Proceedings of the 20th International Conference on Soil Mechanics and Geotechnical Engineering– Rahman and Jaksa (Eds)
© 2022 Australian Geomechanics Society, Sydney, Australia, ISBN 978-0-9946261-4-1

Simplified method for determining the design failure curve of marine silty sand under dynamic loading

Méthode simplifiée pour déterminer la courbe de défaillance de la conception du sable limoneux marin sous chargement dynamique

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ABSTRACT: Wind power plants are the most representative of the environmentally friendly energy power plants built in the ocean. Structures constructed at sea are fixed to the ocean ground, which is continuously subjected to cyclic loads such as wave load, wind load, and tidal load. Therefore, it is very important to evaluate the marine ground behavior under cyclic loading. A design graph indicates the short- and long-term behaviors of soil. Several laboratory tests are typically conducted to create design graphs. In this paper, a simplified method for determining a design failure curve without performing many tests was proposed.

KEYWORDS: Design failure curve; simplified method; dynamic loading; marine silty sand; offshore foundation

1 INTRODUCTION.

Wind farm construction is gradually changing from land to sea due to noise, geography, and various complex problems. Since the marine ground is constantly subjected to cyclic loads such as wave loads, wind loads, and tidal loads, it is very important to understand the ground behavior under cyclic loads. Many researchers conducted an indoor test to create a two-dimensional design graph and analyzed the effect of drainage, relative density, and cyclic loading (Andersen, 2009; Ryu and Kim, 2015; Ko et al., 2017). Son et al. (2017) proposed a three-dimensional design graph using the relationship between cyclic stress ratio (CSR), average stress ratio (ASR), and relative density (Dr). As shown in Figure 1, the design graph shows the number of fractures and the shear strain rate to be fractured with respect to the cyclic stress ratio and the average stress ratio. Using this graph, it is possible to consider the conditions for the number of failures under the superstructure and the dynamic load when designing the foundation ground. In this study, a simple method was proposed by organizing the design failure curve into four steps so that only a minimum number of tests could be performed. Cyclic simple shear test was performed according to ASTM Code(ASTM, 2017).

2 DESIGN FAILURE CURVE

2.1 *Design Graph*

A design graph is the failure diagram according to the stress condition using the number of cycles (Nf), the permanent shear strain (γp), and the cyclic shear strain (γcy) at failure. To create a design graph, a combination of the average and the cyclic shear stress ratios, and number of cycles at failure is required. Figure 2 shows the criterion lines created in three dimensions. When the design graph is drawn, it is possible to identify the failure line corresponding to the static and dynamic load applied to the structure when designing the ground.

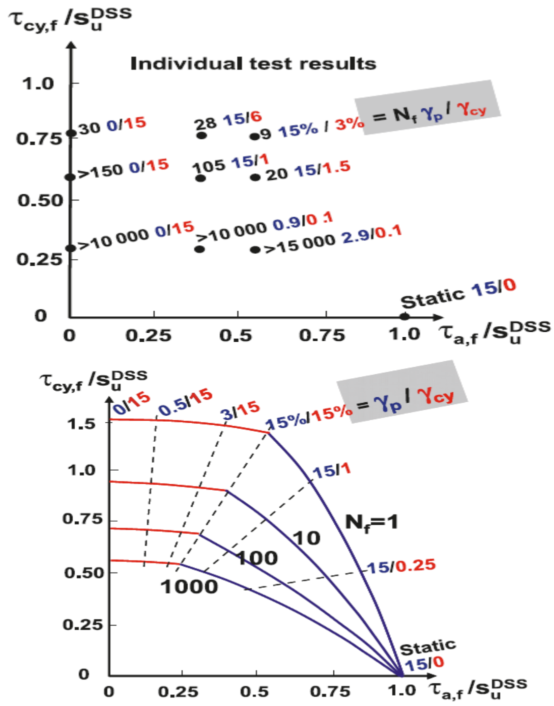

Figure 1. Design graph example by average and cyclic shear stresses. (a) Numerical expression using values at the time of destruction; (b) Graphical expression using design failure curve (Andersen, 2009)

3 PROPOSED DRAWING TECHNIQUE OF DESIGN FAILURE CURVE MODEL

Various shapes such as circles, ellipses, and hyperbolas were considered for the simple model of the design failure curve. The circle shape had a different failure line shape, and the hyperbolas shape had the disadvantage that the x-intercept could not be fixed. Finally, an ellipse was selected and matched with the design graph as shown in Figure 3. As a result of the matching, the design curve is similar to an ellipse and hence can be expressed using an elliptic equation. The elliptic equation was converted to a relation between CSR and ASR. The elliptic equation is as Equation (1). Converting Equation 1 with Equation for y gives Equation (2). Here, if x and y are replaced with the expressions for CSR and ASR, Equation (2) becomes Equation (3).

$$\frac{x^2}{a^2} + \frac{y^2}{b^2} = 1 \quad (1)$$

$$y = b\sqrt{1 - \left(\frac{x}{a}\right)^2} \quad (2)$$

$$CSR = b\sqrt{1 - \left(\frac{ASR}{a}\right)^2} \quad (3)$$

To create a design curve needed the two important parameters.

1) the ASR value when CSR = 0, which is obtained from the static test.

2) the trend line of CSR and Nf when ASR = 0 or 0.1.

The simplified method for determining design failure curve can be summarized in four stages as follows based on the matching results.

1) Perform the static test. Obtain the ASR value when CSR = 0.

2) Perform the cyclic test to obtain the CSR value when ASR = 0 or 0.1, plot the trend line between CSR and N_f when ASR = 0 or 0.1.

3) Using the trend line in step 3, calculate the CSR value for each N_f value when ASR = 0 (N_f = 1, 10, 100, 1000, 10000).

4) Create the graph by applying the elliptic equation parameters 'a' (ASR value when CSR = 0) and 'b' (CSR value for each Nf value when ASR = 0).

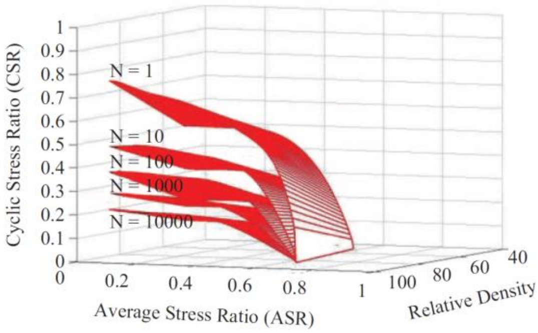

Figure 2. Three-dimensional criterion lines for marine silty sand showing CSR, ASR, and Dr, and the corresponding cyclic and permanent shear strains at failure (Son et al, 2017).

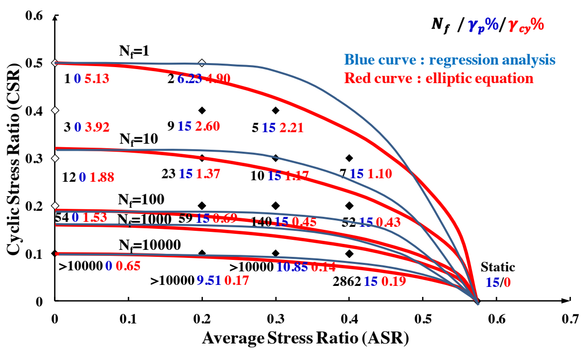

Figure 3. Graph matching of the design curve and elliptic graph (Son et al. 2020).

Figure 4 shows a graph based on the proposed technique. The proposed model curve with similar ASR values shows a lower CSR than the regression analysis curve, indicating a conservative design method. If a conservative design approach is not needed, a graph of 'b' can be created directly without obtaining the trend line in step 3. However, as the number of cycles increases, the design failure curve follows the trend of the trend line, and the behavior of the ground around offshore structures is more important in the long-term than in the short-term. Therefore, the proposed design failure curve drawing technique using a conservative design approach is more appropriate.

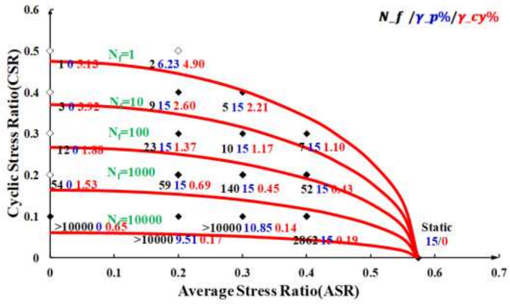

Figure 4. Proposed design curve procedure (200 kPa, Dr = 50%) (Son et al. 2020)

4 CONCLUSIONS

This study proposed a two-dimensional simplified method for determining design failure curve. The main conclusions of the study are as follows. The shape of the design failure curve was compared with various shapes, and it was very similar to the ellipses shape. Therefore, the equations of design failure curves for CSR and ASR were proposed using the elliptic equation. In addition, a four-step simple method was proposed so that the design diagram could be easily drawn. In the future, we will propose a simplified method for creating a 3D-design graph considering the relative density.

5 ACKNOWLEDGEMENTS

This paper was financially supported by the National Research Foundation of Korea (NRF-2019R1I1A1A01060584)

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