# SOIL LIQUEFACTION AND CASE STUDY IN IRAN

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# What is Liquefaction? (Theoretical Explanation)

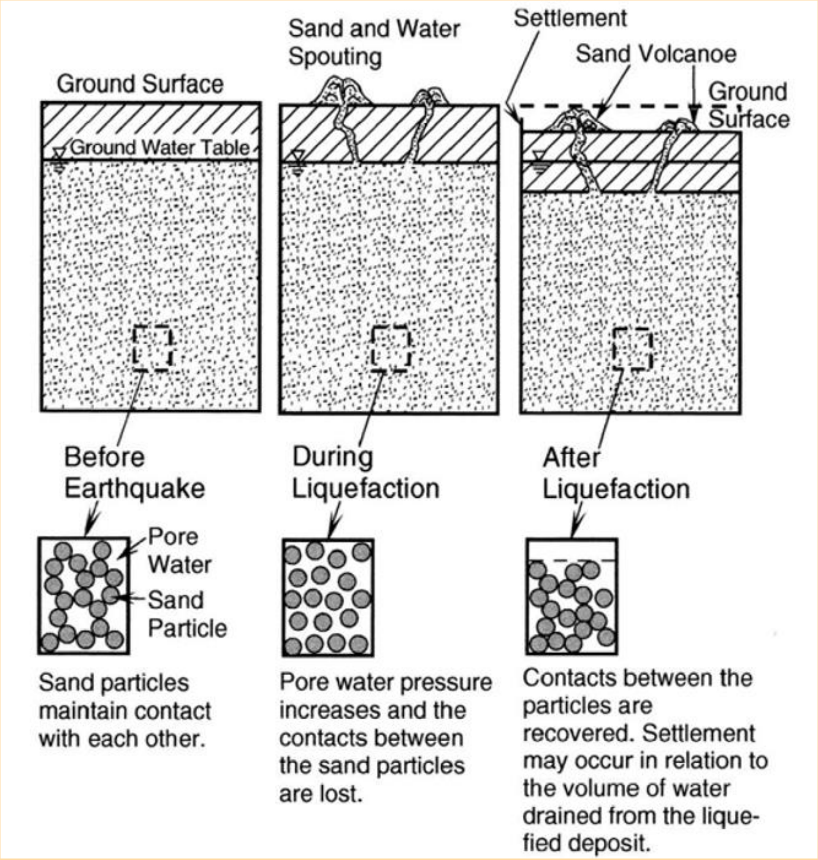
Liquefaction is a phenomenon in which static equilibrium in soil deposit is destroyed by static or dynamic loads.

Shear strength of Soils "τ" can be expressed as:

$$\tau = c + (\sigma - u)\tan\phi$$

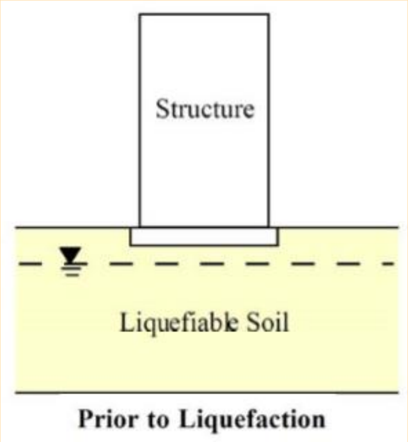
Where "u" is pore pressure and σ is vertical stress. during earthquakes $u=\sigma$ therefore, $\tau=c$, However in cohesion less soils $c=0$, consequently, **$\tau=0$**

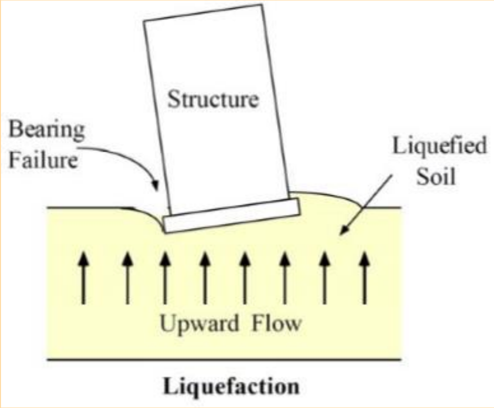
**Soil Looses its strength**



# Consequence of Liquefaction?

## a) Loss of Bearing Capacity :




Yuanlin City, Chi Chi Earthquake,1999

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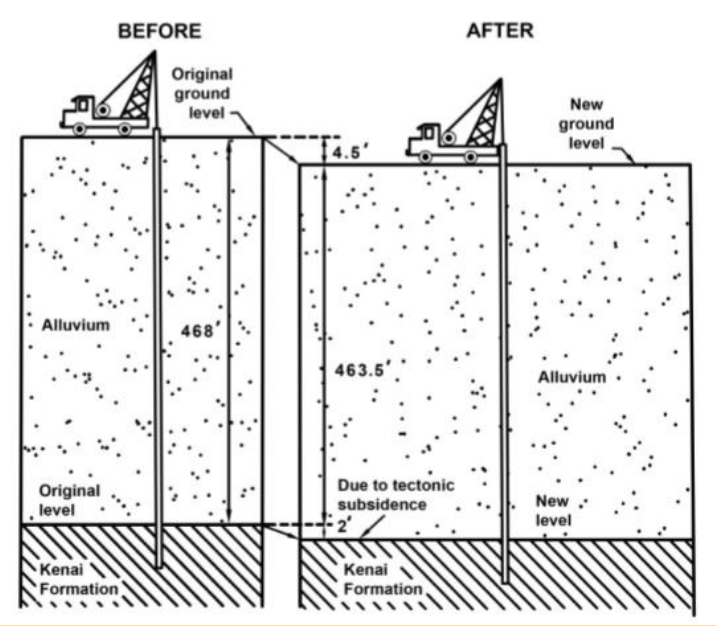
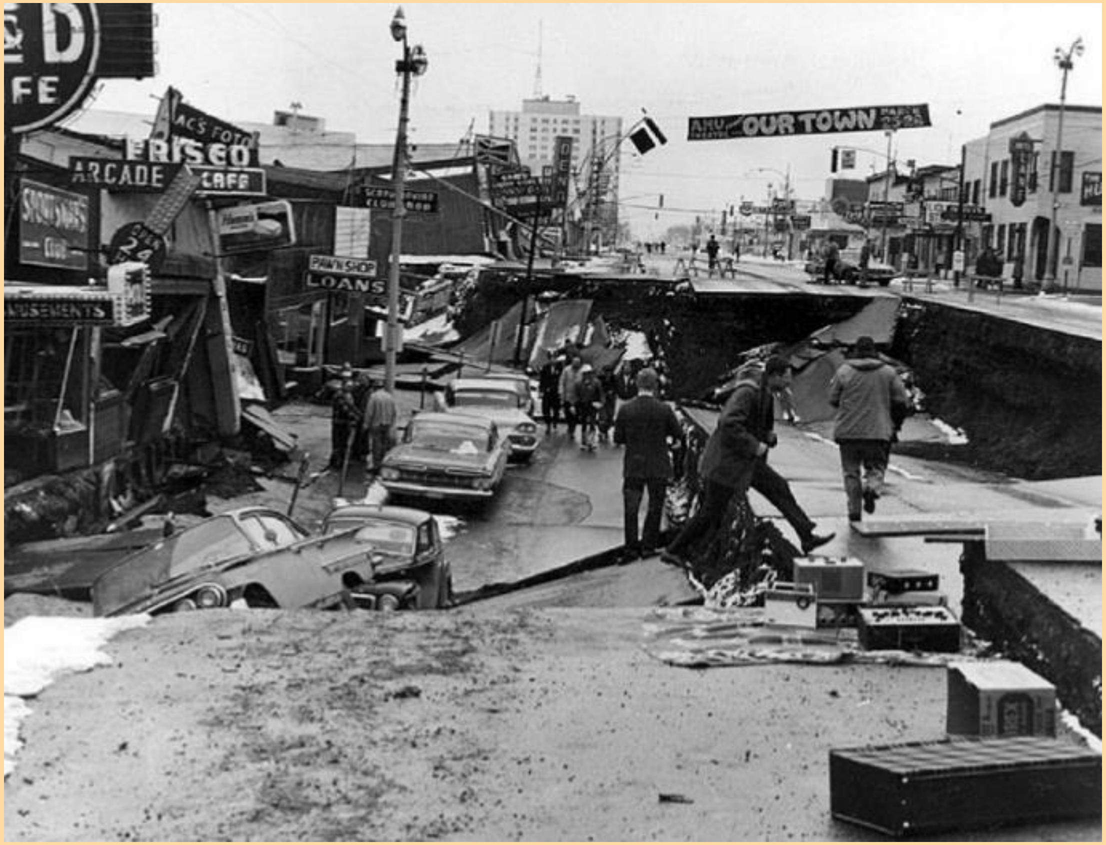
# Consequence of Liquefaction?

## b) Settlement:



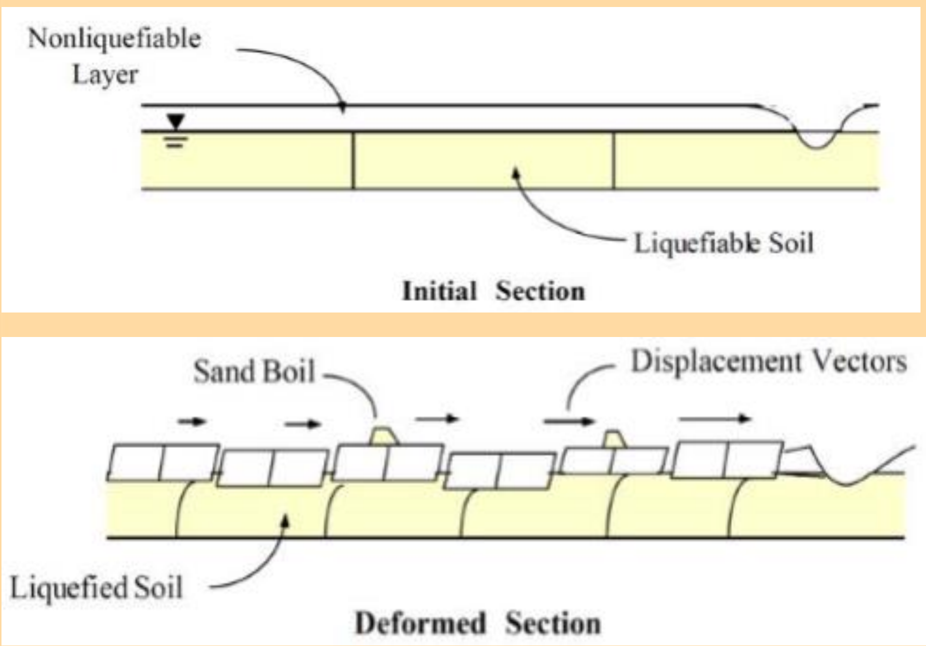

Settlement around oil wells, Alaska Earthquake,1999




Anchorage City, Alaska Earthquake,1999

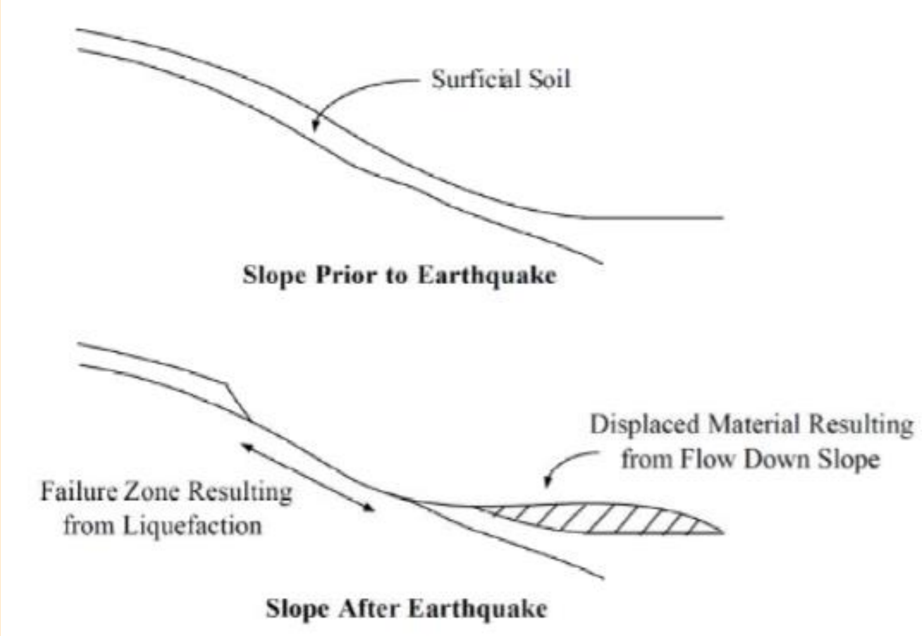
# Consequence of Liquefaction?

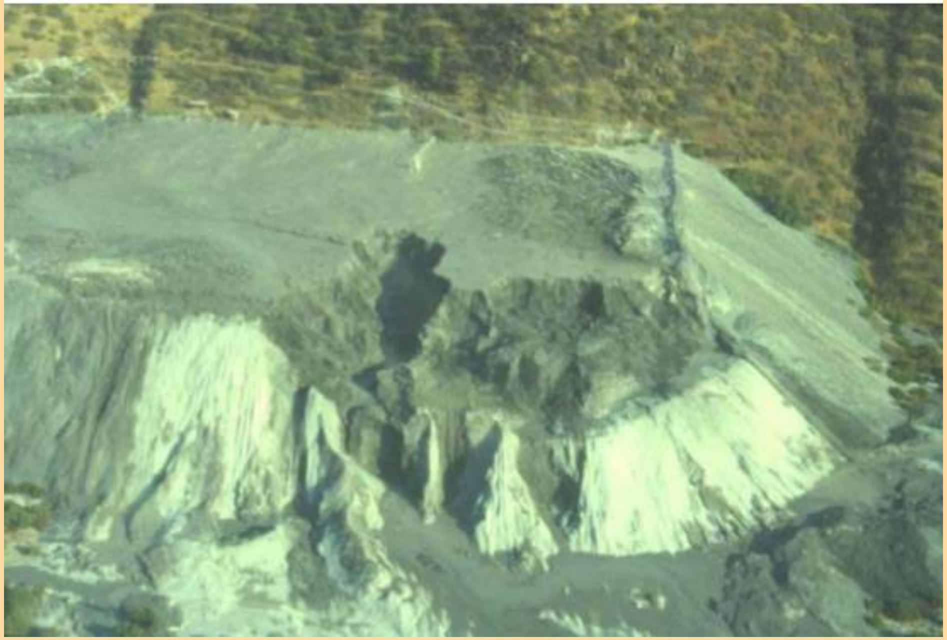
**c) Lateral spreading :** can occur on gently sloping (<3 degree) and on flat ground close to rivers and lakes. Lateral displacement occurs on the surface soil blocks. Building's foundation, pipelines and sewerage system get damage significantly.




# Consequence of Liquefaction?

**d) Flow Failure:** Is the most destructive effect of liquefaction, it can move huge value of soil meters away from its origin. Often occurs in lose sands or silty soil located on slopes more than three degree.



Failure of Cerro Negro Dam
Chile Earthquake,1985

# Consequence of Liquefaction?

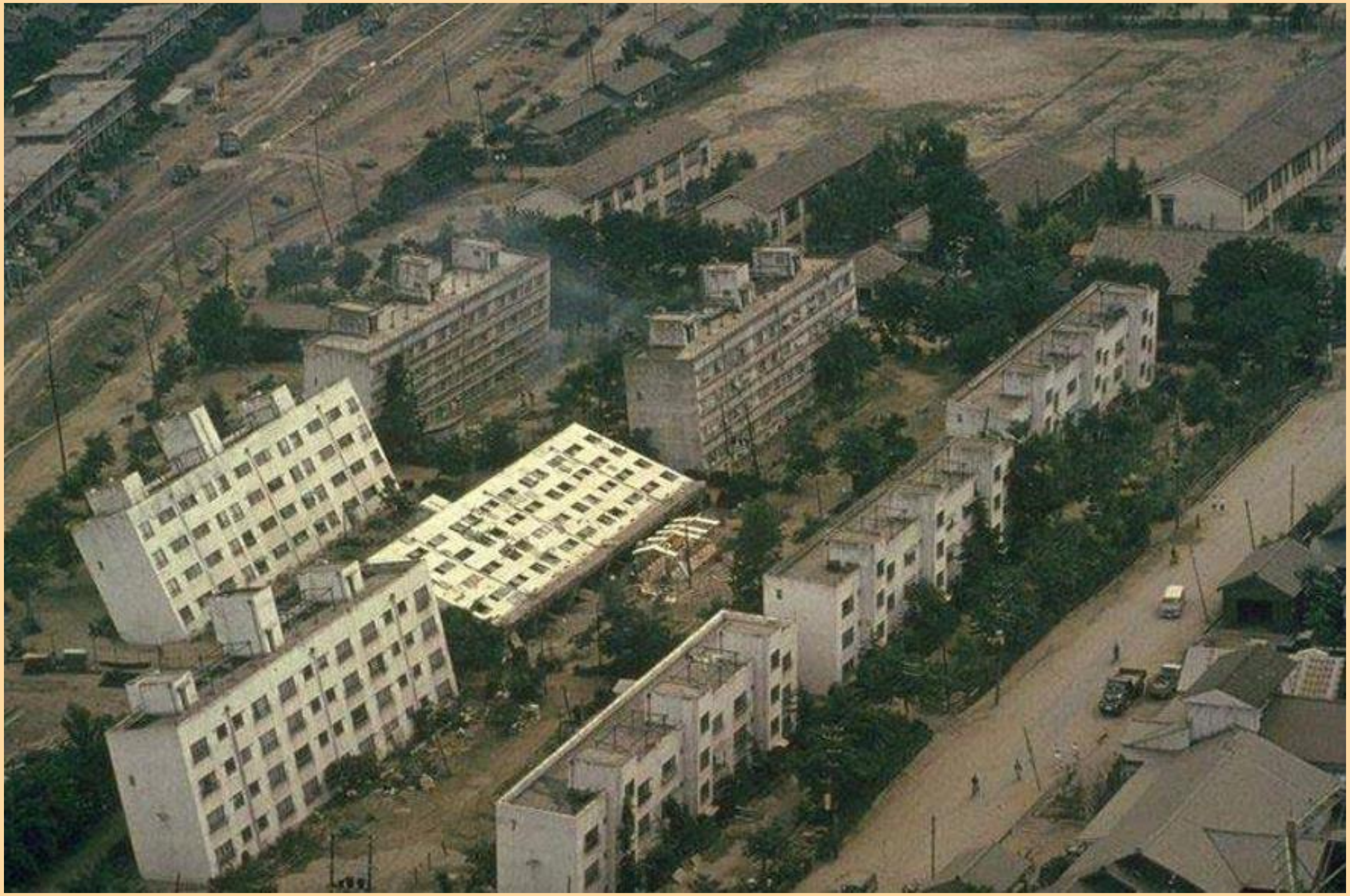
**e) Sand Boiling:** A sand boil is sand and water that come out onto the ground surface during an earthquake as a result of liquefaction at shallow depth.

**Sand Boiling, Imperial Valley Earthquake,1979**

# Experience from Past Earthquakes about Liquefaction

a) 4-Storey
b) RC Buildings
c) shallow foundation

Damage due to significant reduction in soil bearing capacity



Up to 60 degree deviation from vertical axis

Kawagishi-Cho  Apartments after Niigata Earthquake,1964

# Experience from Past Earthquakes (Bridges)

a) 25m length Steel Piles b) Simply Supported beams c) Liquefaction occurred at top 10m of soil

Damage due to rotation of Pile caps after occurrence of liquefaction

"Showa" Bridge after Niigata Earthquake,1964, Japan

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# Experience from Past Earthquakes (bridges)

a) Ave. SPT ground level to 30 m depth =11
b) Soil Type =Silty-Sand

Damage due to significant settlement and rotation of Piers

Iron road on Kenai River after Alaska Earthquake,1964

# Experience from Past Earthquakes (Ports)

a) Ave. SPT at 12 m depth =10-12
b) Soil Type =Silty-Sand

Damage due to Lateral spreading

Port Island in Japan after Kobe Earthquake,1995

# Experience from Past Earthquakes (Buildings)

Damage due to significant settlement

Mariana bay, USA, Loma Prieta Earthquake,1989

Adapazari city ,Turkey, Kocaeli Earthquake,1989

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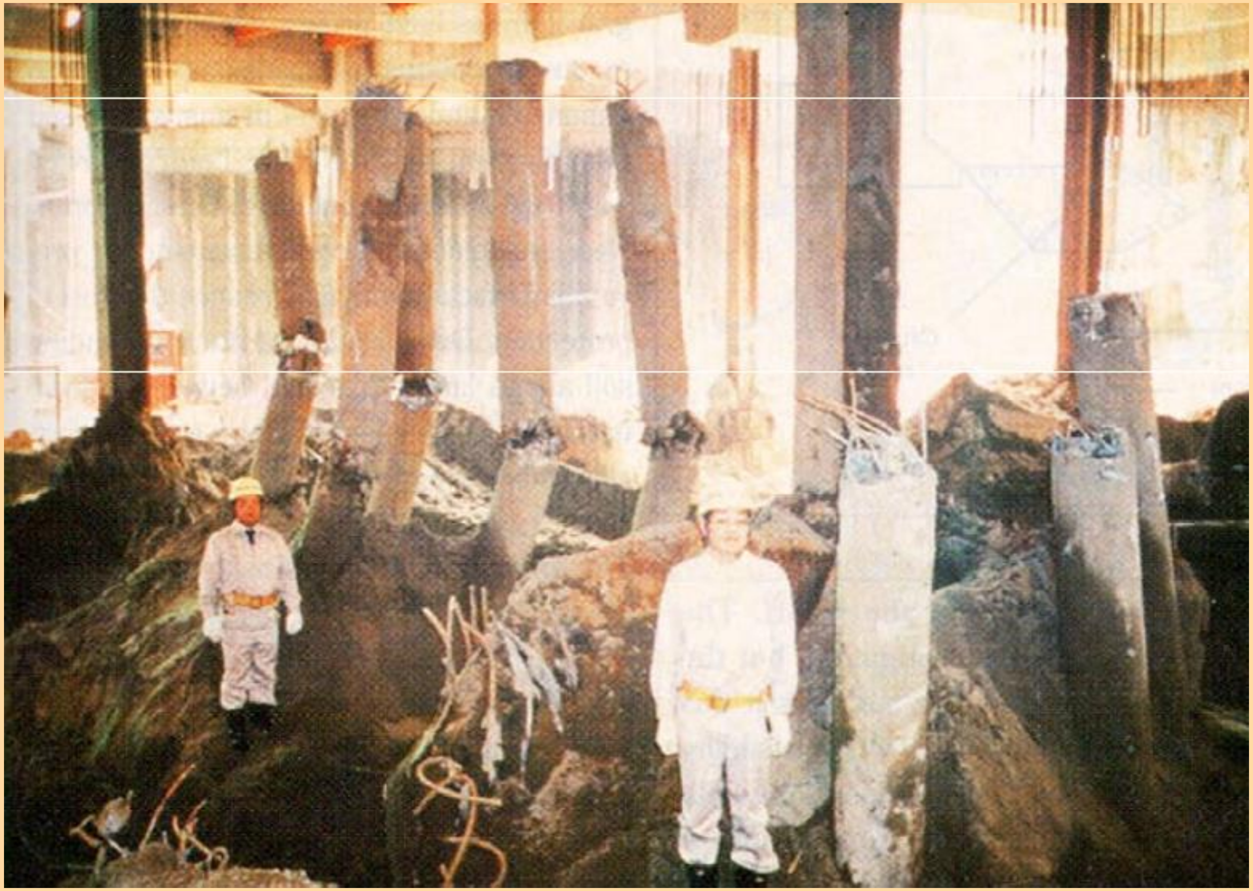
# Experience from Past Earthquakes

a) 4-storey RC building
b) Pile length=12m
c) Water level= 5m



NHK building 20 years after Niigata Earthquake,1964

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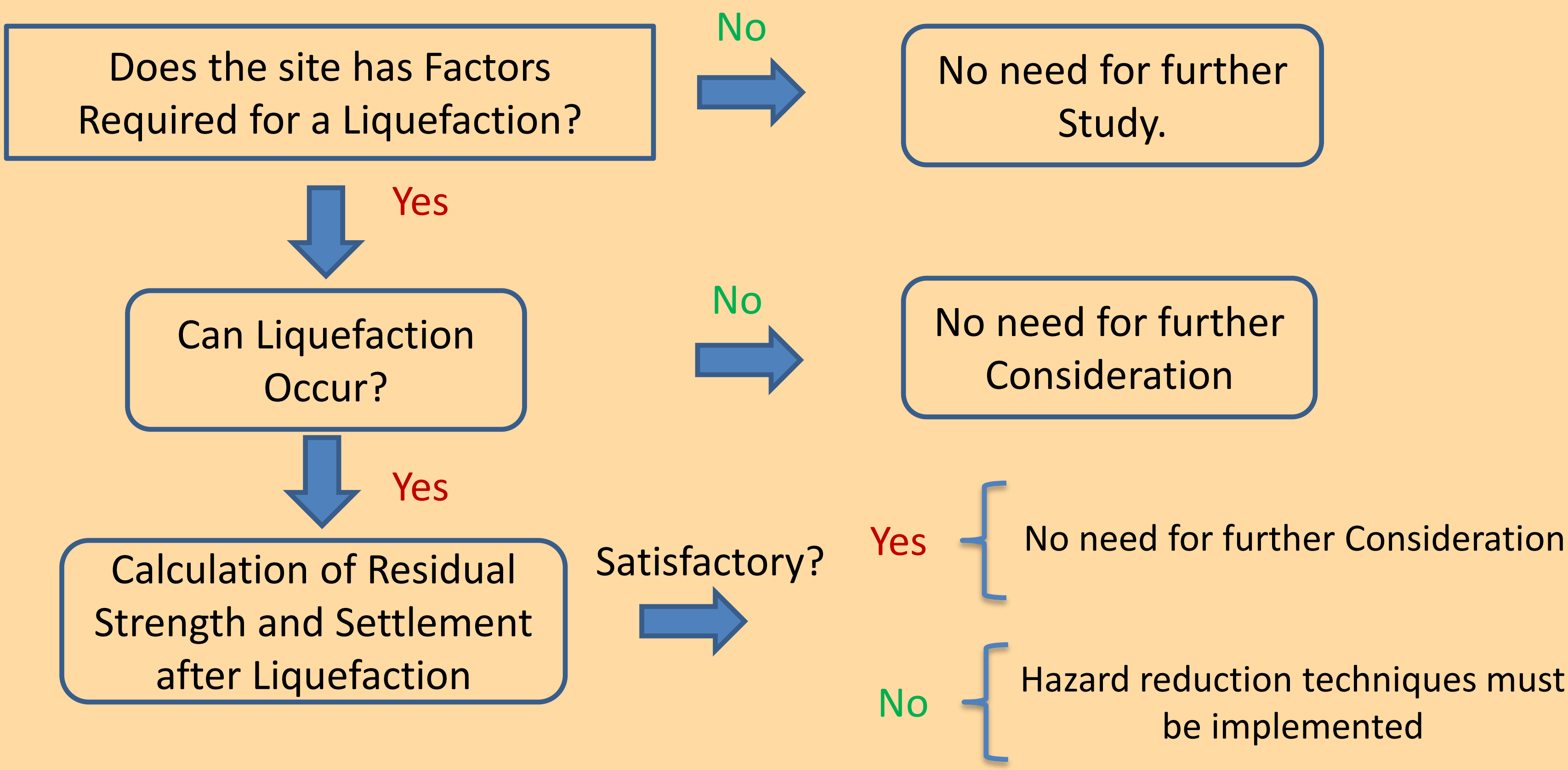
# Experience from Past Earthquakes

a) 8.5 mile away from epicenter
b) Height 35 Feet
c) Soil type, Clay on sand

Damage due to Lateral Spreading

San Fernando Dam after Earthquake,1964

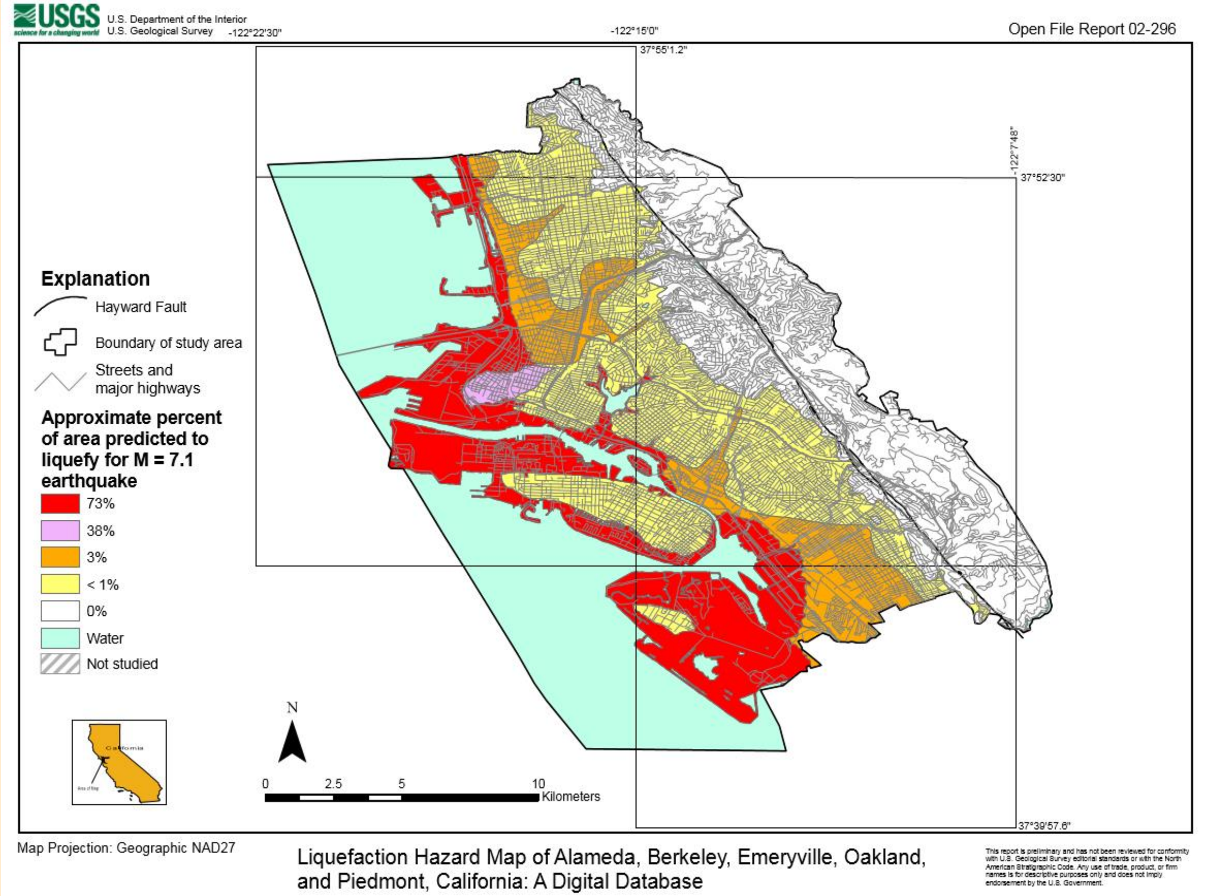
# Assessment of Liquefaction Hazards:



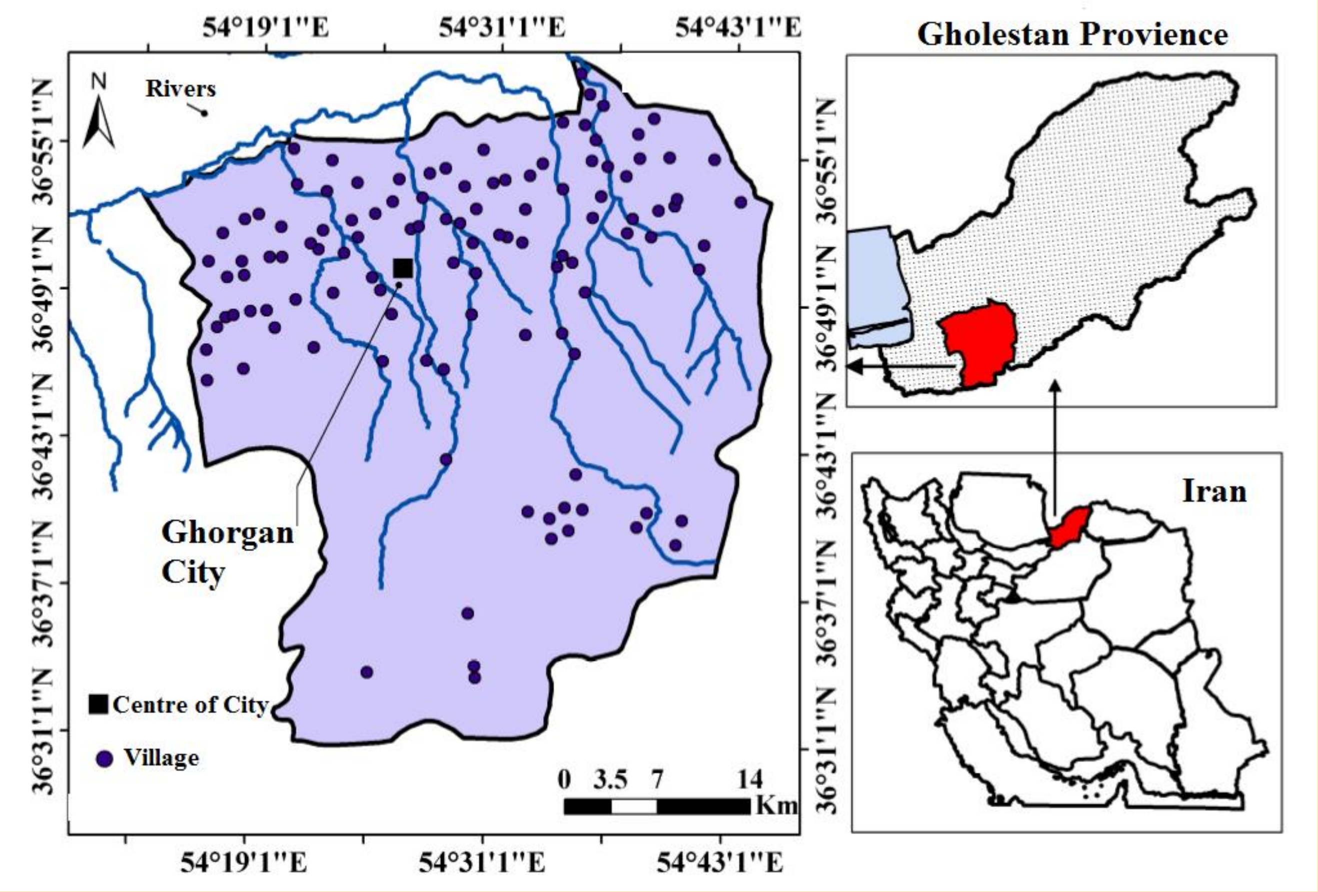
# Does the site has Factors Required for a Liquefaction?

## Liquefaction Hazard Maps

These maps are designed to give the general public as well as land-use planners, utilities and lifeline owners, and emergency response officials, new and **better tools to assess their risk** from earthquake damage.

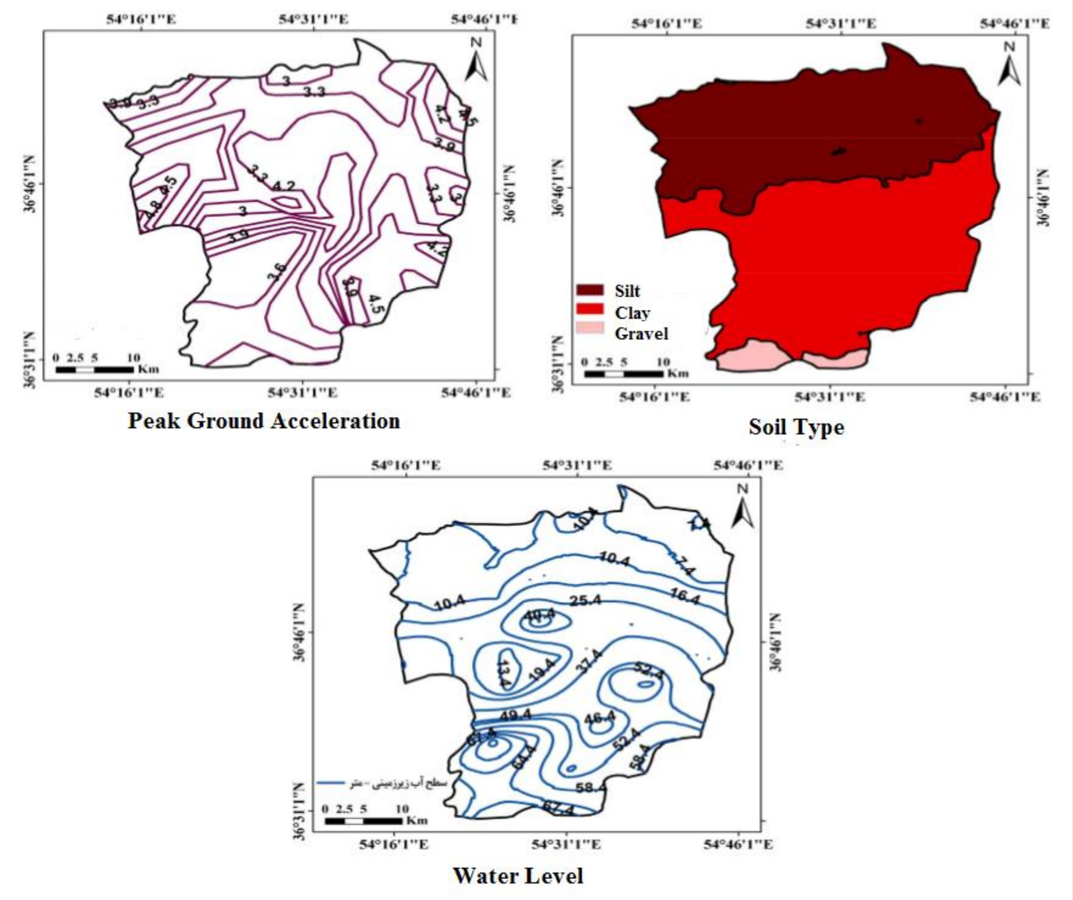


# Liquefaction Hazard Maps (Iran)




Studied Area, Gorghan City, Iran (By Abdolah Zade, et al, 2013)

# Liquefaction Hazard Maps (Iran)




Main Parameters included in the preparation of Liquefaction Hazard Map

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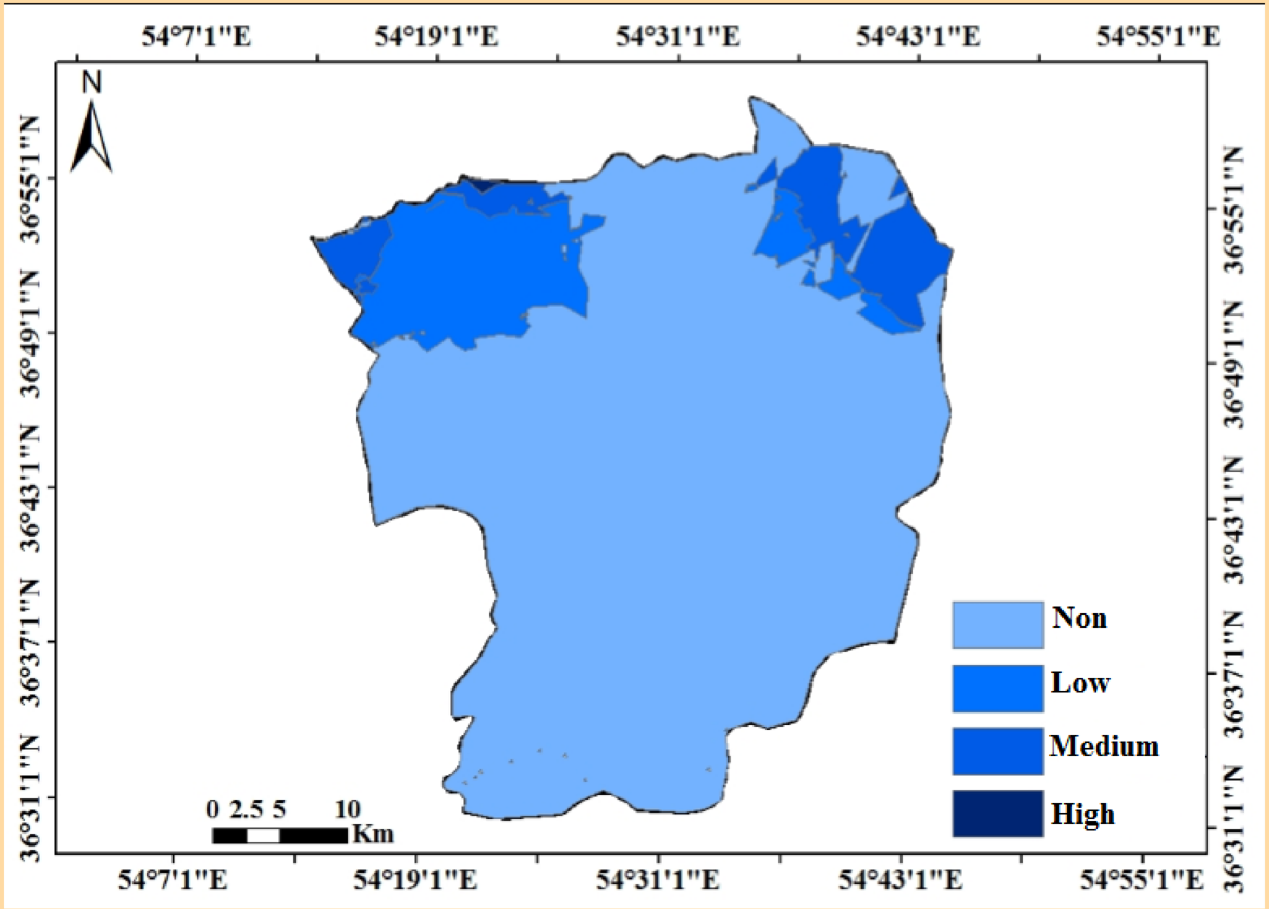
## Liquefaction Hazard Maps (Iran)




Liquefaction Hazard Map for Ghorghan, Iran, by Abdollah Zade et al, 2012)

# Factors Affecting Soil Liquefaction:

**a) Water Level: Liquefaction occurs only in saturated or nearly saturated soils.**

| Water Level | Potential for Liquefaction |
|---|---|
| <3m | Very high |
| 3m~6m | High |
| 6m~10m | Average |
| 10~15M | Low |
| >15m | Rare |

**b) Soil Type: clean sand has the highest potential for liquefaction compared to other soil types.**

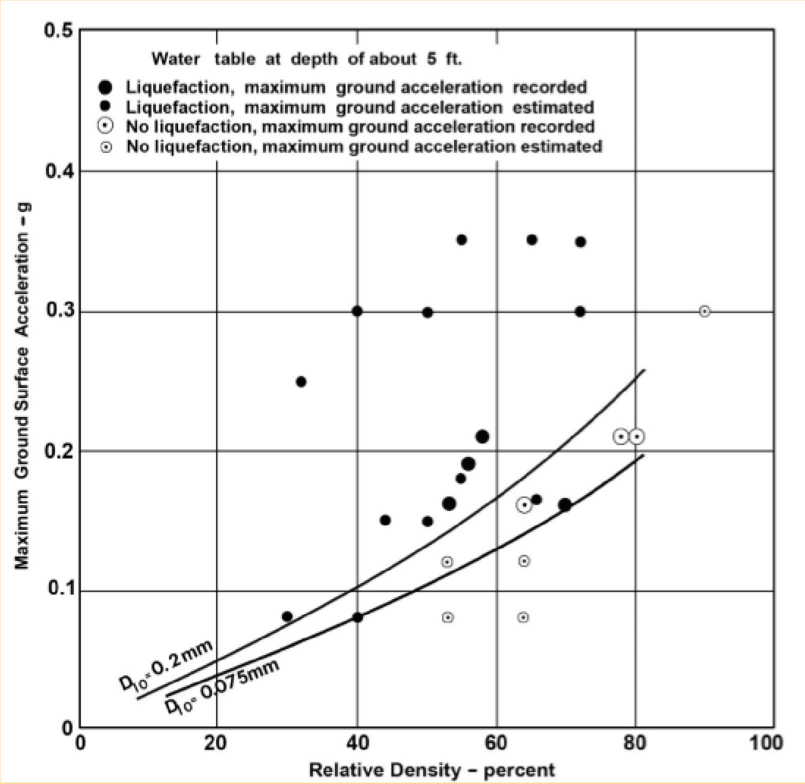
# Factors Affecting Soil Liquefaction:

**c) Relative Density:** The higher is the relative density the lower is the potential for liquefaction.

**d) Soil Gradation:** Soil with uniform or poor graded has higher potential for liquefaction.

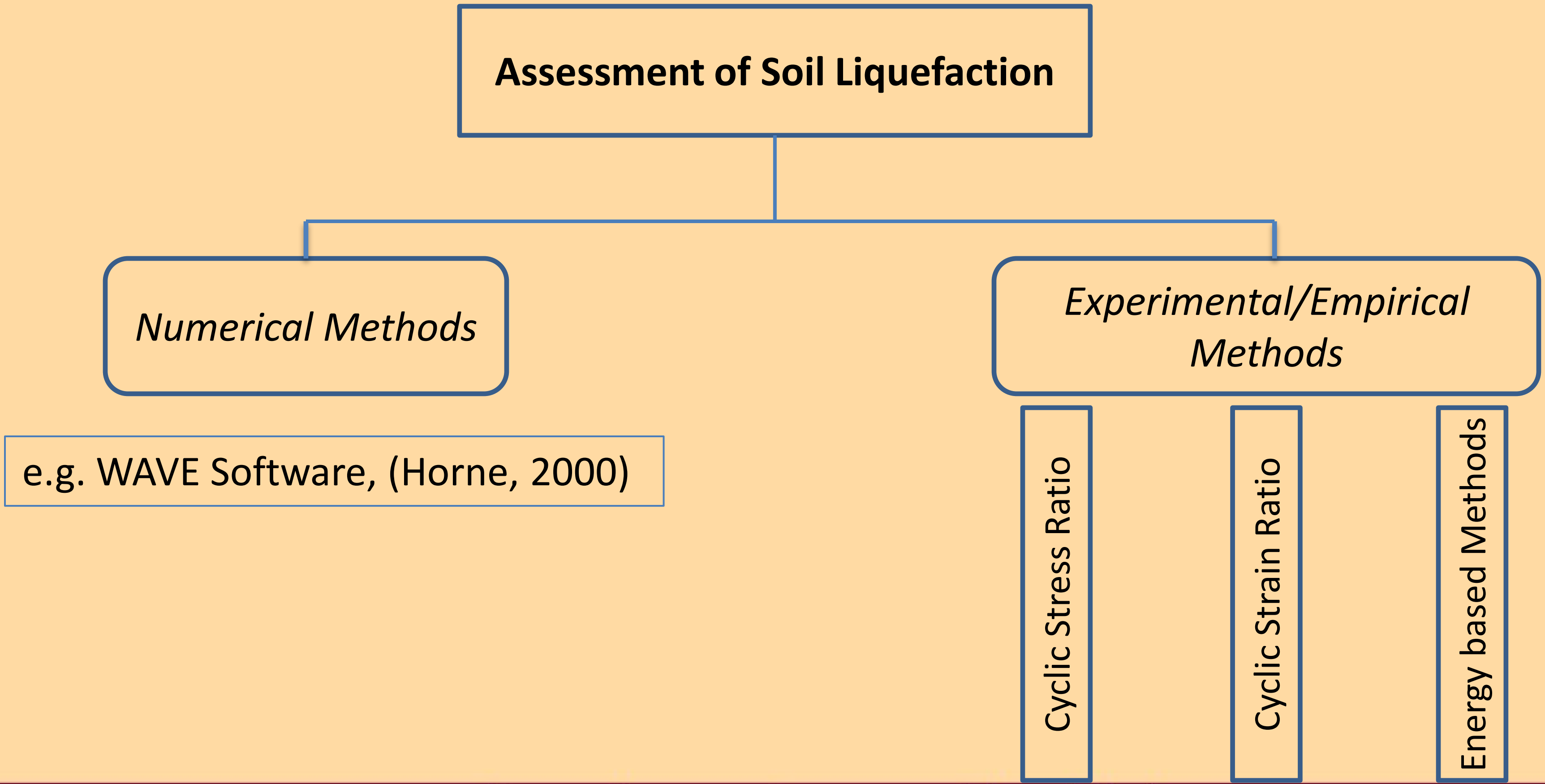
**e) Shape of soil's Particles:** Soils with round edge particles have Higher potential for liquefaction compared to soil with sharp edge particles.

**d) Observed Liquefaction in past earthquakes**

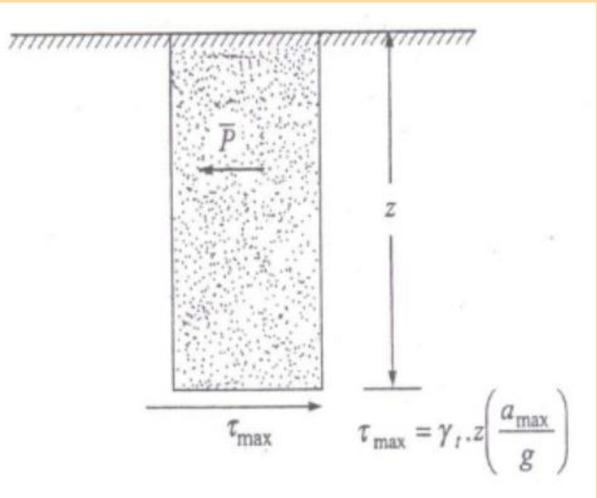



Seed and Idriss (1971)

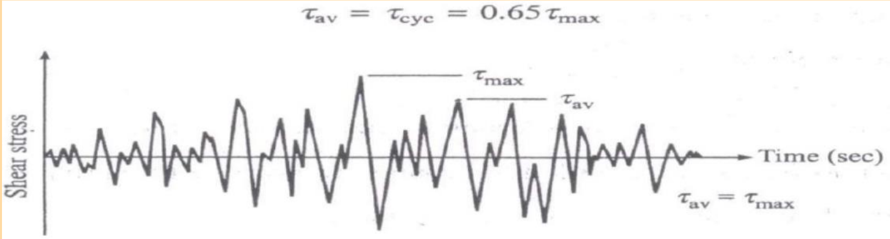
# Methods for Assessing Potential of Liquefaction in Soils:



# Common Method: Cyclic Stress Ratio (CSR)




It is assumed that the soil column moves horizontally as rigid body in response to acceleration exerted by earthquake.




$$CSR_{eq} = \frac{(\tau_{hv})_{eq}}{\sigma'_v} = 0.65\left(\frac{a_{max}}{g}\right)\left(\frac{\sigma_{vo}}{\sigma'_{vo}}\right)(r_d)$$

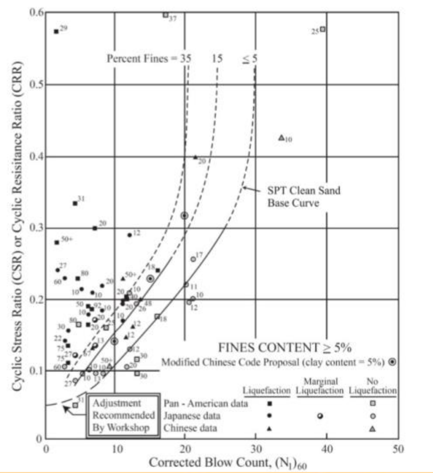
$$(\tau_{hv})_{eq} = 0.65 \times \tau_{hv,max}$$

$$r_d = \frac{(\tau_{max})_{real}}{(\tau_{max})_{rigid\,body}} = \frac{a_{max,\ depth\ of\ intrest}}{a_{max,\ ground\ surface}}$$

**Factor of Safety = CRR / CSR**

CSR= Cyclic Stress Ratio of soil due to probable earthquakes.

CRR= Cyclic Resistance Ratio of Soil

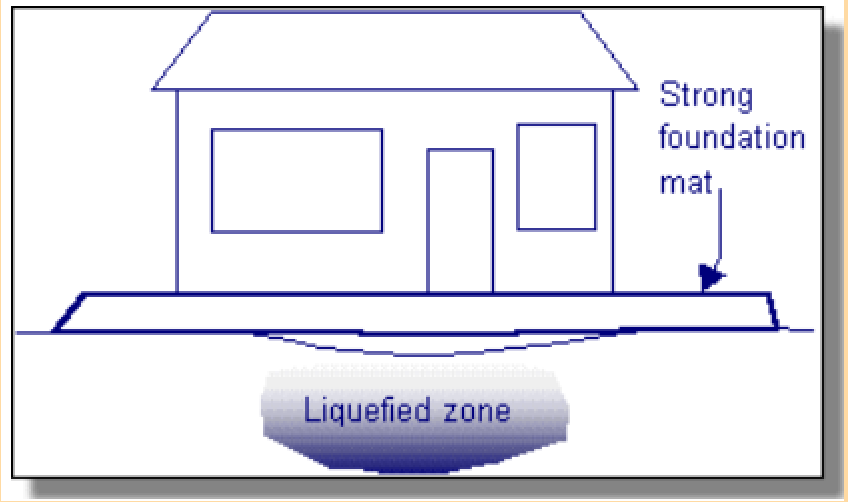


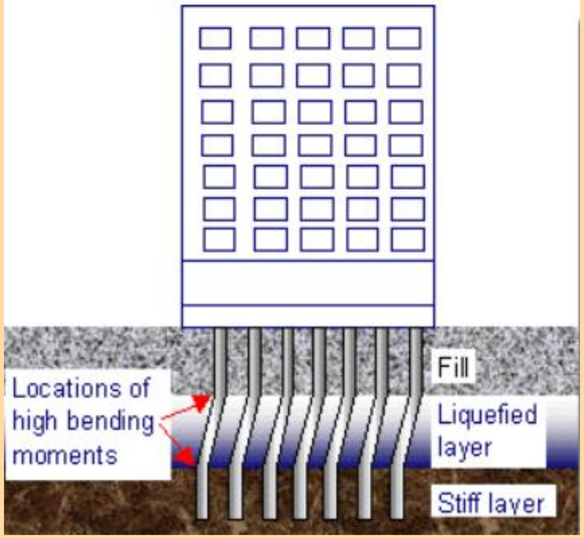

CRR Graph based on SPT

# Strategies for Mitigation of Liquefaction Hazard :

a) Avoid construction on liquefiable soils.

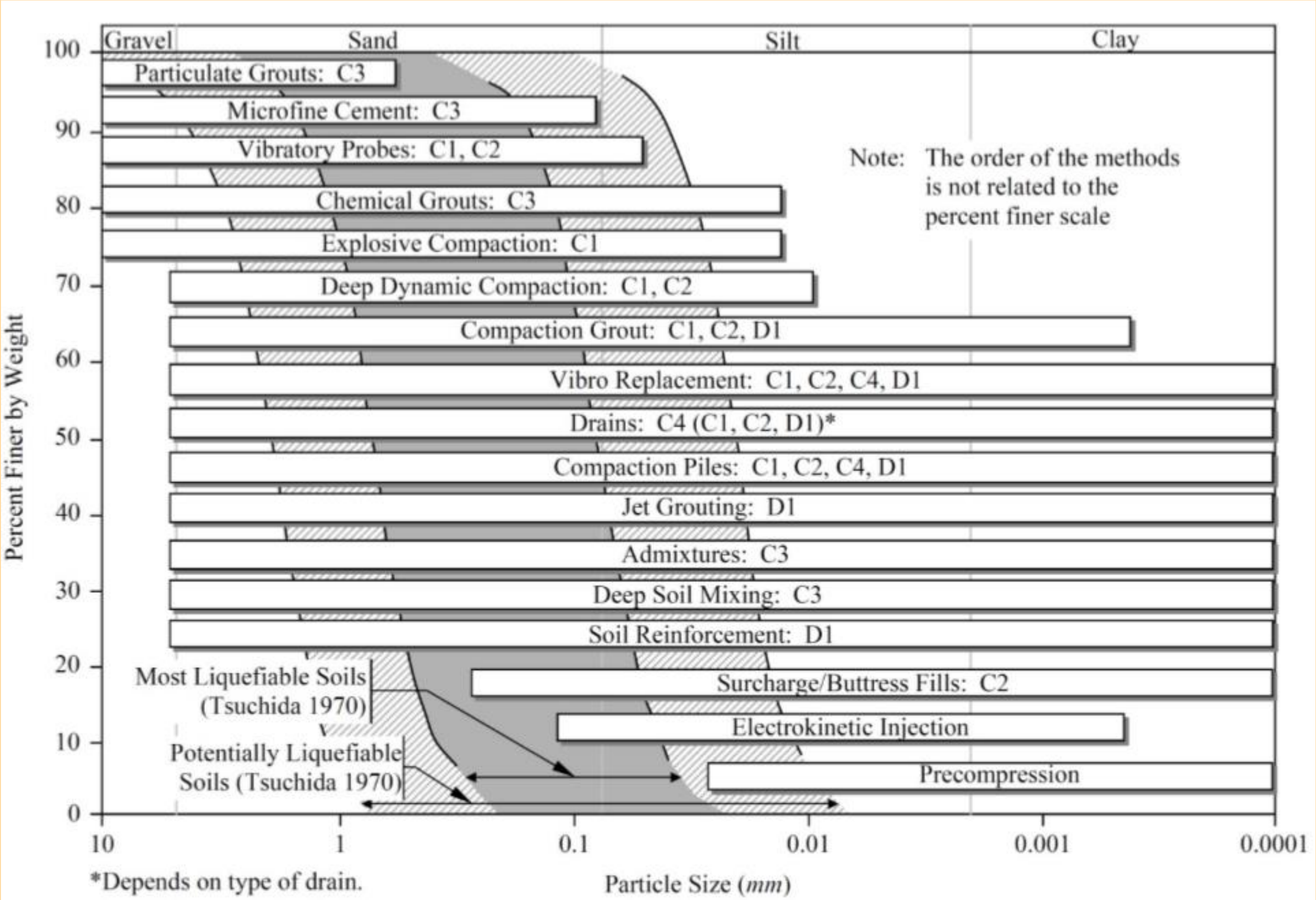
b) Improve resistance of structural components against liquefaction




c) Improve Soil quality

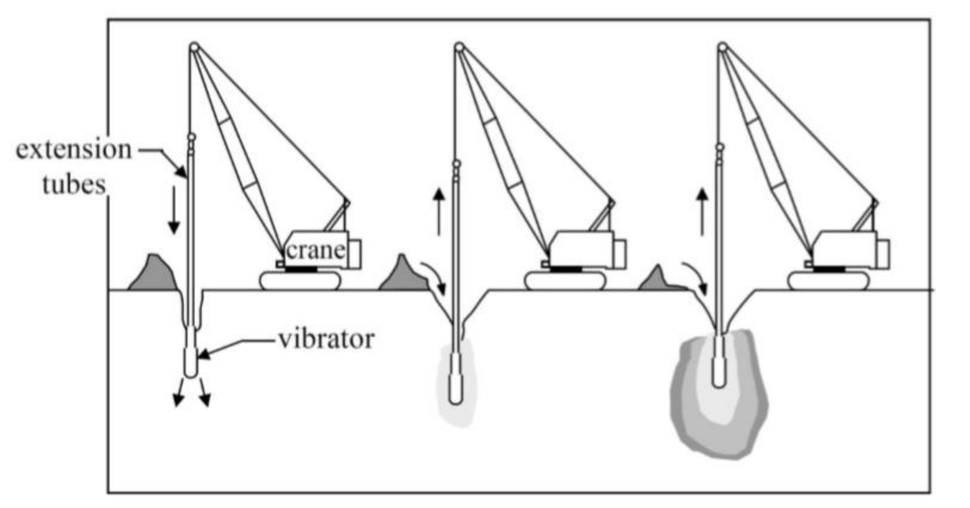
## Mitigation of Liquefaction Hazard : (Improve Soil quality)



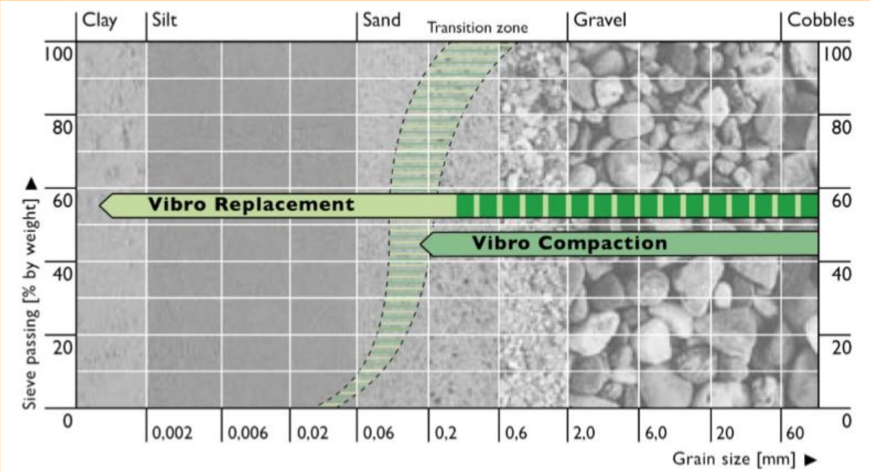

**Improve Soil Quality for reducing liquefaction hazard**

# Mitigation of Liquefaction Hazard : (Improve Soil quality)

## a) Increase in relative density of soil (Vibroflotation)




Vibroflotation method




Particle size for Compaction via Vibroflotation

# Mitigation of Liquefaction Hazard : (Improve Soil quality)

## a) Vibroflotation

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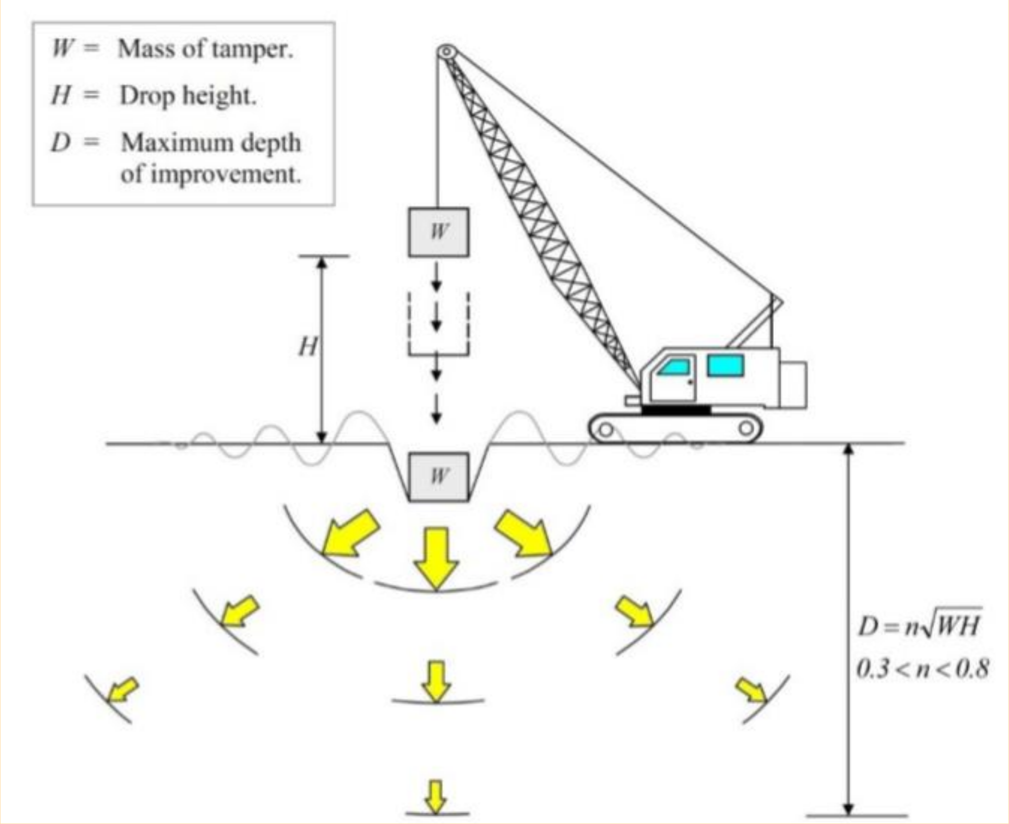
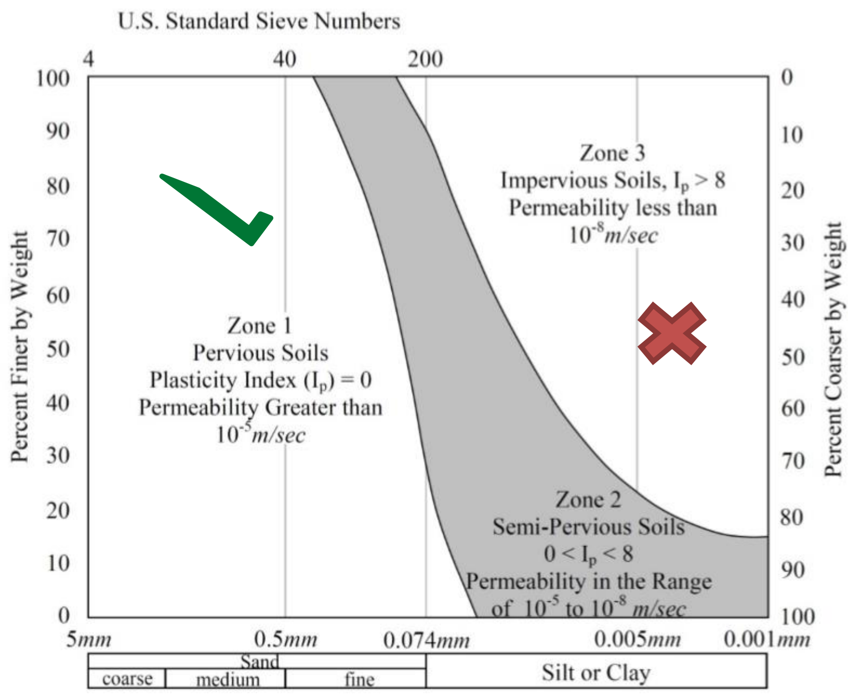
# Mitigation of Liquefaction Hazard : (Improve Soil quality)

## a) Increase in relative density of soil (Dynamic Compaction)



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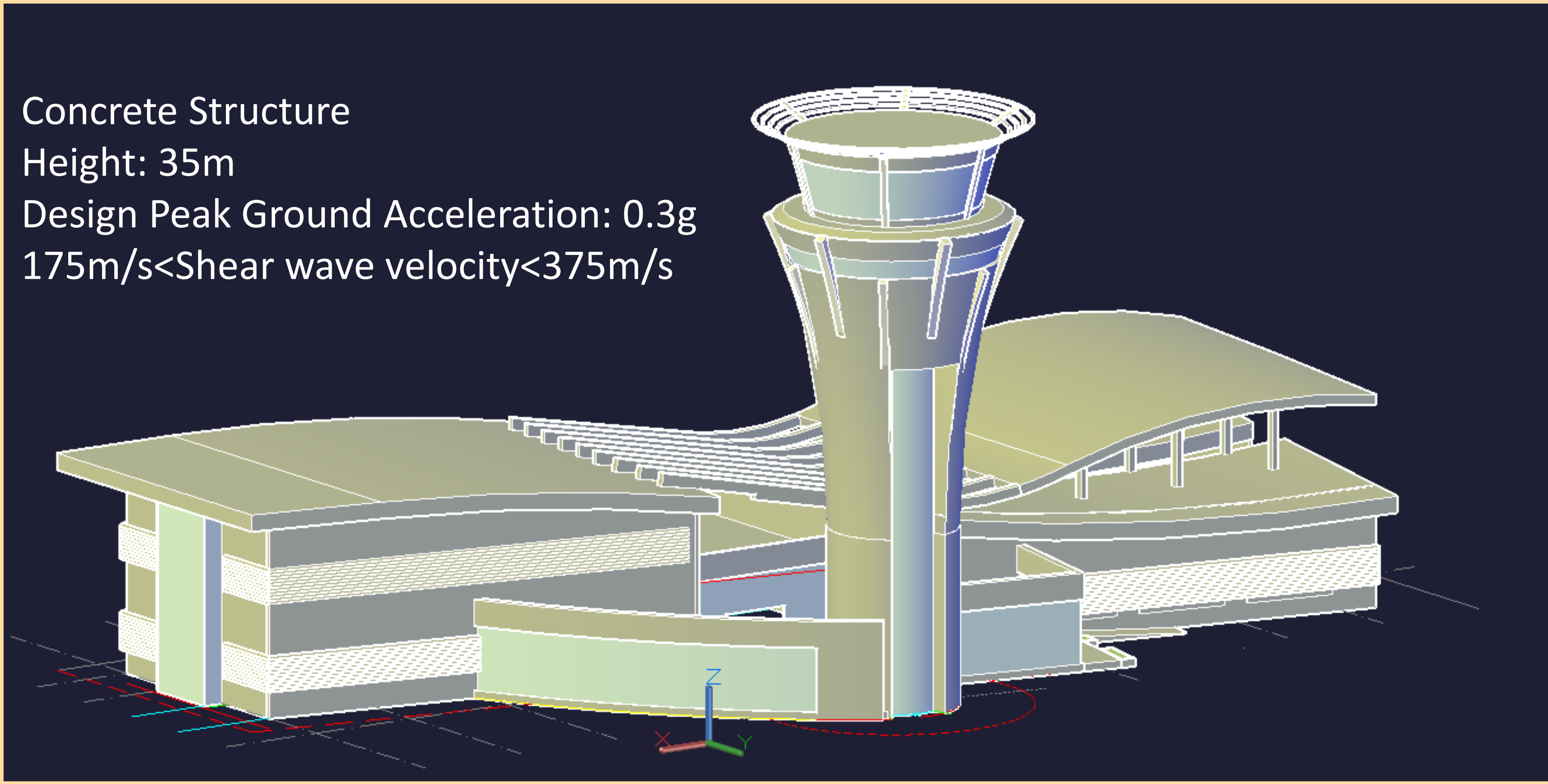
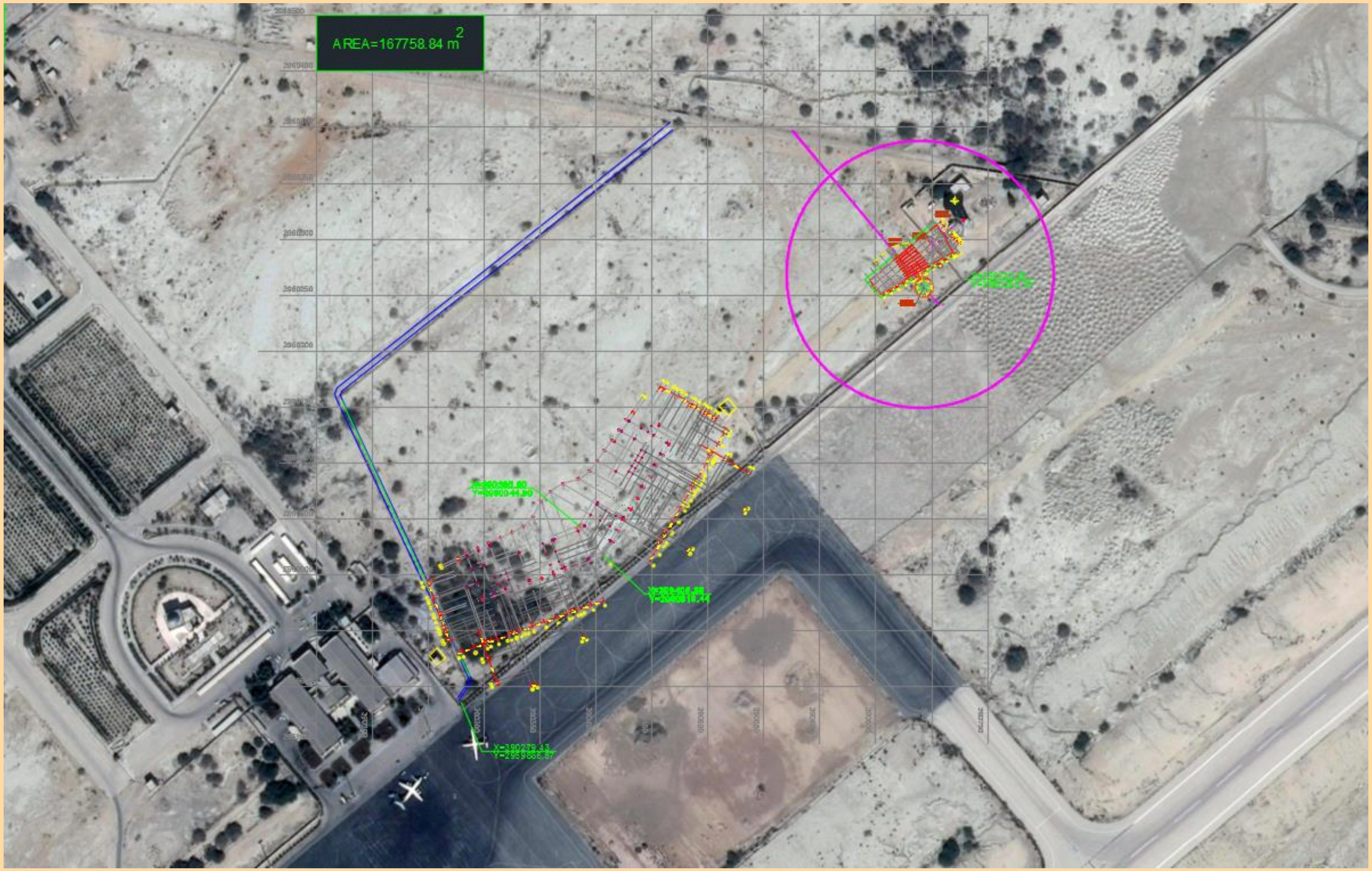
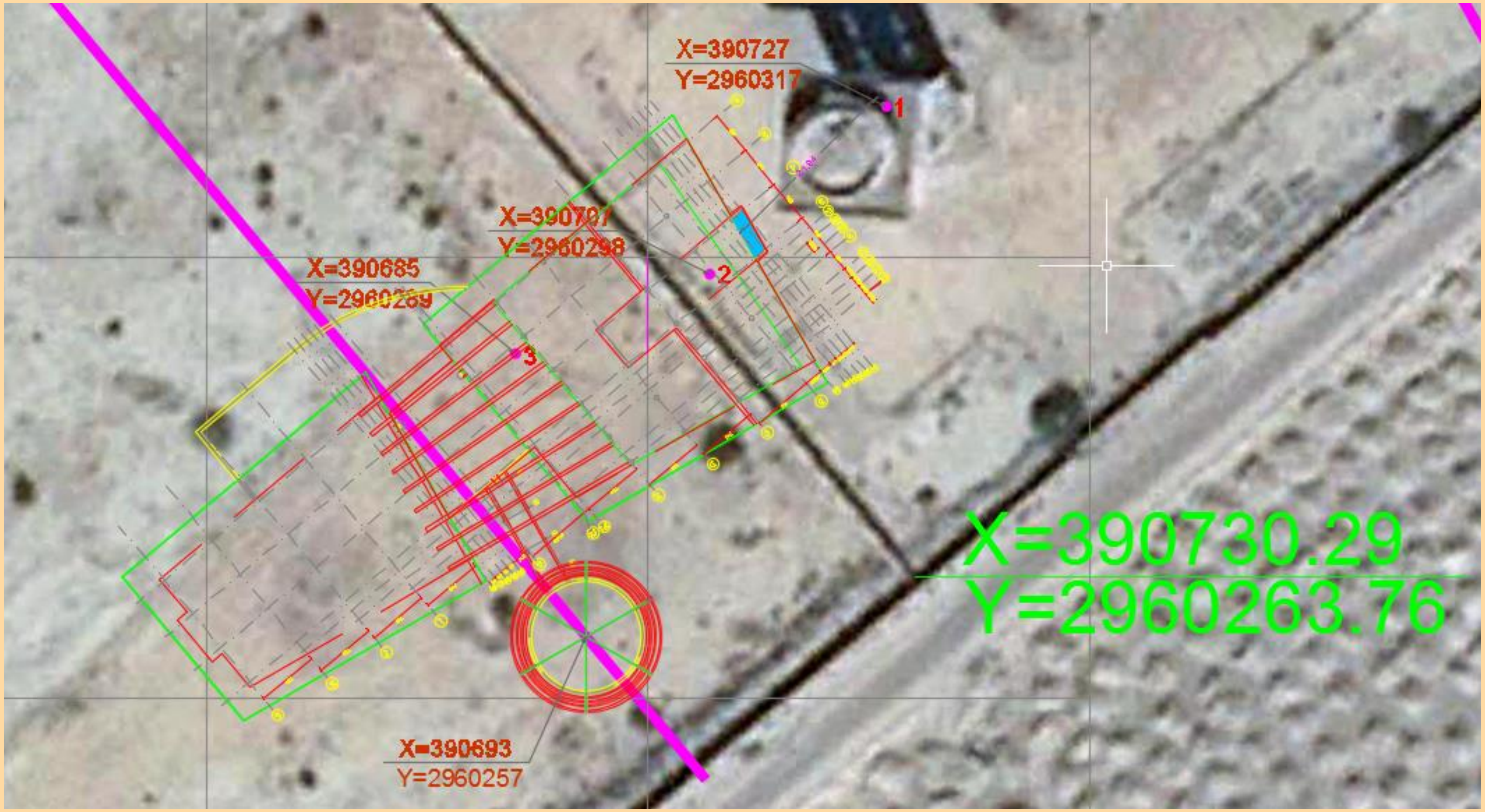
# Case Study Project (ATC tower of Qeshm Int. Airport , Iran)



# Case Study Project (ATC tower of Qeshm Int. Airpot , Iran)



# Case Study Project (ATC tower of Qeshm Int. Airpot , Iran)




1, 2 and 3 are the borehole locations

# Case Study Project (ATC tower of Qeshm Int. Airpot , Iran)

Water Level

| DEPTH | Sample | Type | U.S.C.S. | Soil Descriptions | Liquid Limit (L L) | Plasticity Index (P I) | Unit Weight (g/cm3) | Moisture Content (W %) | Cohesion (Kg/cm2) | Angle of Friction (Deg) | Specific Gravity (Gs) | Passing of 200 (%) | Standard Penetration Test | Other Tests |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0–1 | | | SM | Silty sand ماسه لای دار قهوه ای | | | | | | | | | | |
| 2 | | | ML | Silt لای با پلاستیسیته کم سبز | N.LL | N.PI | 1.73 | 24.55 | 0.08 | 27.0 | | 44.88 | 12,16,22 | |
| 4 | | | | | N.LL | N.PI | 1.66 | 14.10 | | | | 53.91 | 26,28 35 | |
| 6 | | | CL | Lean Clay رس با پلاستیسیته کم سبز | 49.4 | 13.24 | 1.61 | 16.99 | | | | 99.08 | 3,3,4 | qu=1 4Kg /cm2 |
| 8 | | | ML | Silt لای با پلاستیسیته کم سبز | N.LL | N.PI | 1.63 | 26.89 | 0.15 | 22.0 | | 74.59 | 6,5,12 | |
| 10 | | | CL | Lean Clay رس با پلاستیسیته کم سبز | 36.2 | 9.05 | 1.63 | 14.03 | | | | 97.29 | 6,8,11 | qu=3 2Kg /cm2 |
| 12 | | | ML | Silt لای با پلاستیسیته کم سبز | N.LL | N.PI | 1.63 | 16.67 | | | | 86.77 | 7,9,8 | |
| 14 | | | SM | Silty sand ماسه لای دار قهوه ای | N.LL | N.PI | 1.72 | 17.42 | | | | 48.50 | 3,4,4 | |
| 16 | | | | | N.LL | N.PI | 1.65 | 15.55 | | | | 31.17 | 4,5,6 | |
| 18 | | | ML | Silt لای با پلاستیسیته کم سبز | N.LL | N.PI | 1.66 | 13.11 | | | | 65.12 | 12,16,27 | |
| 20 | | | SM | Silty sand ماسه لای دار قهوه ای | N.LL | N.PI | 1.78 | 12.03 | | | | 33.48 | 14,18,26 | |
| 22 | | | | | N.LL | N.PI | 1.78 | 20.72 | | | | 45.26 | 15,32,43 | |
| 24 | | | | | N.LL | N.PI | 1.72 | 13.73 | | | | 40.04 | 18,34,40 | |
| 25 | | | | | | | | | | | | | | |

**Soil in Borehole 1**

# Case Study Project (ATC tower of Qeshm Int. Airport , Iran)

- Evaluation of the potential of liquefaction was accomplished by **comparing equivalent measures of earthquake loading and liquefaction resistance**

**Factor of Safety = CRR / CSR**

CSR= Estimation of Cyclic Stress Ratio of soil due to probable earthquakes.
CRR= Estimation of Cyclic Resistance Ratio of Soil

Soil liquefaction study at borehole 1 (B.H.1)

| Borehole | Depth (m) | Soil Type | SPT | FS = CRR/CSR |
|---|---|---|---|---|
| BH.1 | 12.0 | ML | 17 | 0.67 |
| BH.1 | 14.0 | SM | 8.0 | 0.37 |
| BH.1 | 16.0 | SM | 11 | 0.45 |

<1

# Case Study Project (ATC tower of Qeshm Int. Airport , Iran)

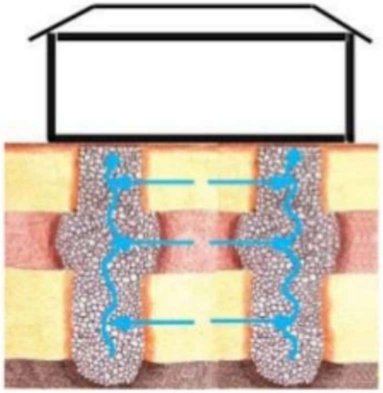
## Selection of Hazard Reduction Method:

1) **Improve resistance of structural components against liquefaction:**

- *Mat Foundation* was used to reduce the effects of settlements

2) **Improve Soil quality:**

- Usage of stone columns and drainage system to reduce pore water pressure



Stone Columns act as vertical drains, thus reducing the excess pore pressures that lead to liquefaction.

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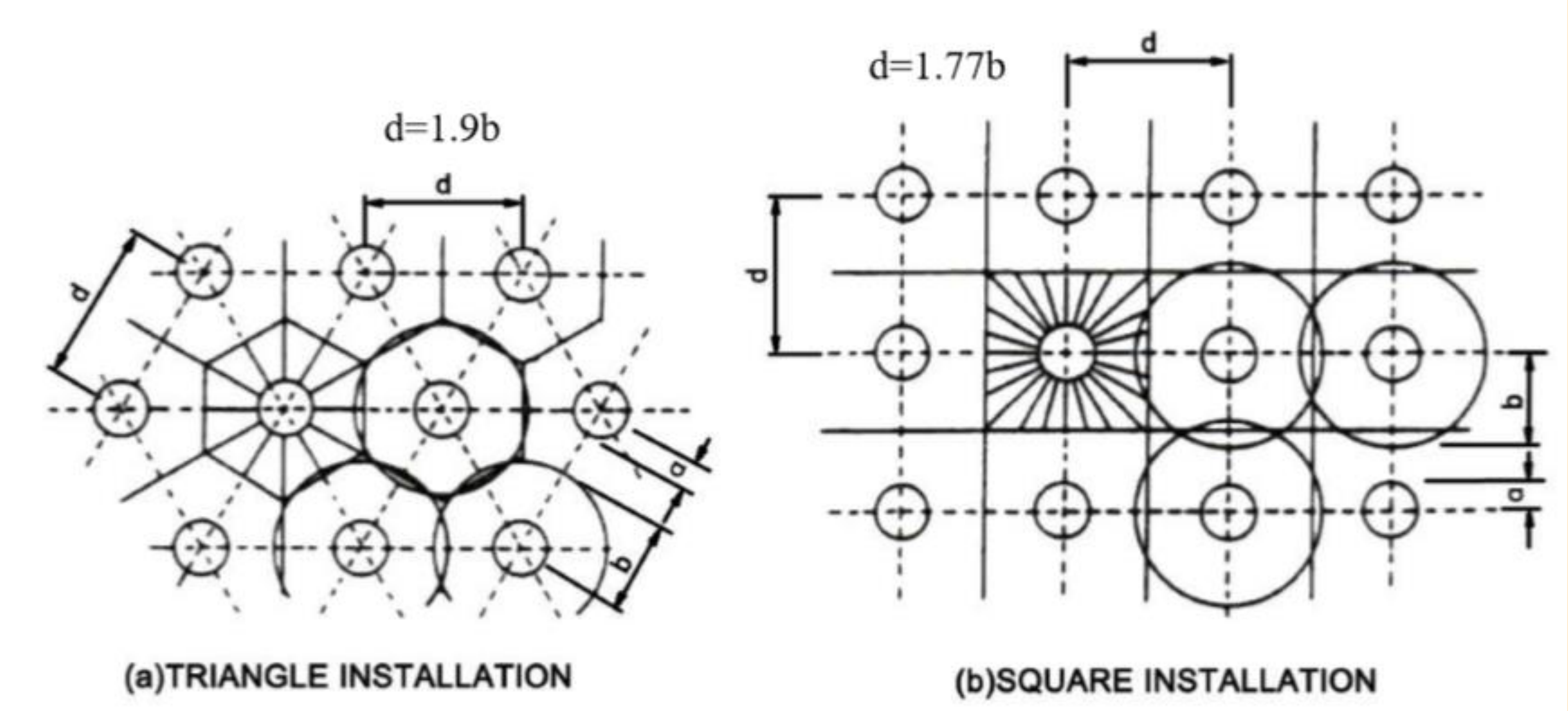
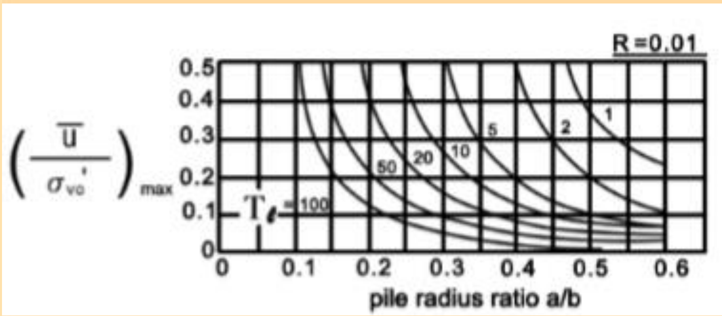
# Case Study Project (ATC tower of Qeshm Int. Airport , Iran)




**Stone Columns' arrangements in Plan**

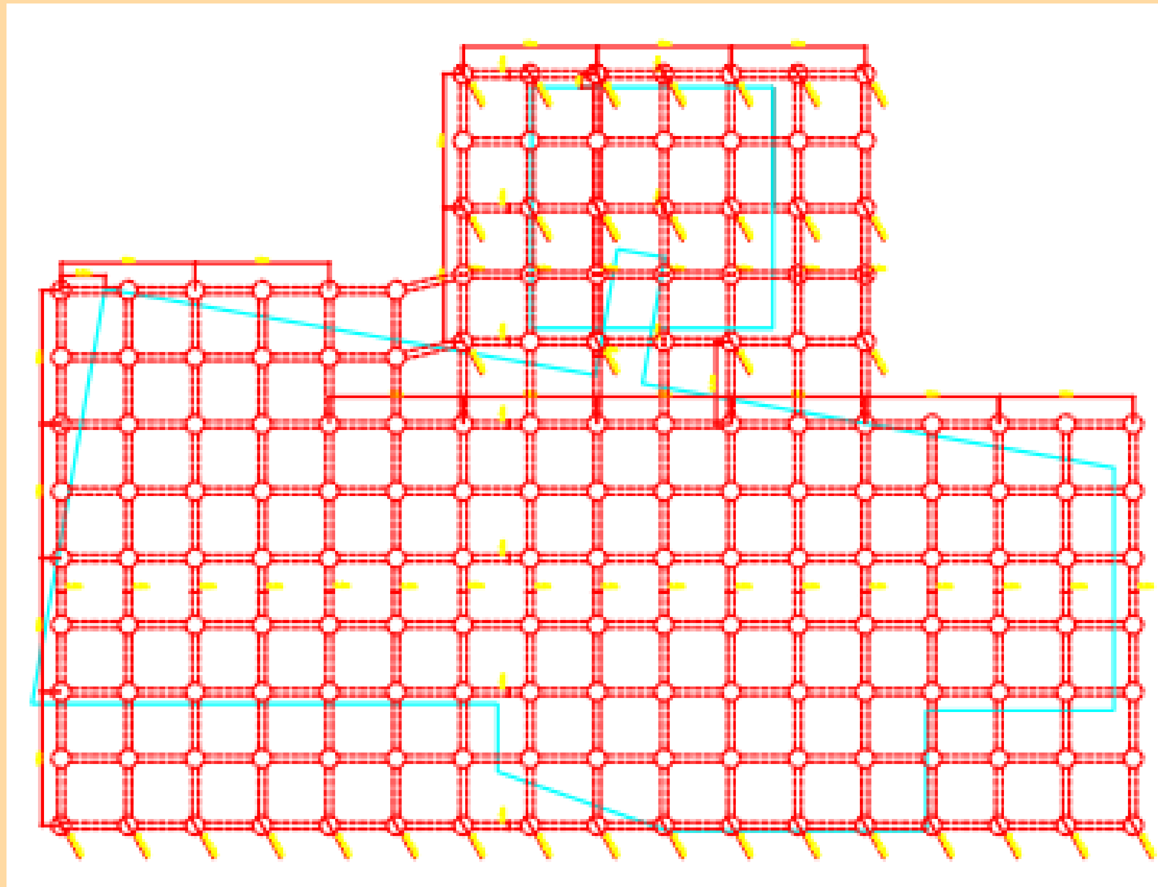
# Case Study Project (ATC tower of Qeshm Int. Airport , Iran)




$$T_l = \frac{k_s \times t_l}{m_v \times \gamma_w \times a^2}$$

$$R = \frac{8}{\pi^2}\left(\frac{k_s}{k_d}\right)\left(\frac{h}{a}\right)^2$$

- 166 stone columns
- Depth=16m, Diameter=0.7m
- Distance 3m



## Case Study Project (ATC tower of Qeshm Int. Airport , Iran)

**THANKS FOR YOUR ATTENTION**