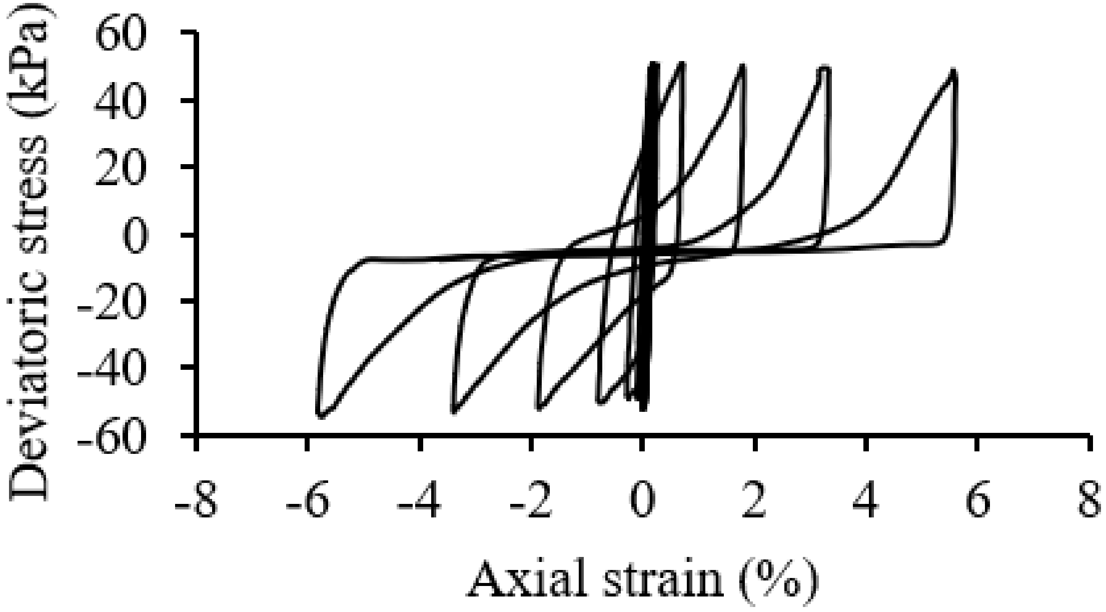
International Conference
on
Tenets for Geosystem Surety: TGS 2026

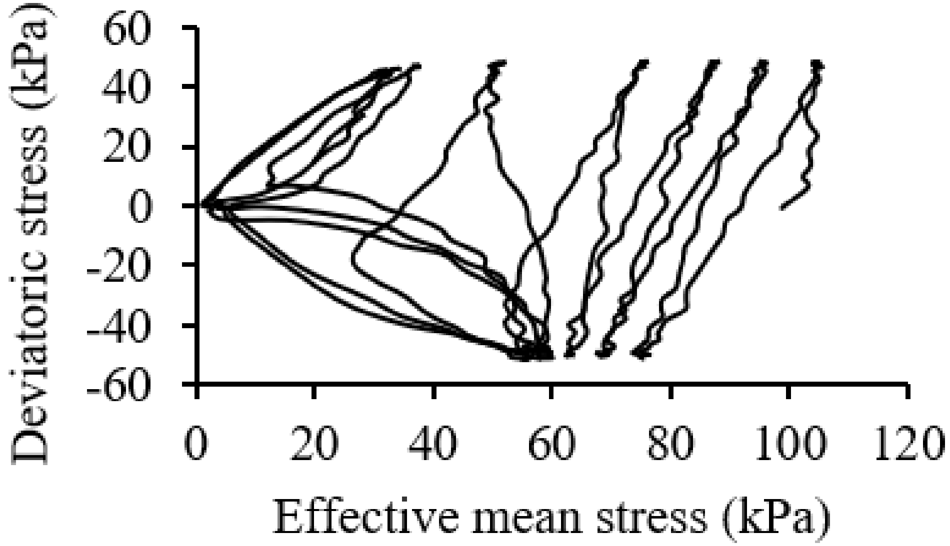
From Bhuj to Beyond: Prof. T. G. Sitharam's Legacy in Soil Liquefaction Research

Contributors:

- Prof Anbazhagan P
- Prof Govindaraju L
- Prof Ravishankar B V
- Dr Vinod J S
- Prof Dash Hemanta Kumar
- Dr Bala Reddy Muthanna
- **Dr Chavan Dhanaji (Theme Speaker)**

Prof TGS commenced the research on **Earthquake Induced Soil Liquefaction** in **2001, the year in which devastating Bhuj Earthquake happened.**





Prof TGS's visit to Bhuj in 2001

Road Embankment failure

Collapse of the Intake Structure at the Tapar dam

When Prof. Commenced research…

- ✓ **fundamental mechanisms** of liquefaction was well understood,
- ✓ **triggering criteria** was well established, and
- ✓ **field evaluation procedures** had been extensively developed through the pioneering work of **Seed, Idriss, Ishihara, Youd**.

<u>However,</u>

liquefaction resistance of region-specific sandy soils, particularly **Indian sands**, under cyclic loading conditions was to be yet investigated.

- **Research on <u>Indian Soils</u> was much needed.**

2001 to 2005: **Cyclic Triaxial Studies** on **Bhuj Sand**

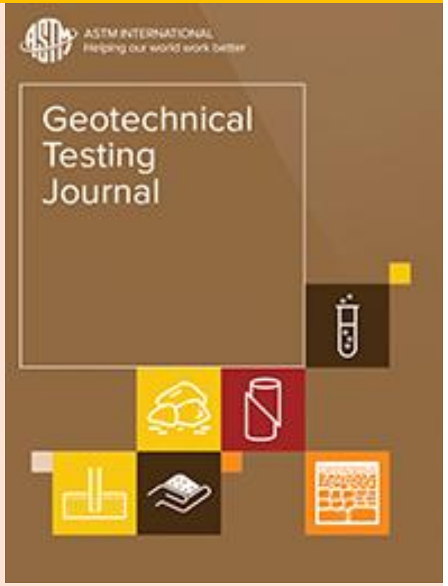
2001 to 2005: Cyclic Triaxial Studies

Dr. Govindaraju, L. performed **cyclic triaxial testing** on liquefiable sands **collected from Indian regions**, including areas affected by the **2001 Bhuj earthquake**.

The work primarily involved:

- **Cyclic triaxial** testing on saturated sandy soils.
- Measurement of cyclic stress–strain response.
- Evaluation of pore-pressure buildup during cyclic loading.
- Determination of dynamic stiffness degradation and damping characteristics at different strain levels.
- Assessment of liquefaction triggering conditions.

2001 to 2005: Cyclic Triaxial Studies



Major Contributions:

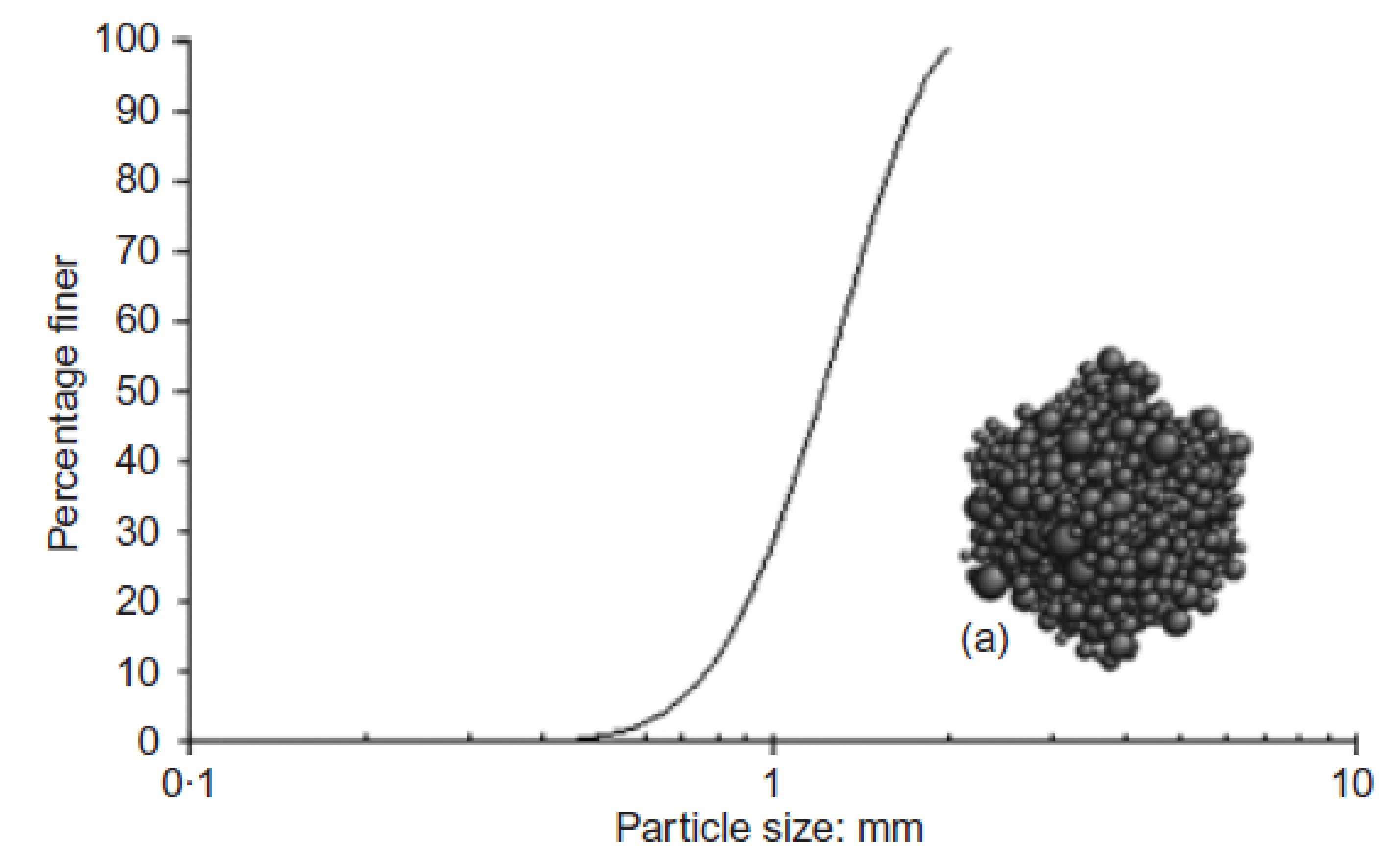
- ❑Evaluation of Liquefaction Resistance of Indian Sands
- ❑Study of Excess Pore Pressure Development
- ❑Dynamic Soil Property Characterization
- ❑Influence of Relative Density on Liquefaction Resistance
- ❑Deformation Characteristics Under Cyclic Loading

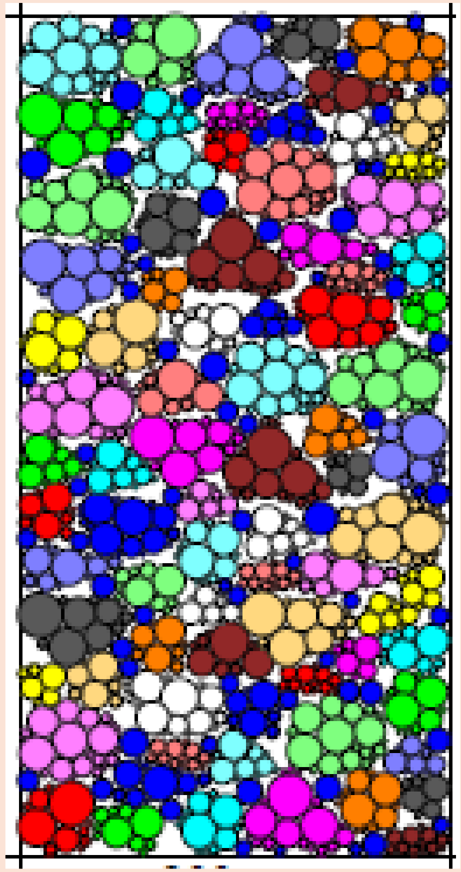
Foundation for Subsequent Liquefaction Research @ IISc

Sitharam, T. G., Govindaraju, L., & Srinivasa Murthy, B. R. (2004). Evaluation of liquefaction potential and dynamic properties of silty sand using cyclic triaxial testing. Geotechnical Testing Journal, 27(5), 423-429.

Cyclic Triaxial And DEM simulations

2004-2006





Ravishankar, B.V. (2006)

The study focused on understanding the behavior of **saturated sandy soils** subjected to :

- Monotonic undrained loading representing **post-earthquake and static loading conditions.**
- Investigation of **deformation mechanisms before, during, and after liquefaction**

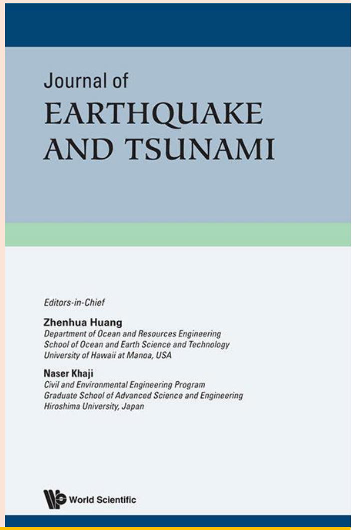
Contributions:

✓Integrated Study of Cyclic and Monotonic Behavior

✓Post-Liquefaction Strength Assessment

✓Relationship Between Liquefaction and Cyclic Mobility

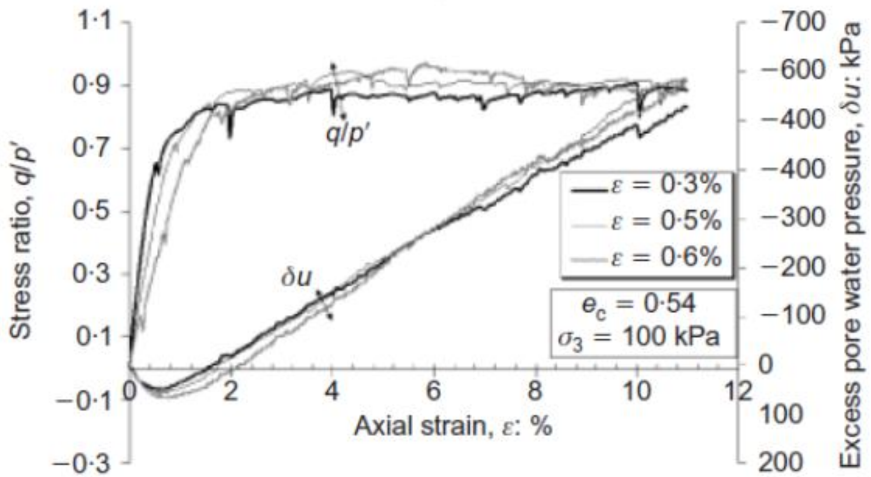
✓Experimental Database for Constitutive Modelling

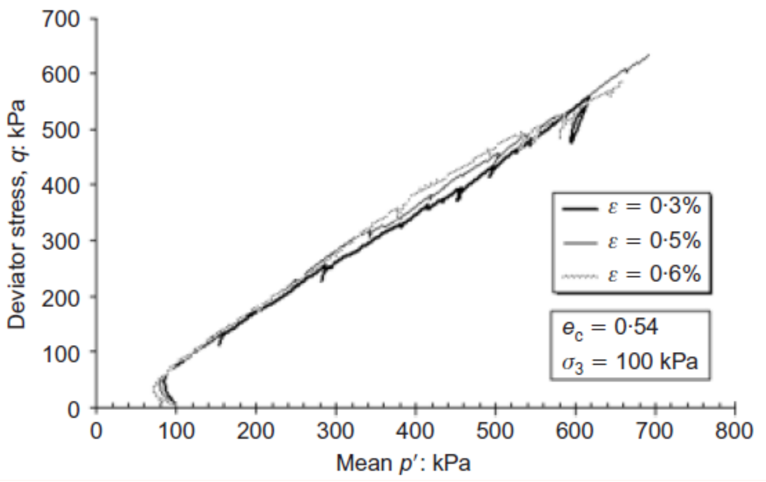


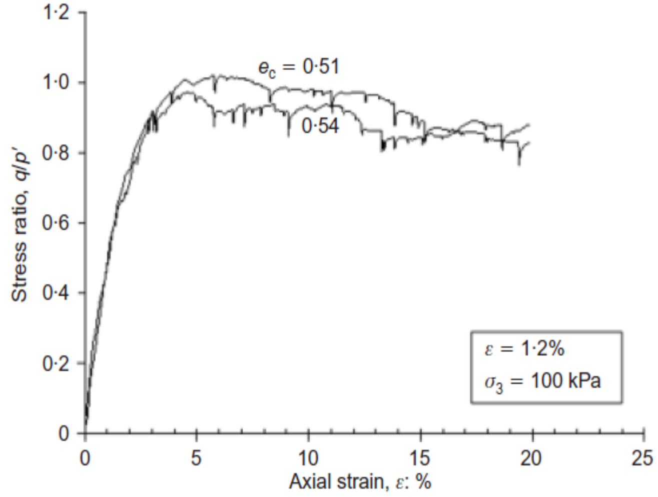
Sitharam, T. G., Ravishankar, B. V., & Vinod, J. S. (2008). Liquefaction and pore water pressure generation in sand—A cyclic strain approach. Journal of Earthquake and Tsunami, 2(03), 227-240.

PhD thesis of **Vinod. J. S. (2006) focused on:**

- **Development and calibration of a three-dimensional DEM model for granular soils.**
- Simulation of cyclic triaxial loading to study pore-pressure buildup and liquefaction triggering.
- **Correlation of macro-scale soil response with micro-scale particle interactions using DEM.**
- Study of post-liquefaction monotonic behavior and strength recovery of sands.





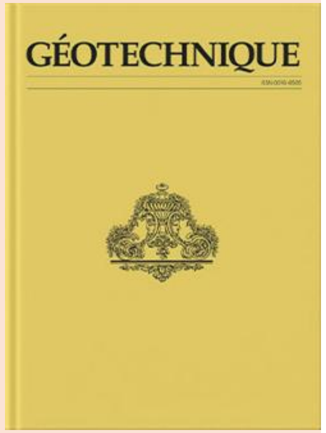


Major Contributions:

✓**Demonstrated** that DEM can successfully reproduce the liquefaction behavior observed in laboratory cyclic triaxial tests.

✓Linked **macroscopic liquefaction** behavior with:

- Contact force evolution
- Particle rearrangement
- Fabric changes within the granular assembly.

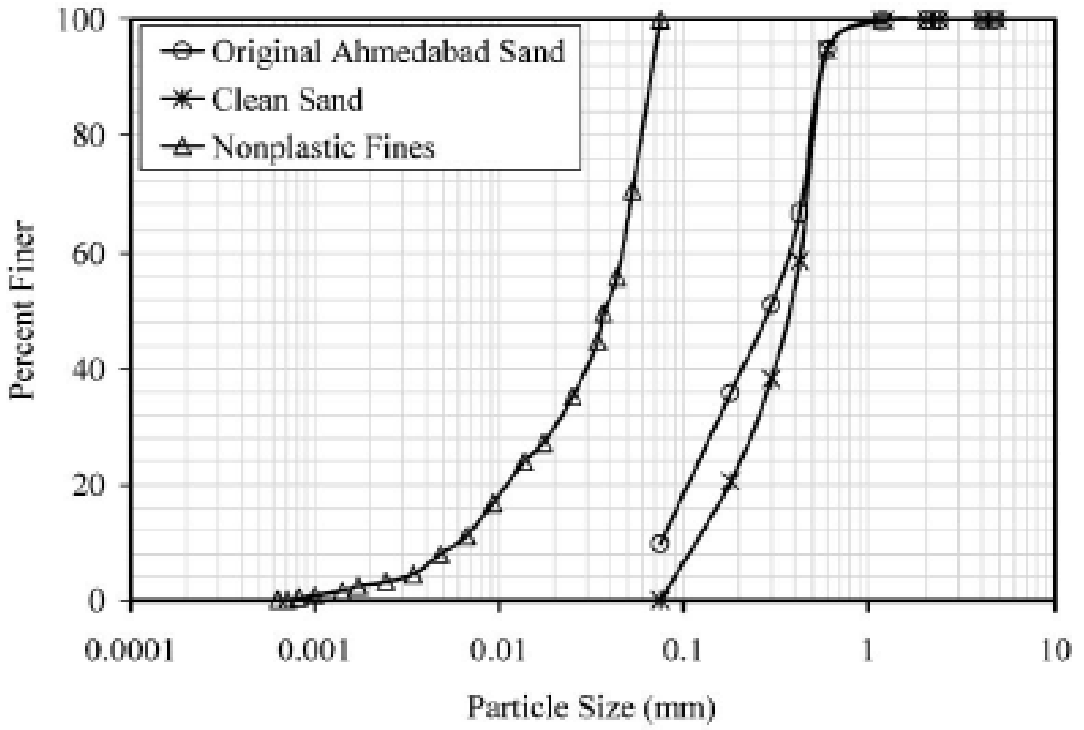


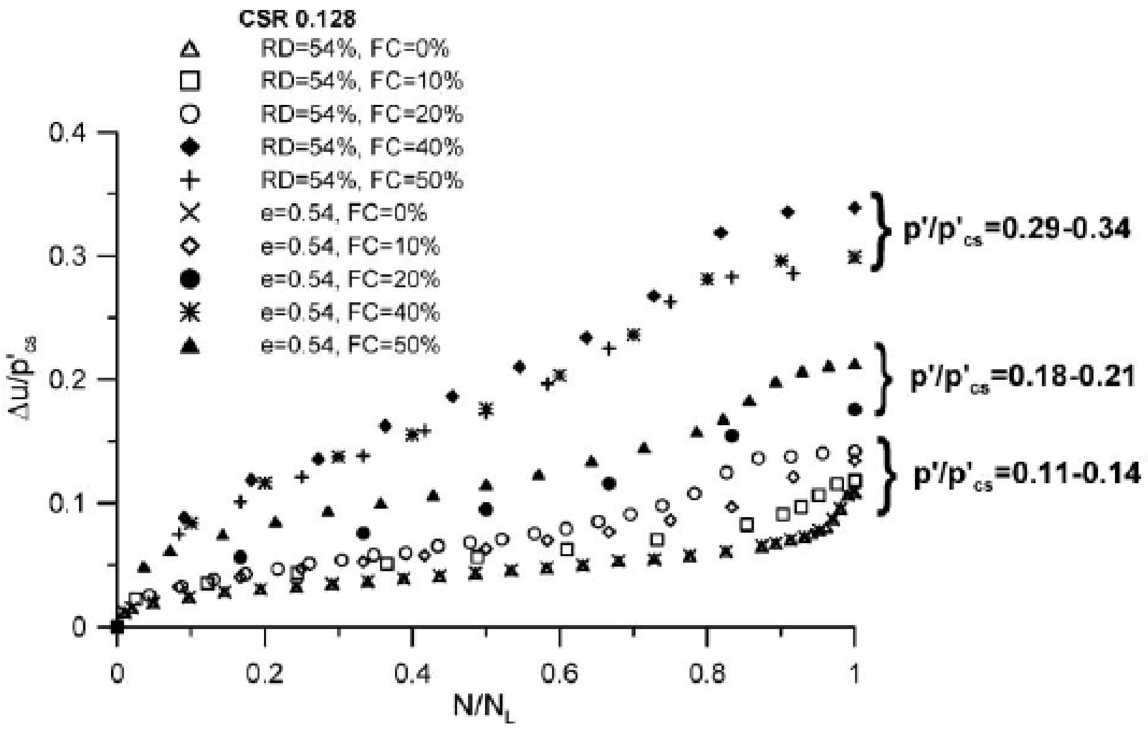
✓Extended DEM analysis beyond liquefaction triggering to study post-liquefaction monotonic response.

One of the earliest comprehensive **Indian studies** applying DEM to liquefaction and soil dynamics

Sitharam, T. G., Vinod, J. S., & Ravishankar, B. V. (2009). Post-liquefaction undrained monotonic behaviour of sands: experiments and DEM simulations. Géotechnique, 59(9), 739-749.

From Clean Sand To Sand with Fines (2006-2014)



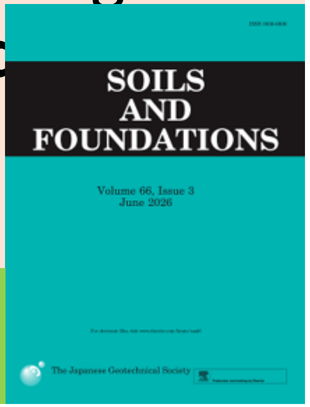


Dash, Hemanta Kumar (2008)

- **Extensive stress-controlled cyclic triaxial tests on saturated sand-silt mixtures**
- **Monotonic undrained triaxial tests on the same mixtures.**
- **Evaluation using different density concepts:**
  - Gross void ratio
  - Relative density
  - Sand skeleton void ratio
  - Inter-fine void ratio
- **Examination of the relationship between cyclic resistance and monotonic strength**
- **Assessment of post-liquefaction behavior of sand-silt mixture**

<u>Major Contributions:</u>

- ✓ One of the most important contributions was the identification of a **limiting silt content**, beyond which the behavior of the soil changes significantly.
- ✓ The thesis helped **resolve contradictory findings** reported in earlier studies by demonstrating that the effect of fines depends strongly on: **Density state**, **Soil fabric**, **Method used to define void ratio**, **Position relative to limiting fines content**
- ✓ The findings are particularly relevant to natural deposits containing non-plastic silt, such as: **River deposits, Alluvial deposits ,Reclaimed**



Dash, H. K., Sitharam, T. G., & Baudet, B. A. (2010). Influence of non-plastic fines on the response of a silty sand to cyclic loading. Soils and Foundations, 50(5), 695-704.

Bala Reddy Muthanna (2014):

The study focused on understanding how different types and percentages of fines influence:

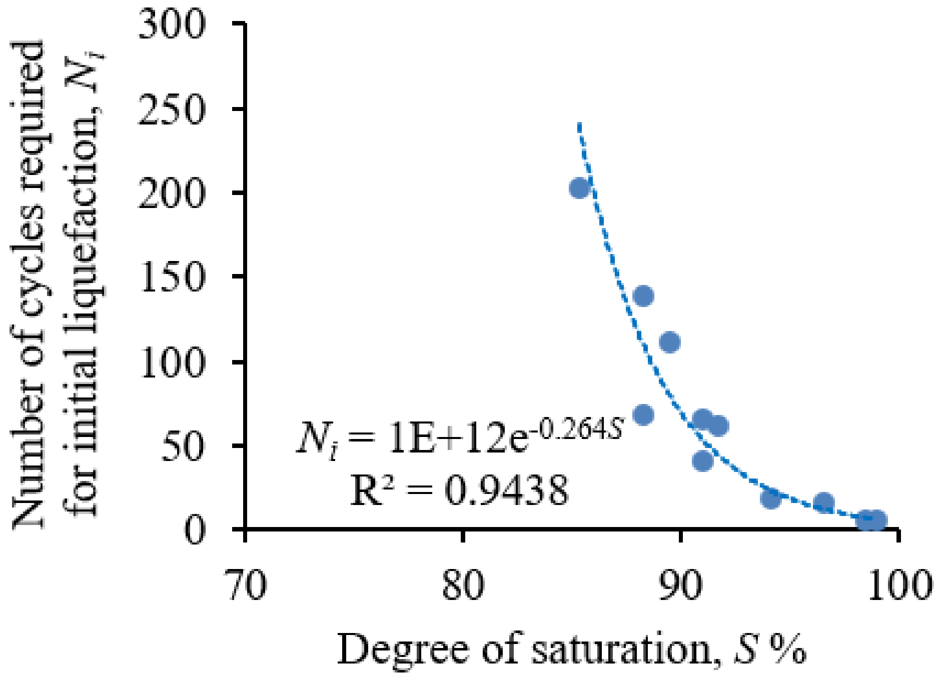
- ❑Liquefaction resistance of sand–fines mixtures.
- ❑Excess pore-water pressure generation during cyclic loading.
- ❑Post-liquefaction monotonic undrained behavior.
- ❑Residual and post-cyclic shear strength.
- ❑Influence of relative density and confining pressure.
- ❑Effect of **low-plasticity clay fines** compared with clean sand behavior

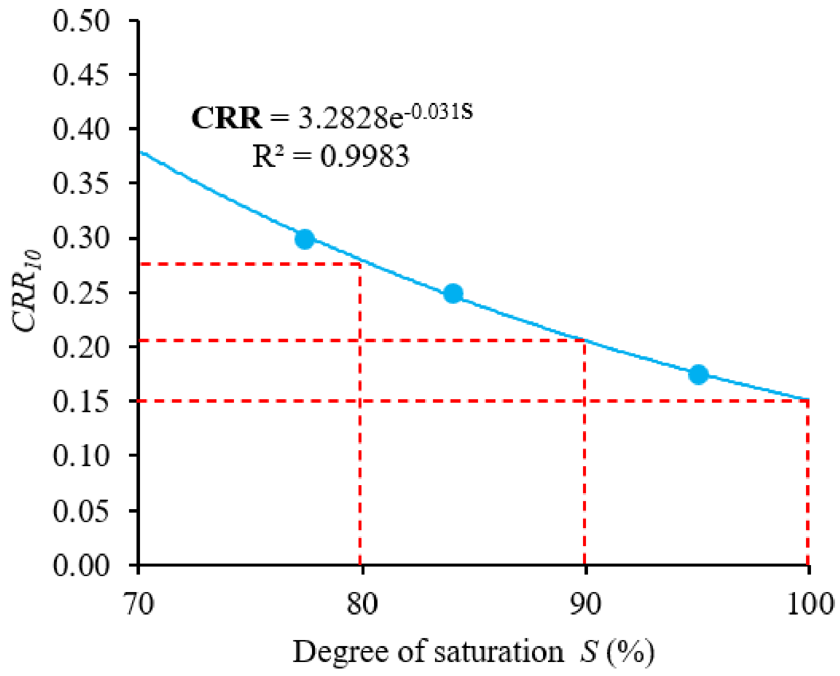
Major Contributions:

- The research demonstrated that liquefaction resistance is strongly affected by both fines content and density.
- Earlier IISc studies by Dash (2008) concentrated mainly on non-plastic silt. Bala Reddy's work extended the investigation to **low-plasticity clay fines**, providing valuable experimental evidence regarding their influence on liquefaction and post-liquefaction behavior.
- The work provided insight into how sand–fine mixtures regain strength after liquefaction triggering and how fines content affects the rate and magnitude of strength recovery during subsequent monotonic loading.

Balreddy, M. S., Dinesh, S. V., & Sitharam, T. G. (2016). Influence of sand and low plasticity clay mixtures on the liquefaction and post-liquefaction behavior. Japanese Geotechnical Society Special Publication, 2(21), 806-810.

Research on emerging technique: Induced Desaturation (2016-2021)





Chavan Dhanaji (2021)

Experimental work

A comprehensive series of **stress-controlled undrained** cyclic triaxial tests was conducted on air-injected desaturated clean sand with:

- Degree of saturation (Sr): 70%–99%
- Relative densities: 30%, 40%, and 60%
- Effective confining pressures: 25, 50, and 100 kPa
- Cyclic Stress Ratios (CSR): 0.175, 0.25, 0.30, and 0.40

Numerical Investigation

The research also developed finite-element models to simulate:

- Cyclic response of desaturated soil
- Pore-pressure evolution
- Ground deformation
- Acceleration amplification
- Influence of desaturated layer thickness

Major Contributions

- Established a **practical laboratory procedure** for desaturating saturated clean sand specimens through air injection.
- Demonstrated that **liquefaction resistance increases significantly** as saturation decreases.
- Systematically identified and classified **five distinct cyclic failure modes** in desaturated sands:
- Numerical studies indicated that desaturation levels of approximately **70–80% can significantly reduce or prevent liquefaction under strong earthquake motions**

This work is among the earliest comprehensive studies **from India** demonstrating that **air-induced desaturation is a cost-effective and environmentally friendly liquefaction mitigation technique**

Chavan, D., Sitharam, T. G., & Anbazhagan, P. (2022). Site response analysis of liquefiable soil employing continuous wavelet transforms. Geotechnique Letters, 12(1), 35-45.

Liquefaction Estimation and Mapping in India (2004-2007)

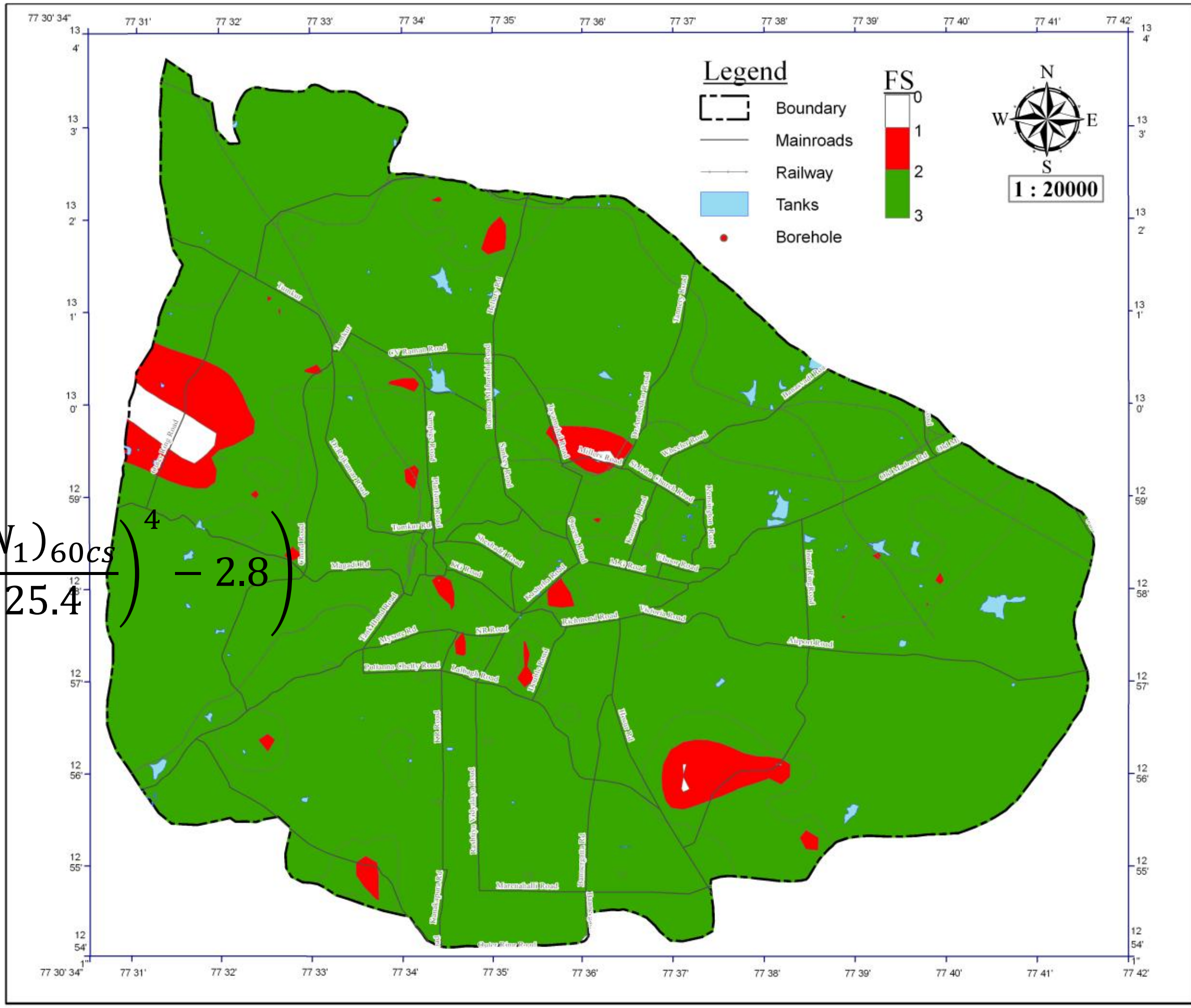
Liquefaction Estimation and Mapping in India

- ✓ Cyclic resistance ratio (CRR) is arrived based on corrected "N" value as per Seed et al. (1985), Youd et al., (2001); Cetin et al., (2004). Seed et al. (1985) presents a plot of CRR versus corrected 'N' value from a large amount of laboratory and field data.

$$CRR_{M=7.5,\sigma'_v=1atm} = \exp\left(\frac{(N_1)_{60cs}}{14.1} + \left(\frac{(N_1)_{60cs}}{126}\right)^2 - \left(\frac{(N_1)_{60cs}}{23.6}\right)^3 + \left(\frac{(N_1)_{60cs}}{25.4}\right)^4 - 2.8\right)$$

Where $(N_1)_{60cs}$ is the fines-content corrected, overburden-normalized SPT blow count.

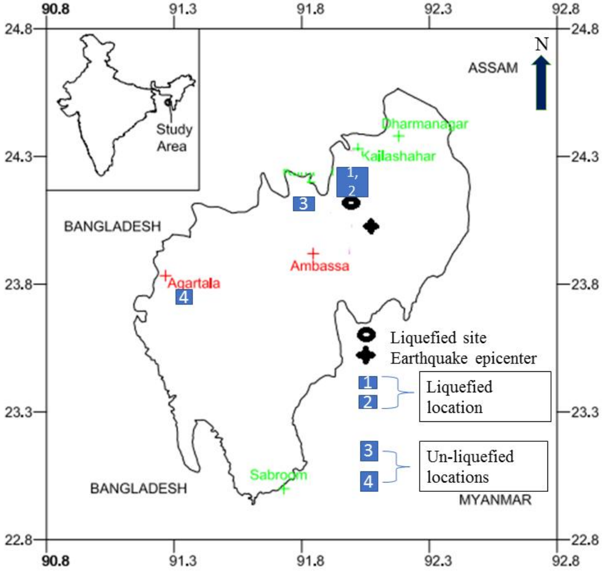
- ✓ N was corrected by assuming hammer energy as there is no equipment and practice of hammer energy measurement in India
- ✓ **Lead to innovation of SPT-HEMA & Revision of IS2131 (2025) code**

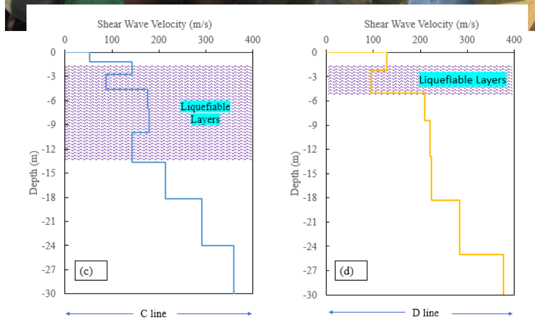


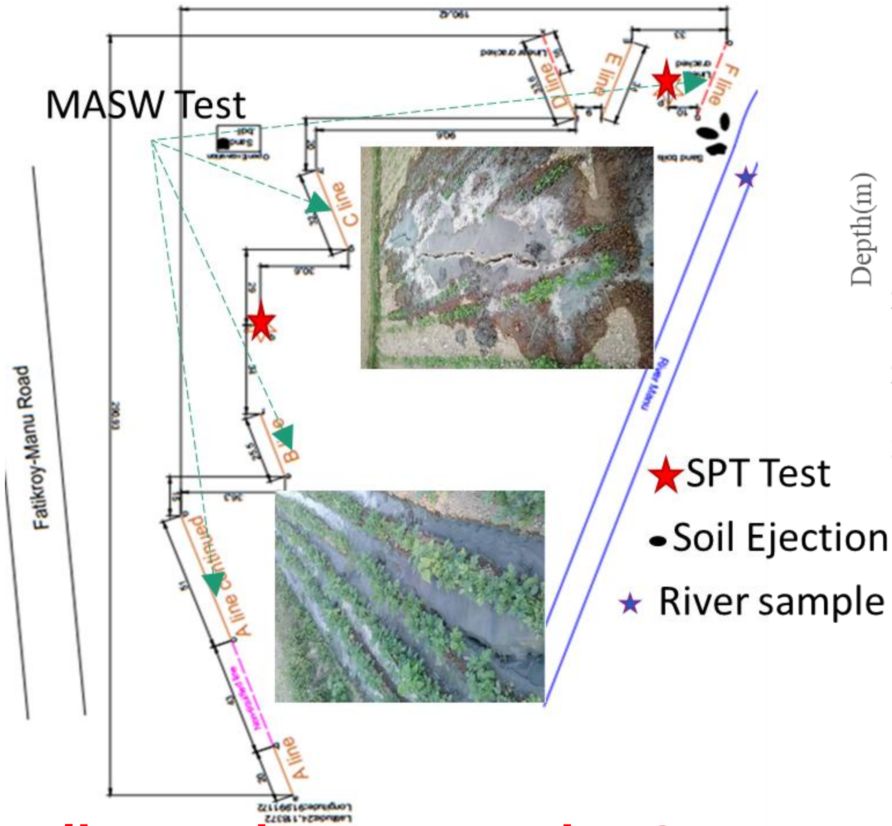
Map of factor of safety against liquefaction

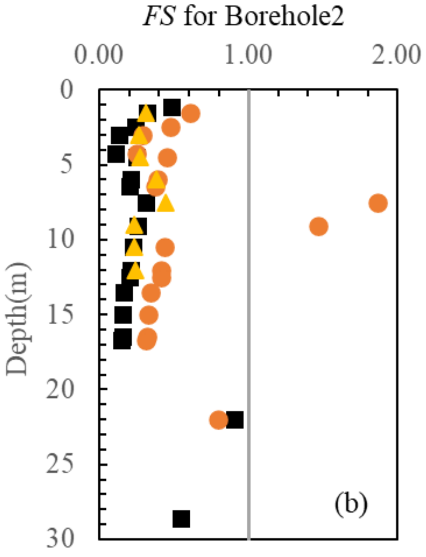
Sitharam, T. G., Anbazhagan. P and Mahesh. G. U. (2007). "3-D Subsurface Modelling and Preliminary Liquefaction Hazard Mapping of Bangalore City Using SPT Data and GIS", Indian Geotechnical Journal, 37(3): 210-226.

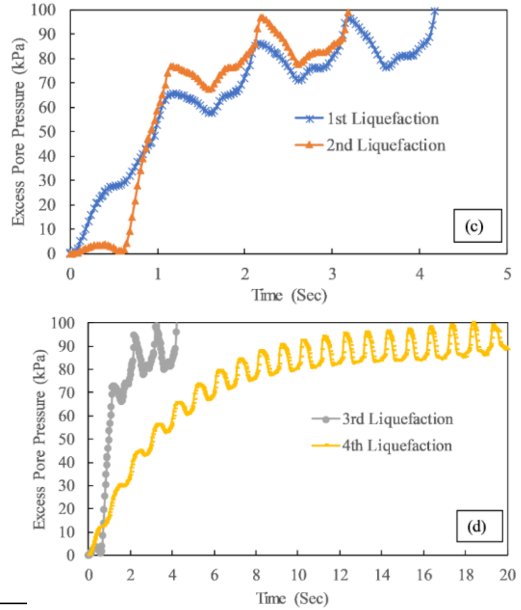
Recent research @ **IISc** and future scope

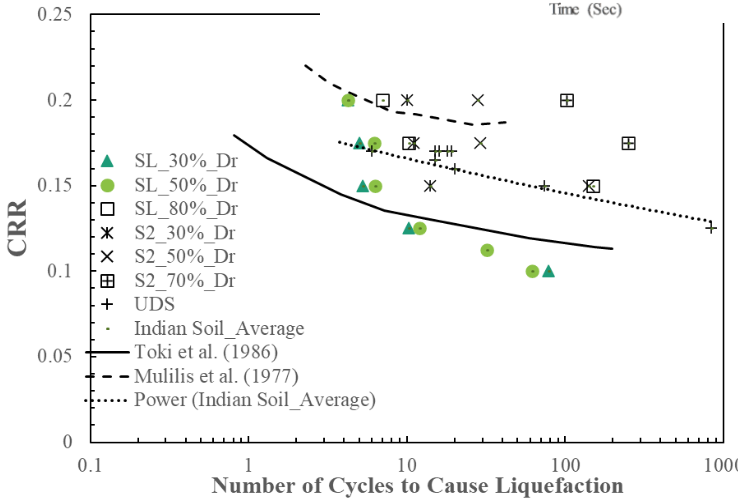












- **Cyclic Resistance Ratio Curves used for liquefaction assessment need to be revisited & developed for silt rich (>15 %) soil**
- **Need to establish methodology for assessment of seismic liquefaction of soil due to moderate Earthquakes**

Kunjari Mog and Anbazhagan P (2024)"Liquefaction Susceptibility and Re-Liquefaction Potential of the liquefied soil site caused due to Mw 5.7 Tripura earthquake" Sadhana 49, 290. https://doi.org/10.1007/s12046-024-02640-

List of students worked on Soil Liquefaction

1. **Govindaraju L (2005),** “Liquefaction and Dynamic Properties of Sandy Soils”.
2. **Ravishankar B V (2006),** “Cyclic and monotonic undrained behaviour of Sandy soils”.
3. **Vinod J S (2006),** “Liquefaction and dynamic properties of granular materials: A Discrete element approach”.
4. **Dash Hemanta Kumar (2008),** “Undrained Cyclic and Monotonic Response of Sand-silt Mixtures”.
5. **Bala Reddy Muthanna (2014),** “Liquefaction and Post liquefaction behavior of sand fines mixtures”.
6. **Chavan Dhanaji (2021),** “Liquefaction resistance and cyclic response of air–injected desaturated clean sandy soil: experimental and numerical investigations”
7. **Anbazhagan P (2007),** “Site Characterization and Seismic Hazard Analysis with Local Site Effects for Microzonation of Bangalore”

Thank You !