

Failure Behavior on Saturated Clean Sand due to Cyclic Loading Repetition

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Abstract: A failure on a soil specimen due to dynamic loading repetition was examined in this research. Soil as a medium wave propagation was changed due to repetition of applied load. A series of undrained dynamic triaxial testing was conducted in order to obtain comprehensive results of soil behavior which suffered dynamic loading many times. All specimens were used in saturated condition which indicated by B-value more than 0.95. Soil sample classified as medium clean sand according to Unified Soil Classification System (USCS). Various type of time delay of loading (Δt), relative density (D_r), frequency of loading (f) and amplitude of cyclic shear strain (γ_e) which were respectively applied $\Delta t = 1, 3$ and 5 minutes, $D_r = 25\%$, $f = 0, 1$ Hz also $\gamma_e = 1,6\%$. When the delay of loading repetition $\Delta t = 1$ minute, the results revealed that pore water pressure behavior (Δu) reached an equivalent to effective confining pressure (σ'_3) of soil at third repetition. Thereafter, it depicted a phenomenon of settlements which indicated by decreasing of pore water pressure but after that, the specimens were in failure condition again. This phenomenon was repeated several times. For the delay time $\Delta t = 3$ minutes and 5 minutes, the behavior as mentioned above also occurred in the specimen but it required more repetition load applied.

Keywords: dynamics loading, loading repetition, pore water pressure, clean sand

1. Introduction

Indonesia lay down on three active tectonic plates, there are Pacific plate, Indo-Australian plate and Eurasian plate. These plates shift and move in order to reach their stability. Since the plate find their stability, an amount of energy dissipate through soil layer as a medium wave propagation thus it trigger an earthquake on the surface. Previous research classified Indonesia as a country with highest potential earthquake magnitude more than 4 [2]. Indonesia also located on Pacific ring of fire which characterized with many active volcanoes ([6], [7]). For this case, the activities of volcano trigger a repeatedly a lower intensity vibration beneath on the soil layer ([5]). In this paper, firstly presents the research on dynamic behavior of saturated soil is explained. Secondary the failure condition of clean sand was examined based on triaxial testing result with water responses taken into consideration.

More recently research mentioned that loose clean sand under dynamic loading contribute settlement phenomenon followed by increasing of density relative ([1], [4], [8]). According to previous research report, an application of dynamic loading on loose clean sand triggers an increasing of force contact between grains surface. It also contributed an increasing of soil resistance on applied shear stress. In this paper, behavior of soil under dynamic loading repetition is discussed by using loose clean sand as representative sand. The hypothesis of behavior loose clean sand due to two types of dynamic loading is illustrated in Figure 1.

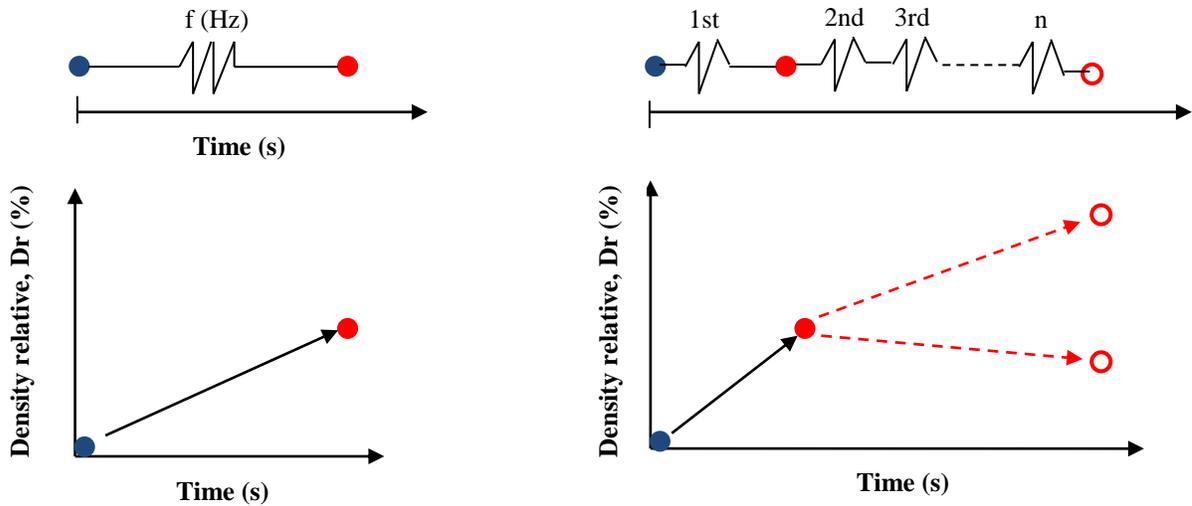


Fig 1: Behavior of loose clean sand under two types of dynamic loading

2. Methodology

2.1 Materials properties

The soil samples called Yogyakarta sand were collected from Universitas Muhammadiyah Yogyakarta area. This sand was representative of clean sand in Java Island. It has dry and wet densities are 1.67 gr/cm^3 and 1.92 gr/cm^3 . Maximum and minimum void ratios are 0.81 and 0.48 respectively. This sand has no fine particle which indicated by grain distribution curve in Figure 2. According to Unified Soil Classification System (USCS), it classified as medium clean sand.

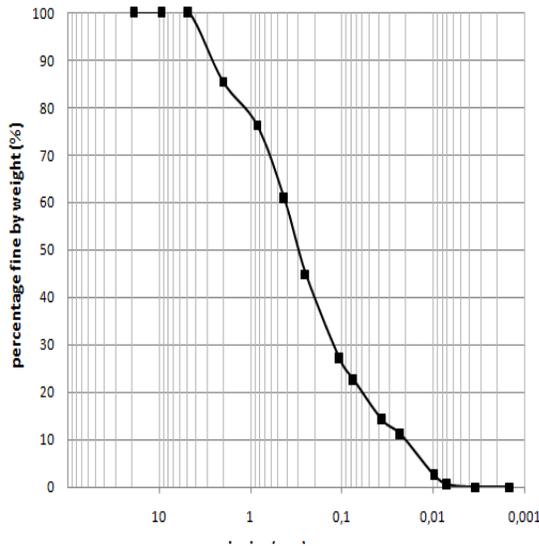


Fig 2: Grain size distribution of Yogyakarta sand

2.2 Testing Method

A series of testing was carried out by using undrained cyclic triaxial equipment. All specimens were assured on saturated condition which indicated by Skempton (B) value more than 0.95 and pore water response was measured during the testing. Some parameters of testing as initial of soil condition were applied such as density relative ($D_r = 25\%$), time delay of loading ($\Delta t = 1, 3$ and minutes), frequency of loading ($f = 0.1 \text{ Hz}$), effective confining pressure ($\sigma'_3 = 100 \text{ kPa}$) and cyclic shear strain amplitude ($\gamma_\varepsilon = 0.1\%, 0.8\%$ and 1.6%).

2.3 Triaxial Apparatus

The specimens were prepared in diameter $d = 50$ mm and height $h = 100$ mm respectively. A porous stone was installed at the bottom of specimen. Three digital volume-controller were attached on the machine in order to measure precisely confining pressure, axial force and volume change of water pressure. All controller were connected to a storage system which could detected every second. A personal computer was installed and also connected to triaxial system in order to conduct research procedure easily.

2.4 Specimen Preparation Method

The specimens were prepared as follows. To begin with 330 gram dry clean sand was prepared and dropped through the air into the mold until reached fifth of specimen height. Thereafter, water flowed into the mold through the bottom of specimen until reached fully saturated condition. During this process, the specimen compacted by using a ram corresponds to density relative ($D_r = 25\%$). This process repeated four times until obtained appropriate height. All stages of sample preparation should be fulfilled sequentially in order to achieve a uniform density relative and moisture state.

2.5 Type of Loading

After whole process above, cyclic triaxial tests were conducted under undrained condition and the loading frequency was 0.1 Hz. Type of loading which applied on specimen is illustrated in Figure 3. A sinusoidal wave correspond to axial shear strain amplitude 0.1%, 0.8% and 1.6% was applied on the specimen. In order to obtained comprehensive results, this testing used cyclic shear strain controlled method which its concepts was shown in the literature (Vucetic, 1991; Kazama, 2000).

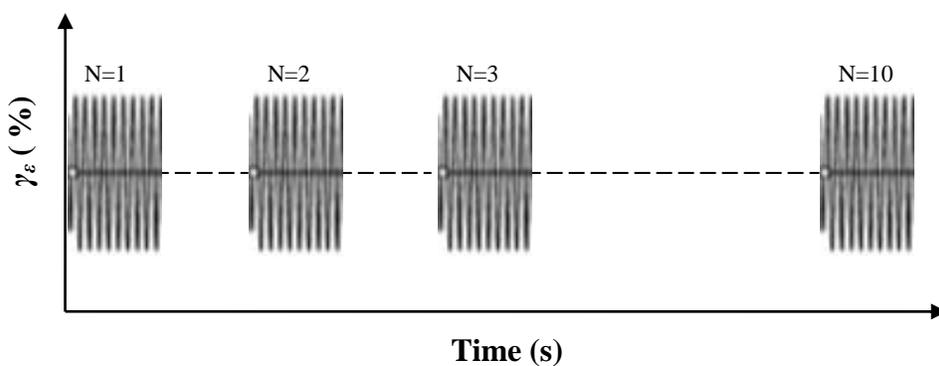


Fig 3: Type of applied loading during the testing

3. Results and Discussion

3.1 Representative Results

Cyclic loading repetition with various applied cyclic shear strain amplitude on specimen revealed that pore water responses have different characteristic. Time history of pore water pressure ratio on specimen was illustrated in Figure 4. From the figure, it depicted that cyclic shear strain (γ_e) was a variable which contribute a great influence of pore water responses. For amplitude cyclic shear strain (γ_e) 0.1 % and 0.8% pointed out that in the beginning of loading, the pore water pressure increased then reached constant value even though number of loading repetition increased. For $\gamma_e = 1.6$ %, it show that pore water pressure ratio equal to 1 after suffered four times repetition of cyclic loading. It indicated that soil in weak response considering to applied loading. In fifth repetition, pore water pressure was decreased. Subsequently, repetition of cyclic loading was continued and surprisingly, the pore water response increased until obtain the equal value between pore water pressures and confining stress. For $\gamma_e = 3.2$ %, the maximum pore water ratio occurred at second loading repetition. After that, it gradually decreased with increasing of number loading repetition.

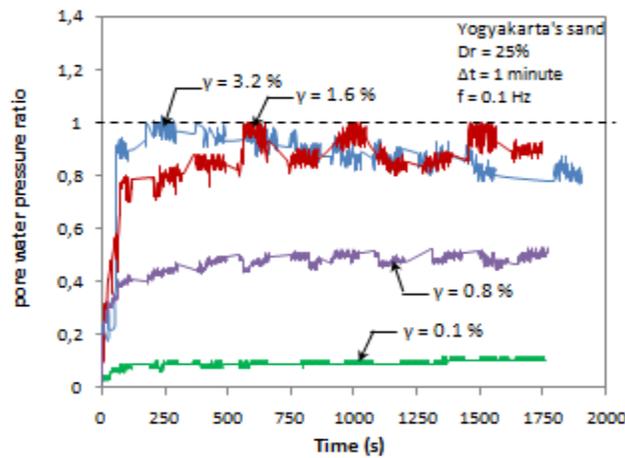


Fig 4 : Time history of pore water responses

According to figure above, it revealed that could trigger weakness response of soil was 1.6%. This condition could occurred many times depend amplitudo cyclic shear strain (γ_e) applied. But for amplitudo cyclic shear strain (γ_e) 3.2%, it appeared once times and thereafter specimen revealed seems that it followed by a settlement phenomenon and more denser. Another conclusion is a repetition of cyclic loading on saturated clean sand tends experienced a weak response more than one if an amplitudo cyclic shear strain (γ_e) applied were $1.6\% < \gamma_e < 3.2\%$.

The influence of time delay of loading could be explained in detail by referring at Figure 5. From this figure it revealed that the responses of water pressure were not affected by time delay of loading parameter at the first loading repetition. The difference occurred after second number of loading repetition. For $\Delta t = 1$ minute, pore water pressure ratio reached a maximum value. This phenomenon also occurred on the specimens when $\Delta t = 3$ minutes at four times of cyclic loading repetition and $\Delta t = 5$ minutes when cyclic loading repeated six times. From this graphic, it noted that a variable of time loading delay affected pore water response on specimen. A specimen got in weak response indicating by pore water pressure ratio equal to 1. A shorter time delay of loading, it accelerate the specimen tends to failure. For longer time delay of loading, a failure of specimen also occurred but it also need more time to reached it. Indication of specimen failure could be seen in Fig. 5 when it obtain pore water pressure ratio equal to 1.

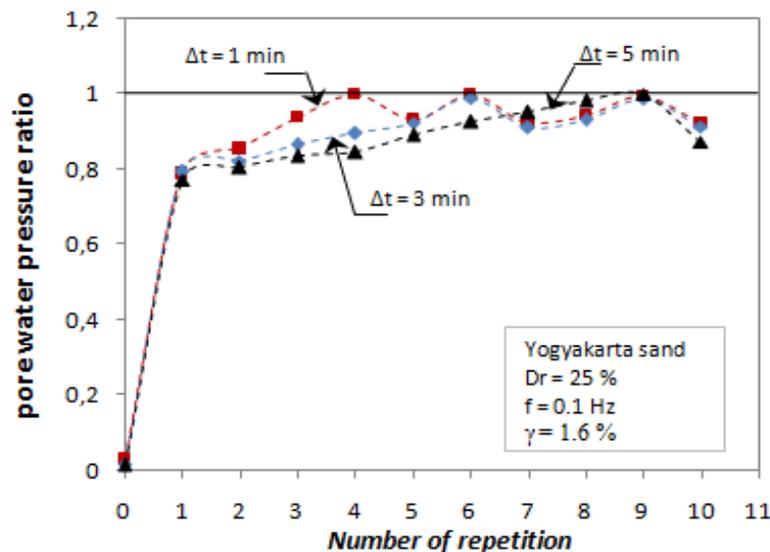


Fig 5 : Relation between pore water pressure ratio and number of cyclic loading repetition (N) at various time delay of cyclic loading (Δt)

4. Discussion

When a saturated soil mass induced by cyclic loading, it need a several time for pore water pressure to release their energy and it ensured that this process encouraged decreasing of soil resistance. If a mass of

saturated soil suffered of cyclic loading repetition in a short time, it could trigger excessive energy and it continued by release process of them in order to reach soil stability. In field, the releasing process of energy indicated by a boiling of sand or water release in surface of soil layer. In this research, it was shown by increasing of pore water pressure tends to 1. When the pore water pressure was equal to effective stress of soil, it could be said that soil in the weak response in order to resist of cyclic loading which applied on it. If a cyclic loading repetition taken in longer time, it gave a sufficient time for water to release their energy before

According to the test results above, it can be understood that cyclic shear strain amplitude (γ_e) and time delay of cyclic loading (Δt) were the parameter which trigger the failure of saturated loose sand subjected to cyclic loading. Specimen reached the failure when minimum value of γ_e was 1.8%. Below of this value, it does not show any indication a specimen tends to failure. Another case according to the time delay of loading, the results depicted that probability a specimen tend to failure increase at $\Delta t = 1$ minute compare to $\Delta t = 3$ or 5 minutes. It could be understood that a specimen has a weak responses at ratio of water pressure equal to 1.

5. Conclusion

- General conclusion revealed the loose sand subjected to cyclic loading turned to dense due to of decreasing of void ratio. In order to develop understanding of soil behavior under low loading frequency, its necessity of further investigation into soil dynamics behavior.
- For saturated loose clean sand subjected to cyclic loading repetition under undrained condition, the pore water responses revealed the different behavior between one and another number of cyclic loading applied. Some of them reached equal to total stress.
- Parameters which have a great influence on specimen failure are cyclic shear strain amplitude (γ_e) and time of cyclic loading (Δt)

6. Acknowledgement

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