# Experimental study of the pullout resistance of ribbed anchors in sands

M. Irsyam
*Bandung Institute of Technology, Indonesia*

L. Hasan
*Islamic University of Indonesia, Indonesia*

R. D. Hryciw
*University of Michigan, USA*

ABSTRACT

An experimental study into the pullout resistance of cylindrical anchor in sands was carried out in a triaxial testing tank that applied horizontal and vertical confining pressures. The experiment was carried out on both dense and loose sand conditions at various confining pressures. Several types of anchors were investigated, they included smooth, rough, and ribbed anchors with different rib spacings. In dense sand, degradation that results in increasing void ratio occurs at the interface, therefore anchor resistance decreases in subsequent cycles. In loose sand, the degradation tends to decrease the void ratio at the interface. As a result, anchor resistance in subsequent cycles is either relatively constant or increases. The contribution of passive resistance on the ribs and friction at the interface results in a coefficient of apparent friction (μ*) for both the peak and the residual conditions. The value of μ* is influenced by compressive normal stress, soil density and rib spacing, whereas the coefficient of lateral earth pressure at rest (Ko) has little influence on the anchor resistance.

RESUME

Etude expérimentale de résistante tendu de l'ancre cylindrique dans un sable est conduite au basin d'un essai triaxial qui a été supplie par une pression horizontale et verticale. L'expérimentale a été conduite dans un sable dense et lège pour plusieurs pression confine. Quelques type d'ancre ont été utilise, Ils incluent les ancre lisse, rugueux et strie avec un écartement de cote différentes. Pour sable dense, la dégradation qui aboutit l'augmentation du rapport de vide se produit à l'interface. Il en résulte, la résistance d'ancre au cycle suivant soit constante ou augmente. La contribution de la résistance passive au cote et la friction a l'interface aboutit d'un coefficient de la friction apparent (μ*) a la condition du somme et du résidu. Le valoir de la friction (μ*) est influence par la tension normale, la densité du sol et l'écartement du cote, tandis que le coefficient de pression latéral du sol au repos a peu l'influence a la résistance de l'ancre.

Keywords : anchors, triaxial testing tank, rib spacing, cyclic loading.

## 1 INTRODUCTION

Ribbed inclusions are widely used in geotechnical engineering applications. They can be found in the form of ribbed strips in Reinforced Earth walls, deformed rods in Anchored Earth walls, rebar anchors in anchored geosynthetics systems and as nails in soil-nailing applications. Evidence shows that the ribs can significantly increase the pullout resistance and enhance the transfer of stress between soil and the inclusions. The transfer of stress occurs by two basic mechanisms; friction and passive soil resistance with both mechanisms acting simultaneously. The mechanical interaction between sand and plane ribbed inclusions was reported by Irsyam and Hryciw (1991), Hryciw and Irsyam (1992), and Irsyam and Hryciw (1993). Following the work, an experimental study for cylindrical ribbed anchors in sand was conducted at the Civil Engineering Department of Bandung Institute of Technology. The interactions between sand and ribbed anchors were observed at the micro mechanistic level through optical observation of the movement of sand particles around the anchors and at the macro mechanistic level by measuring pullout resistance in a triaxial testing tank. This paper presents the results of pullout tests in the tank.

The pullout resistance of ribbed anchors may be affected by several factors such as: sand density, rib geometry, rib spacing, surface roughness, number of loading cycles, normal stress, Ko condition, grain shape, grain size, and anchor stiffness. Several factors that may be considered influential were investigated. To account for the effect of surface geometry, several types of cylindrical anchors were selected; smooth, rough, and ribbed anchors. To study the effects of density and confining pressure, the experimental study was carried out on both dense and loose sand conditions at various confining pressures and at different Ko conditions.

## 2 EXPERIMENTAL SETUP

The experimental set up for the anchor pullout test consisted of four basic components: (1) a triaxial testing tank, (2) a loading system, (3) a data acquisition system, (4) and a testing platform as shown Figure 1. The testing tank is comprised of a stack of three steel tubes with an inside diameter of 40 cm and a height of 26.7 cm. To provide horizontal pressure to the sand, the inside walls of the tubes were lined with a rubber membrane (Figure 2). To account for different soil stress conditions within the triaxial test tank, the tank was constructed with pressurized membranes at the top side of the tank. Vertical stress was applied through an independent air pressure pillow constructed out of a steel plate, steel pipe, and rubber membrane.

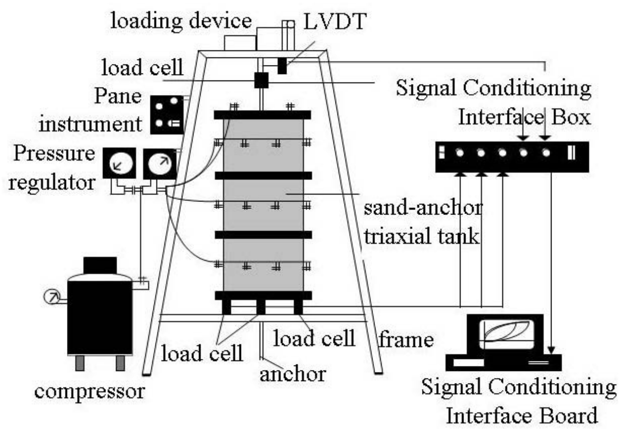


Figure 1. Configuration of the anchor test.

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Three types of anchors were used in this work; smooth, rough, and ribbed anchors with an outside diameter of 10 mm. In order to represent a simple generic form of rib, a square rib geometry was used. The rib size was maintained at 1 mm, however, rib spacings of 0, 6, 12, 20 mm were used (Figure 3).

Testing was performed at loose and dense soil conditions using Ottawa 20-30 sand. To obtain loose sand conditions, sand was allowed to slowly flow out of the bottom of a PVC pipe. Relative densities were found to be 35%. To get dense soil conditions, an air pluviating system was used. Sand was pluviated into the test tank from a position above the anchor with a constant height of drop. Relative densities for dense sand conditions were about 85%.

After the completion of soil placement and the assembly of the testing tank, an effective confining pressure $\sigma_n$ of 0.5, 1.0, and 1.5 kg/cm$^2$ was applied to the sand. For most tests, the initial loading cycle was conducted in the downward direction or compressive loading of the anchor. The anchor was allowed to displace downward 53 mm and then 53 mm back to its starting position. The test was continued by cycling the anchor between compression and tension.

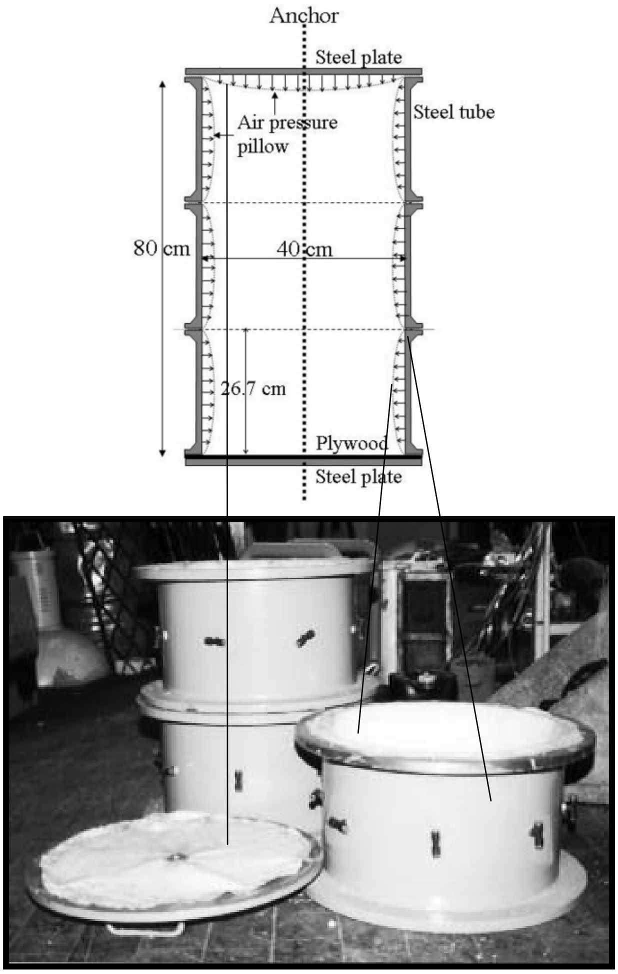



Figure 1. Triaxial test tank.

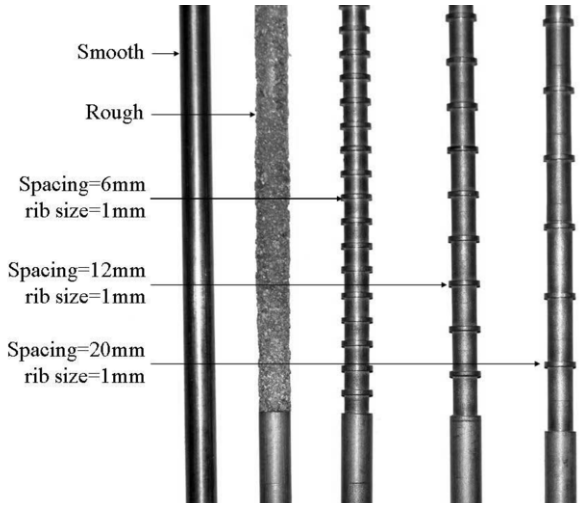
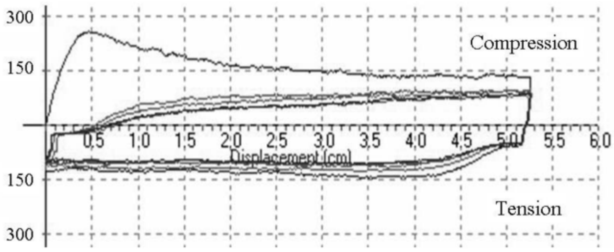



Figure 3. Types of anchors for the experimental study.

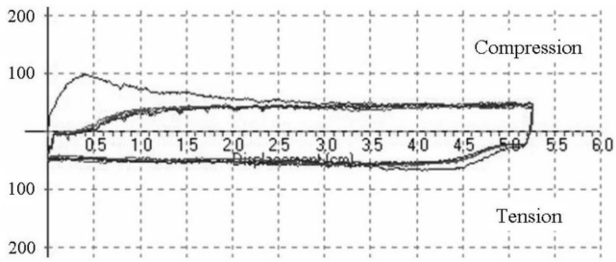
A total of forty anchor pullout tests were conducted. They were performed in order to study the effects of soil density, number of cycles, confining pressure, anchor roughness, Ko condition, and rib spacing.

## 3. EXPERIMENTAL RESULTS AND ANALYSIS

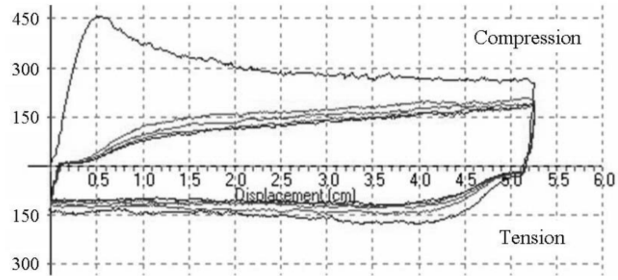
The experiment was carried out on both dense and loose sand conditions at various confining pressures. Loading of ribbed anchor in dense sand resulted in a load-displacement pattern that was similar to loading in a triaxial shear strength test. However, in the loose sand condition, loading of the ribbed anchor indicated the presence of a peak load as a result of the mobilization of passive resistance against the ribs (Irsyam and Hryciw, 1991), whereas in the triaxial shear strength test the peak load does not occur. Typical examples of cyclic load-displacement tests for a ribbed anchor are presented in Figure 4.



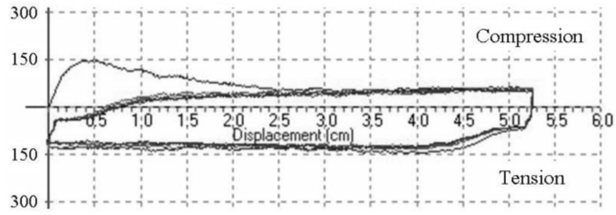

(a) Dense, $\sigma_n$=0.5 kg/cm$^2$




(b) Loose, $\sigma_n$=0.5 kg/cm$^2$




(c) Dense, $\sigma_n$=1.0 kg/cm$^2$



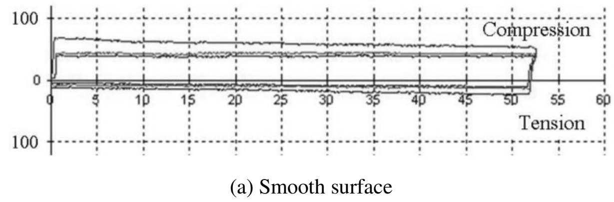

(d) Loose, $\sigma_n$=1.0 kg/cm$^2$

Figure 4. Two-way cyclic load-displacement tests for a ribbed anchor with rib spacing of 12mm.

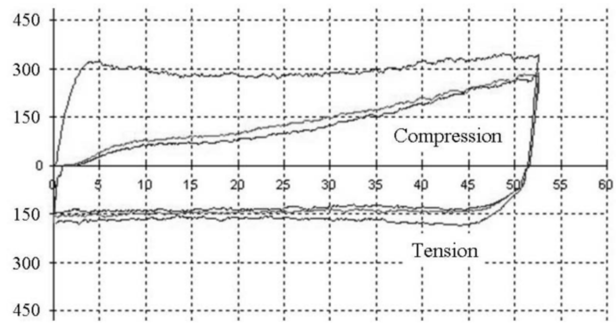
The experimental results indicated that there were significant differences between tests in dense and loose sand. For all tests, the initial loading resulted in a high peak load, $P_{peak}$. After achieving $P_{peak}$, continued displacement resulted in the establishment of a residual load, $P_{res}$. In dense sand, the peak load was followed by higher residual load compared to that of loose sand. Upon load reversals for both loose and dense sand, a zone of negligible resistance was observed. After continued displacement, a relatively constant pullout resistance was obtained in both dense and loose conditions. Similar observation was also reported by Vitton (1991).

Ribbed anchor resistance in cyclic loading exhibits different mechanisms depending on the density of soil. In dense sand, degradation that results in increasing void ratio occurs at the interface. Therefore, anchor resistance decreases in the following cycles. In loose sand, the degradation that occurs tends to decrease the void ratio at the interface, as a result, anchor resistance in the following cycles is either relatively constant or increases.

The load-displacement for smooth and rough anchors are presented in Figure 5. For smooth anchors, the initial load-displacement is very straight with only small displacement required to reach a constant anchor resistance. For smooth anchor, sand is sheared uniformly without developing a shear zone and displacement of the interface consists mostly of particles slipping on the metal surface. Upon reversal there appears to be only limited displacement used to mobilize full pullout resistance. For rough anchors, instead of sliding along the contact surface, the shear resistance may be related to the shear strength of soil (Irsyam and Hryciw, 1993). The resulting load-displacement for rough anchor is also similar to that of ribbed anchors having small rib spacing where part of the grains between adjacent ribs are trapped and move as a unit with the anchor.




(a) Smooth surface




(b) Rough surface

Figure 5. Two-way cyclic load-displacement tests for rough and smooth anchors for dense condition with $\sigma_n$=1.5 kg/cm$^2$.

Anchor resistance depends on the development of interface friction that occurs between sand and the anchor. The interface friction is commonly expressed in term of a coefficient of apparent friction, $\mu*$, where $\mu*=\tau_n/\sigma_n$ and $\tau_n$ and $\sigma_n$ are the shear stress (including passive resistance from rib) and normal stress acting at the interface. The values of coefficient of apparent friction at peak, $\mu*_{peak}$ and residual, $\mu*_{res}$ for smooth, rough, and ribbed anchors and for dense condition are shown in Figure 6. For ribbed anchors, the contribution of passive resistance against the ribs results in a higher coefficient of apparent friction ($\mu*$) for both the peak ($\mu*_{peak}$) and residual loading conditions ($\mu*_{res}$) compared to that of smooth anchors. Similar results were also reported by Hryciw and Irsyam (1991) and for plane ribbed inclusions by Hasan et. al. (1997).

The effect of confining pressure ($\sigma_n$) on the coefficient of apparent friction ($\mu*$) is also shown in Figure 6, higher compressive normal stress acting on the anchor surface results in a smaller $\mu*$ value, which is in accordance with the results of previous research on ribbed strips (Schlosser, 1978 and Irsyam, 1991). Besides being influenced by compressive normal stress at the anchor surface, the $\mu*$ value is also influenced by the coefficient of lateral earth pressure at rest (Ko) as shown in Figure 7. However, the effect of Ko on the anchor resistance is insignificant.

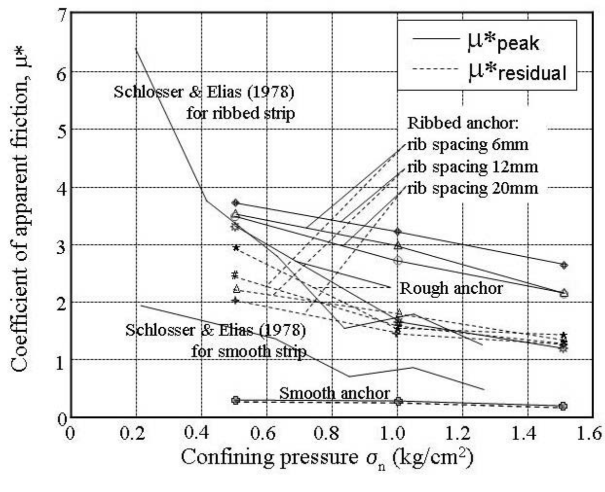



Figure 6. Apparent coefficient of friction versus confining pressure for dense condition.

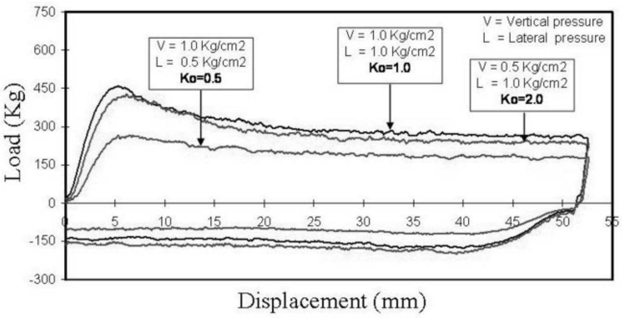



Figure 7. The effect of Ko on the pullout resistance.

The effect of rib spacing on the anchor resistance is shown in Figure 8. The rib spacing was an important factor controlling peak and residual anchor resistance and the coefficient of apparent friction for both dense and loose sand. An increase in rib spacing results in an increase in peak strength and the coefficient of apparent friction, up to an optimum rib spacing of 12 mm. Beyond the optimum spacing, however, an increase in rib spacing will decrease the shear resistance.

For rib spacing smaller than optimum, the rib spacing has an important role in controlling a zone of dilation for dense sand and a zone of contraction for loose sand. Optical observation conducted by Irsyam and Hryciw (1993) and by Hasan et. al. (1997) indicated that part of the grains between adjacent ribs are trapped and move as a unit with the anchor and results in smaller anchor resistance. Conversely, if the rib spacing in increased beyond optimum, part of the anchor surface between adjacent ribs will act as a smooth anchor where grain displacement around the interface consists mostly of particle slipping on the metal surface.

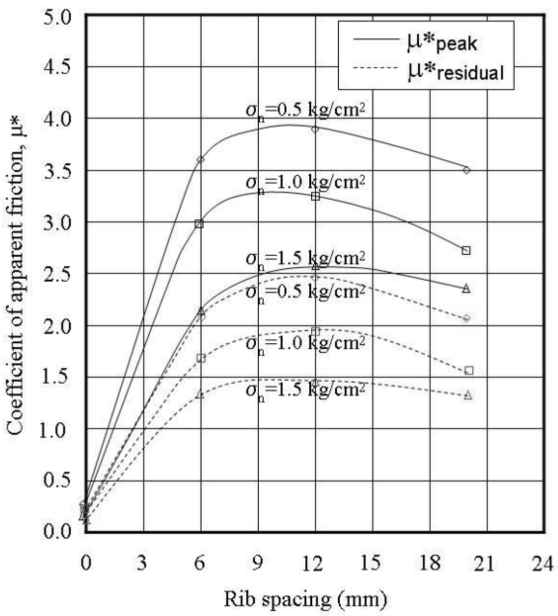



Figure 8. Effect of rib spacing on the coefficient of apparent friction.1

## 4. CONCLUSIONS

An experimental study into the pullout resistance of cylindrical anchors in sands was carried out in a triaxial testing tank. The experiments were carried out on both dense and loose sands at various confining pressures. For ribbed and rough anchors, the initial loading resulted in a high peak load. After achieving the peak load, continued displacement resulted in the establishment of a residual anchor resistance. In the following cycles, anchor resistance decreased for dense sand and was either relatively constant or increased for loose sand. For smooth anchors, the initial load-displacement is very straight with only small displacement required to reach a constant anchor resistance. Displacement of the interface consists mostly of particles slipping on the metal surface. For rough anchors, instead of sliding along the contact surface, the shear resistance may be related to the shear strength of the soil.

For ribbed anchors, the contribution of passive resistance at the rib results in a higher coefficient of apparent friction ($\mu^*$) at both the peak ($\mu^*_{peak}$) and residual ($\mu^*_{res}$) loading conditions compared to that of smooth anchors.

The anchor resistance is also influenced by compressive normal stress; higher compressive normal stress acting on the anchor surface results in a smaller $\mu^*$ value. Besides being influenced by compressive normal stress at the anchor surface, the pullout resistance is also influenced by the coefficient of lateral earth pressure at rest (Ko), however, the effect of Ko is not significant.

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