Numerical validation of cyclic triaxial tests conducted on saturated Kasai river sand

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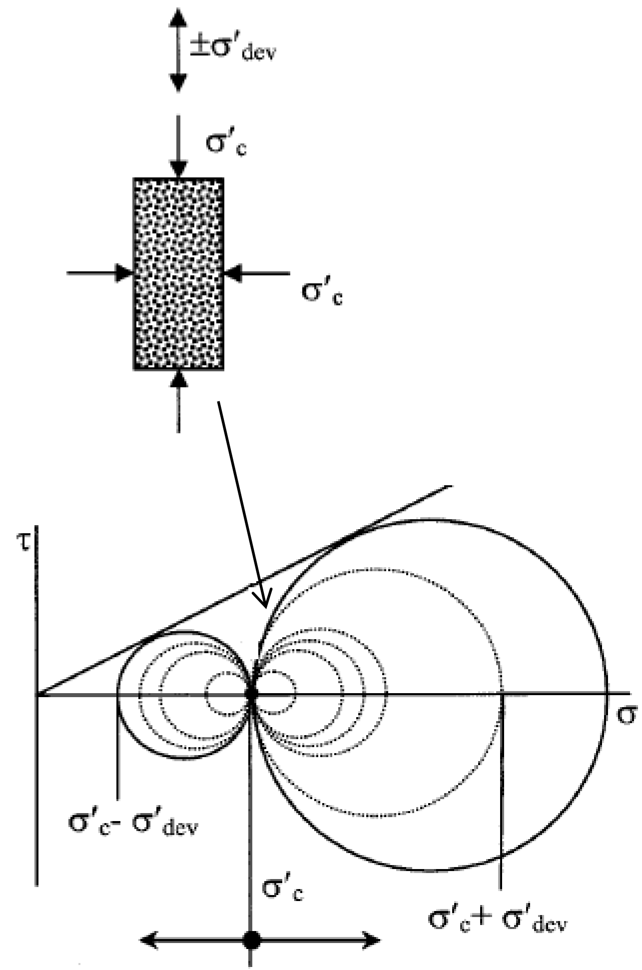
Introduction

- Several important structures like railway or road bridges, underpass, buildings, etc. are built on the banks of Kasai river which is located on Kharagpur, West Bengal as shown in the figure.

- To assure the seismic safety of the existing structures, it is essential to study the dynamic behavior of the underlying foundation sand.

Introduction (contd..)

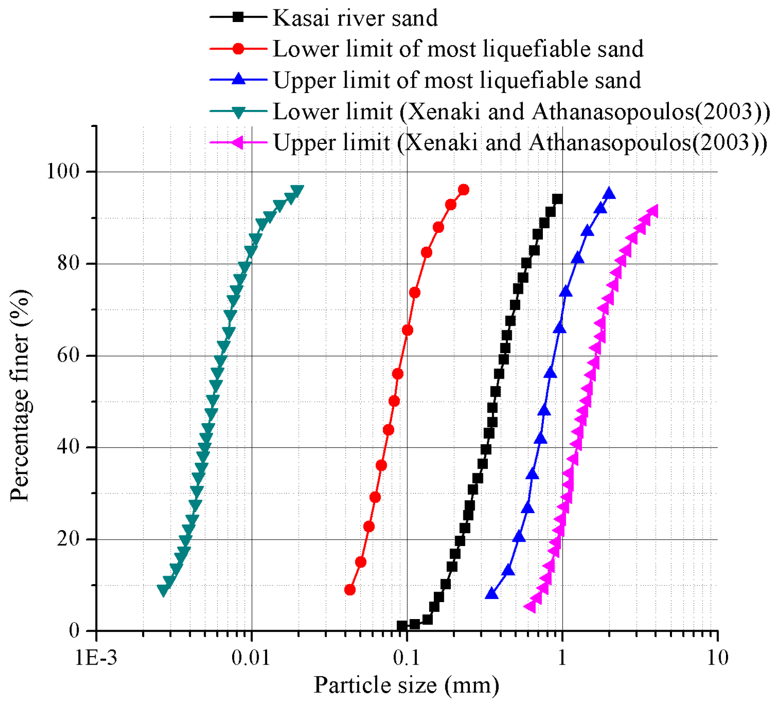
- Nonlinear analysis is done to study the dynamic response of the structure and soil, which requires the usage of advanced constitutive models for soil (Prevost (1985), Dafalias (2004), Elgamal et al. (2003) and Boulanger and Ziotopoulos (2015)); structure is assumed to be elastic.
- The calibration parameters of these constitutive models require cyclic tests to be done on the sand under consideration.
- Presently, a set of **load controlled cyclic triaxial tests** are done on Kasai river sand and numerically simulated using a bounding surface plasticity model known as PM4 sand (Boulanger and Ziotopoulos (2015)).



GSD of Kasai river sand

- Characteristics:
- Poorly graded clean sand.
- The GSD of Kasai river sand lies between the bounds of the most liquefiable zone.
- The small strain modulus of the Kasai river sand is given by (Chattaraj and Sengupta (2016)):

$$G_{max} = \frac{611.58(Pa)^{0.532}(\sigma)^{0.468}}{(0.3+0.7e^2)}$$



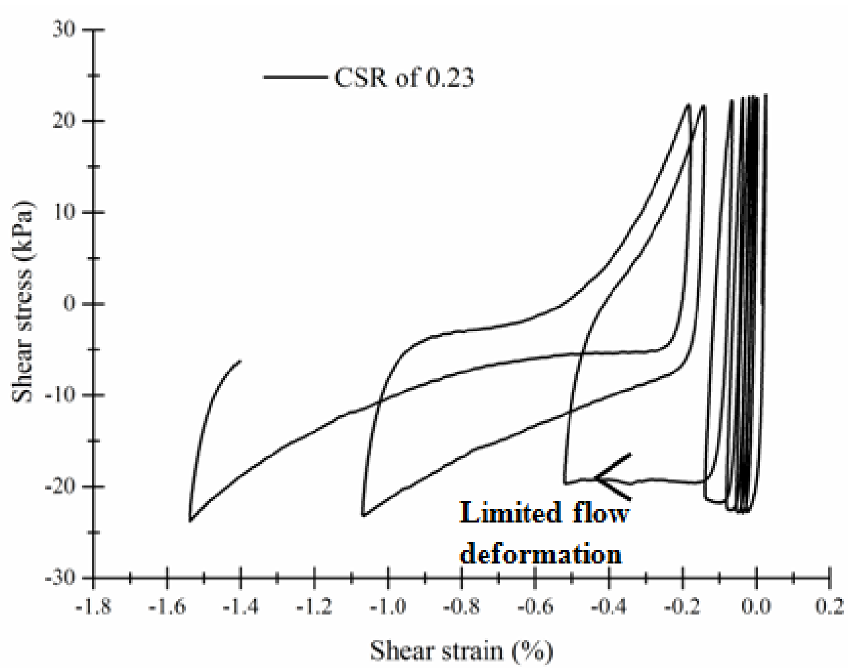
Parameters for the foundation sand	Value
Specific gravity	2.64
D_{10}	0.20
D_{30}	0.32
D_{60}	0.47
Coefficient of Uniformity(C_u)	2.36
Coefficient of Curvature(C_c)	1.08
Mass (saturated) density(kg/m^3)	1928
Cohesion(Pa) (c')	0
Angle of internal friction, φ'	32°

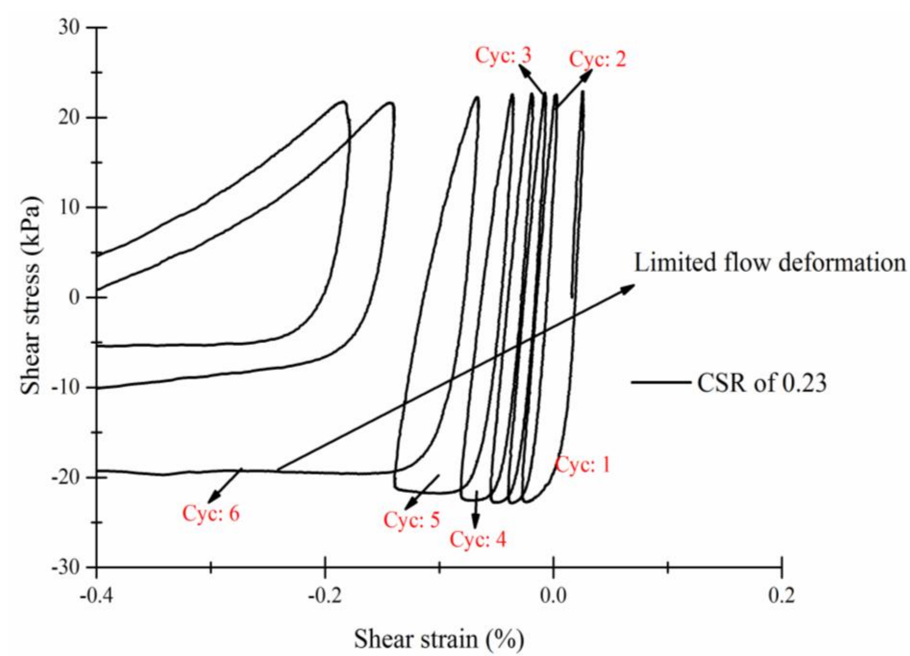
Testing program

- Sample size of 70mm internal diameter and 140mm in height prepared by tamping method (ASTM D-5311-11).
- A series of **load controlled** cyclic triaxial test (constant amplitude deviator (σ_{dev}) stress) was conducted with a harmonic frequency of **1** Hz with CSR ($\sigma_{dev}/2\sigma_{c,}$ where σ_d is the deviator stress and σ_c is the confining stress (of **100** kPa)) values ranging from **0.10 to 0.33**.
- Relative density of soil: **25%,40% and 60%.**

Cyclic test data for RD 60% with CSR 0.23

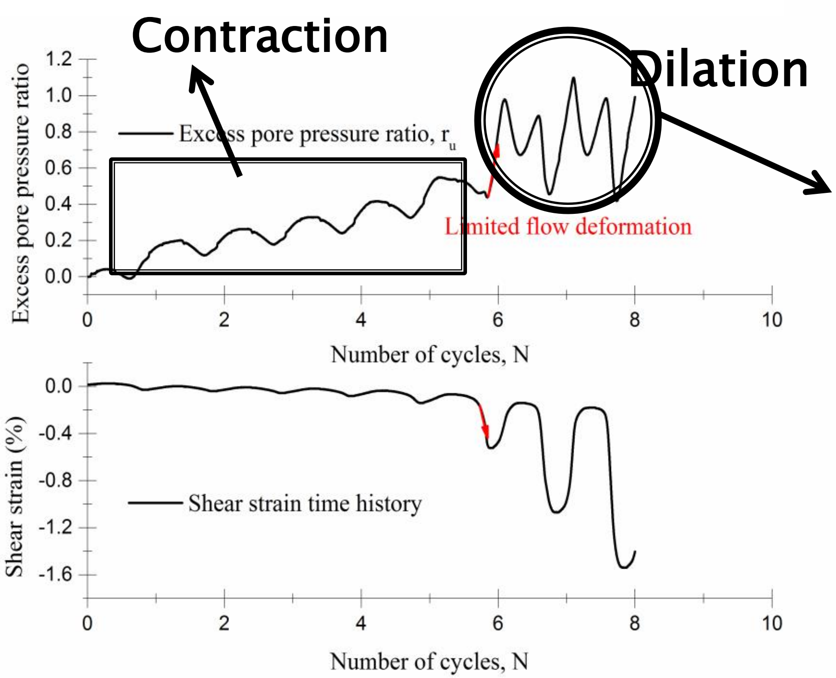
- A test data of the Kasai sand with RD of 60% with CSR value of 0.23 is shown in the figure **(After conversion of deviator stress to shear stress and axial strain to shear strain)**.
- It also identifies that the soil undergoes **limited flow** followed by **cyclic mobility**.

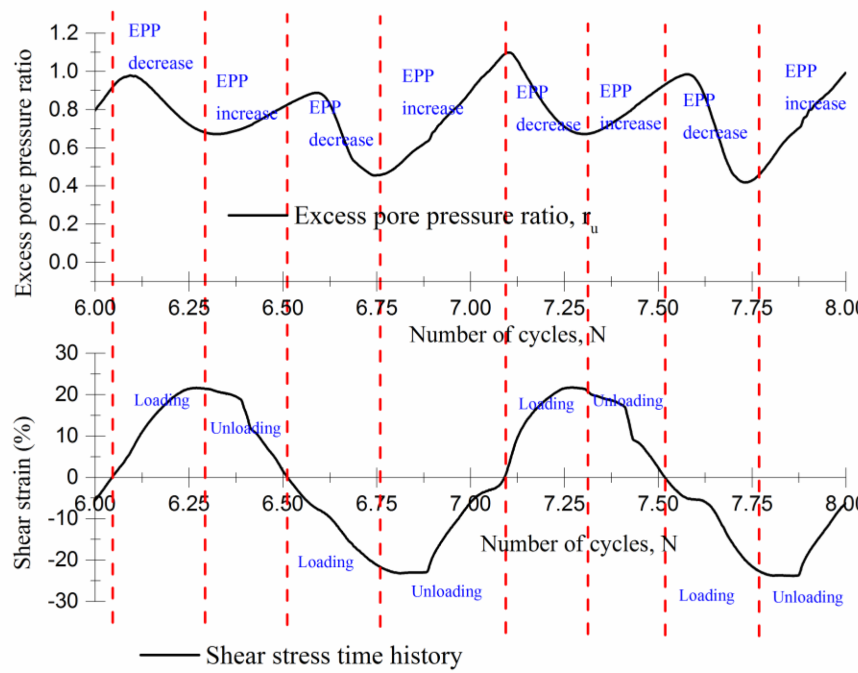




Cyclic test data for RD 60% with CSR 0.23 (contd..)

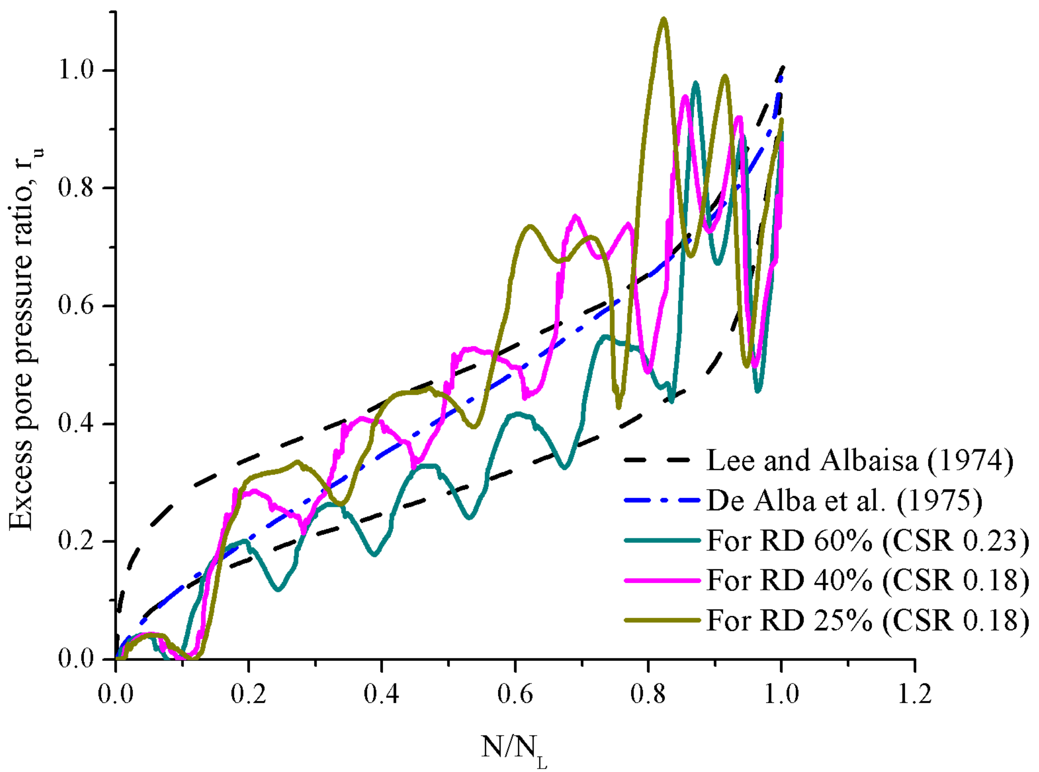
- The shear-stress time history along with the excess pore pressure ratio has been divided into **loading and unloading portions**.
- It is clearly seen that when there is loading in the soil sample, the excess pore pressure ratio decreases and vice versa, which is a clear indication of the **dilative behaviour** of the soil.





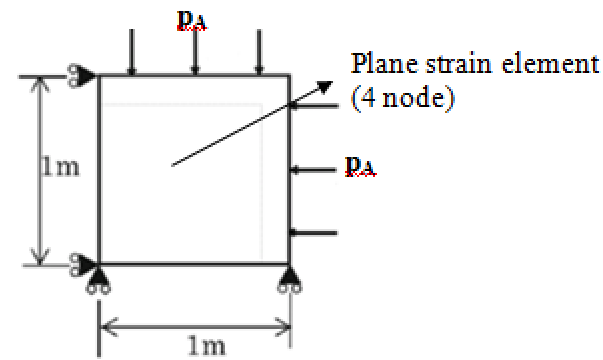
Comparison of experimental pore pressure records with the literature

- The experimentally generated excess pore pressures for CSR values of **0.18 and 0.23** with RD of **25%, 40 % and 60%** is compared with the literature curves proposed by De Alba et al. (1975) (with α=0.7) and Lee and Albaisa (1974) as shown in the figure.

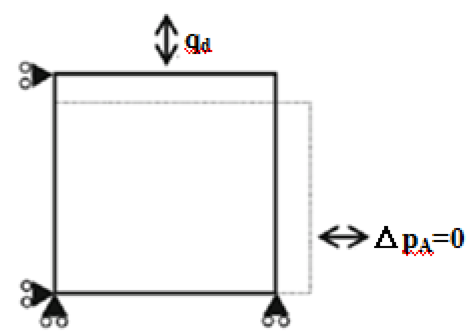


Calibration of parameters for PM4 sand

- 4-noded **plane strain (undrained)** quadrilateral element (Q4) is used in a finite difference program FLAC 2D.
- As the tests are load controlled, hence in addition to the initial hydrostatic consolidation effective pressure (**p_A=100 kPa** in this study) acting on the element as shown in figure (a), a cyclic deviator stress (**q_A**) acts on the element with a frequency of **1 Hz** (test frequency) till liquefaction of soil as shown in figure (b).



(a)



(b)

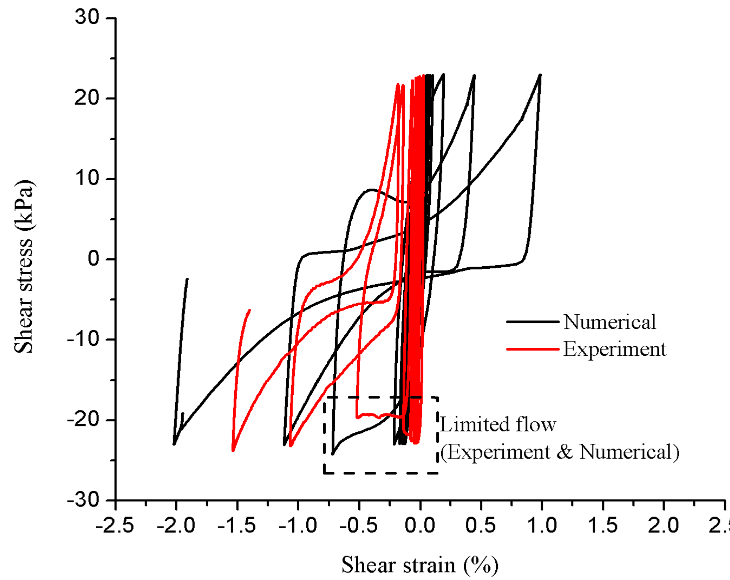
Calibration of parameters for PM4 sand (contd..)

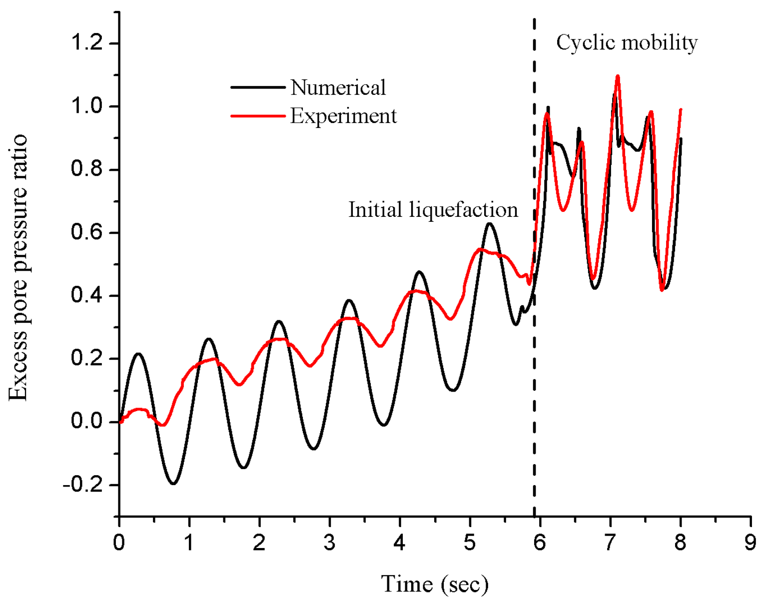
- The values of the calibrated parameters for PM4 sand model is tabulated below. The details of the parameter is given in Boulanger and Ziotopoulos (2015).

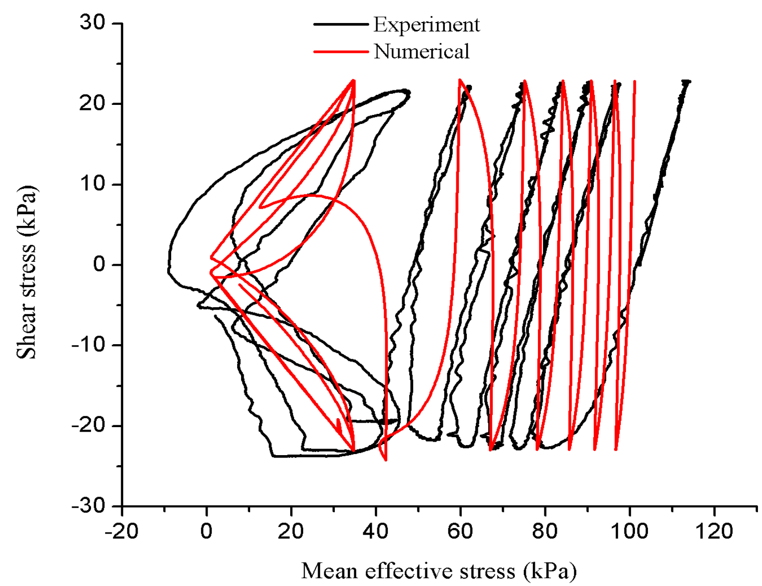
Parameters of PM4 model	**Values**
$N_{1,60}$	9 (for RD 40%), 15 (for RD 60%)
V_{s1} (based on the relationship derived by Chattaraj and Sengupta (2016))	221 (for RD 40%), 228 (for RD 60%)
h_{po} (contraction rate parameter)	0.47
φ_{cv}	34
n_b	0.4
h_o	0.2

Calibration of parameters for PM4 sand(contd..)

- Comparison of stress-strain curve, pore pressure time history and effective stress path for **RD 60%** with **CSR value of 0.23** is shown in the figure(s).

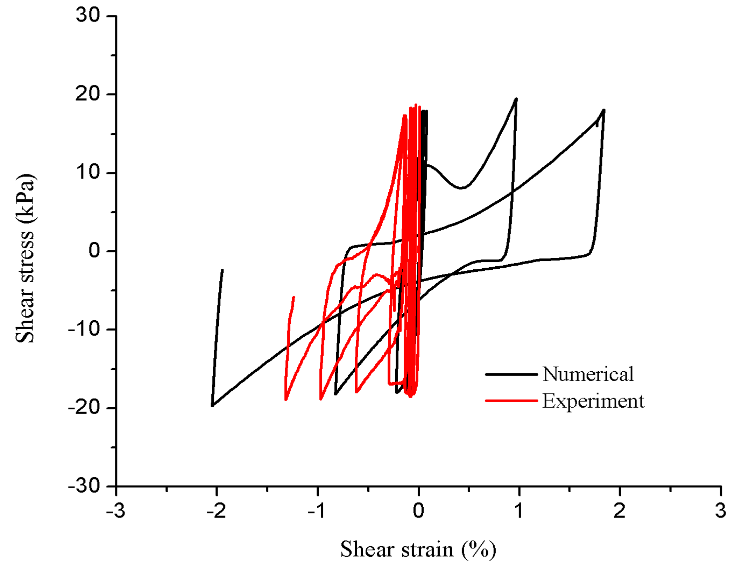


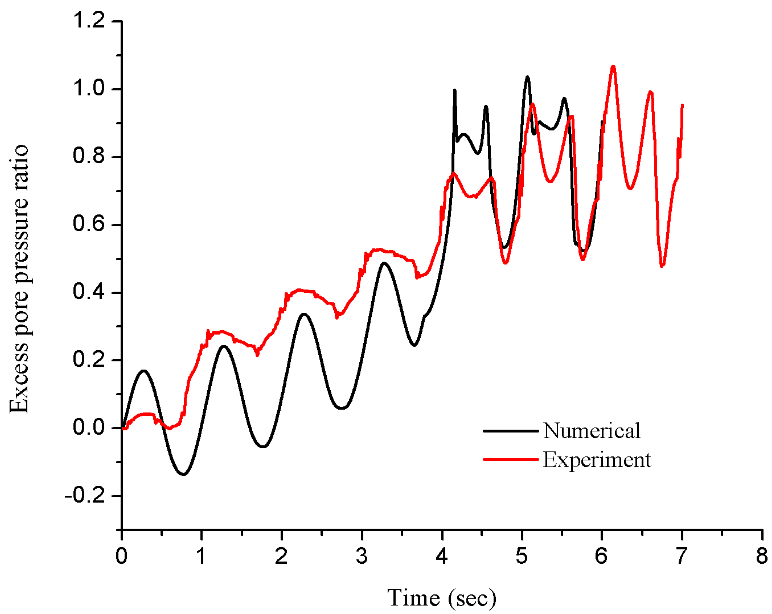


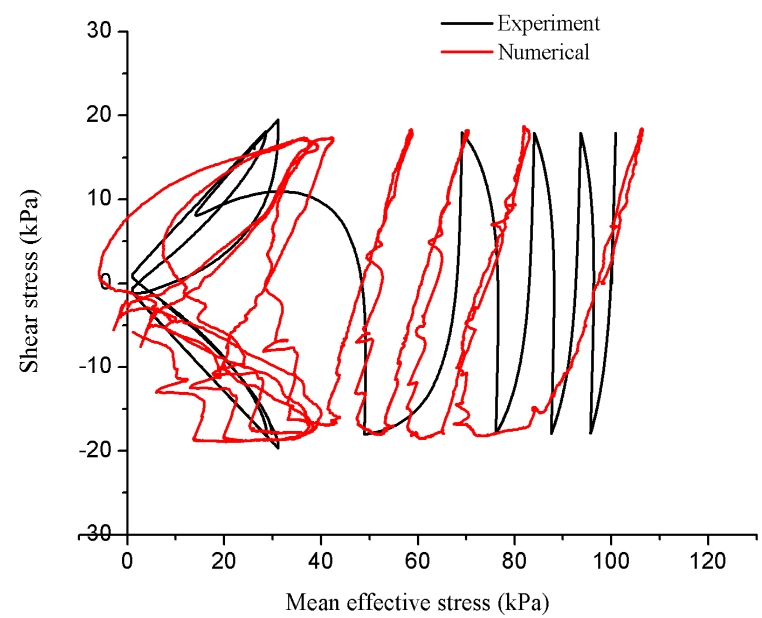


Calibration of parameters for PM4 sand(contd..)

- Comparison of stress-strain curve, pore pressure time history and effective stress path for **RD 40% with CSR value of 0.18** is shown in the figure(s).

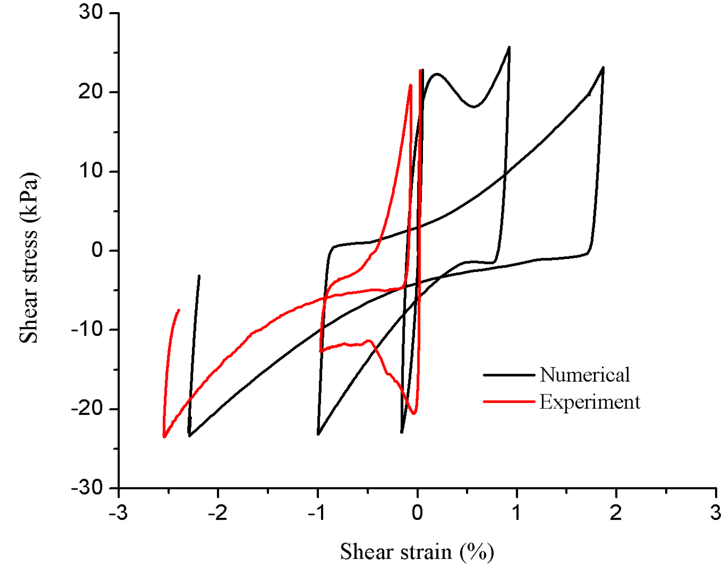


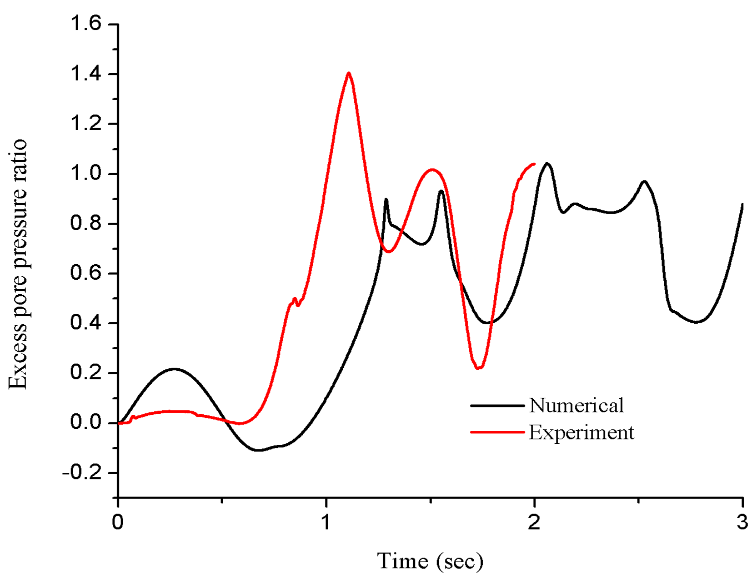


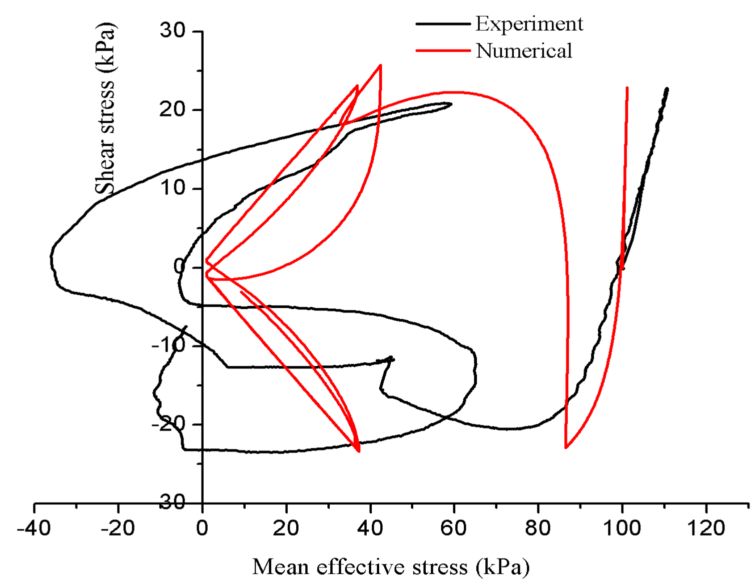


Calibration of parameters for PM4 sand(contd..)

- Comparison of stress-strain curve, pore pressure time history and effective stress path for **RD 40%** with **CSR value of 0.23** is shown in the figure(s).

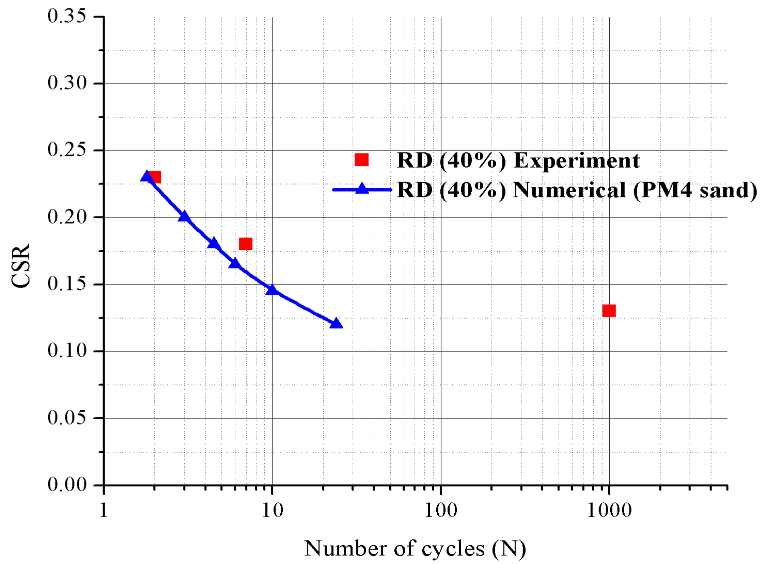


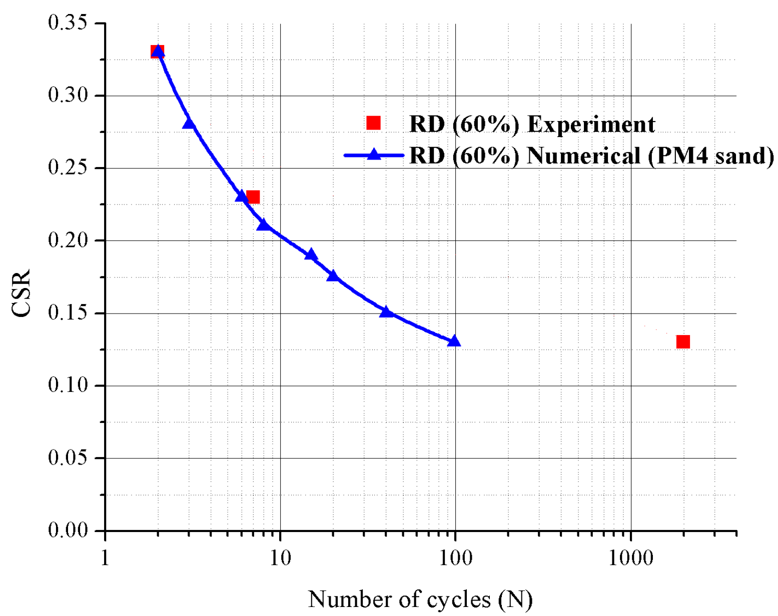




Numerical and experimental cyclic resistance curves

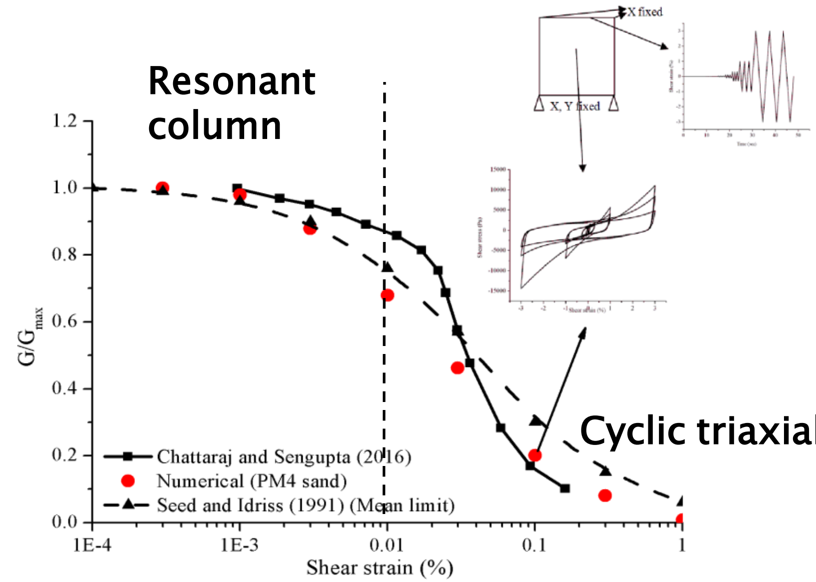
- The CSR values vs Number of cycles (N) to liquefaction (**using the criteria that r_u=1.0**) for **RD of 60% and 40%** is plotted in the figure(s).
- Numerical prediction is good up to 10 cycles ,but the model under predicts the soil resistance beyond 10 cycles, i.e., for a given CSR value (or shear stress) the number of cycles to liquefaction is predicted less than the experimentally obtained value.

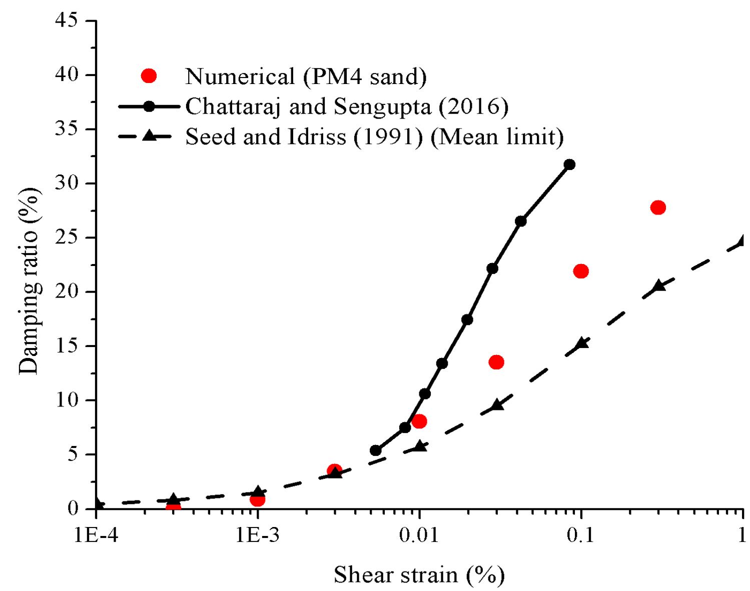




Strain dependant properties of Kasai river sand

- Numerical predictions using a single element of 1m x 1m (**undrained**) with calibrated properties of PM4 sand with a confinement of **100 kPa (RD 40% and 60%)** .
- A cyclic excitation with controlled shear strain amplitude is applied and shear stress is recorded. Strain amplitude is varied in steps (**each amplitude continued for 3 cycles**) in order to cover the range of interest.





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Thank you