Nagaoka University of Technology **Civil and Environmental Engineering**
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<u>Title:</u> -Shaking Table Tests on Liquefaction Strength Considering Orientation of Sand Particles.

Abstract

This study investigates the influence of sand particle orientation on liquefaction resistance using shaking table tests. Toyoura sand was used to prepare model ground with relative densities of 30% and 60%. The model ground was prepared using the air pulviation method. Horizontal shaking was applied to the ground at three different orientation angles: 0°, 45°, and 90°. To simulate seismic loading conditions, a range of input accelerations was used: 200, 225, and 250 gals for a relative density of 30%, and 300, 350, and 375 gals for a relative density of 60%.

The results showed that samples with a 0° orientation (horizontal alignment) exhibited the highest liquefaction resistance, followed by 45° and 90°. This trend was consistent in both relative density conditions, although denser ground showed greater liquefaction strength. Microscopic observations revealed that after the first shaking, particles tended to realign in a more vertical direction. This reorientation weakened the soil structure and reduced reliquefication strength because of loss of stable particle structure against shaking.

Reliquefication tests, simulating aftershock or following earthquake events in the ground, confirmed that all samples exhibited lower strength during the second shaking phase. The reduction in liquefaction strength was attributed to vertical particle realignment, which made the soil particles more prone to liquefaction. Additionally, the differences in liquefaction strength among the orientation angles became less significant during reliquefication, because particle alignment became more similar in all cases through liquefaction history.

These findings emphasize the critical role of particle orientation in influencing both initial liquefaction and subsequent reliquification behavior. Understanding this mechanism can provide a new evaluation method of liquefaction potential and can improve seismic design cords in the practice of geotechnical engineering.

Introduction

The study of this kind is important particularly for active earthquake prone region like Japan and Bangladesh etc. Bangladesh is highly susceptible to earthquakes due to its location at the convergence of three tectonic plates: the Indian Plate, the Eurasian Plate, and the Burmese Plate (Myanmar). Over the past 50 years, the country has experienced more than 66 significant earthquakes, with some exceeding a magnitude of 6.0.

Notable examples include the 6.7 magnitude earthquake in Comilla (2023), the 6.8 magnitude earthquake in Dhaka (1997), and the 6.1 magnitude earthquake in Chittagong (1997). Many regions in Bangladesh have saturated sandy ground, particularly in coastal and riverine areas, making them prone to liquefaction during seismic events. This phenomenon can cause severe damage to infrastructure. Therefore, the deep understanding of liquefaction potential is crucial for earthquake hazard mitigation in Bangladesh.

RESEARCH OBJECTIVES

The objectives of this study are follows:

1. To investigate how sand particle orientation affects liquefaction strength.
2. To examine how particle reorientation change after shaking.

METHODOLOGY

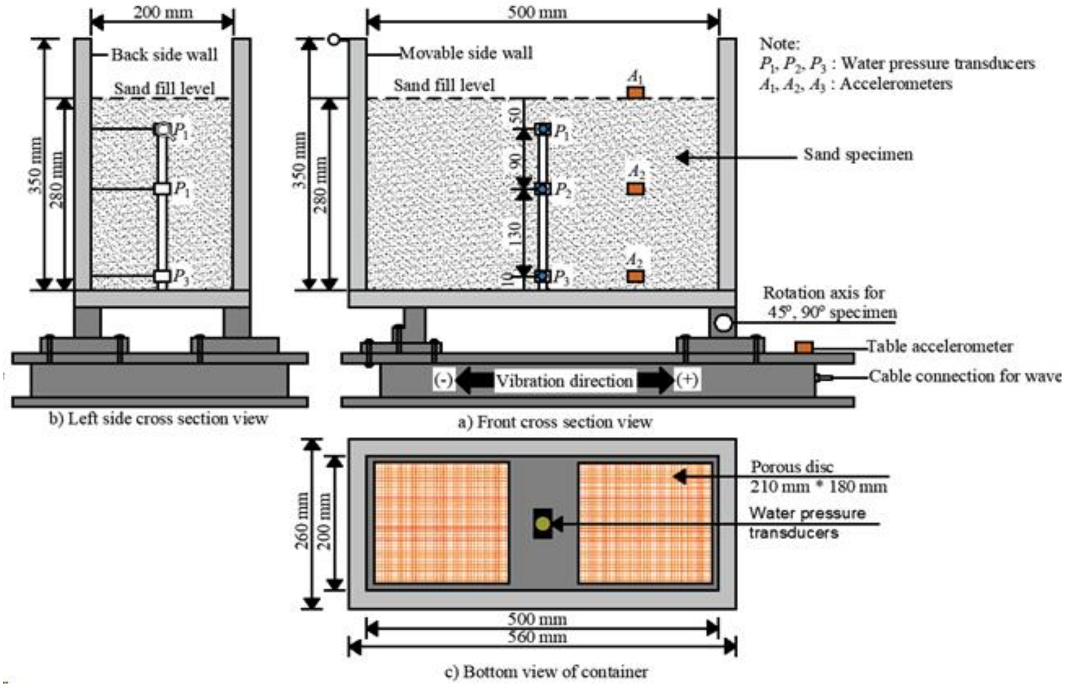

Figure 1. Dimension of container and sensors position

A model sand ground was created in a specifically designed rectangular container (dimensions: 50 cm length × 20 cm width × 40 cm height), as illustrated in Figure 1. Toyoura sand, selected because of its consistent and uniform properties, was carefully placed into the tank using the air pluviation method, ensuring uniform particle distribution. The final ground height reached 28 cm, leaving adequate space at the top to prevent spillage liquefied sand during shaking.

Three pore water pressure transducers (P_1, P_2, and P_3) were installed vertically at different depths within the sand ground (Figure 1a, b), positioned strategically to measure pore water pressures at the top, middle, and bottom regions. Accelerometers (A_1, A_2, and A_3) were placed at different locations to accurately capture accelerations experienced during shaking.

Following sand placement, saturation was conducted by gradually introducing water from the bottom of the specimen under deair condition to ensure uniform saturation and elimination of air voids. The container base incorporated porous discs can facilitate both supply and drainage of water (Figure 1c).

Subsequently, shaking table tests were carried out at predefined acceleration intensities of 200, 225, and 250 gals to induce liquefaction in the sand ground. The shaking direction was horizontal and clearly indicated in Figure 1(a). Following the initial shaking test, microscopic analyses were conducted to observe and document particle orientation changes.

Figure 2 shows microscopic measurement of the sand particles before liquefaction, where particles display an initial depositional oriented distribution. After liquefaction, microscopic analysis revealed significant rearrangement and reorientation of particles, highlighting the substantial changes induced by liquefaction history.

After allowing the specimen to rest for 30 minutes, a second shaking test was performed to evaluate reliquefaction potential. To study the effect of particle orientation on liquefaction resistance, tests were conducted with sand particles oriented at angles of 0°, 45°, and 90° relative to the shaking direction, as enabled by the rotation axis shown in Figure 1(a).

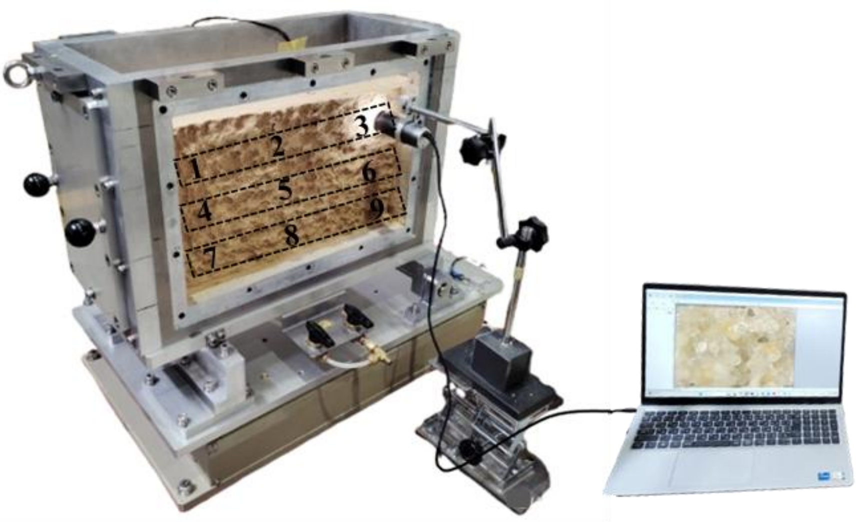

Figure 2. Setup for capturing sand particle orientation using microscope

This comprehensive procedure allowed a detailed analysis of liquefaction resistance and particle orientation effects, providing valuable insights into soil behavior under seismic loading conditions.

RESULTS

In the first liquefaction test, the ground with 30% relative density showed that those with 0° particle orientation had the highest resistance to liquefaction, followed by 45° and then 90°, indicating the liquefaction strength trend of 0°>45°>90°.

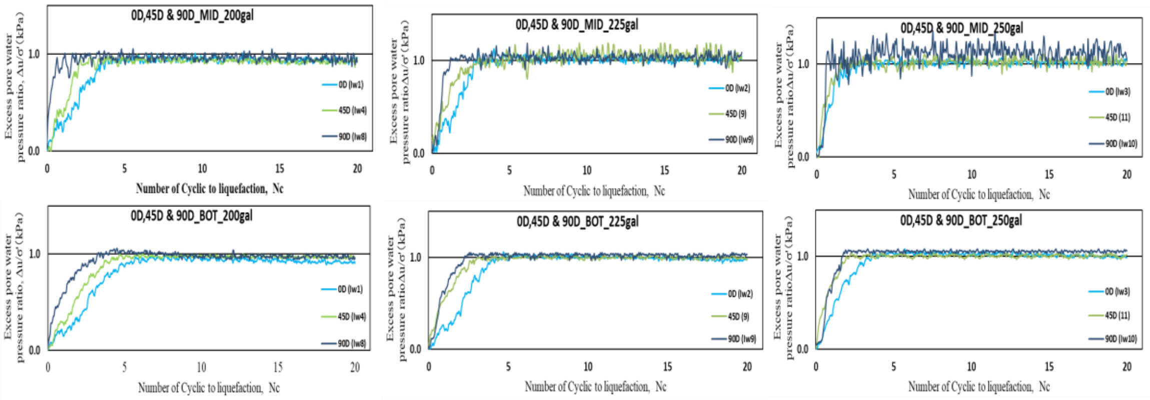

Figure 3. First liquefaction test for 30% relative density)

Similarly, the 60% relative density ground demonstrated greater overall resistance compared to the 30% ground, but tendency is the same.

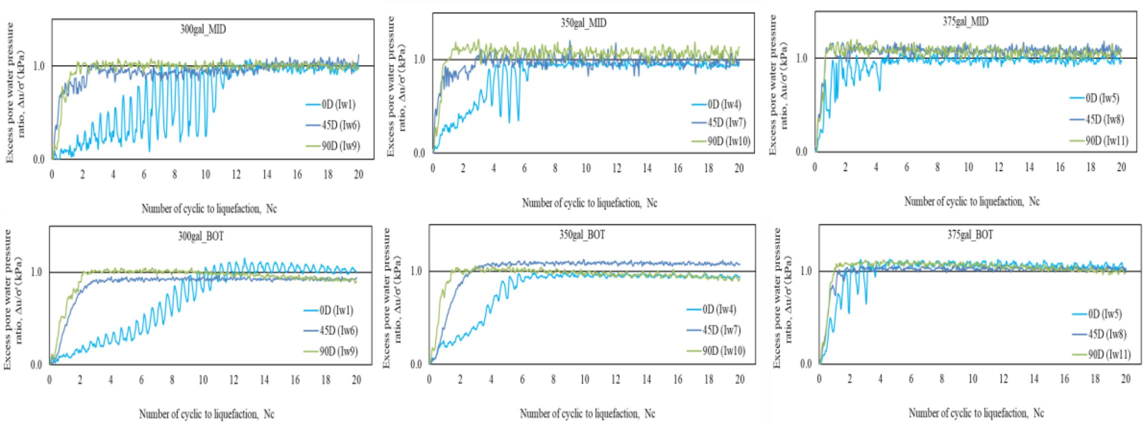

Figure 4. First liquefaction test for 60% relative density

During the reliquefaction test (second shaking) in Figs 5 and 6, it was observed that, regardless of the initial density, liquefaction strength significantly reduced in all cases.

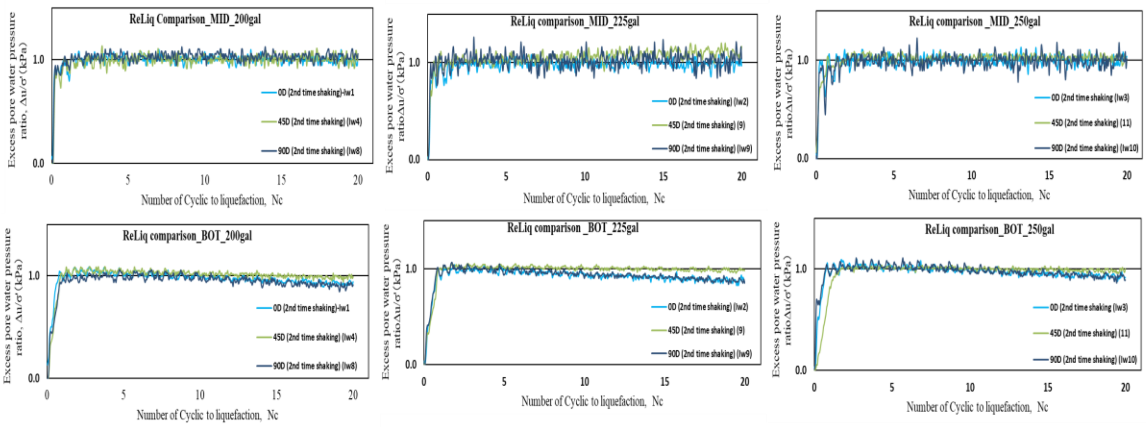

Figure. 5 Reliquefaction test for 30% relative density

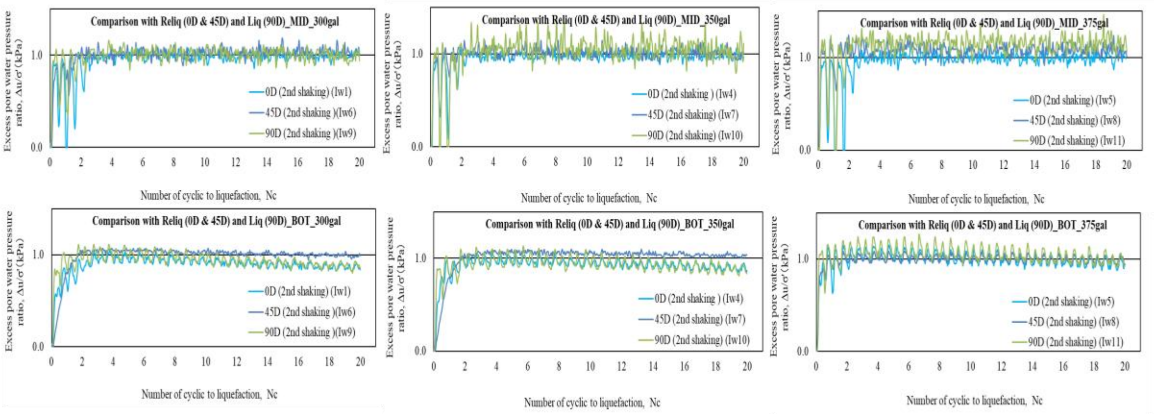

Figure 6. Reliquefaction test for 60% relative density)

For the 30% relative density ground, 0° and 180° were considered horizontal orientations, while 90° represented the vertical direction. As shown in Figs. 7 and 8, particle orientations before shaking were dispersed, with 0° samples peaking near 0-10°, 45° around 50°, and 90° near 90°. After shaking, all cases showed a clear shift toward vertical alignment around 90° after first liquefaction.

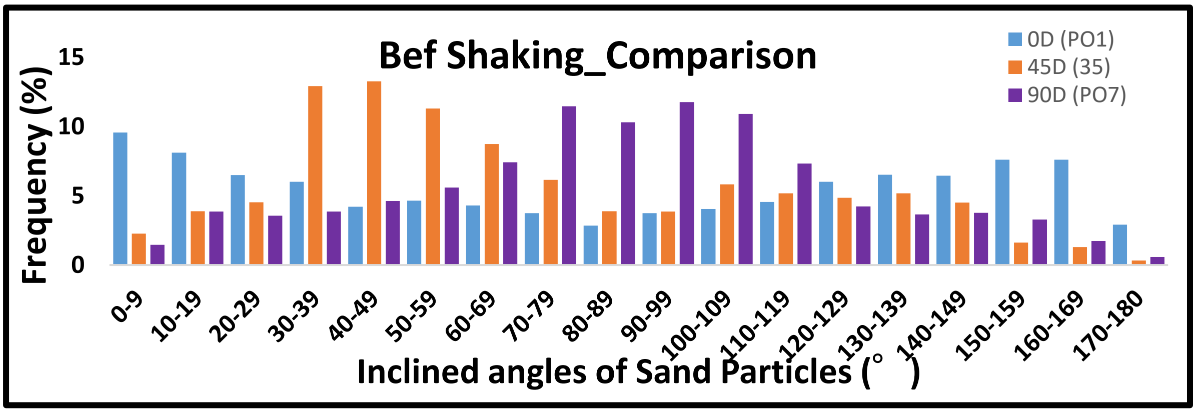

Figure 7. 30% Relative density sample particle orientation before liquefaction

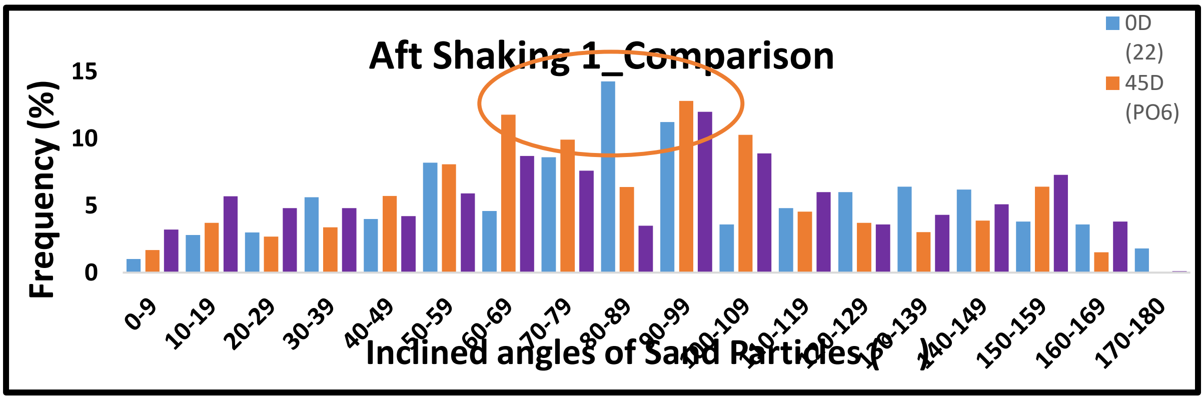

Figure 8. 30% Relative density sample particle orientation after liquefaction

At 60% relative density, particle orientations shifted significantly after the first shaking. Before liquefaction (Figure 9), the 0°, 45°, and 90° samples showed peak inclinations around 0°, 40°, and 100°, respectively. After shaking (Figure 10), all samples converged toward vertical alignment near 90°, with the 0° sample angle increasing from 18.45° to 82.07°, and the 45° from 53.41° to 86.27°. This vertical reorientation suggests enhanced change of structural resistance against reliquefaction.

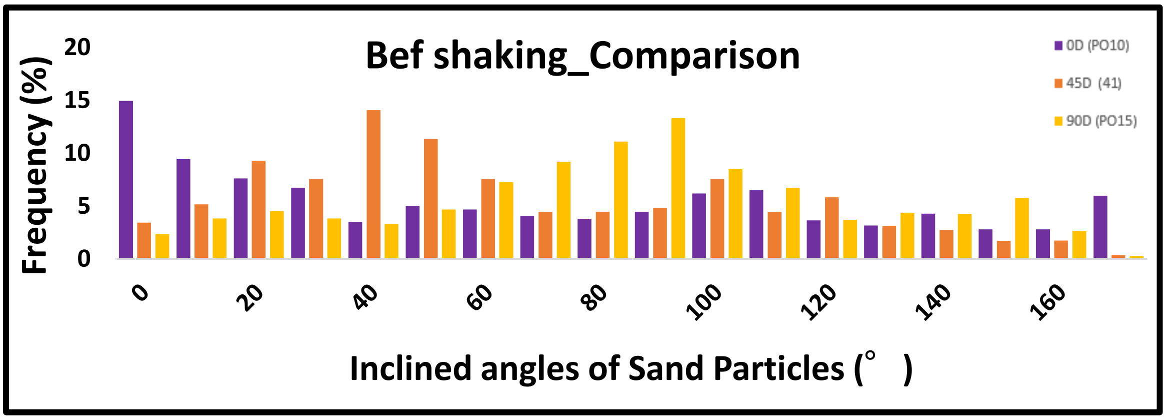

Figure 9. 60% Relative density sample particle orientation before liquefaction

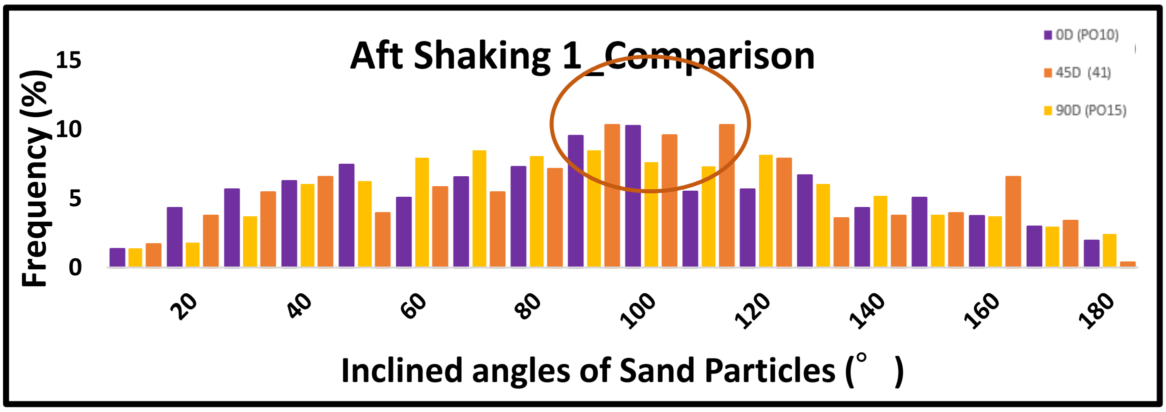

Figure 10. 60% Relative density sample particle orientation after liquefaction

Comparison of liquefaction resistance between 30% and 60%

Figure 11 illustrates that significantly higher cyclic resistance was observed in the 60% dense ground compared to the 30% ground. Table 12 presents the cyclic resistance ratio for Toyoura sand ground at 30% and 60% relative densities.

A detailed comparison shows that the increase in cyclic resistance ranged from approximately 56% to 76% in the middle section of the ground, and 35% to 50% in the bottom section. This increase reflects the enhanced stiffness and interlocking behavior of the denser sand structure, resulting in improved resistance to cyclic loading. These findings emphasize the critical influence of relative density on liquefaction resistance and confirm that medium-dense sand can substantially mitigate liquefaction potential under seismic loading.

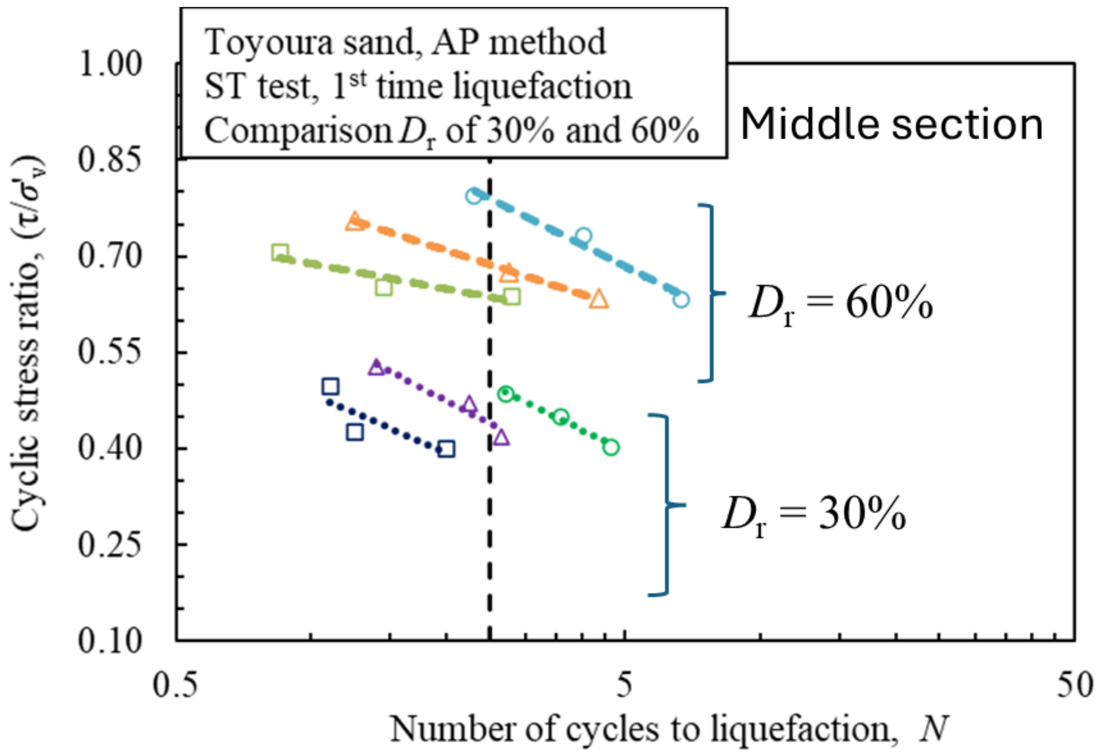

Figure 11. Relationship between cyclic stress ratio (τ/σ′v) and number of cycles to liquefaction

α (degree)	ST tests					
	30%		60%		CRR1(M)	CRR1(B)
	CRR1(M)	CRR1(B)	CRR1(M)	CRR1(B)	incresed (%)	incresed (%)
0D	0.5	0.586	0.789	0.876	57.89	49.42
45D	0.439	0.548	0.687	0.740	56.47	35.00
90D	0.362	0.479	0.636	0.673	75.75	40.60

Table 12. Cyclic resistance ratio (CRR) at different particle orientations for relative densities of 30% and 60%.

CONCLUSION

- Specimens with 0° orientation exhibited the highest liquefaction resistance, followed by 45° and 90°, for both D_r = 30% and 60%.
- Higher relative density (D_r = 60%) improved liquefaction resistance with increased ratio of 56% to 76% in the middle section, and 35% to 50% in the bottom section of the ground.
- Reliquefication strength degradation was confirmed by changes in particle orientation data.
- Particle orientation played a key role in reliquefaction behaviors. Initially aligned particles of 0° and 45° showed greater strength loss because of particle orientation change.
- The bottom section consistently exhibited higher liquefaction potential than the middle because of stronger confinement of the deformation by bottom plate.