SEISMIC PERFORMANCE OF EMBANKMENTS

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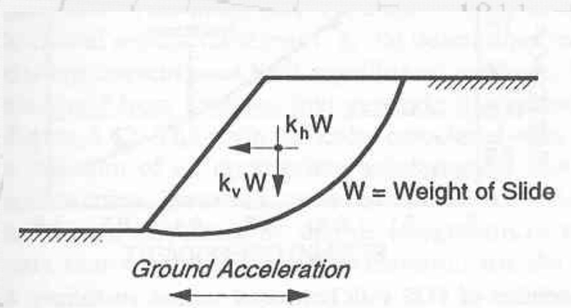
FAILURE MODES

- Slope failure
  - Rotational Slide
  - Block Slide
- Lateral Spreading and Associated Settlement

METHODS OF ANALYSIS

- Pseudostatic analysis,
- Newmark sliding block analysis,
- Makdisi-Seed analysis,
- Stress-deformation analysis,
- Physical modeling (shaking table testing, etc.).

PSEUDOSTATIC ANALYSIS



- A horizontal, down-slope inertia force (M*a) is applied to the sliding mass.
- $a=k_hW$
- Routine slope stability analyses conducted
  - Bishop
  - Method of slices,
  - Etc.

- Advantages
  - Relatively simple
  - Produces and index of stability (FS)
- Disadvantages
  - Rigid body analysis
  - Cannot simulate complex dynamic effects
  - Cannot evaluate influence of porewater pressure buildup
  - Cannot evaluate effect of degradation of shear strength.

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Embankment - 5

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Newmark Sliding Block Analysis

- First method to assess stability in terms of deformations rather than factor of safety.
- Assumes rigid-plastic materials
- Assumes knowledge of the time history of the acceleration acting on the embankment.

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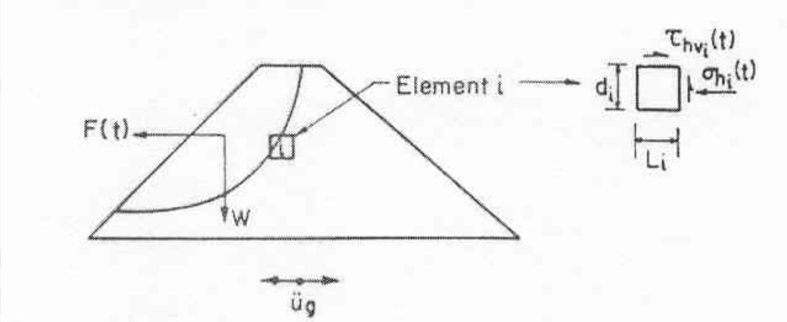
- Advantages
  - Estimates deformations
  - Relatively easy to use.
- Disadvantages
  - Potential failure mass and embankment are assumed to be rigid
  - Lateral displacements may be out of phase with the inertial forces at different points .
  - Can significantly over predict deformations

Makdisi-Seed Analysis

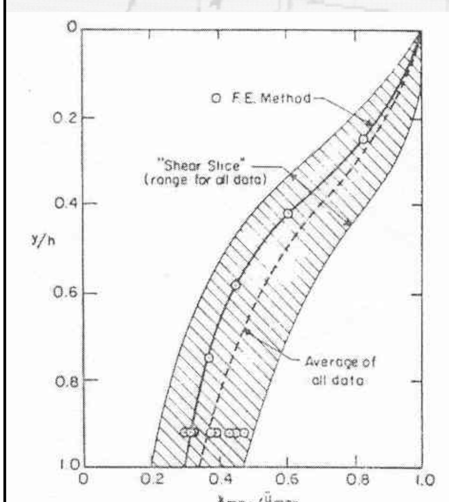
- Based on the sliding block method
- Uses average accelerations and the shear beam method.
  - Plot of average maximum acceleration with depth of the potential failure surface
  - Plot of normalized permanent displacement with yield acceleration.

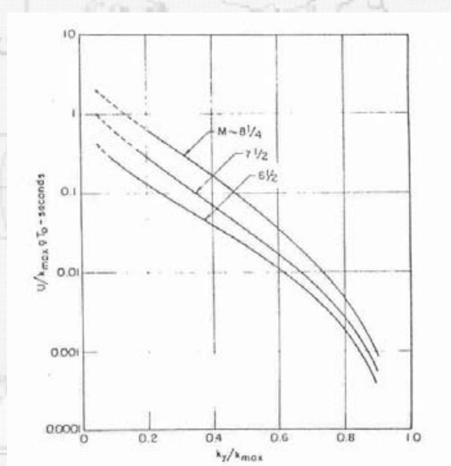


$$F(t) = \sum_{i=1}^{n} \tau_{hv_i}(t)\, L_i + \sigma_{h_i}(t)\, d_i$$

n = number of elements along the sliding surface

$$k_{av}(t) = F(t)/W$$

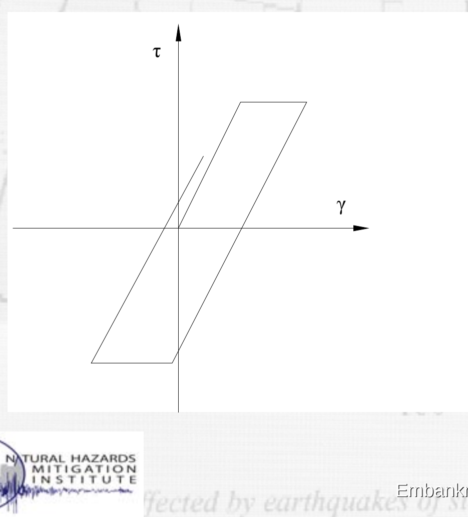


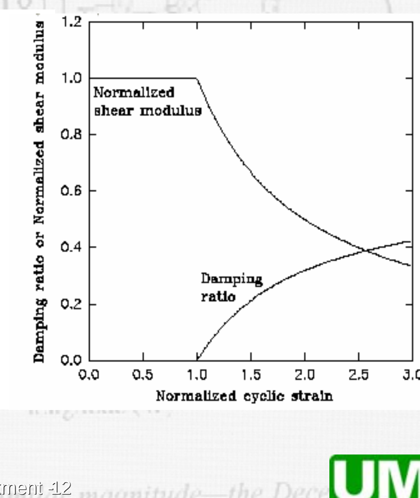


STRESS-DEFORMATION

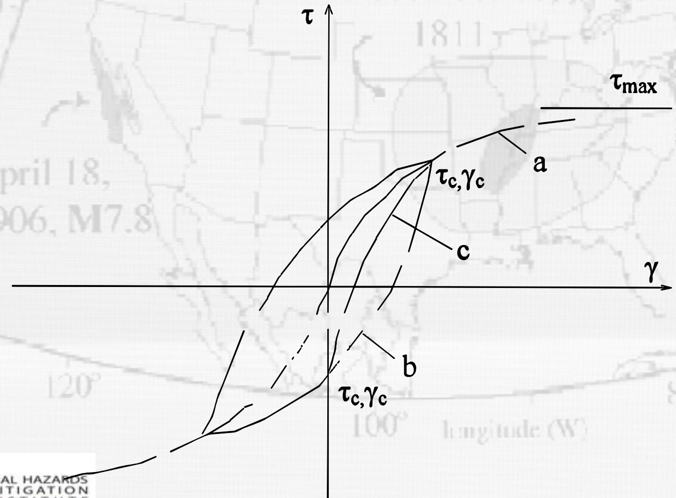
- Dynamic computer programs
  - Strain potential approach
    - TARA-3
  - Stiffness reduction approach
    - DYNAFLOW
  - Nonlinear analysis approach
    - Finn Models (FLAC)
    - Hyperbolic model

Finn Model





Hyperbolic-Martin/Byrne Model



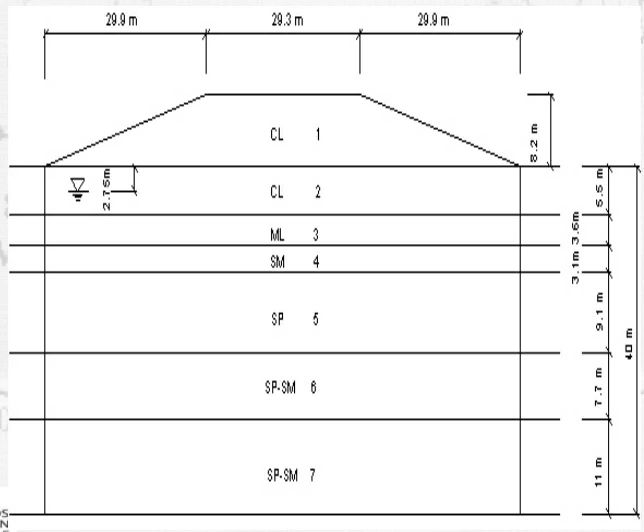
Pore Pressure Calculation

$$\Delta p = -\frac{k_w}{n}\Delta\varepsilon_{ii}$$

$$\Delta\sigma_{ij} = 2G\Delta\varepsilon_{ij}$$

$$\frac{1}{3}\Delta\sigma_{ii} = (k + \frac{k_w}{n})\Delta\varepsilon_{ii}$$

EMBANKMENT MODELING



Soil unit	Soil Material	Density (Mg/m^3)	(kPa)	(°)	Shear modulus G (kPa)	Porosity n	$(N_1)_{60}$
1	CL	2023	10.8	25	59848	0.4	19
2	CL	1947	34.5	25	44393	0.44	11
3	ML	1876	0	32	56136	0.48	9
4	SM	2161	0	31	89935	0.3	8
5	SP	2181	0	45	118429	0.28	40
6	SP-SM	2120	0	44	112163	0.32	36
7	SP-SM	1916	0	44	179445	0.44	36

Embankment modeling

- Two cases studied
  - Embankment alone
  - Embankment with soil beneath
- Two source ground motions
  - motion at the ground surface
  - motion at 40 m below the ground surface.

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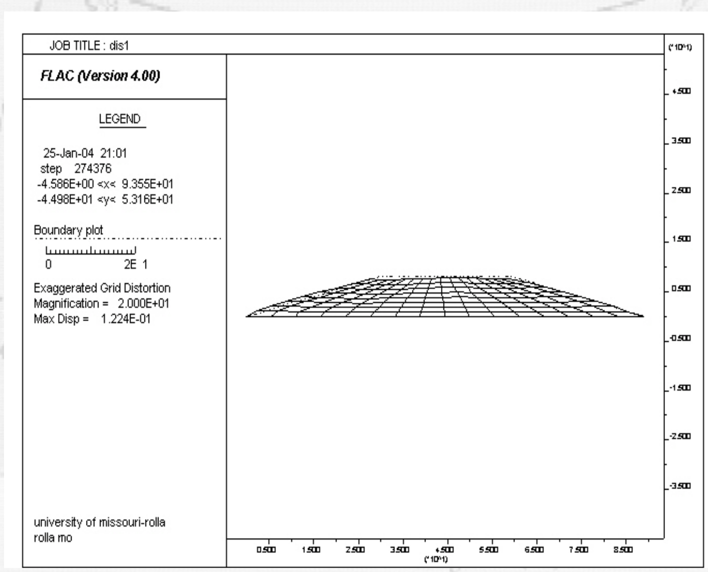
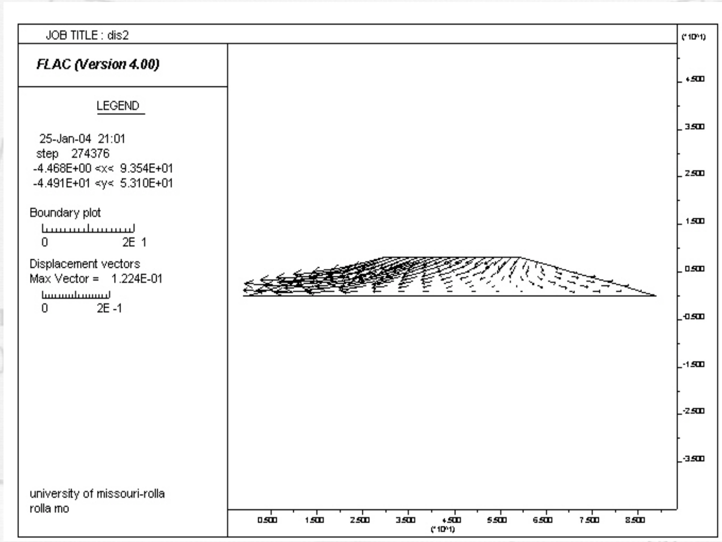
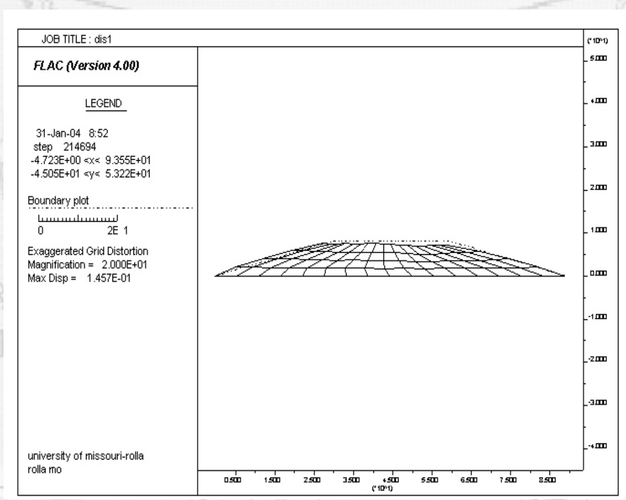


Finn Model

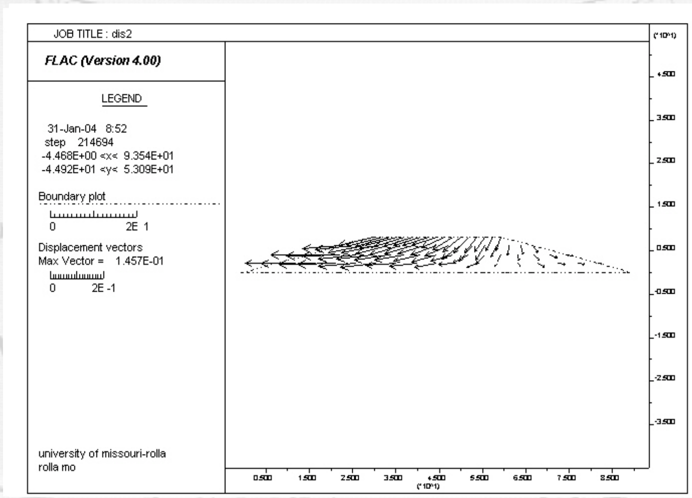
Embankment -18



Finn Model



Hyperbolic model



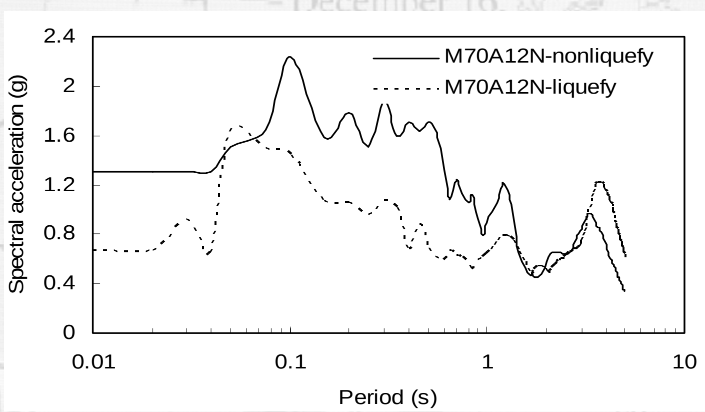
Hyperbolic model

LIQUEFACTION EFFECT ON THE DEFORMATIONS OF THE EMBANKMENTS

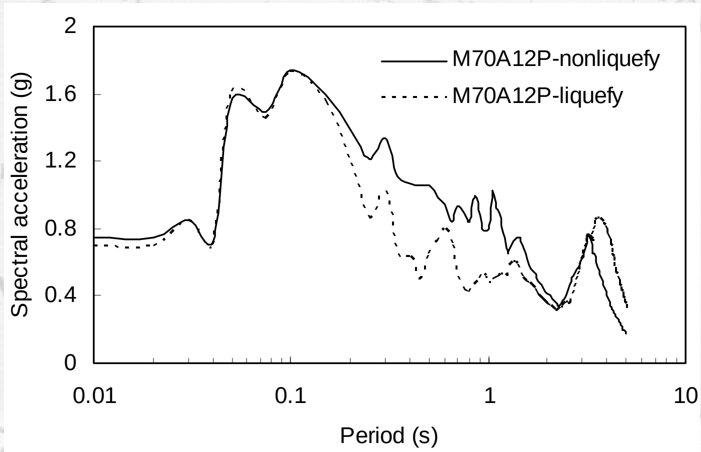
Two cases studied:

- Input motion without accounting for liquefaction of the subsoils.
- Input motion accounting for liquefaction of the subsoils.
  - Free-field site response analyses were performed to obtain acceleration-time histories at the level ground surface as input motions for the dynamic analysis of the approach embankments.

Response Spectra



Normal Direction



Parallel direction

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Results

- Spectral accelerations for the cases accounting for liquefaction are smaller than those without accounting for liquefaction.
- Predominant period shift to a shorter period in the normal direction.

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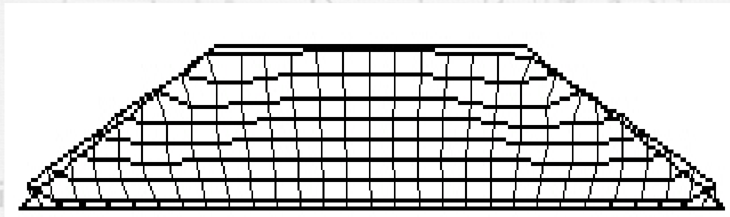
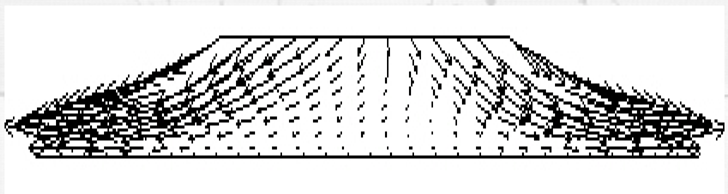
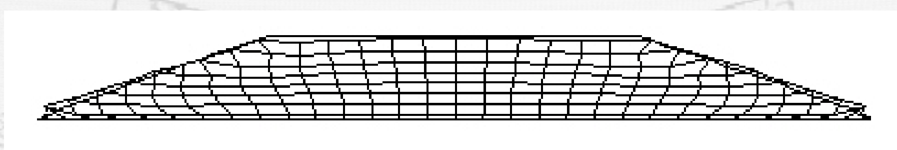
DEFORMATIONS

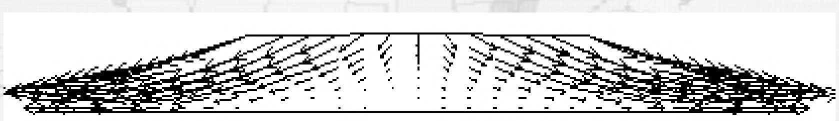




Normal direction w/o liquefaction

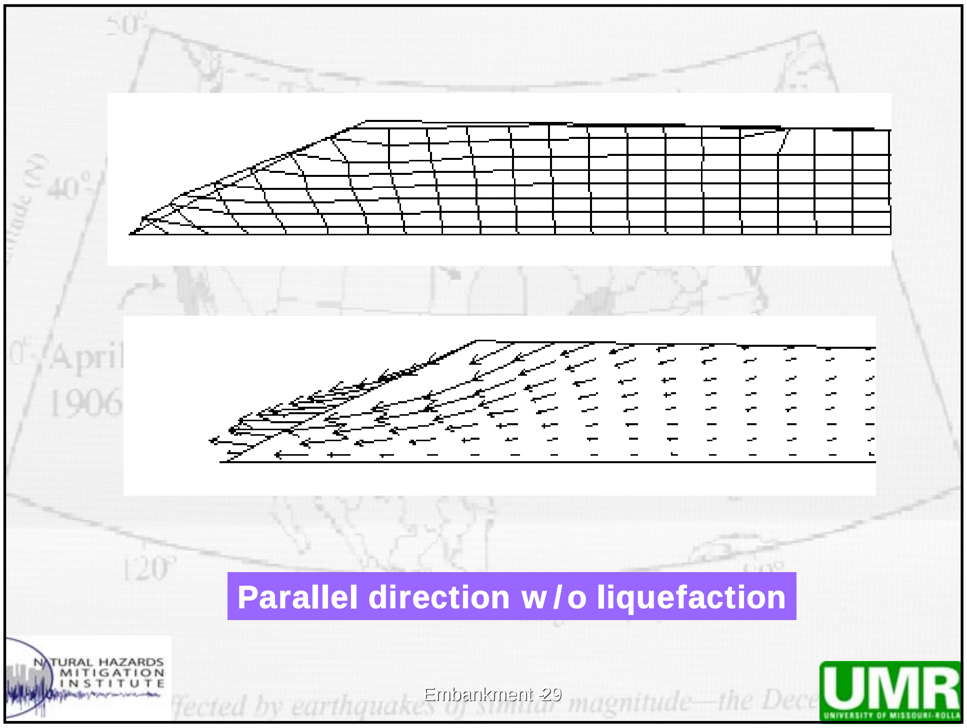
Embankment 27





Normal direction with liquefaction

Embankment 28


Parallel direction w/o liquefaction
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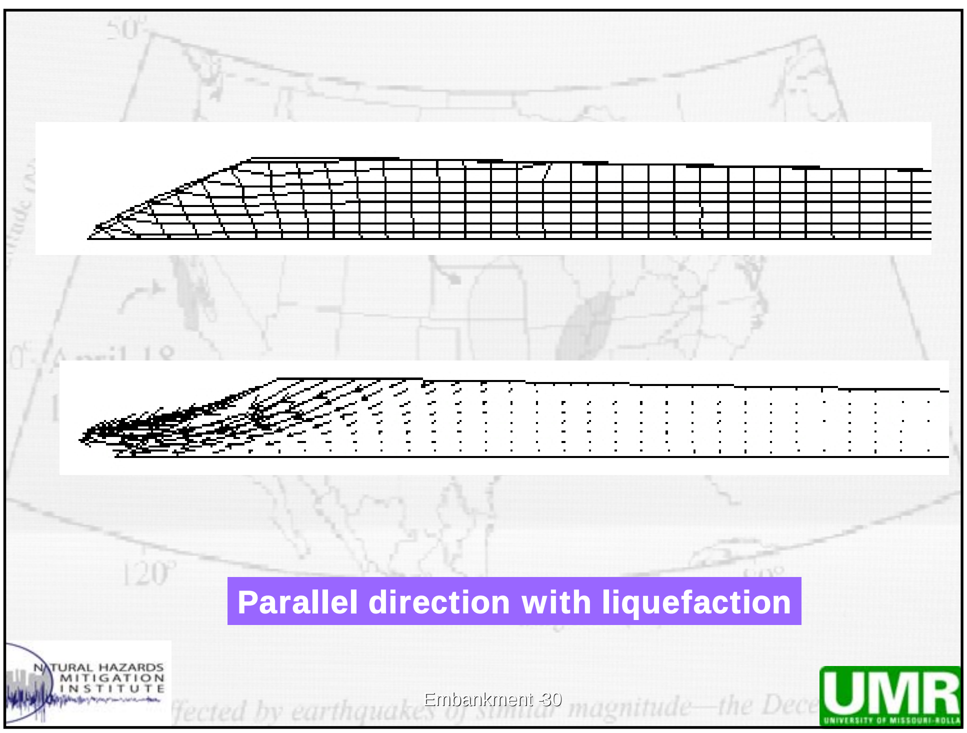
Parallel direction with liquefaction
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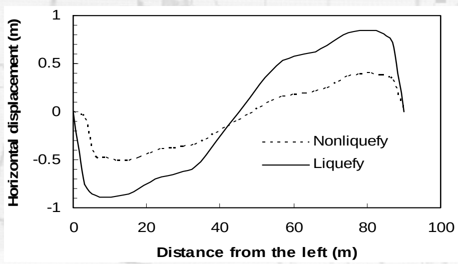
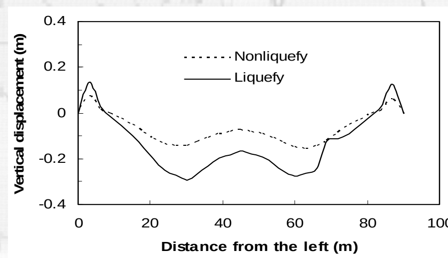
Displacements along embankment profile Normal Direction





Horizontal **Vertical**

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CONCLUSIONS

- Large deformations will occur with a large earthquake.
- Deformations mainly due to foundation soil movement.
- Lateral spreading may occur.

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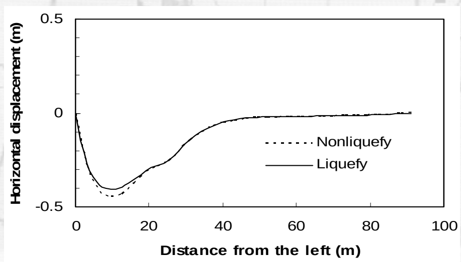
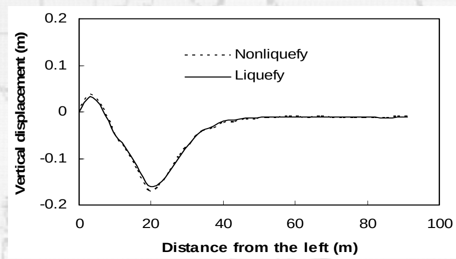
Displacements along embankment profile Parallel Direction





Horizontal **Vertical**

Shake Table Testing

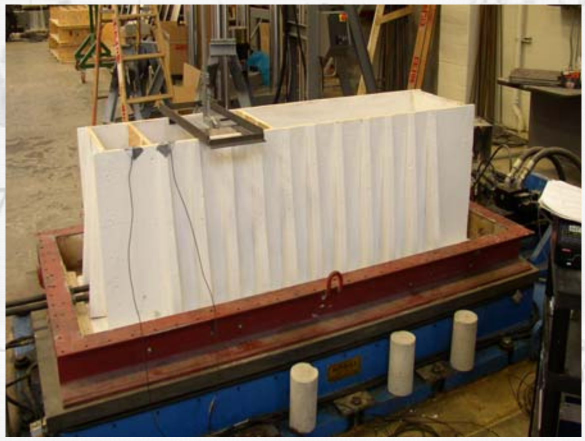
Purpose

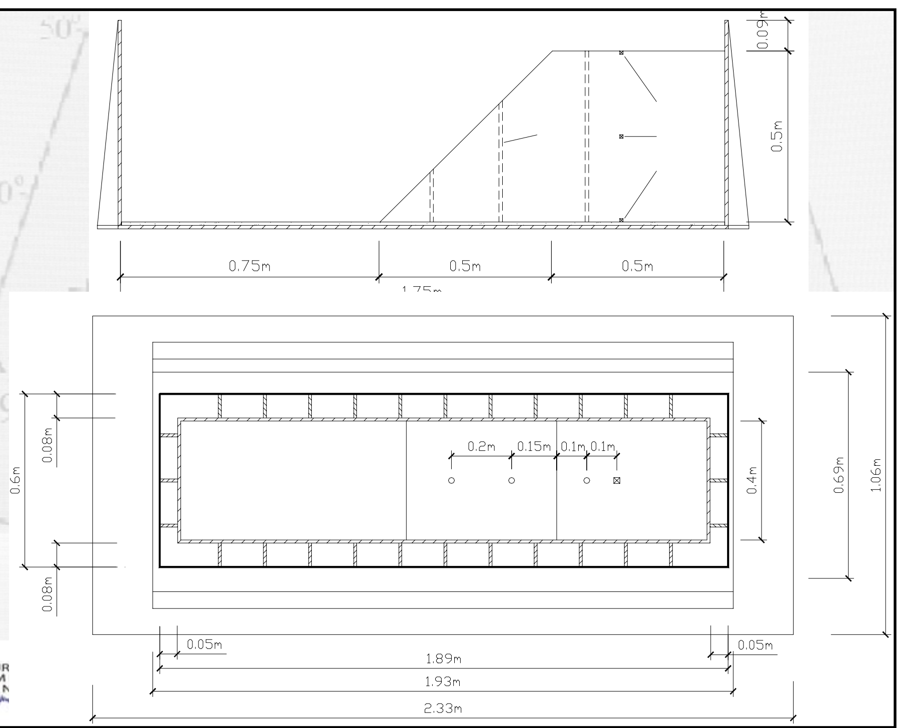
- Determine the shaking-induced displacement and dynamic response of a model of the A1466 embankment and to compare it to the numerical model.

Scaling Laws

Mass Density	1	Acceleration	1	Length	λ
Force	λ^3	Shear Wave Velocity	$\lambda^{1/2}$	Stress	λ
Stiffness	λ^{2}	Time	$\lambda^{1/2}$	Strain	1
Modulus	λ	Frequency	$\lambda^{-1/2}$	-	-

CONTAINER




0.09m
0.5m
0.75m
0.5m
0.5m
1.75m
0.2m
0.15m
0.1m
0.1m
0.08m
0.6m
0.08m
0.4m
0.69m
1.06m
0.05m
0.05m
1.89m
1.93m
2.33m

Deformations