Shear strength behaviour of liquefiable sand of petobo on treated by agarose under direct shear test

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Abstract Liquefaction process is associated with the loss of the shear strength of the saturated loose sands caused by strong earthquakes. Due to mitigation of liquefaction hazard, an appropriate mitigation of liquefaction using environmentally friendly methods is critical and becoming increasingly important and unavoidable. The laboratory investigation was carried out to study the shear strength behaviour of liquefiable sand of Petobo treated by agarose on different concentration 1%,3% 5%. A series of direct shear test were conducted under three level of vertical stress 10 kPa, 20 kPa, and 30 kPa on the specimen. It was found that the optimum content of agarose which can be considered is at 1%-3%, using stress ratio (t/σv) analysis shows that stress ratio decreases with increasing the vertical stress on the same agar content. The implication this result that the application of this method must consider variation of material source and characteristic, and the suitable level of vertical stresses.

Keywords: Liquefaction, Agarose; Shear strength, Petobo Sand, Direct Shear.

1. Introduction
Petobo sub-district is one of the areas that was affected by liquefaction on due to the 7.5 Mw Palu Central Sulawesi Earthquake in 2018. Lateral spreading, surface fracture and flow sliding occur massively and cover a large area. Although, the mechanisms and effects of liquefaction have been studied by a number of researchers [1][2] but because the coverage area affected is very broad, massive research in various reviews to study further this phenomenon includes behavior of shear strength characteristic of soil sand which can be useful for the purposes of numerical analysis, empirical methods, experimental studies for the purpose of mitigation and remediation.

The mechanism that occurs during the liquefaction process is associated with the loss of the shear strength of the saturated loose sands as a result of the loss of effective stress as a consequence of increased pore water stress due to seismic force propagation [3][4]. Currently, the most common methods propose to improve the mitigation and remediation of liquefaction hazards are vibration, grouting and injection methods, chemical stabilization using lime, cement and fly ash, geosynthetic stabilization [5][6]. However, due to environmental considerations some of these methods are not recommended, therefore the need to find sustainable technology is becoming increasingly important and unavoidable. In this regards, several alternative environmentally friendly methods that have been researched, the use of biopolymers such as agarose seems quite promising and effective [7].

Recent previous studies related to the use of agarose as a polymer to improve sandy soil strength have done, include by [8] using the unconfined compression test, using 1%-4% agarose concentration, have certain the strength and deformation characteristics behavior in stiffness and ductility. Likewise other researcher [9]the results of their study as passive stabilization using colloidal silica, while [10][7] which specifically focused their research on the dynamic loading aspect using the triaxial test concluded that increasing the behavior of shear strength in agarose content 0.5%, 1% and 2%. However, from these research, the type and source of the test materials used were slightly limited, so...
to see its behavior, it still requires various sources of sand material and the type of study, includes material from the liquefaction site and using other types testing such as direct shear tests.

Therefore, in this study, experiment were conducted to explore the behavior of agarose using a different sand source from previous studies where in this case the sand was taken from a location that affected liquefaction. Sand were taken from Petobo, testing using a direct shear test with three levels of vertical stress, respectively are 10 kPa, 20 kPa and 30 kPa. Using agarose content of 1%, 3% and 5%, and untreated was 0% agarose content. The effectiveness of using agarose as a stabilizing agent through variations in the sand source being tested and certain types of conditions such as different loading and testing conditions, so that agarose could be used as option for liquefaction mitigation according to the conditions and properties of the material being tested.

2. Method experiment

2.1 Material Used

2.1.1 Sand

Sandy soil presented in this research were taken from Petobo, located in Palu city, Central Sulawesi at the depth of 1.5m-2.0m. The physical properties are presented in Table 1, with Cu 4.67 and Cc 0.87 was categorized as poorly graded sand soils. Minimum and maximum void ratio figures seem appropriate value that has a very large range of 0.58 to 0.98, so that the soil can be in a very loose and can be very dense conditions. The plot range of grain size materials in Figure 1 shows the compares of the susceptible curves according to Japanese liquefaction susceptibility criteria for port and harbour facilities [11]

| Property                        | Value |
|---------------------------------|-------|
| Effective size ($D_{10}$)       | 0.15  |
| Effective size ($D_{30}$)       | 0.30  |
| Effective size ($D_{60}$)       | 0.70  |
| Uniformity coefficient (Cu)    | 4.67  |
| Curvature coefficient (Cc)      | 0.87  |
| Initial void ratio ($e_i$)      | 0.78  |
| Minimum void ratio ($e_{min}$)  | 0.58  |
| Maximum void ratio ($e_{max}$)  | 0.98  |
| Specific Gravity (Gs)           | 2.66  |
| Plasticity index, PI (%)        | NP    |

![Figure 1](image_url) Over lay gradings boundaries of liquefaction susceptible soil according to according to Japanese liquefaction susceptibility criteria for port and harbour facilities[11], where 68% portion grain size distribution of soil was lay in most liquefiable soil range border and 32% portion was in potentially liquefiable border.
2.1.2 Agarose
The commercial agarose was used in this study in powder form produced by PT Agar Swallow, without preservatives and food hardener. Agarose powder products begin to dissolve at 85°C and solidify at 32°C - 40°C where the viscosity are constant at this temperature. A preliminary test was carried out to obtain the viscosity of agarose solution in a mixture of 1%, 3% and 5%.

2.2 Sample Preparation
A quantity of natural sandy soil was sieved to separately sand passed sieve number #8(2,36mm) and retained sieve number #100 (0,15mm) to obtain some clean sand samples with zero fines content. The clean sand soil specimens are prepared using the wet mixing method. The required dry weight of clean sand to meet of the specimens mixing weight then is recalculated as function of the relative density and saturated water content.

The content of agarose water mixture solution were carried out for all of the test specimens by weight which ranged at 1%, 3% and 5% portion. The mixture of agar and water which has previously heated at temperatures over 85°C, was poured into a cup that has been filled with a number of dry sand, then stirred softly until evenly mixed well.

The mixture was filled into specimen molds, 63 mm in diameter by 35 mm height, with the weight adjusted to produce wet densities of 15,0 kN/m³ to 15,5 kN/m³, relative densities of 36%–47%. The same initial wet densities were maintained during test preparation. Trial test was undertaken to meet a sample preparation method that was simultaneously easy and reproducible. All sample has been cured for one day before being tested.

\[ \text{Figure 2. The test specimen preparation process; (a). mixing agarose solution and dry sand; (b). pouring the mixture into a direct shear test mold; (c). specimens that have been left for one day and prepared are put in a direct shear test box} \]

2.3 Test procedure
The testing apparatus used in the current study is direct shear test of soils. All tests were conducted with the ASTM D-3080 procedures. The shear loading is controlled using automated system at rate of 1.0 mm/minute. The specimen were tested under three different vertical normal stress values of 15 kPa, 20 kPa and 30 kPa.

3. Results and discussions
3.1 Effect of agar content on shear strength parameter
The direct test results at three levels vertical stress for all specimen with specified agar concentration is tabulated in Table 2. The calculation of shear strength parameters, cohesion (c) and angle of internal friction (\(\phi\)) refers to the Mohr Coulomb formula. Meanwhile, peak shear strength is obtained from the shear stress vs shear displacement relationship curve in the direct shear test. It was found that 1% agar content increased soil cohesion by 11.84% from 8.86 kPa to 9.91 kPa and for 3% agar content the increase was 9.81% from 8.86 kPa to 9.67 kPa while 5% agar content decreased the cohesion value by 8.24% from 8.86 kPa to 8.13 kPa. These results as shown in Table 2, indicate that the volume of
agarose mixed in the soil grains that fill the pores forms a proportional condition that changes the cohesion and friction values between soil particles, high concentrations cause weak bonds and friction between grains.

**Table 2.** Strength parameter of soil sample tested by direct shear test

| Agar Concentration (%) | Strength Parameter | Peak Shear Strength at Vertical Stress |
|------------------------|--------------------|---------------------------------------|
|                        | c (kPa)            | 10 kPa | 20 kPa | 30 kPa |
| 0                      | 8.86               | 16.33  | 22.19  | 29.99  |
| 1                      | 9.91               | 17.80  | 23.89  | 32.67  |
| 3                      | 9.67               | 17.31  | 21.21  | 30.72  |
| 5                      | 8.13               | 14.63  | 19.50  | 26.82  |

**3.2 Effect of agar content on Peak Shear Strength behaviour**

The mixtures of specimen samples were tested under three different normal vertical stress values of 10 kPa, 20 kPa and 30 kPa in the direct shear test as shown in Table 2. The maximum shear strength was 32.67 kPa and the minimum value was 14.63 kPa which is lower than minimum value of untreated sample. The peak of shear strength on the different level of vertical stress values and variation of agarose content are plotted Figure 2. The shear test result found that the optimum value of shear strength was reached at 1% for all concentration of agarose. The curves at 10 kPa and 20 kPa vertical stresses change slightly at each given agar content, which differs to the 30 kPa vertical stresses. For 5% agarose content, the shear strength fell below the untreated soil at all levels of applied vertical stress. At 5% level of agarose content, the achieved shear stress was lower than untreated soil at all vertical stress levels, this is due to the volume of agarose is no longer effective in forming cohesion and friction bonds between grains, from this result the optimum content of agarose between 1% to 5%.

![Figure 3](image-url)  

**Figure 3.** Peak shear strength of specimen mixed agar content at three levels vertical stress respectively are 10 kPa (■), 20 kPa (●) and 30 kPa (▲); for untreated sample 0%, agar content 1%; 3%, 5%.
3.3 Effect of agar content on vertical normal stress

According to the Coulomb formula, the shear strength of the soil is a combination of the cohesion value, the shear angle and the vertical stress given. As a result of changing the value of the shear angle and soil cohesion, it gives a different value of shear strength. The analysis was carried out using stress ratio ($\tau/\sigma_v$) in term normalized shear stress to each vertical stress level applied for each specimens test. It was found that peak shear stress depends on the level of vertical stress applied, where the value of shear stress ratio decreases with increasing the vertical stress, as can be seen from Figure 4-6. These results show that the increase in vertical stress increases the shear strength due to the confining stress of the shear ring, and the greatest is at 1% level, and decreases drastically at 5% level which is lower than the shear stress of untreated soil. This indicates that the high vertical stress causes the adhesions and bonds formed between the grains and the agarose gel to break. The implication is that the application of this method must consider vertical stresses, or in other words its application is more suitable in conditions of low vertical stress, this result relevant to previous research by [10].

![Figure 4. Stress ratio ($\tau/\sigma_v$) versus shear displacement at vertical stress $\sigma_v$ 10 kPa](image1)

![Figure 5. Stress ratio ($\tau/\sigma_v$) versus shear displacement at vertical stress $\sigma_v$ 20 kPa](image2)
4 Summary and Conclusions

This study investigated the shear stress behavior of a mixture of sand and agarose using a direct shear test under 10 kPa, 20 kPa and 30 kPa vertical stress. Mixing solution of agarose content tested at 1%, 3% and 5% for 24 hours curing using sand which has previously been examined for criteria of most liquefiable soil, taken from the Petobo village, previously exposed to liquefaction due to the 7.5Mw earthquake in 2018 so that it represents a liquefiable soil. The effectiveness so far has been observed using the ratio of normal stress to shear stress according to the agarose content. The significant conclusions drawn from this study include the following. The optimum content of agarose which can be considered is at 1%-3%. Whereas at 1% agarosa content, the cohesion value decreases but the shear angle does not change significantly, but for 3% the cohesion and sediment of soil shear changes significantly. So that the choice of 1% level can be selected if the target of modification is to change the cohesion value without changing the friction angle, while 3% changes both the cohesion value and the friction angle. Peak shear strength shows the highest value at 1% content of agarose, for all vertical stress levels, while for 5% peak shear strength is lower than untreated soil at all levels of vertical stress, this is due to the high volume of agarose is no longer effective in forming cohesion and friction bonds between grains. The high vertical stress causes the adhesions and bonds formed between the grains and the agarose gel to break. The implication is that the application of this method must consider vertical stresses, or in other words its application is more suitable in conditions of low vertical stress. This conclusion is drawn based on a limited number of tests and methods, therefore it can be developed using more test samples, with variations in moisture content and mixed viscosity and saturation, the test method on dynamic loading with the measurement of pore water pressure and long term of treatment must be considered in the next develop research. The results of this study may be different or same as previous research, therefore it is important to conduct more research using different sand sources to assess the significance of agarose as a stabilization material for mitigating of liquefaction hazard.
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