Discussion of Proper Ribs in Hollow Torsion Test using Numerical Method

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Abstract. In the numerical simulation hollow torsion test, the number of rigid ribs applied on the top surface of the specimen is the key to guarantee the success of the calculation. If the number of rigid ribs is too large, the stiffness difference between the pedestal and the specimen would be too big to get a reliable result. While if the number of ribs is too little, the torque cannot be transferred to the specimen faithfully. A numerical calculation is carried out to determine the suitable number of rigid ribs from the aspects of shear strain, apparent mechanical behavior and torque rate and the results show that 6 ribs are suitable for the numerical hollow torsion test.

1. Background

For the geotechnical engineering it is very difficult to capture the mechanical response of soil considering its complex stress state and loading condition. The laboratory tests are developed and conducted to grasp the characteristics of the deformation and strength and the hollow cylinder torsional shear test is regarded to be the most useful method because there are four individual external forces to reproduce the complex stress path during the in-situ constructions. The mechanical response of soil specimen can be simulated through the stress path by different loading condition (Lade 1981, Hight et al. 1983, Nataka et al. 1998, Frost & Drnevich 1994).

For the torsional test, the torque is usually applied on the top surface by several ribs installed at the pedestal, as shown in Fig. 1. The torque control methods can be divided into strain control and stress control. In the numerical simulation, when the specimen is controlled by strain, a group of constant angular velocity is applied at the top surface initially.

The relative slippage, namely the different pace, exists in the practical experiments even though the frictional stone is installed. The torque is transferred from the pedestal to the top of the specimen. To enhance the connection between the pedestal and the specimen the rigid rib is increasing as shown in Figure 1. However, the number of the ribs is always uncertain. If the rib is too many, the uniformity of the specimen is destroyed. If the rib is few, the torque cannot be transferred. In this paper, a numerical method is used to discuss the suitable number of ribs.
For the torque control, a method employing Lagrange constraint conditions is applied to the nodes on the top surface, and the optimum number of rigid ribs is discussed.

2. Lagrange constraint conditions
When simulating the loading condition of torque control, it is impossible to designate constant stress rate to each node on the top surface considering the unknown distribution of stress rate under the loading pedestal. The constraint conditions including “no-length change”, “no-angle change” and “no-direction change” are used to make the movement of the node simultaneously.

Along the radius direction the no-angle change condition is used to several nodes on the top surface with certain interval angle. The interval angle is taken as 90, 60 and 45 degree which corresponds to 4, 6 or 8 “no-angle change” conditions, as shown in Figure 2, which represents the rigid ribs on the pedestal. As for the no-length change constraint, it is assigned to the nodes along the circumferential direction from the inside to the outside. The friction of porous stone that can transfer the torque from the rigid ribs to the specimen is indicated by the “no-length change” condition. The stress rates are 1.0 kPa/s for 4 ribs, 0.67 kPa/s for 6 ribs and 0.5 kPa/s for 8 ribs respectively. The other boundary conditions are same with the actual experimental conditions. The following calculation will compare three kinds of conditions with different ribs to determine the proper number in the hollow torsion test.

3. Calculation results
3.1. Distribution of shear strain
As the function of the rib in the porous stone is transferring the torque to the top surface of the specimen, one way to check whether the number of ribs is enough or not is to see the distribution of shear strain at the top surface. Fig. 3 shows the shear strain distribution on the top surface at \( \gamma_s = 12\% \).
with 4, 6 and 8 ribs respectively. As can be seen, when there are only four ribs there is significant shear strain at the location of ribs compared with other two cases and the shape of circle cannot be maintained when the apparent shear strain is large. While for the cases with 6 and 8 ribs, the circle shape can be kept on the top surface even though the apparent shear strain is 12%. But the circumferential distribution of shear strain is more uniform for the case with 8 ribs compared with case with 6 ribs. Therefore, in the view of uniform shear strain in the circumferential direction, 8 ribs are preferred.

![Figure 3. Distribution of shear strain at the top with n ribs at $\gamma_s=12\%$ (n=4, 6, 8).](image)

3.2. Apparent mechanical behavior

The apparent mechanical behavior behaviours are shown in Figs. 4-6, where “Bottom” and “Top” indicate the excess pore water pressure calculated at the bottom and at the top respectively. The apparent mechanical behavior including the deviator stress-axial strain ($q - \varepsilon_a$) relationship, the deviator stress-mean effective stress ($q - p'$) relationship (in other words, the effective stress path), the pore water pressure-axial strain ($u - \varepsilon_a$) relationship, and the specific volume-mean effective stress ($v - p'$) relationship is obtained when the whole specimen is regarded as one mass.

![Figure 4. Apparent mechanic behavior of specimen with 4 ribs.](image)

![Figure 5. Apparent mechanic behavior of specimen with 6 ribs.](image)

For the case when 4 ribs are used, the apparent deviator stress is smaller than that in the perfect response. It can be concluded that when the number of the ribs is few the friction between the soil specimen and the pedestal is not enough and there is relative slippage between the soil specimen and the pedestal. It can also be seen that the excess pore pressure calculated at the top surface and the bottom surface are slightly different, which can be ascribed to the non-uniformity in the deformation along the circumferential direction. When the number of the rigid rib increases to 6 or 8 ribs the
apparent behavior of the soil specimen is quite similar to the perfect path. In the view of apparent mechanical behavior, 6 ribs are enough and 8 ribs are better.

![Figure 6. Apparent mechanic behavior of specimen with 8 ribs.](image)

In addition, the relation between the total torque and the time is shown in Fig. 7 for three cases. The torque rates are constant and almost equal due to the different stress rates applied on the loading nodes. There is only slight deviation of the case with 4 ribs from the other two cases. And in view of the torque rate 6 ribs are suitable. Therefore, according to Figs. 3 (b), 5 and 7 it can be reasonable to conclude that six ribs are enough to transfer the torque from the pedestal to the soil specimen reliably for the torque control under this analysis conditions.

![Figure 7. Relation between the torque and the time for three cases.](image)
Figure 8. Distribution of magnitude and direction of reaction forces at $\psi = 0^\circ$.

4. Conclusions

In the hollow torsion experiments, the torque action is usually applied to the soil specimen at the top surface by rigid ribs installed at the porous stone. In the numerical simulation, the number of ribs is doubtful. In the paper, the suitable number of rigid ribs required to transfer the torque faithfully is discussed numerically from the aspects of shear strain, apparent mechanical behavior and torque rate and the conclusions are as follows:

1) If the number of ribs is 4, the circle shape of the top surface cannot be kept and there would be great shear strain at the location of ribs.

2) For the apparent mechanical behavior, there is only slight deviation between the case with 6 ribs and 8 ribs, while the error of case with 4 ribs is greater.

3) The suitable number of rigid ribs is 6 which can satisfy both the mechanical response and deformation requirement.

References

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