Liquefaction Resistance of Chitosan Treated Sand Using Cyclic Triaxial Test

Rupa Dalvi [1] Vittal Shinde[2] and Sunil Dalvi[3]

Abstract—Liquefaction of saturated granular soils during earthquakes is one of the most important problems in the field of geotechnical earthquake engineering. Various eco-friendly approaches have been attempted by researchers for liquefaction mitigation. In the present study, strain controlled cyclic triaxial tests were carried out on loose sand to investigate the effect of chitosan on pore water pressure ratio and cyclic stress ratio. Total 15 tests were carried out using the specimen size 75 mm diameter and 150 mm height with three confining pressures of 50 kPa, 100 kPa and 200 kPa at 30% relative density. The chitosan at 2.5%, 5% and 10% was used, as an admixture to increase the liquefaction resistance of sand. It was observed that the deviator stress, shear modulus and normalized shear modulus increased as the percentage of chitosan increased in soil mixture. In continuing to investigate the effect of curing time, the specimens containing 5% chitosan were cured for 1, 3 and 7 days and tested under 100 kPa effective confining pressure. The result indicated that the liquefaction resistance of the sand containing chitosan increased with increase in curing time. Thus, the chitosan's role in enhancing liquefaction resistance of sand with sustainable approach is reported.

Index Terms— Cyclic Triaxial Test, Liquefaction Resistance, Clean Sand, Chitosan Biopolymer, Confining Pressure..

1 Introduction

LIQUEFACTION occurs in loose and saturated soil subjected to earthquake loading. The liquefaction occurs due to generation of excess pore water pressure and reduction of mean effective stress. Liquefaction causes reduction in shear strength and shear modulus of soil resulting in failure of various geotechnical structures such as roads, building foundations, bridges etc. Hence, study on liquefaction mitigation is important. Various liquefaction mitigation methods such as densification technique, reinforcement technique, grouting technique and mixing method are used. Researchers have reported the effect of nano materials and biopolymers on liquefaction behavior of sand. Huang & Wang (2016) conducted cyclic triaxial tests using laponite as an admixture in sand and reported that the liquefaction resistance of the laponite–silty sand samples was stronger than that of the pure silty sand samples. Jooyoung et al. (2017) studied effect of gellan gum and xanthan gums on dynamic soil properties of sand. It has been stated that formation of a gellan gum and xanthan gum gel in the pore space increased the shear modulus and decrease the damping ratio. According to Khatami and O'Kelly (2013) biopolymers effectively increased the cohesion intercept and stiffness of sand treated in agar and starch. The effect of colloidal silica grout on the liquefaction strength of sand was investigated by Gallagher and Mitchell (2002) and observed that the addition of colloidal silica as an agent led to an increase in the deformation strength of the sand. Result of Hataf et al. (2017) showed that incorporation of chitosan biopolymer improved the mechanical properties of soil. The effect of chitosan on dynamic properties of sand has been not reported earlier. In present work effect of chitosan on liquefaction resistance of sand has been reported using cyclic triaxial testing. A total 15strain controlled triaxial tests were conducted with varying chitosan concentration sand confining pressures.

1.1 Properties of sand

The grain size distribution curve of sand used in present work is as shown in Figure 1. According to Indian standards specification (IS 2720 Part 4-1985) the sand used is poorly graded sand (SP).

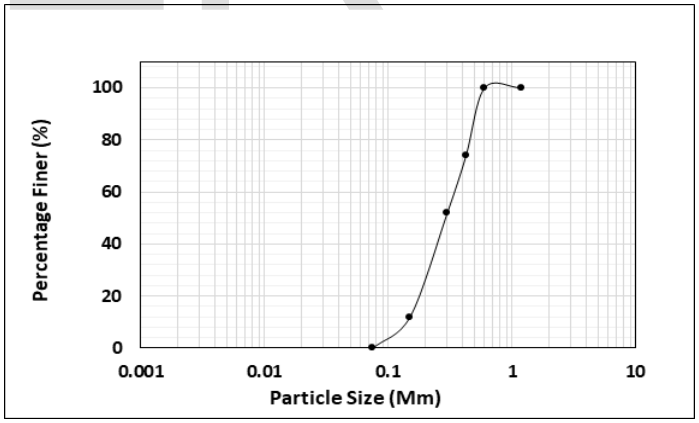

Fig 1. Grain size distribution curve of the tested sand

The index properties of the sand are given in the Table 1.

TABLE 1
INDEX PROPERTIES OF SAND

Soil properties	Value
Specific gravity	2.63
Maximum unit weight of sand γ_{max}	17.51kN/m^3
Minimum unit weight of sand γ_{min}	14.32 kN/m^3
Maximum void ratio e_{max}	0.73
Minimum void ratio e_{min}	0.502
D_{50}	0.28 mm
D_{10}	0.145 mm
D_{30}	0.2 mm
D_{60}	0.325 mm
Coefficient of uniformity Cu	2.24
Coefficient of curvature Cc	0.85

1.2 Properties of Chitosan

Chitosan used in this study was from seafood industry discarded shrimps shells, which was obtained from M/s. Mahatani Chtiosan India Ltd. Veraval, India. Fig. 2(a) shows chitosan in powder form and Fig. 2(b) shows scanning electron microscopy (SEM) image of the chitosan particles.

Fig.2. (a)Chitosan particles in powder form

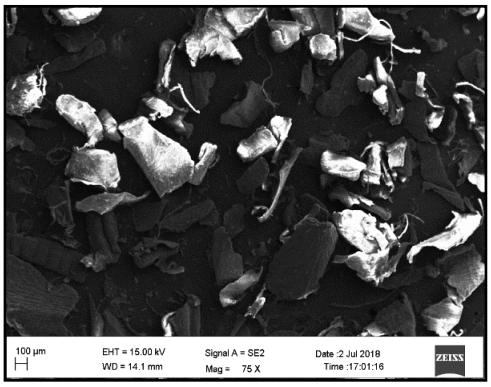

Fig.2 (b)Scanning electron microscopy of the chitosan particles in powder form.

2 Experimental Program

2.1 Chitosan hydrogel preparation

Chitosan solution was prepared taking 400 ml of warm water(80^{0}C) in which 10 gm of chitosan powder was added under continuous stirring. Later 2.5 ml of acetic acid was added to solubilize chitosan particles completely. Then volume of solution was adjusted to 500 ml and whole solution was stirred for1 hr.to obtain uniform suspension. This solution was used to treat sand in this study.

2.2 Cyclic triaxial test

In the present study, total 15 strain controlled cyclic triaxial tests were performed according to ASTM 3999-11 on sand and chitosan incorporated sand. The chitosan was added relative to the mass of the dry sand i.e. 0%, 2.5%,5% and 10%atdifferent confining pressure (i.e. 50 kPa,100 kPa and 200 kPa) and frequency 1 Hz. The size of specimen was75mmdiameterand 150mm a height(H/D=2). The relative density of treated and untreated sand specimens was 30 %.

The moist tamping method was used to prepare untreated and treated sand specimens. In pre-weighted quantity of sand 5% water was added and placed in a split mould in three layers. Similar approach was used for chitosan-sand specimens. All the specimens were compacted carefully by using tamper in three layers in order to achieve desired density (30%). Total 22 % of water was used for saturation of all specimens. Then filter paper and porous stone placed on the specimen. Top cap with vacuum ring was placed on porous stone and rubber membrane was pulled over it.

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Fig.3 (a)Triaxial mould and Plunger

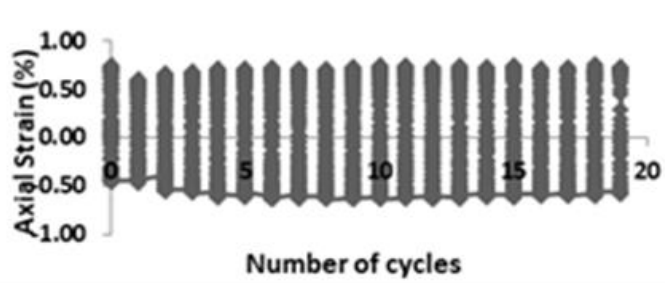
Fig.3 (b) Specimen preparation

Fig. 3 (c) Specimen ready for testing

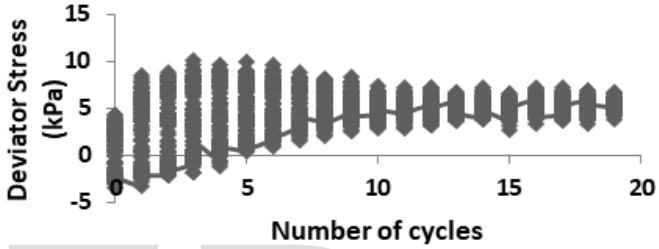
Figures 3 (a,b and c) shows details of specimen preparation method for cyclic triaxial testing. After specimens were prepared, all the specimens were isotropically consolidated with different effective confining pressures. After consolidation desired frequency, amplitude and number of cycle were applied. The test was continued till the specimen pore pressure increased up to the applied confining pressure. During the cyclic test, pore pressure and LVDT data was acquired through data acquisition system.

3 Results and Discussions

Variation of shear stress, shear strain, pore pressure ratio and effective confining pressure with number of cycles for relative density30% for untreated and treated sand for 50 kPa confining pressure is shown in Fig.4a,b,c and d.



(a)



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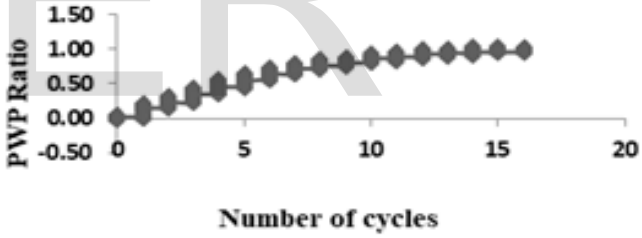

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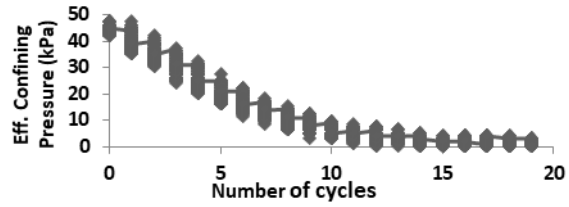


(d)

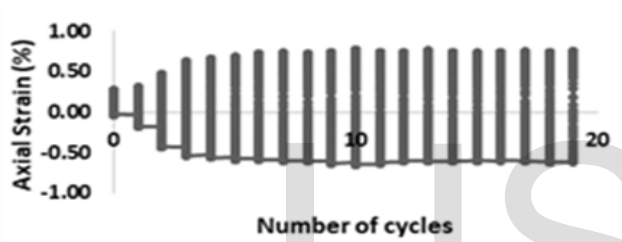
Fig. 4. Results of a strain-controlled test on untreated sand (Freq. 1Hz, CP 50 kPa and 30% RD) (a) Shear Strain Vs Number of cycles; (b) Shear Stress Vs Numbers of cycles; (c) Pore water pressure ratio Vs Number of cycles; (d) Effective confining pressure Vs Number of cycles.

From Figures 4 and 5, it is evident that value of shear stress increases initially and later decreases with the increase in number of cycles and initially becomes constant at a small value. Further, increase in pore water pressure results in a corresponding decrease in the effective stress (Figures 3c and d), which finally reduces to zero when excess pore water ratio (r_u) is equal to 1. It is also seen that number of cycles required to reach pore pressure ratio 1 is more for sand mixed with 5 % chitosan in sand (Figure4 c) than that of sand without chitosan.

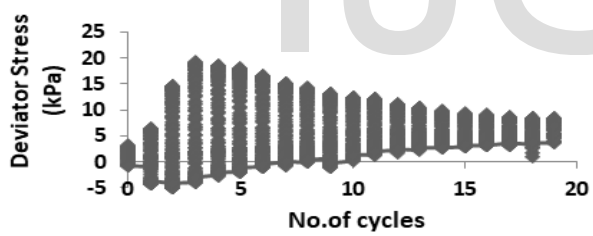
The pore water pressure ratio is the ratio of excess pore pressure to that of initial effective vertical stress (Eq. 1). If the excess pore water pressure ratio reaches to 1.0 then initiation of liquefaction takes place.

$$r_u = \frac{\Delta u}{\sigma_v'} \quad (1)$$

Where, r_u = Pore pressure ratio; Δu = Excess pore pressure; and σ_v' = Initial Effective vertical stress.



(a)



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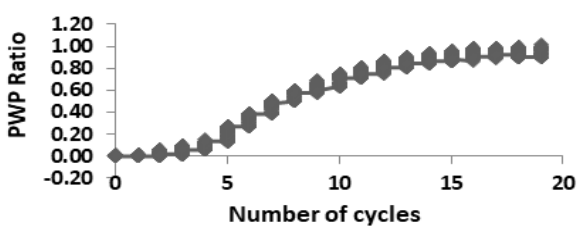

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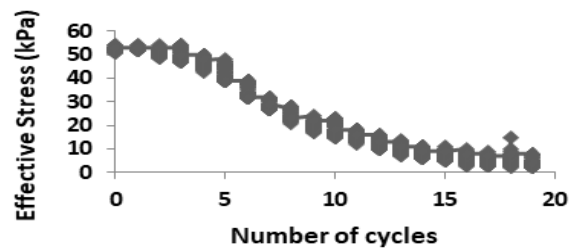

(d)

Fig. 5. Results of a strain controlled test on sand with 5% chitosan (Freq. 1Hz, CP 50 kPa and 30% RD) (a) Axial Strain Vs Number of cycles; (b) Deviator Stress Vs Numbers of cycles; (c) Pore water pressure ratio Vs Number of cycles; (d) Effective confining pressure Vs Number of cycles.

3.1 Effect of chitosan content on dynamic soil properties

In the present study available equations (2,3 and 4) are used to determine the dynamic soil properties i.e.,
shear modulus and normalized shear modulus (Towhata 2008).

$$\gamma = (1 + \mu)\,\varepsilon \quad (2)$$

$$E = \frac{\sigma_{dmax}}{\varepsilon_{max}} \quad (3)$$

$$G = \frac{E}{2(1 + \mu)} \quad (4)$$

Where, G = shear modulus, γ = shear strain and ε=axial strain
μ = Poisson's ratio that may be taken as 0.5 for saturated undrained specimen (Towhata, 2008).
σ_{dmax}-Maximum deviator stress,ε_{max}-Strain corresponding to maximum deviator stress.

Fig. 6(a) shows variation of shear modulus corresponding to shear strain for 0%, 2.5%, 5% and 10% chitosan incorporation in sand for 50 kPa confining pressure. It is seen that higher the chitosan content in soil higher the value of shear modulus

Fig. 6(b) shows the normalized shear modulus versus shear strain for 0%, 2.5%, 5% and 10% chitosan admixture in sand under 50 kPa confining pressure. It has been observed that the variation of chitosan content had a significant effect on normalized shear modulus (G/G_{max}). As higher the chitosan content in sand higher the normalized shear modulus. When chitosan suspension was mixed with the sand it is distributed among the sand particles and changes the porous network of sand by forming thick coating around sand particles due to cationic properties of chitosan which enhances the sand strength.

Similar behavior has been observed for 100 kPa and 200 kPa confining pressure.

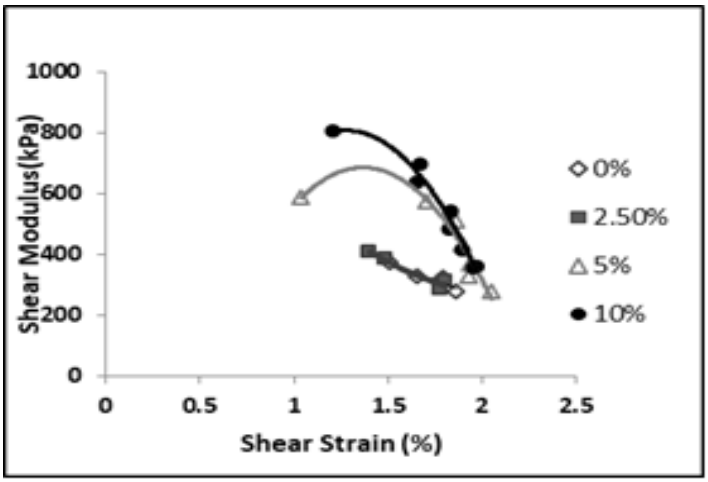

Fig. 6. (a) Variation of Shear modulus for various chitosan content

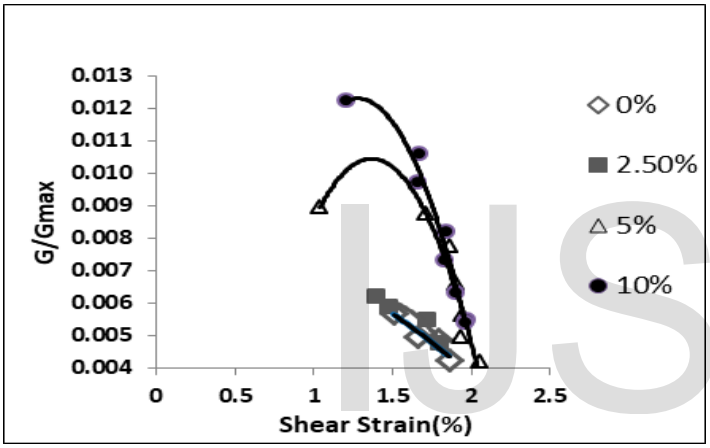

Fig. 6. (b) Variation of normalized shear modulus for various chitosan content.

3.2 Effect of chitosan content on pore pressure ratio

In present study various criteria have been used to identify number of cycles leading to liquefaction. To identify initiation of liquefaction pore water pressure ratio has been determined for all the test performed in the present work.

Fig. 7 shows the pore water pressure ratio versus number of cycles for treated and untreated soil specimens under 100 kPa confining pressure. It is seen that number of cycles required to reach excess pore water ratio 1 increased corresponding to increase in the chitosan percentage in sand. Maximum number of cycles required for sand incorporated with 10 % chitosan. Similar behavior was also observed for 50 kPa and 200 kPa confining pressure.

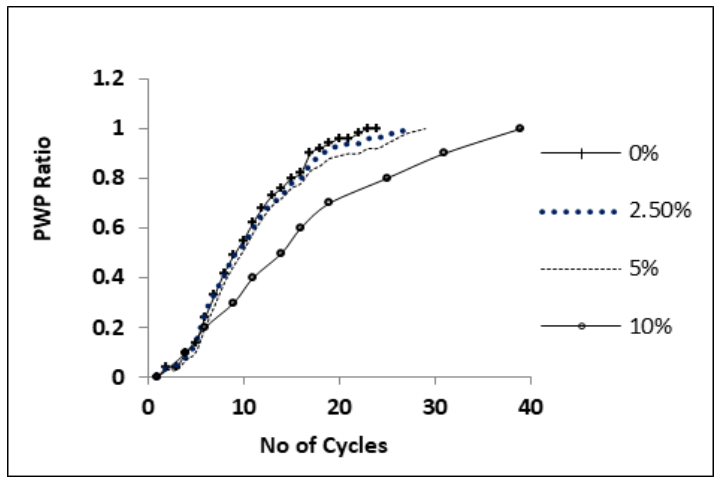

Fig. 7. Variation of pore water pressure with number of cycles for 100 kPa confining pressure

3.3 Effect of chitosan content on cyclic shear stress ratio

Cyclic stress ratio is the ratio of average cyclic shear stress to the effective vertical stress at a particular depth. In the present study cyclic stress ratio has been evaluated using formula given by, Noorzad & Amini (2014).

$$CSR = \frac{\sigma_a}{2\sigma'_3} \quad (5)$$

Where,

σ_a= Single amplitude cyclic axial stress and σ'_3= effective confining stress.

To determine enhancement of liquefaction resistance the relationship between CSR and number of cycles was obtained for different chitosan percentages at 100 kPa confining pressure and shown Figure 8. A sand specimen chitosan percentage withstand more loading cycles than that of untreated. For same CSR untreated specimens entered liquid phase after few cycles compared with treated cycles. However, in case of treated specimen strain increase was small with increase in number of cycles and specimen remained intact.

The increasing in strength with the percentage of chitosan can be explained considering that the suspension of chitosan. Once it is incorporated in soil, it increases inter particle cohesion of the specimens and increase liquefaction resistance.

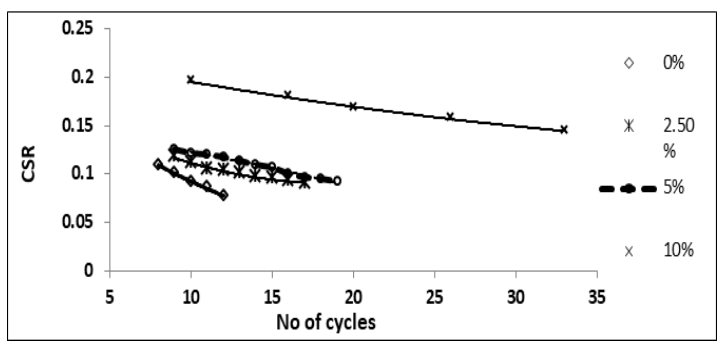

Fig. 8. Cyclic stress ratio versus number of cycles for various chitosan content for 100 kPa confining pressure.

3.4 Effect of curing time

Liquefaction resistance also affected by the curing time therefore specimen prepared using 5% chitosan in sand was kept for 1, 3 and 7 days of curing period using membrane curing method. In membrane curing method soil sample kept inside rubber membrane to retain the moisture. After completion of curing period specimens were tested under 100 kPa effective confining pressure.

Fig 9 (a) shows the variation of peak deviator stress for 1, 3 and 7-days curing time for 5% chitosan in sand. It is seen that peak value of deviator stress increased with increase in curing time and maximum value of deviator stress observed for 7 days curing time. As chitosan solution is a cohesive liquid and distributes uniformly through the sand particles. The increase in shear strength of the specimens is attributed to the interparticle cohesion improvement. Further as the curing time increased the bond between sand particles and chitosan enhanced which increased interparticle resistance resulting in increase in soil strength.

Furthermore, the variation of cyclic stress ratio with number of cycles for 1, 3- and 7-days curing time for 5% chitosan content under 100kPa confining pressure is shown in Figure 9(b). From figure it is observed that the specimen with curing time of 7 days can withstand more loading cycles. The formation of gel in chitosan-sand mixtures increased the liquefaction resistance of the sand.

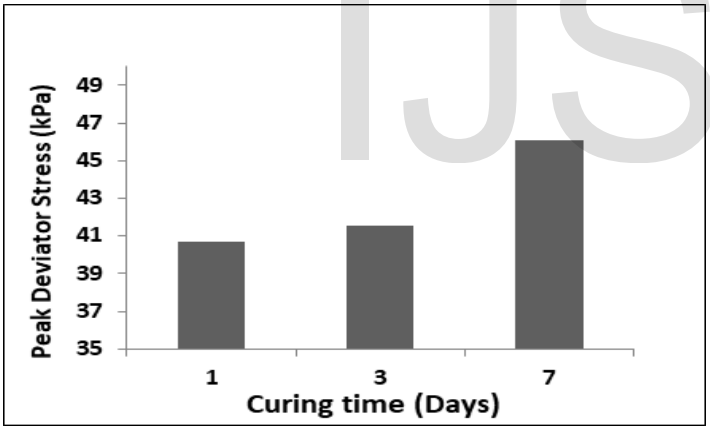

Fig. 9 (a)Peak deviator stress vs curing time

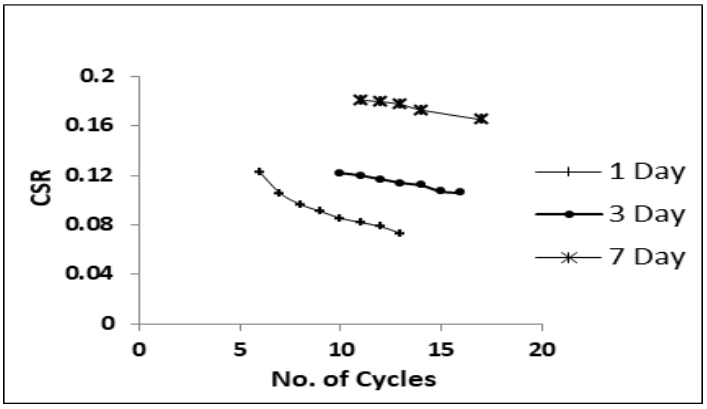

Fig.9.(b) CSR vs No. of cycles for 5% chitosan content.

4 CONCLUDING REMARKS

From the investigation the potential of chitosan utilization as an alternative stabilizer to conventional materials and the effects of chitosan concentration, curing time were studied by performing cyclic triaxial tests.

1. Addition of chitosan in the pure sand increases shear modulus and normalized shear modulus.
2. Number of cycles required to reach pore water pressure ratio 1 increased with increase in chitosan content.
3. Cyclic stress ratio increased with increase in chitosan percentage.
4. The liquefaction resistance of chitosan treated sand is higher than untreated sand.
5. As the curing period increased liquefaction resistance increased accordingly.
6. Chitosan concentration mitigates liquefaction potential due to enhancement of bond between sand particles, sand grain cementation and delay in pore pressure generation.

5 REFERENCES

[1] Gallagher P. M, Mitchell J. K. Influence of colloidal silica grout on liquefaction potential and cyclic undrained behavior of loose sand. *Soil Dynamics and Earthquake Engineering*, 2002; *22*(9-12), pp.1017-1026.

[2] Hataf N, Ghadir P, Ranjbar N. Investigation of soil stabilization using chitosan biopolymer. *Journal of Cleaner Production*, 2018; *170*, pp.1493-1500.

[3] Huang Y, Wang L. Laboratory investigation of liquefaction mitigation in silty sand using nanoparticles. *Engineering Geology*, 2016; *204*, pp.23-32.

[4] Im J, Tran A. T, Chang I, Cho G. C. Dynamic properties of gel-type biopolymer-treated sands evaluated by Resonant Column (RC) Tests. *Geomechanics And Engineering*, 2017; *12*(5), pp.815-830.

[5] IS 2720-4, 1984.*Methods of test for soils, Part 4: Grain size analysis*

[6] JooyoungIm An, T. P. Tran, Ilhan Chang, Gye-Chun Cho. Dynamic properties of gel-type biopolymer-treated sands evaluated by Resonant Column (RC) Tests. *Geomechanics and Engineering*, 2017; Vol. 12, No. 5, 815-830.

[7] Khatami H. R, O'Kelly B. C. Improving mechanical properties of sand using biopolymers. *Journal of Geotechnical and Geoenvironmental Engineering*, 2012; *139*(8), pp.1402-1406. Kramer, Steven. *Geotechnical Earthquake Engineering*, 2012; Prentice Hall, Englewood Cliffs, New Jersey.

[8] Noorzad R, Amini P.F. Liquefaction resistance of Babolsar sand reinforced with randomly distributed fibers under cyclic loading. *Soil Dynamics and Earthquake Engineering*, 2014; *66*, pp.281-292.

[9] Towhata I. *Geotechnical earthquake engineering*. 2008; Springer Science & Business Media.