Blasting Effects On Impoundments

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Definition of Liquefaction

- Traditionally, the term “liquefaction” was used to describe several related, but distinctly different phenomena :

1. Flow slide failures of embankments and dams
2. Lateral spreading of gently sloping ground
3. The development of 100% pore pressure during undrained cyclic loading
4. The development of high shear strains and/or high excess pore pressures in cyclic laboratory tests.

Terms used in MSHA’s Engineering and Design Manual

- Cyclic Mobility – Progressive softening and resulting large cyclic strains
- Flow slide – shear strength approaches the steady state or residual strength – very large strains
- Strength loss – shear strength between peak undrained strength and steady state strength

- For this presentation, the term liquefaction will be used to describe flow slides, cyclic mobility, and strength loss.

Blast-Induced Liquefaction Cases

- Calaveras Dam, California - 1918
- Swir III Dam, Russia – 1935
- Hague, the Netherlands – World War II
- Pacific Attolls – 1950’s
- Snowball Event, Canada – 1964
- Prairie Flat Event, Canada – 1968
- Dial Pack Event, Canada – 1970
- Pre-Dice Throw, New Mexico – 1975
- Hayman Igloo Test, Utah - 1988
- Source: “Soil Liquefaction Resulting from Blast-Induced Spherical Stress Waves,” Thomas Bretz, 1990

Calaveras Dam

Calaveras Dam – Post Failure

Contributing Factors (Soil Characteristics)

- Degree of Saturation
- Relative Density
- Gradation
- Cohesion
- Particle Shape and Hardness (crushability, roughness, roundness)
- Soil Fabric (orientation of sand grains)
- Overburden Pressures
- Cementation
- Permeability
- Loading

Contributing Factors (Blasting)

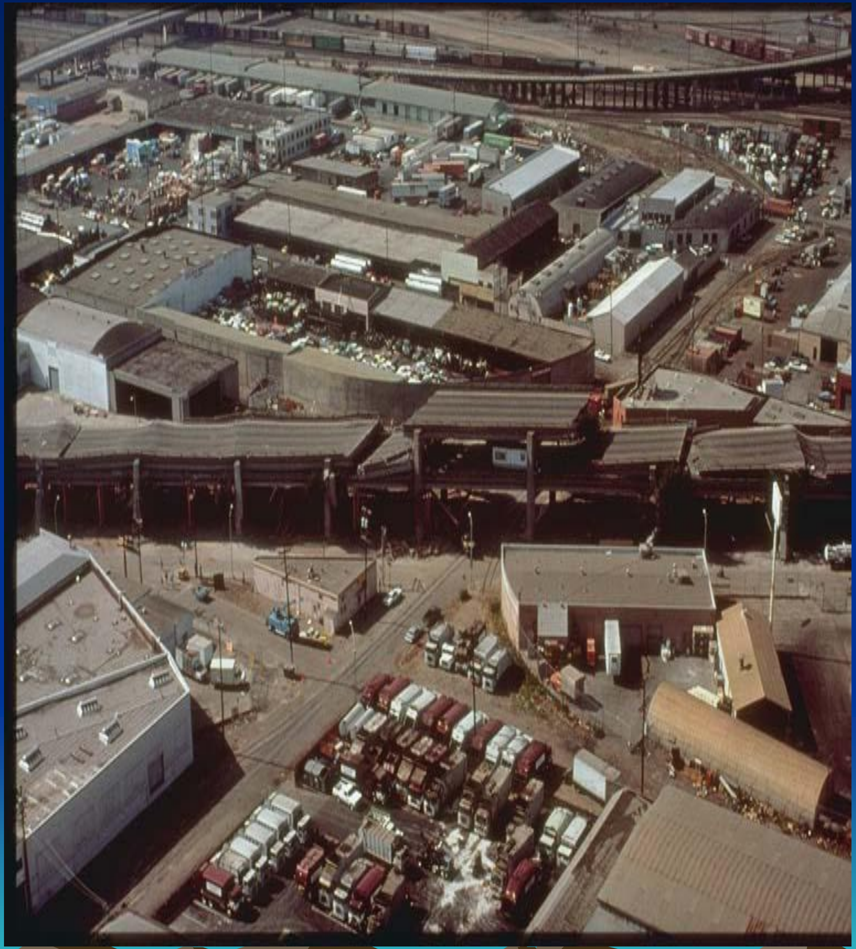
- Distance separating blast area and structure.
- Charge weight per delay (quantity of charge).
- Charge-delay patterns (millisecond delays results in multiple ground strains).
- Depth of burial (fully contained blast creates significantly greater ground vibrations than surface or near-surface blasts).
- Local geology and attenuation.
- Existing excess pore pressures (repeated blasts will magnify excess pore pressures). It may take several hours for excess pore pressures to dissipate.

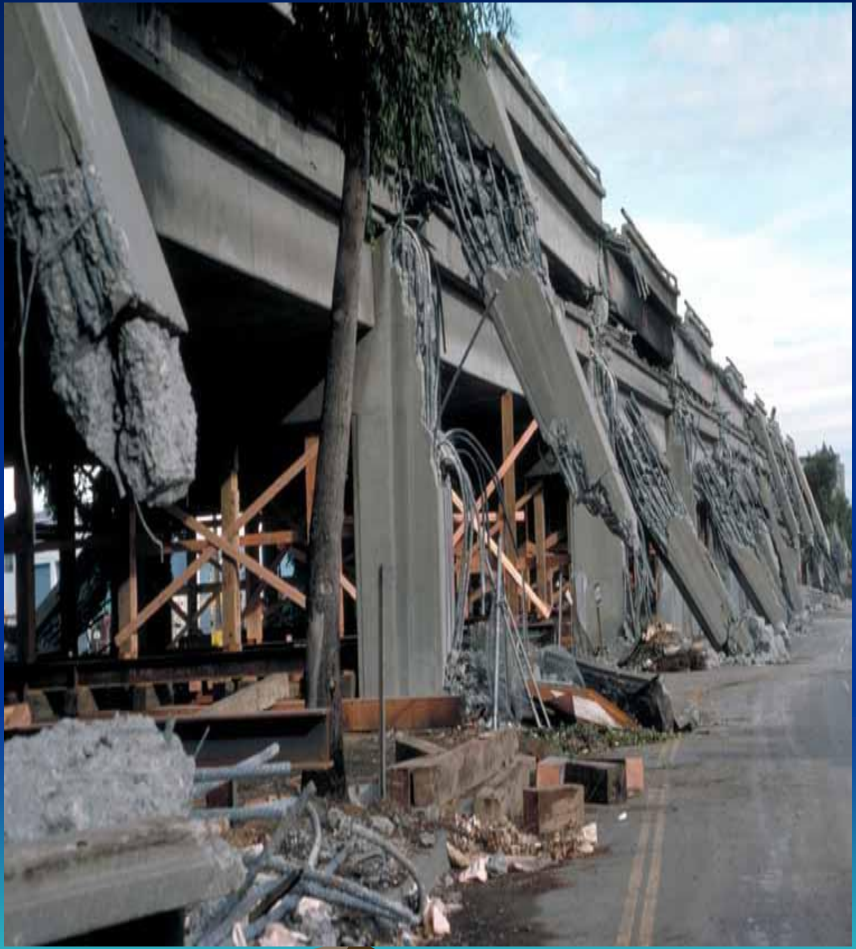
Previous Studies on Damage from Blasting

- Numerous field studies where blasts were conducted using 1 to 2 kg of explosives buried < 10 meters – liquefaction observed within 20 meters of the blast.
- It is generally agreed that the amount of damage from blasting correlates best to the peak particle velocity (ppv).
- Peak ground acceleration (pga) is more appropriate when evaluating damage from earthquakes.

0.3g Vibration from a Blast

0.26g Vibration from an Earthquake Nimitz Freeway, Oakland, CA





Summary of Previous Studies

- Russia – no liquefaction when dry density of soil material is above 1.6 g/cm^3. Also found no liquefaction at ppv < 7 cm/sec (2.8 in/sec)
- India – tests indicated increased pore pressures at distances of up to 3.5 x charge depth

Previous Studies

- Japan – 10% pore pressure increase at a distance of 10 meters from the blast. 1 kg charge placed at a depth of 6 meters.

- North America – No liquefaction at ppv < 2 cm/s (0.8 in/s). Increased pore pressures at 5 cm/s (2 in/s). Researchers recommend maximum ppv of 1 to 4 in/s.

Summary of Previous Studies – Europe

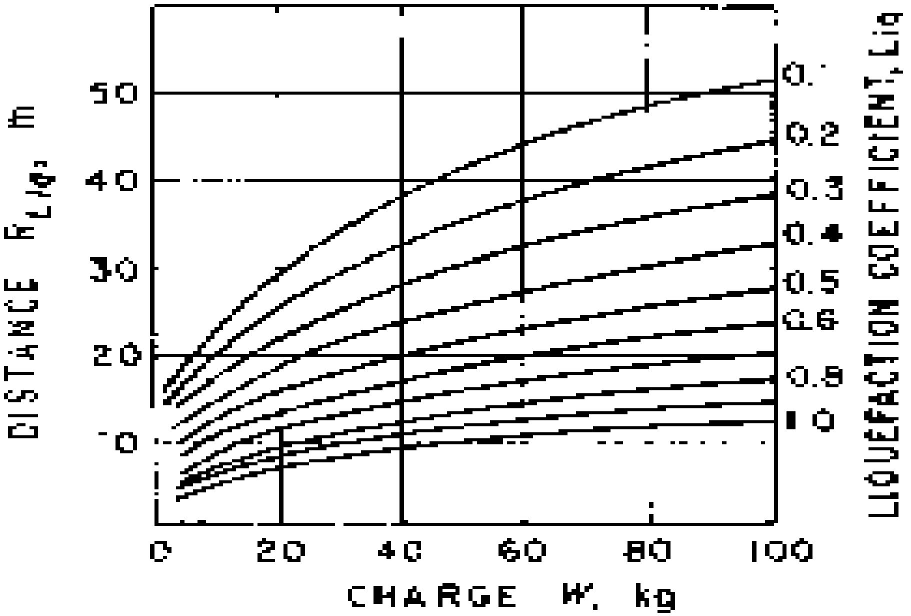


Figure 4. – Liquefaction coefficient for a single buried TNT explosive as a function of charge quantity and distance [44].

Published Guidelines

- U.S. Dept. of the Interior, Bureau of Reclamation – “Review of Present Practices Used in Predicting the Effects of Blasting on Pore Pressure – 1985.”

- Recommends that blasting not be done in the vicinity of dams constructed of or having foundations consisting saturated loose sand or silts that are sensitive to vibrations.

BOR Guidelines- Continued

- If blasting is required, the ppv should be kept below 2.5 cm/s (1 in/s).
- Time between shots should be long enough to allow dissipation of blast-induced excess pore pressures.
- Ppv < 5 cm/s (2 in/s) for medium dense sands or silts.

Should we be Concerned with Ground Motions from Blasting?

- A majority of the submitted design plans assume that the fcr will liquefy and use the residual strength in the stability analyses.

- Therefore, it doesn’t matter how much or how long the ground motions are. The steady state strength (residual strength) is the lowest theoretical shear strength that can occur at a given void ratio.

MWGED Analyses – Can the Blasting Vibrations Trigger Liquefaction?

- Shake2000 – A computer program for the 1D analysis of geotechnical earthquake engineering earthquake problems.
- Dynamic response analyses using ground motions recorded from several blasts.
- Also estimated the settlement and permanent deformation (Newmark sliding block analysis).

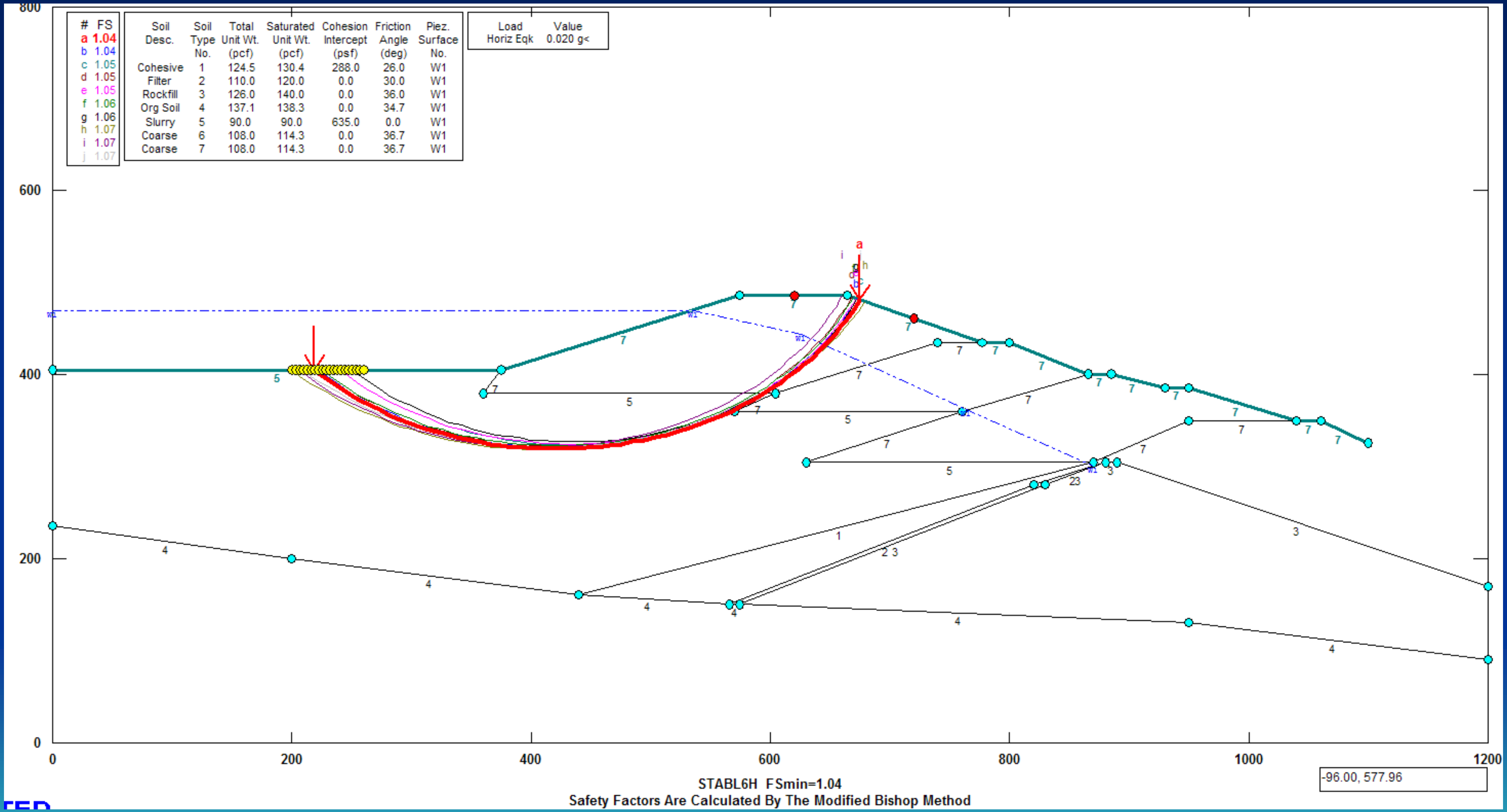
Characteristics of Blasting Ground Motion Analyzed

- Duration approximately 2 seconds
- Maximum ppv from 0.15 in/s to 3.5 in/s.
- Ground motion maximum pga > 5g
- Analyzed ground motion >3g

Analyses Summary

- Max pga in a layer = 0.24g
- Maximum permanent deformation from the Newmark sliding block analyses = 1.6 in.
- Maximum estimated settlement = 2.3 in.
- Lowest Factor of Safety against liquefaction CRR/CSR = 1.4

Stability Analysis to Determine the Yield Acceleration



Conservative Assumptions

- SPT = 1 (fines, 6 at the top and bottom of the column)
- Yield Acceleration = 0.0001 (typically in the range of 0.02 to 0.15
- Scaled to 5.5 & 7.5 magnitude EQ
- Relatively high ground motion frequencies used in the analyses (> 50 Hz).
- Assumed clean sand (worst case, no fines)

End

Questions?