LATTICE ELEMENT METHOD WITH REFINED BEAM THEORY FOR FAILURE IN CEMENTED GRANULAR MEDIA

Shahbaz Ahmad, Dr-ing. Zarghaam H. Rizvi, Prof. Frank Wuttke

INTRODUCTION

- Techniques for Soil Improvement has been a widely discussed and debatable topic from a long time. Popular methods such as use of Natural/Synthetic resins or usage of Chemical Injections have been disregarded due to lack of efficiency as well as environmental consideration.
- As the world is moving more towards "Sustainable and Green Technology" use of such options isn't a smart choice.
- The study focuses on the application of Microbiologically Induced Calcite Precipitation (MICP) technique by the use of common soil bacterial organism *Sporosarcina pasteurii* "The Good Bacteria." This bacteria is chosen because of easy availability, beneficial environmental considerations and wide applications.
- This posters presents the developed model with an embedded discontinuity that can capture the macroscopic behavior from meso-scale element failure, where the diagonal shear cracks which are seldom inherent to compression failure of highly cemented granular media lead the specimens to final failure.

EXPERIMENTAL ANALYSIS

- The experimental tests were performed on Houston sand, which is a fine-grained, sub-angular to angular, siliceous sand. The sand is uniformly graded between 0.50 mm and 0.063 mm sieves of DIN series (see Table below).

Table 1 Physical properties of Houston Sand

D50	Cu	Shape	Gs	emin	emax
0.33	1.7–1.9	Subangular to angular	2.64	0.62–0.65	0.96–1.0

- The Uniaxial Compression test was performed for which numerical modelling was carried out using the lattice element method. Also, the SEM analysis was carried out for qualitative analysis, shown in Fig. 1 (a) Loose Sand (b) Bio – Cemented Sand.

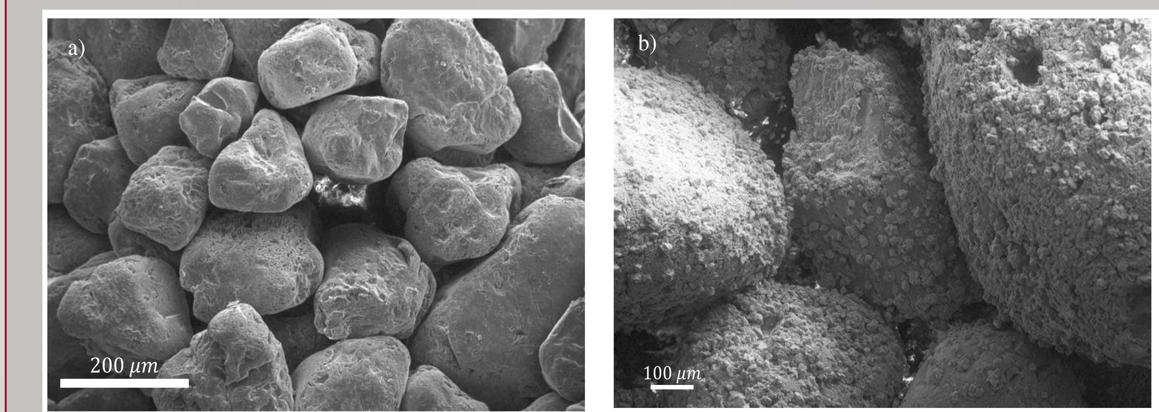
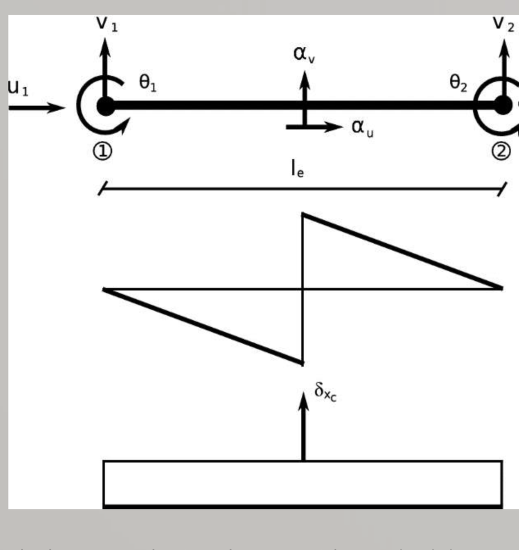


FIG. 1

LATTICE ELEMENT METHOD

Timoshenko beam with embedded discontinuity



Kinematics for Timoshenko Beam

$$\epsilon(x) = \begin{bmatrix} \epsilon(x) = \dfrac{du}{dx} \\ \gamma(x) = \dfrac{dv}{dx} - \theta \\ \kappa(x) = \dfrac{d\theta}{dx} \end{bmatrix}$$

Element failure model

$$q = \sigma_u \left(1 - exp\left(-\xi \frac{\sigma_u}{G_f}\right)\right)$$

Timoshenko beam as a lattice element with standard degrees of freedom and additional ones related to jumps in the displacement fields

- We have used here a lattice element method based approach to compute the unconfined compressive strength of bio-cemented sands with variable higher amounts of cementation.
- The approach is used to model the mesoscale constituents of bio-cemented sand, namely sand grains, voids and bio-cementation inside the voids. Shown in Fig 2. is the Meso-scale representation of bio-cemented sand in: (a) initial state with sand grains and voids and (b) in deformed state.

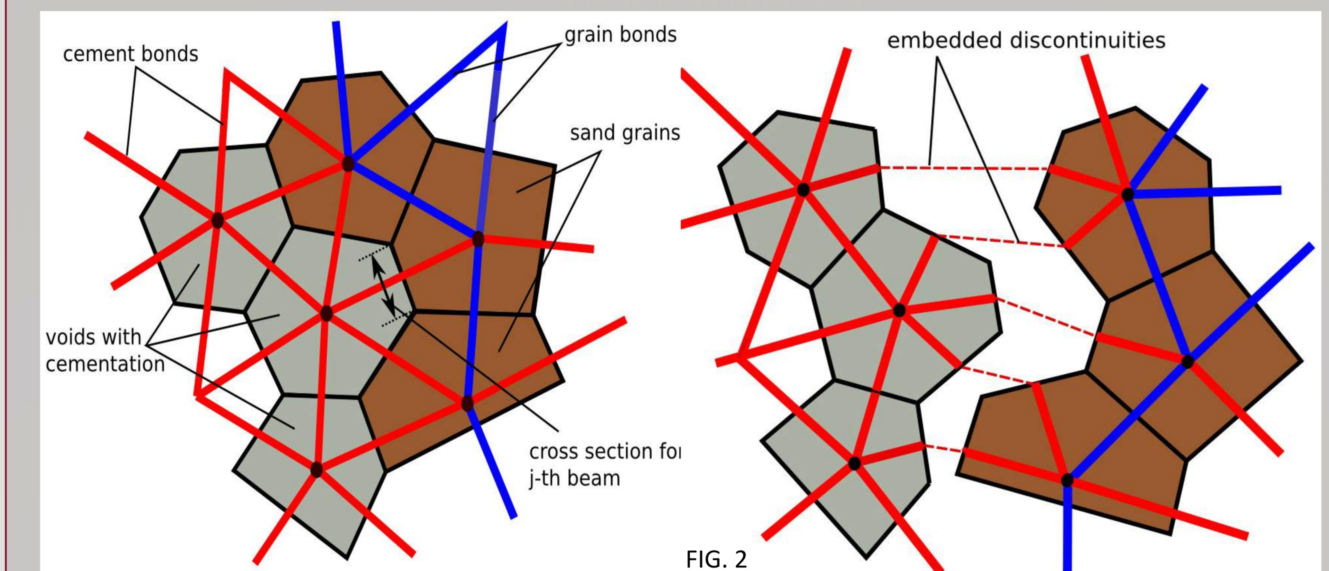


FIG. 2

RESULTS

- To model the unconfined compression tests of the bio-cemented sand, three different meshes are generated viz. 800, 3200 and 7200 cells. Shown below in FIG. 3 is the (a) stress- strain curve for 8.24 % bio-cementation level and at different mesh sizes (b- 800) (c-medium) & (d- fine).
- The coarse and the finer meshes follow the same path when it comes to macroscopic curves. The medium mesh shows a stiffer response and attends the closest in terms of the peak value against the experimental observation.

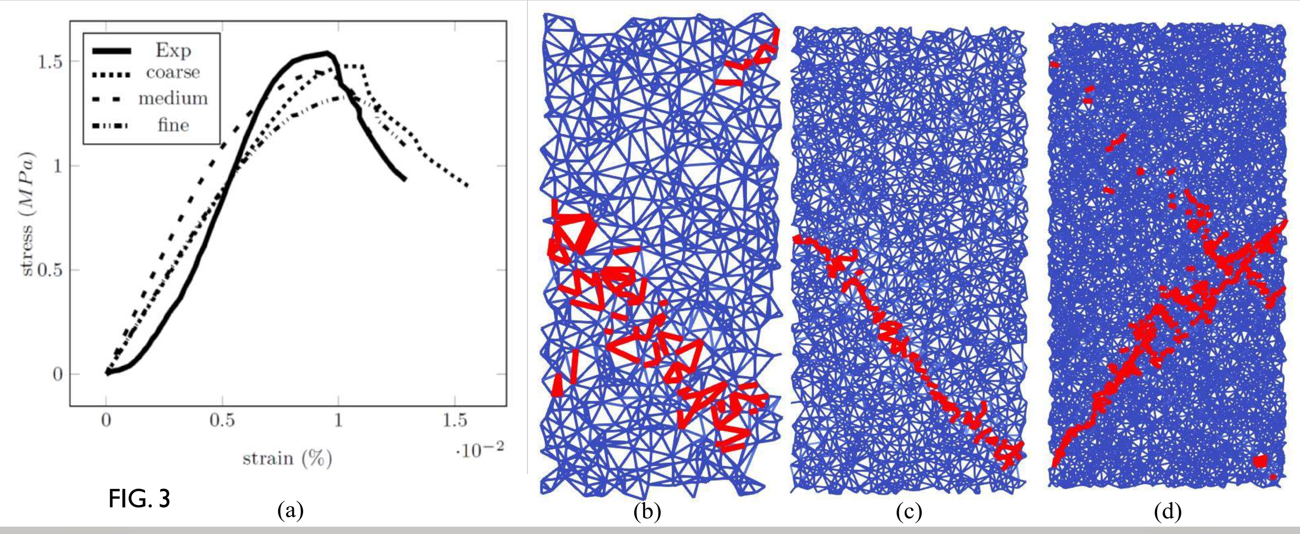


FIG. 3

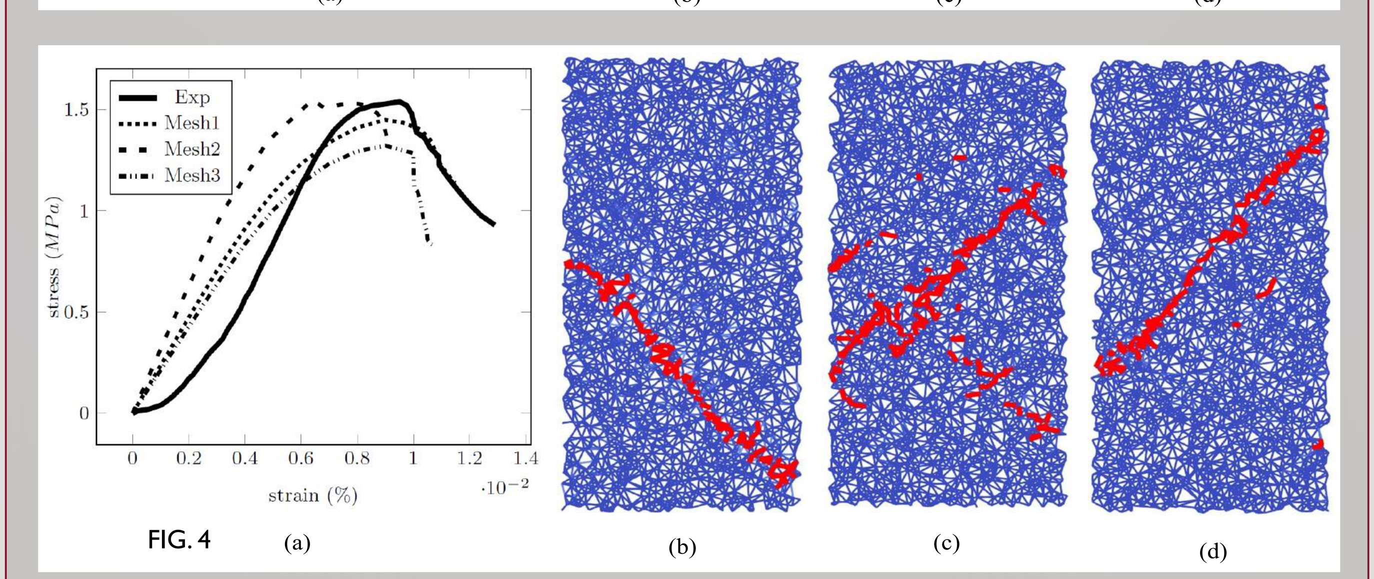


FIG. 4

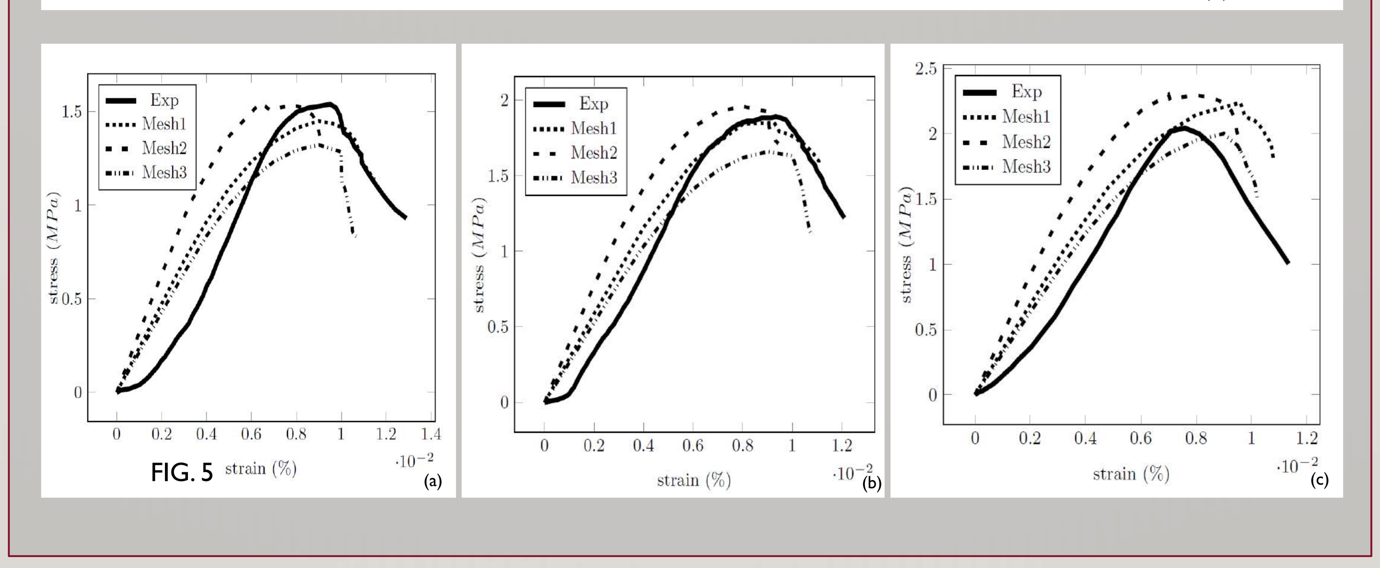


FIG. 5

- FIG 4 shows results for 8.24% of precipitation obtained with medium mesh (3200 cells)

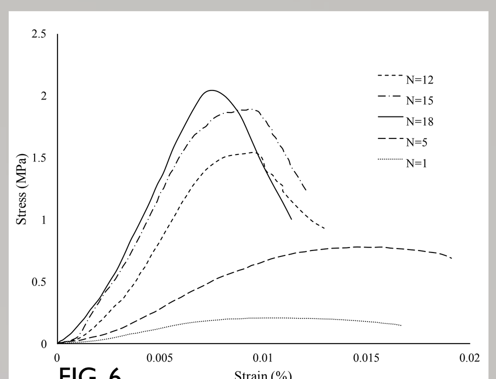


FIG. 6

- FIG 5 shows comparison of stress strain curve for (a) 8.24%, (b) 10% and (c) 11.7% precipitation obtained with medium mesh (3200 cells)
- FIG 6 shows Unconfined Comp. Strength of sand after different treatment cycles.

Table 2 Sample density and the amount of carbonate precipitated with each treatment cycle

Serial No.	Number of treatment cycles (N)	Initial dry density (g/cc)	Treated dry density (g/cc)	Deposited mineral content (%)
1	1	1.7	1.73	1.76
2	5	1.7	1.75	2.95
3	12	1.7	1.84	8.24
4	15	1.7	1.87	10
5	18	1.7	1.9	11.76

APPLICATIONS

- In geotechnical engineering, the induction of carbonate precipitating bacteria among the sand grains had lead to an improvement in thermo-hydro-mechanical properties of the sand.
- This method can be applied to study the strength and porosity, stiffness and compressibility, impermeability, shear strength, mitigation of liquefaction of loose sand and thermal conductivity.
- The method can also be applied to study the influence of bio-cementation on strength in the marine sand, wellbore cement integrity enhancement and uranium tailings reinforcement.

CONCLUSIONS

- MICP with bacteria Sporosarcina pasteurii is able to cement the fine sand to attend a maximum compression strength of 2 MPa.
- The mesoscale study suggest the formation of Calcite and Aragonite among and on the surface of the gains. The bio-mineralization contributes to the increase in the cohesion and friction angle of the granular media.
- Nonlinear lattice element method with Poisson random generation and embedded strong discontinuity can properly capture the mesoscale fracture phenomena in highly cemented sands that behave like quasi-brittle materials. The macroscopic mechanical behavior of the bio-cemented sand is obtained from the mechanisms occurring at lower scale.
- The developed model with parallel processing abilities could be used for engineering application of bio-cemented granular media for field application.
- The developed model is applied to study the bio-cementation process. However, it is general and could be used to model any well cemented granular media.

SELECTED LITERATURE SITED

- Feng, K., Montoya, B.M., Evans, T.M.: Discrete element method simulations of bio-cemented sands. Comput. Geotech. 85, 139–150 (2017)
- de Bono, J., McDowell, G., Wanatowski, D.: Investigating the micro mechanics of cemented sand using DEM. Int. J. Numer. Anal. Methods. Geomech. 39(6), 655–675 (2014)
- Nikolic, M., Karavelic, E., Ibrahimbegovic, A., Miscevic, P.: Lattice element models and their peculiarities. Arch Comput. Methods Eng. 25, 753–784 (2018)
- Rizvi, Z.H., Shrestha, D., Sattari, A.S., et al.: Numerical modelling of effective thermal conductivity for modified geomaterial using lattice element method. Heat Mass Transfer 54, 483 (2018)

ACKNOWLEDGEMENTS

Authors would like to thank project BioSolidEncap for the financial support. The experimental work was performed in part at Sansatec, Kiel by Svantje Gottschlich, and the numerical work by Dr. Nikolic. The material characterisation has been done at the Institute for Geosciences, Kiel.

More information on this and related study could be found by scanning the given QR Code.

AUTHOR AFFILIATION

- Shahbaz Ahmad, (MS Student) Zachry Department of Civil and Environmental Engineering, Texas A&M University, College Station, USA
- Dr-ing. Z. H. Rizvi, Institute for Geosciences, University of Kiel, Germany
- Prof. Frank Wuttke, Institute for Geosciences, University of Kiel, Germany

This Poster is presented at EMI 2019 at Caltech.