t)\sin(\alpha - \phi)}{\cos(\delta + \phi - \alpha)} \]
Dynamic Analysis using MSD Model

Governing Equation of Motion of 2-DOF MSD Model for Rigid Retaining Wall,

\[
\begin{pmatrix}
M_1 & 0 \\
0 & M_2
\end{pmatrix}
\begin{bmatrix}
\ddot{x}_1 \\
\ddot{x}_2
\end{bmatrix}
+ \begin{pmatrix}
(c_1 + c_2) & -c_2 \\
-c_2 & c_2
\end{pmatrix}
\begin{bmatrix}
\dot{x}_1 \\
\dot{x}_2
\end{bmatrix}
+ \begin{pmatrix}
(k_1 + k_2) & -k_2 \\
-k_2 & k_2
\end{pmatrix}
\begin{bmatrix}
x_1 \\
x_2
\end{bmatrix}
= \begin{bmatrix}
f_1(t) \\
0
\end{bmatrix}
\]

Dynamic Active Earth Pressure on the Wall,

\[|Q_b| = M_2 \ddot{x}_2 + c_2 (\dot{x}_2 - \dot{x}_1) + k_2 (x_2 - x_1)\]

Effect of damping on non-dimensional dynamic earth force with harmonically excited system having \(\mu_{\text{soil}} = 0.3\) 

[Choudhury and Chatterjee (2006)]
Dynamic Analysis using MSD Model

Comparison between SDOF and 2-DOF model results
[Choudhury and Chatterjee (2006)]

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