



Liquefaction During the Loma Prieta Earthquake; Marina District

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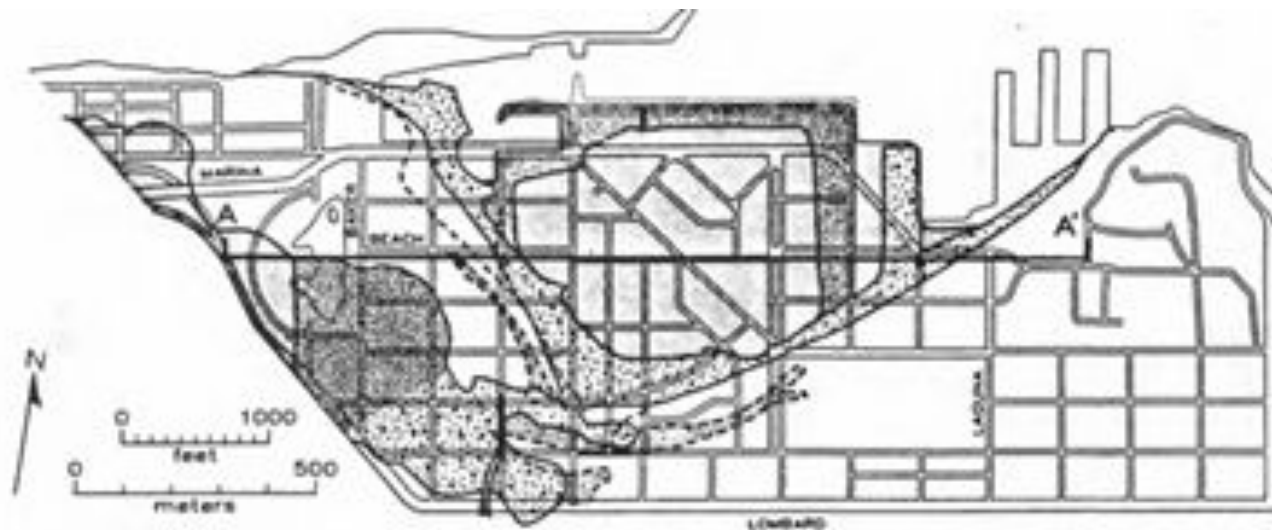
Liquefaction

- Most likely to occur in saturated sandy soils (artificial fill)
- Earthquake shaking causes soils particles to go into suspension
- Loads transferred to water, induces excess pore pressures
- Soil behaves like a liquid and can flow and settle







Marina District Soils

- Located along the northern shoreline of San Francisco, CA
- Was underwater prior to the mid 1800s
- Several phases of hydraulic fill occurred from 1870 to the early 1900s
 - First phases were dune sand
 - Middle phases were sand dredged from the Bay floor
 - Final phases were public dumping, debris, covered with fill



ARTIFICIAL FILLS

 1906–1917 (principally 1912)	 1869–1895
 1895–1906	 1851–1869

<https://pubs.usgs.gov/of/1990/0253/report.pdf>



Loma Prieta Earthquake Background

- October 17, 1989
- Magnitude 6.9, twenty seconds of shaking
 - Thousands of aftershocks
- \$10 billion+ of damage
- Liquefaction throughout Bay Area

Marina District Damage



- Sand Boils
 - Hydraulic fill
- Pavement and sidewalk cracking
 - Lateral cracks-horizontal and vertical displacement
 - Tenting-compression of sand
 - Worst at boundary between different fill zones
- Building damage
 - Differential settlement
 - Damage to underground utilities
 - Many had to be demolished

<https://www.kqed.org/news/11799297/large-parts-of-the-bay-area-are-built-on-fill-why-and-where>



Soil Analysis

- SPT blow counts much lower for fill than natural deposits
 - Fill: 7-12 blows/ft
 - Natural: 15-25+ blows/ft
- Fill was much less dense/stiff than natural deposits

Soil Analysis

$$CSR = 0.65 \frac{a}{g} * \frac{\text{total stress}}{\text{effective stress}} * r_d$$

Where:

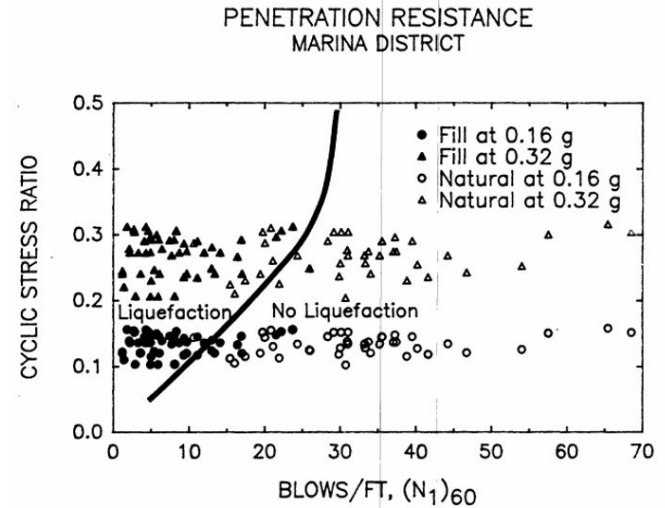
a = maximum earthquake acceleration

g = acceleration due to gravity

total stress = total weight of overlying soil and water

effective stress = initial vertical effective stress

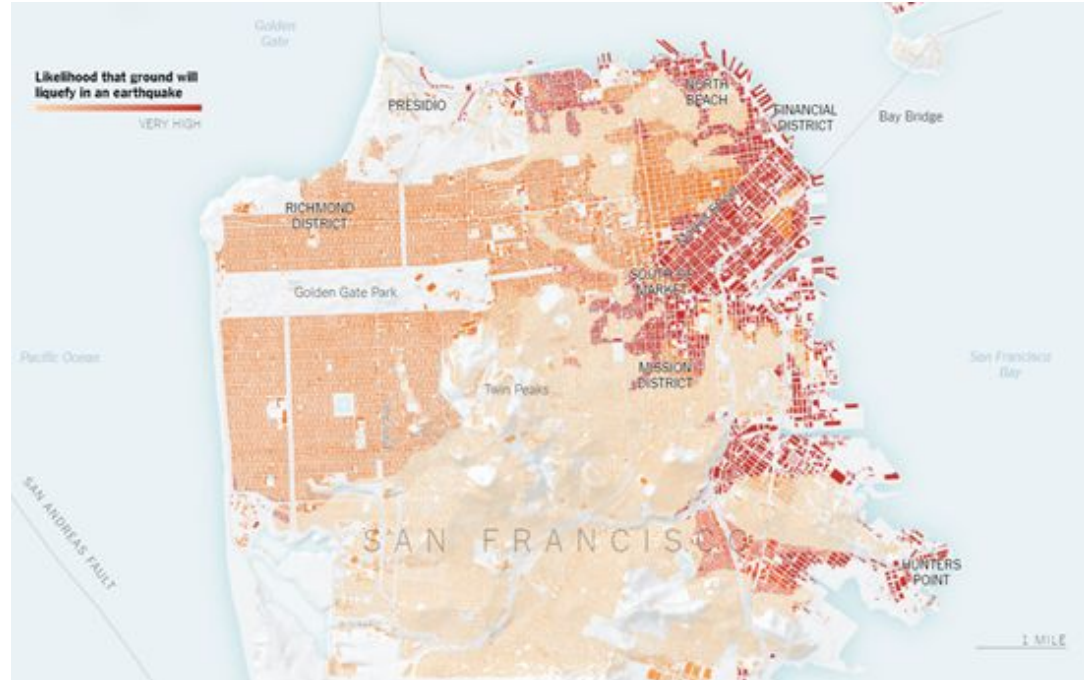
r_d = stress reduction factor



<https://pubs.usgs.gov/of/1990/0253/report.pdf>

Current Conditions

- Much of the SF Bay Area infrastructure is located on fill
- Current building codes are not strict enough
- 1 in 4 buildings will likely be uninhabitable after the next earthquake



<https://www.nytimes.com/interactive/2018/04/17/us/san-francisco-earthquake-seismic-gamble.html>



Mitigation Strategies

- Soil Improvement
 - Vibroflotation, dynamic compaction
 - Piles, columns, grouting
- Structural Mitigation
 - Shallow foundations
 - Deep foundations
- Best mitigation strategy-do not build in liquefaction zones

Conclusion

- Future earthquake will happen in the area
- Millions of people already living in liquefaction zones
- Retrofitting of structures and/or improvement of soils will be costly and time consuming
- What do we do?



<https://sf.curbed.com/2019/4/15/18311670/earthquake-map-california-geological-survey-liquefaction>