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Research article

Influence of brick dust on the undrained cyclic shear strength of sand

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ABSTRACT

Sandy of soils losing its shear strength due to liquefaction is a serious concern in seismic prone areas. Experimental investigations were done on sand-brick dust mixture to study the undrained shear strength and liquefaction characteristics and the results are presented in this paper. On the specimens made from medium fine sand, strain controlled undrained dynamic cyclic shear tests are conducted. The percentage of brick dust added to sand is from 0% to 50 % (increments of 5%) by weight of sand. The effect of number of cycles on strain, deviator stress and pore pressure with the addition of brick dust is analysed. The number of cycles required to cause liquefaction (when the pore pressure ratio reached the value of 1 is computed for each increment of brick dust added to sand. The cyclic resistance of the sand increased up to addition of 25% of brick dust by weight of sand and thereby decreased with the increase in the percentage of brick dust.

1. Introduction

Liquefaction of sand and subsequent settlement of structure is a serious concern for structures build in earthquake prone areas. Studies have been done to know the behaviour under cyclic loading of different type of sands and sand-clay mixtures. A study has been done to know the liquefaction resistance of Babolsar sand from the seismic region near Caspian Sea. Manne et al. (2016) reported that the strength loss of granular soil when subjected to cyclic loading is affected by particle size, shape and its distribution. Choobasti et al. (2018) reported that Addition of nano silica improves the brittle behaviour. Moreover, by increasing the weight ratio of nano silica up to 10%, the dynamic deformation modulus and damping ratio of cemented sand increases at first and then decreases. Dash et al. (2011) state that the effect of relative density and confining pressure on these strengths was studied. Facciorusso et al. (2016) reported that surface PGA values (recorded or provided by the shaking maps) generally seemed to be insufficient to trigger liquefaction phenomena or justify their intensity, where liquefaction occurred. Krishnan et al. (2020) state that the present study revealed that the optimum percentage of colloidal silica decreases with an increase in relative density. Lentini et al. (2019) reported that the results show that the cyclic resistance increases with the decrease in the initial confining stress and decreases as the silt content increases and confirmed that the coarsest material has a lower tendency to liquefy. Babolsar sand has been compared to other sands that have been tested for steady state and flow liquefaction lines. Investigation is conducted to determine the impact of the state parameter, relative state parameter index, and lateral earth pressure ratio at failure on the susceptibility to liquefaction. The result shows that the sand started dilating when relative density is 8.485 and initial confining pressure is 40 kPa. A comparative study of residual strength between Yamuna, Ganga and Toyoura sand was made. The Yamuna sand has a steady state line curvature that is comparable to the other two sands. To assess the

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liquefaction resistance of sandy soils, an undrained cyclic triaxial test is used. The results indicate that cyclic resistance is inversely proportional to initial confining pressure and silt content. Studies are also done to evaluate the undrained cyclic strength of marine sand-clay mixtures, sand-silt mixtures and paleo-river Reno leeves. In another study, influence of fines percentage and grain size distribution on shear strength of sand is analyzed. It is observed that percentage of fines such as Cu and D50 influence the static and dynamic behaviour of sand. Recently studies are done to know the increase in cyclic shear strength when sand is mixed with admixtures. Experimental investigations are done on reinforced clay to study the dynamic behaviour under cyclic loading. Results shows that deviator stress ratio influences optimum fibre content. A study also has been done to know the static cyclic triaxial behaviour of sandy soil when mixed with nano silica and cement. It has been determined that 10% of nano silica is the ideal amount to provide the highest levels of shear strength, dynamic shear modulus, and damping ratio for cement sand. Undrained triaxial tests are conducted on sand and shredded tire mixtures to know the dynamic properties and it is found that 10% rubber content can seismically isolate low-rise buildings. It is observed from experimental study that cyclic resistance strength, damping ratio and shear modulus of foundation soil is increased when mixed with colloidal silica and in turn reduces damages in building during earthquakes. A comparative study has been made between cyclic triaxial test and direct shear test for sand-tire mixtures. The shear moduli value from the cyclic triaxial test is on the higher side, despite the tight damping ratios obtained from the two experiments. An energy-based methodology is used to investigate the liquefaction properties of Babolsar sand reinforced with fibers. The number of cycles required to cause liquefaction increases with the presence of fibers. This study examines the properties of sand liquefaction utilizing brick kiln dust as a stabilizing factor

Table 1 Physical Properties of Material

Properties	Sand	Brick Dust
Specific gravity	2.59	2.21
Percentage of fine particles (0.075 – 0.425 mm) %	20.41	35.21
Percentage of medium particles (0.425 – 2 mm) %	52.28	42.30
Percentage of coarse particles (2 – 4.75 mm) %	27.31	22.49
D_{10} (mm)	0.3	0.18
D_{30} (mm)	0.6	0.38
D_{50} (mm)	1.2	1.0
D_{60} (mm)	1.4	1.2
Coefficient of uniformity, C_U	4.66	6.67
Coefficient of curvature, C_C	0.86	0.67
Maximum void ratio, e_{max}	0.823	-----
Minimum void ratio, e_{min}	0.635	-----

2. Materials and Methods

Tests were conducted to determine the physical properties of sand (locally available) and brick dust (from brick kiln) (as shown in Table1). The various factors which affect liquefaction resistance is cyclic loading, fines content and relative density. According to studies, liquefaction resistance persisted up to a limiting value even if it declined with an increase in fine content. Beyond the limiting fine content, the addition of fines increased liquefaction resistance. The percentage of finer fraction is more in brick dust than sand which can help the dust to act as fillers and occupy the soil void. Particle size and shape have an influence on dynamic properties of soil. It is seen that shear stiffness is high for rounded particles when compared with other shapes.

2.1 Specimen preparation and testing program

For the strain-controlled undrained dynamic cyclic shear testing, test specimens with dimensions of 50 mm in dia and 100 mm in height were utilized. The specimens were prepared at 50% relative density. To create a dense specimen, the ingredients were layered in the split mould three times, and each layer being tamped with 25 blows.

When the Skempton pore pressure coefficient (B value) approaches 100%, the specimens were fully saturated. After the saturation period, isotropic consolidation took place at a consolidation pressure of 50 kPa. To create shear strains of 0.5%, the range of horizontal displacement amplitudes must be within 0.5 mm. All of the cycling tests were used uniform sinusoidal cycles with constant amplitude and a 1 Hz frequency was applied the loads. There have been 75 cycles of loading.

3. Results and discussion

3.1 Initial Characterization of sand and brick dust

The images taken with Scanning Electron Microscope shows angular shape for both sand and brick dust (as shown in Fig. 1). Fig. 2 shows Particle size distribution curve it represent that the percentage of fines was found more in brick dust than sand and chances are there for increase in liquefaction resistance.

Brick dust is mixed with sand and the amount of brick dust added is increased by increments of 5% by weight of sand. It started from 0% and continued till 50%.

Graphs were plotted for a no. of cycles of loading vs strain (Fig. 3) axial displacement vs deviator stress (Fig. 4) no. of cycles of loading vs deviator stress (Fig. 5) no. of cycles of loading vs axial load (Fig. 6) no. of cycles of loading vs pore pressure ratio (Fig. 7).

It is seen that even after 75 cycles of loading there is no appreciable deformation with the addition of brick dust. The reason may be when the sample is tamped dust particles will occupy the void space of sand and made the sample denser.

The graph of axial displacement vs deviator stress shows that area of hysteresis loop is decreasing with increase in percentage of brick dust particularly after 25%. This is an indication that there is a degradation of dissipated energy. The increase in pore pressure is directly related to dissipation of seismic energy.

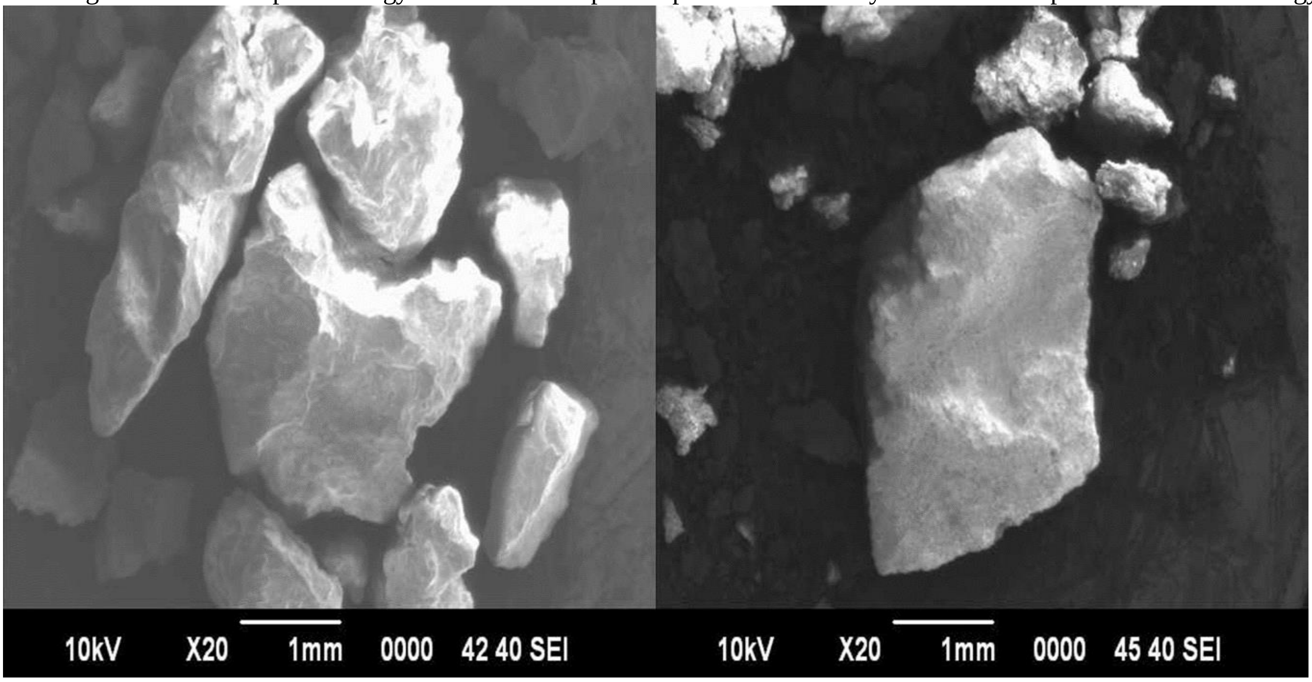

Fig. 1 SEM image of Sand and Brick Dust

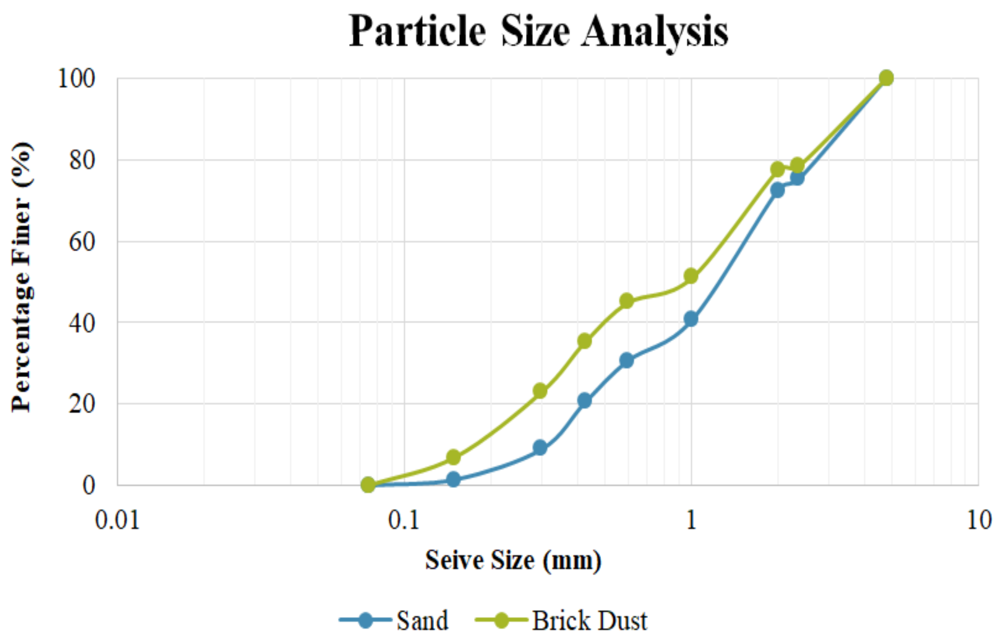

Fig. 2 The grain size distribution curve

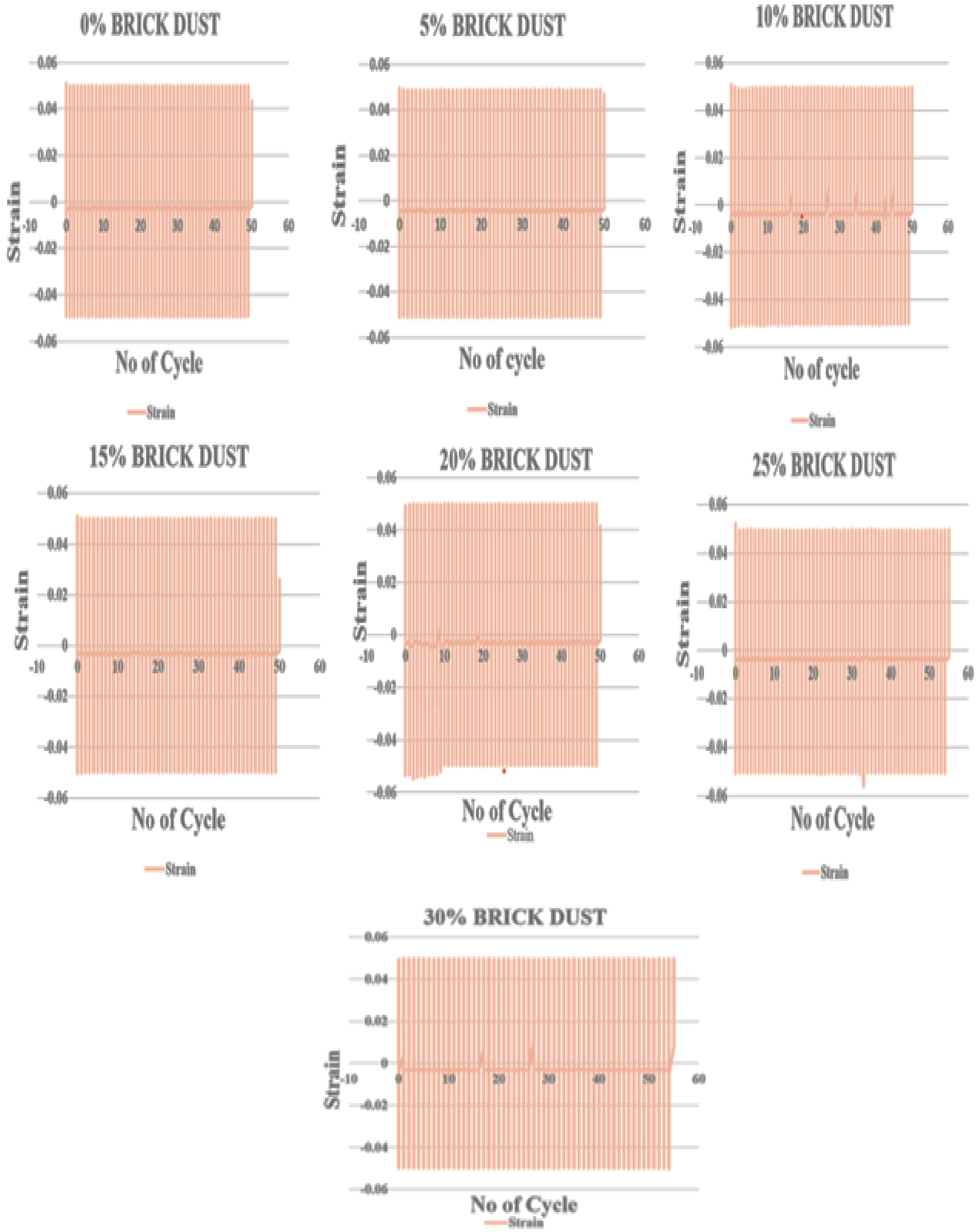

Fig. 3 No. of cycle vs Strain with different percentages of brick dust

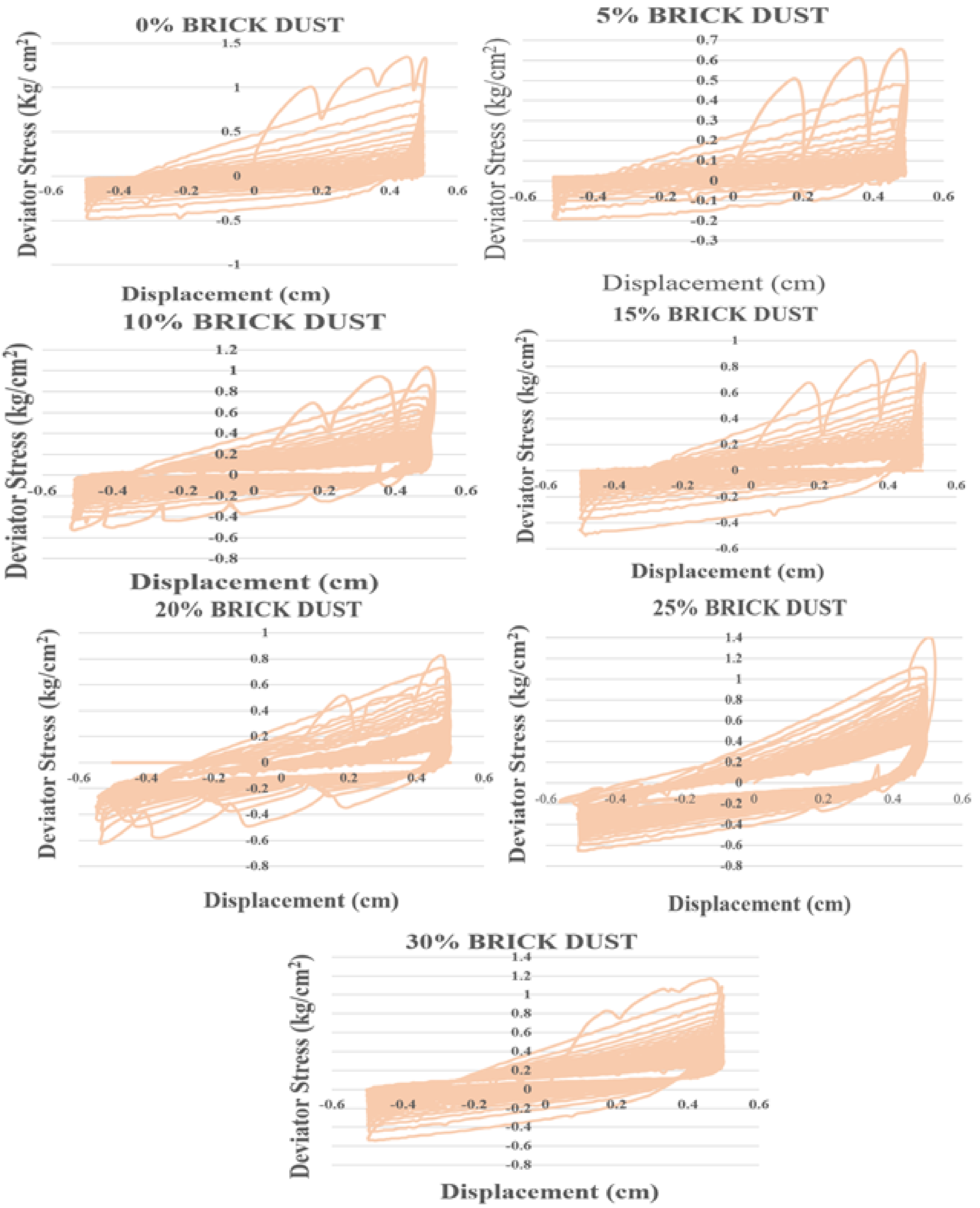

Fig. 4 Axial Displacement - Deviator Stress

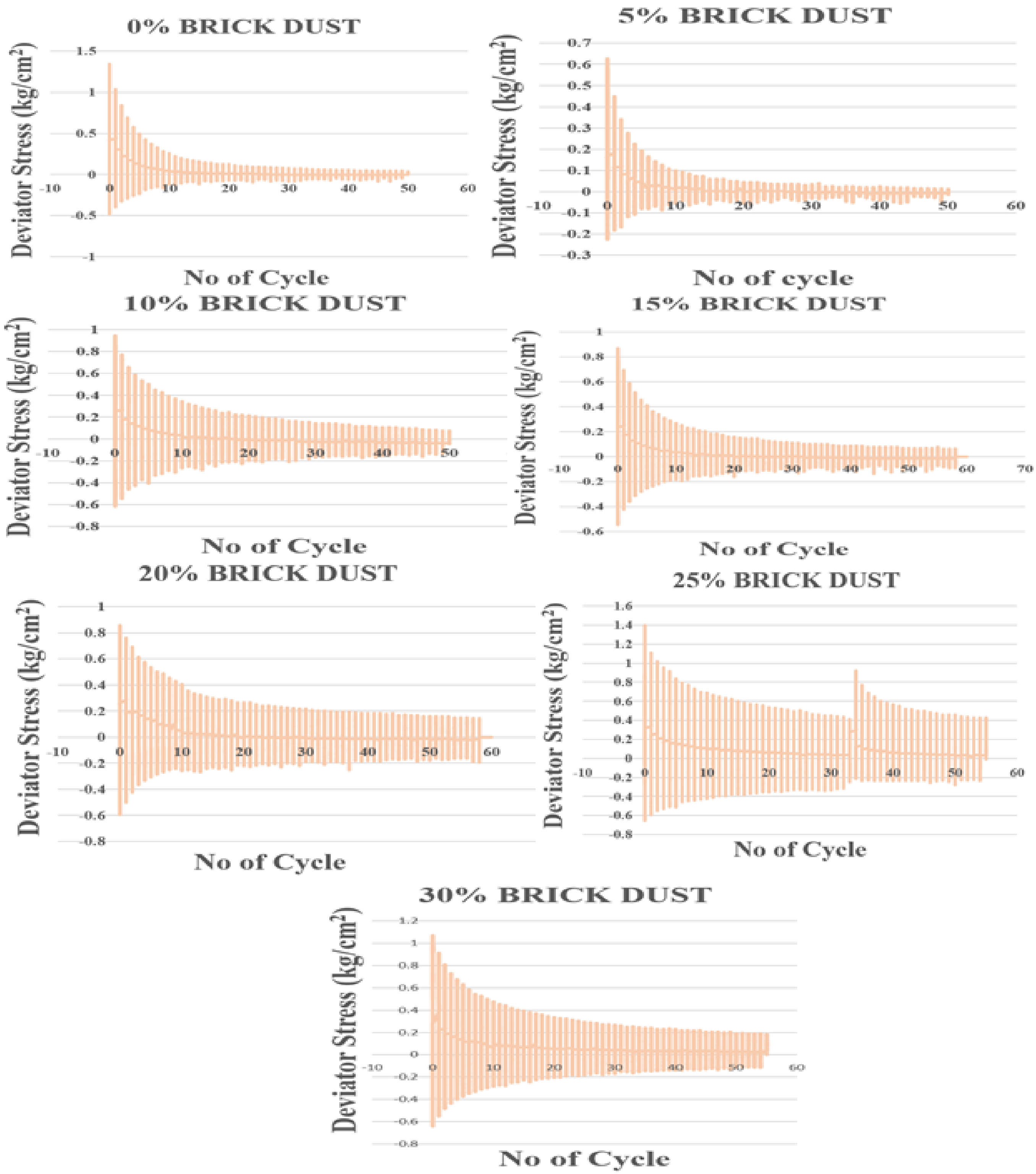

Fig. 5 No. of cycle - Deviator Stress

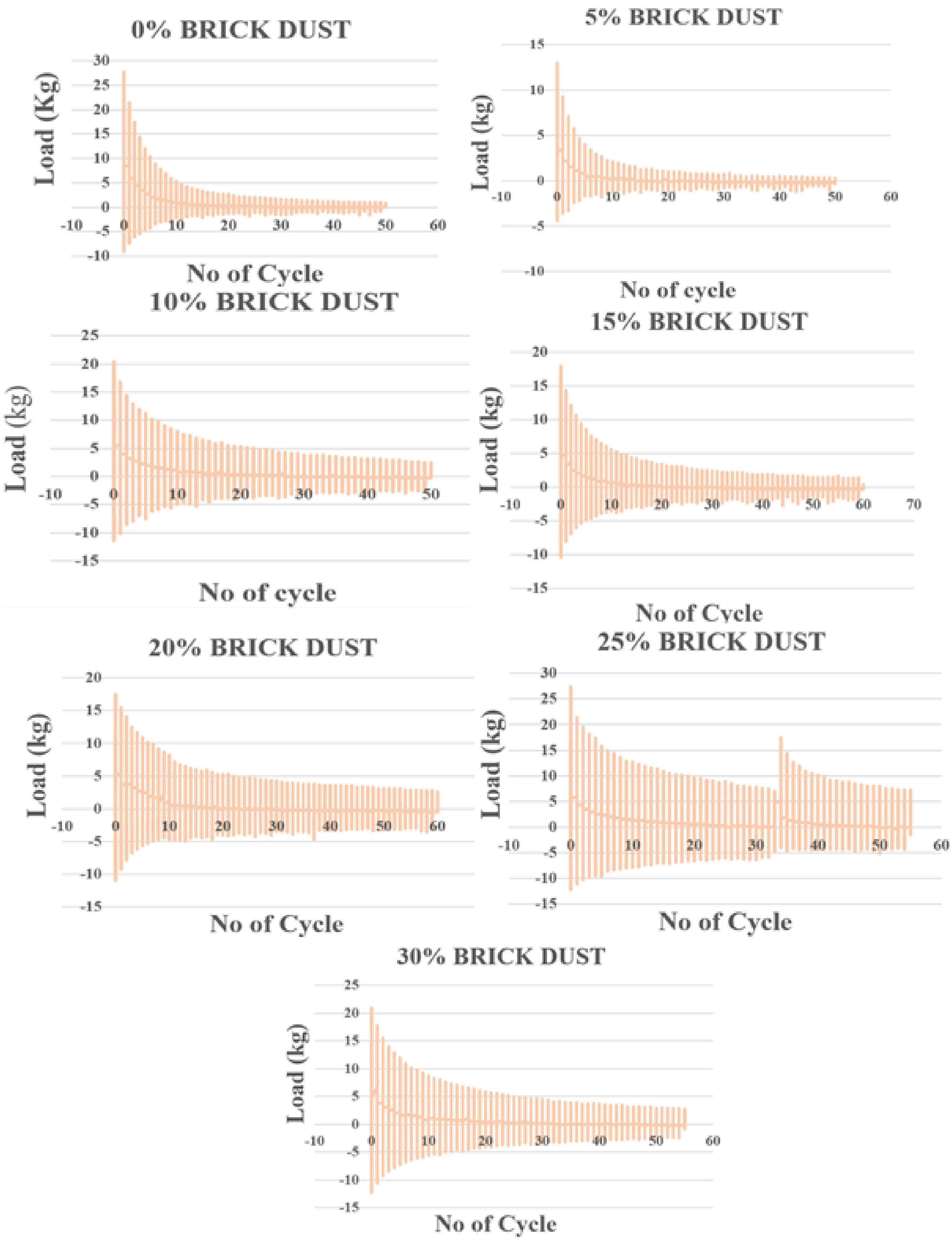

Fig. 6 No. of cycle - Load

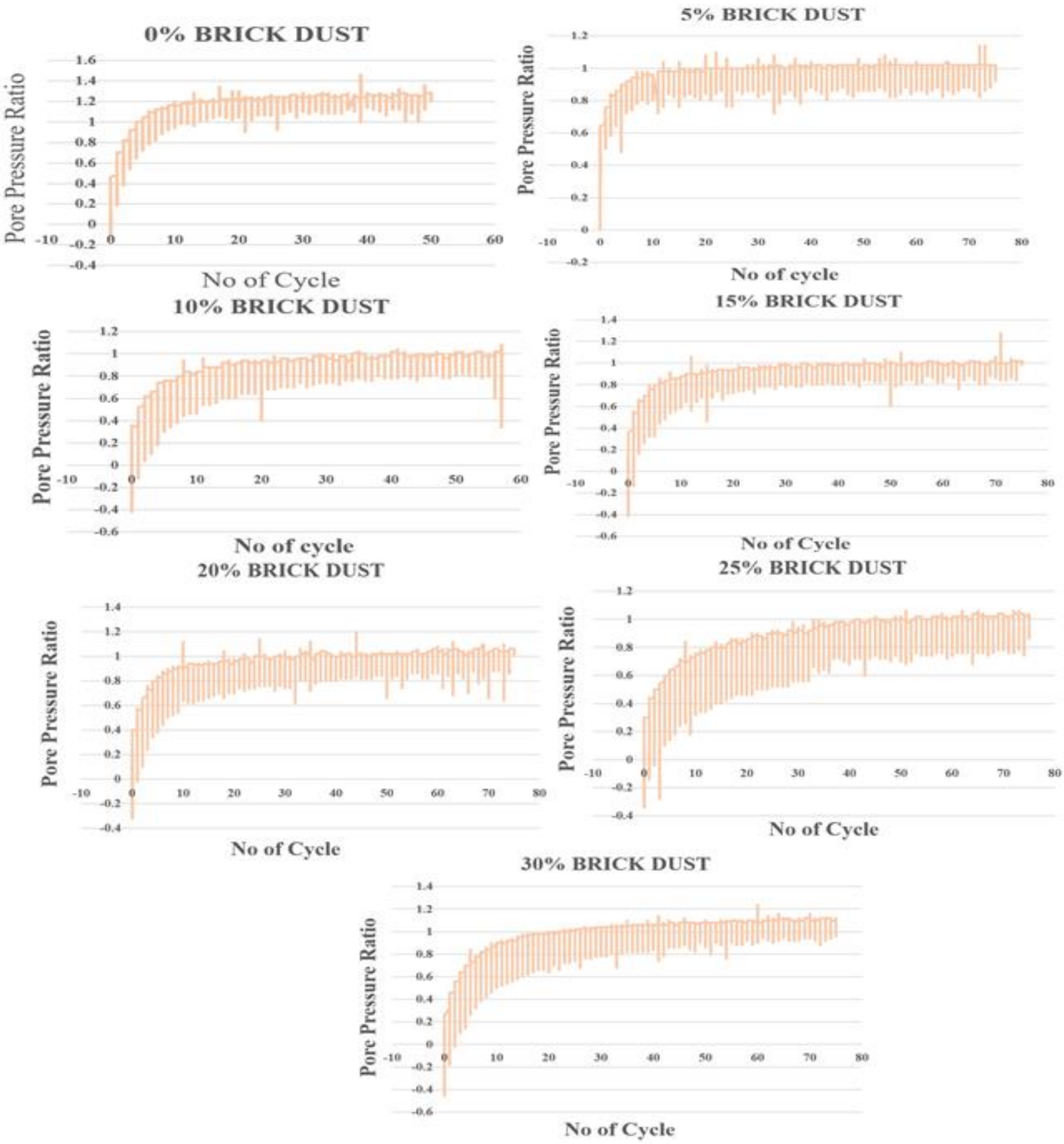

Fig.7: No. of cycles – Pore Pressure Ratio

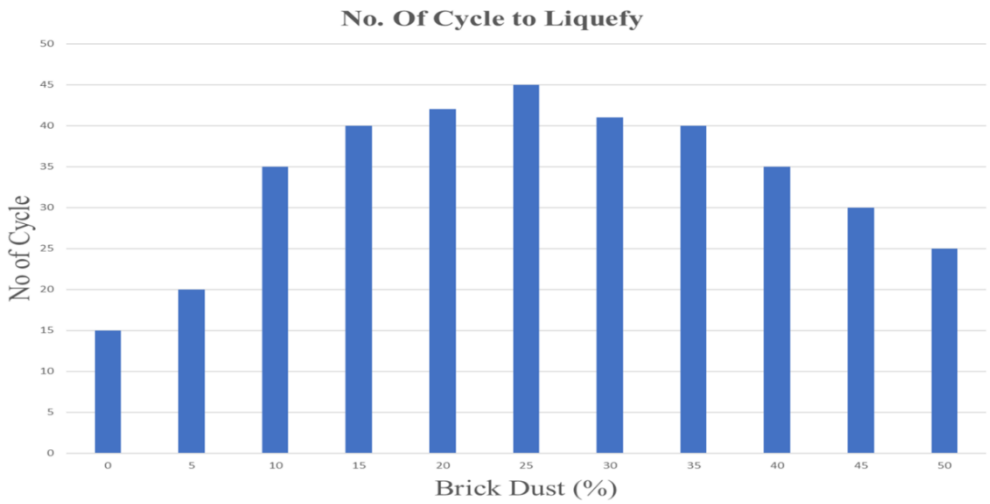

Fig. 8 No. of cycle vs percentage of Brick Dust

It is also observed that the exponential decay of both deviator stress and load with number of cycles is fast up to 15% addition of brick dust and thereafter the rate is slow. After the application of same number of cycles of loading on soil samples mixed with different percentages of brick kiln dust, it is seen that the sample having 25% brick kiln dust by weight of sand is having the maximum value of load and deviator stress after 50 cycles.

Table 2 Percentage of Brick Dust and number of cycles to liquefy

% of Brick Dust	No. Of Cycle to Liquefy
0	15
5	20
10	35
15	40
20	42
25	45
30	41
35	40
40	35
45	30
50	25

The pore pressure ratio is an indication of liquefaction of soil. When the pore pressure ratio reaches a value of 1, the effective stress reduces to zero and the soil liquefies. The graph of pore pressure ratio versus number of loading cycles demonstrates that as brick dust content in the soil sample increases, more cycles are needed for the pore pressure ratio to liquefy at a rate of 25%. Further addition of brick dust tends to increase the chance of liquefaction when lesser number of cycles are applied. This emphasis the fact that increase in fines decrease resistance of soil to liquefaction. Hence the optimum value is 25%, which means that addition of 25% brick kiln dust can improve the liquefaction characteristics of virgin sand.
Fig. 8 and Table 2 shows comparison between percentage of brick dust and number of cycles to liquefy.

4. Conclusions

Experimental investigations are carried out to study the liquefaction resistance of sand when admixture is added to it. The admixture used is brick dust obtained from brick kiln. It is the mixture of ash of fuel and dust of brick after combustion and considered as a pollutant.
To investigate the cyclic characteristics of sand and brick dust mixtures, strain-controlled undrained cyclic triaxial experiments are performed. The brick dust is added in varying percentages by weight of sand (0% - 50%, increments of 5%). According to the findings of the laboratory inquiry, the cyclic resistance of the tested sand increases as the percentage of brick dust increases up to 25% and falls as the percentage grows beyond 25%. The no. of cycles required for the sand to liquefy is 45 cycles when mixed with 25% brick dust. The results confirm that as the percentage of fines increases, soil have a tendency to liquefy faster.

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Conflict of interest
The writers don't have any competing interests.

Contribution of authors
Neha: Writing original draft, conceptualization and formal analysis, provided data, graphical images and testing of Soil.
Vishal Rawat: Provided supervision and validated the manuscript.

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