Residual Strength of Colluvium and Stability Analysis of Farmland Slope

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ABSTRACT

Since 1960, optimum land utilization has become part of the national policy in Japan. In particular, residential development near and around large cities, reclamation of coastal regions, and construction of dams and highways are growing to respond to the improvement of local living conditions. On the other hand, these developments have severely altered the existing topography. As a consequence, landslides are occurring at an alarming rate and vigorous countermeasures have to be taken urgently to prevent these disasters. In view of this fact, land consolidation works were undertaken in the Hyogo Prefecture to permit the setting up of new rice fields. The ongoing stabilization works were started during the fiscal year 1993 and covers about 1700 hectares. These installations after completion will contribute not only to the stabilization of slopes for safety life, but also to the stabilization of agricultural management in the region. In this paper, the risks of landslide occurrence after completion of the project are pointed out by the use of the Bromhead Ring Shear Apparatus for testing samples of soils from the project site. Residual strength parameters (cohesion and friction angle) obtained by these tests were then used, in the limit equilibrium stability analysis through three different methods (the standard slice method, the simplified Bishop method and the simplified Janbu method) for the calculation of the factor of safety under different ground water level conditions, and the results were compared.

[Keywords] Ring shear test, Slope stability, Landslide, Rice field, Irrigation

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INTRODUCTION

Researchers in the field of geotechnical engineering have concluded that slope failure is essentially due to changes in the geometry and external loading, changes in the internal state of total stress and changes in the pore pressure and seepage. Therefore any human activity that tends to modify the topography or the ground water condition must be investigated closely. In this paper, the Kita Kobe Landslide Project, located in the Hyogo Prefecture (Figure 1), is investigated. The paper explains particularly the stability condition of slopes located in the Ichihara District after the completion of the works. Samples were taken and tested for strength characteristics. Since soil along sliding surface of a landslide plays an important role in the instability behavior, if the strength is known, the soil mass susceptible to sliding can be analyzed and its stability condition can be pointed out and if necessary suitable mitigation works can be proposed.

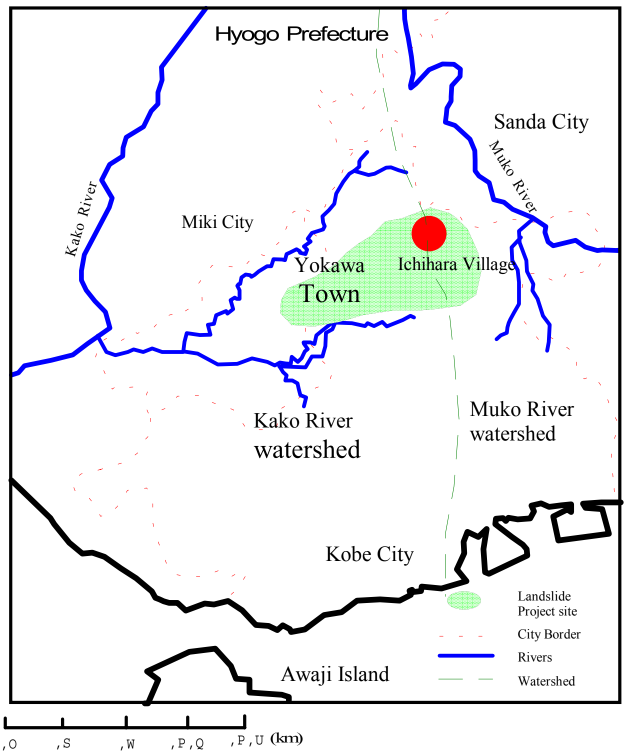


Figure 1: Location of the project

Ecological features of the region

The site is located along the north side of Rokko-san at an elevation of 100 to 250 meters and underlain by the upper tertiary Kobe Group. Active tectonic movement in the region raised Rokko-san (called the Rokko-san Uplift), resulting in the majority of the beds to dip towards the west. The geology of the area consists of highly weathered mudstone, and fine-grained tuff that shows a high level of argilization (to montmorillonite). This mudstone lies below colluviums representing the superficial layer in which the slide planes developed due to the combined actions of ground water and human activities

History of landslide in the region

The history of landslide in this region dates from the Edo Period. At that time the only mitigation works were pine trees planted by rural communities for landslide prevention. Since 1897, a considerable and cyclic number of landslide phenomena have occurred year after year. The largest to be recorded occurred in April 1986 and resulted in large-scale damage to farmers. Based on this background of cyclic reactivated landslide, the residual strength parameters were investigated in this paper as opposed to primary sliding where peak strength is of concern (Figure 2 shows the strength characteristics used as design parameters).

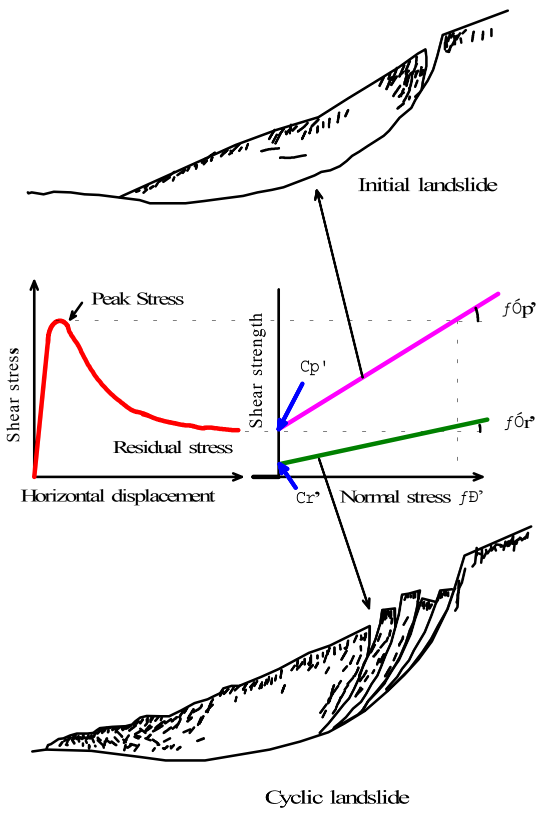


Figure 2: Strength parameters and their utilization in stability analysis

APPROACH

Torsion shear tests were conducted for the measurement of the residual strength of samples at different consolidation pressures. This leads to the residual internal friction angle and the residual cohesion, which are the main factors of resistance against failure. These parameters obtained were then used for stability analysis to point out the factor of safety of three slopes in the project area.

LABORATORY TEST

Laboratory tests were carried out by means of the Bromhead ring shear apparatus (Appendix), fully described in its design and principles by Bishop (1971) and Bromhead (1979). This apparatus, developed by Bromhead and manufactured by Wykeham Farrance Engineering Limited, is becoming widely used because of its low cost and ease of operation. Bishop et al. (1971) have shown that this apparatus yields results that are in good agreement with those obtained using the more sophisticated ring shear apparatus developed by the Norwegian Geotechnical Institute and Imperial College. It uses a ring shaped specimen of sample in which the lower half is rotated while the upper part is held stationary (Figure 3-1).

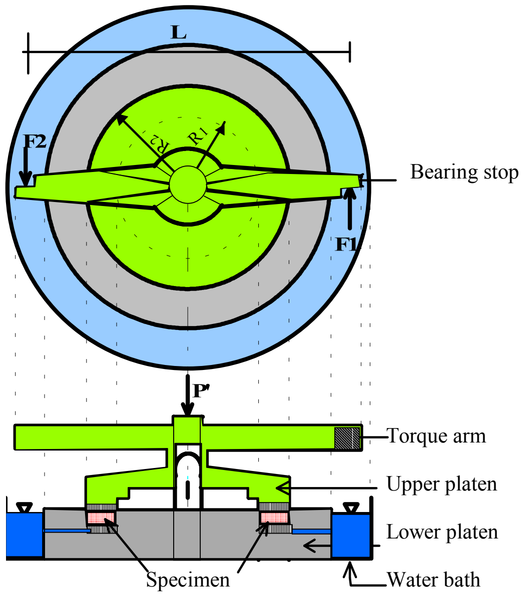


Figure 3-1: Specimen in the Bromhead ring shear apparatus

Table 1: Specimen origin

Name of specimen	Block origin	Depth (m)
10-2	A-61	5.50-6.00
10-4	A-7-2	8.50-9.00
10-5	A-4-1	9.10-9.50

Testing Procedure

The tests were carried out on remolded samples from the project site as shown in Table 1. The flush test procedure proposed by Stark (1992) was used. Its name is derived from the fact that the upper platen of the confining ring is to remain at (or nearly "Flush" with) the surface of the specimen. For this reason, the specimen's thickness was increased prior to shearing.

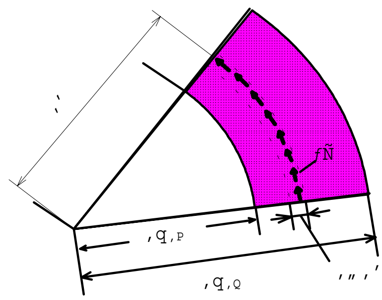


Figure 3-2: Dimensions of the specimen

This technique has the advantage of reducing the wall friction developed around the shear plane.

The torsion shear stress is obtained by means of two torque arms that tend to keep the specimen stationary when a motor causes the lower part of the container to rotate.

The resistance to torsion is obtained through a couple of torsion F1 and F2 (Figures 3-1 and 3-2) measured by means of the dial gauge connected to a digital data logger.

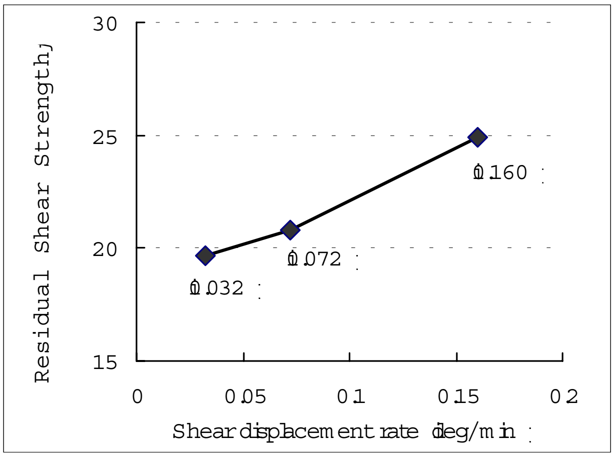


Figure 4.1: Effect of rate of displacement on residual strength

The shear resistance •, induced by the torsion moment, is calculated following the steps below:

$$M = \int_{R_1}^{R_2} r(2\pi r\tau dr) \qquad (1)$$

where M is the moment of torsion and the other dimensions are as shown in Figure 3-2

$$M = \int_{R_1}^{R_2} (2\pi r^2 \tau dr)$$
$$= [2\pi\tau(R_2^3 - R_1^3)]/3 \qquad (2)$$

Deriving the shear strength τ:

$$\tau = 3M/[2\pi (R_2^3 - R_1^3)] \qquad (3)$$

with $$M = \frac{(F_1 + F_2)L}{2} \qquad (4)$$

and $\pi = 3(F1+F2)/ [\, 4\pi(R_2^3 - R_1^3)\,]$ (5)

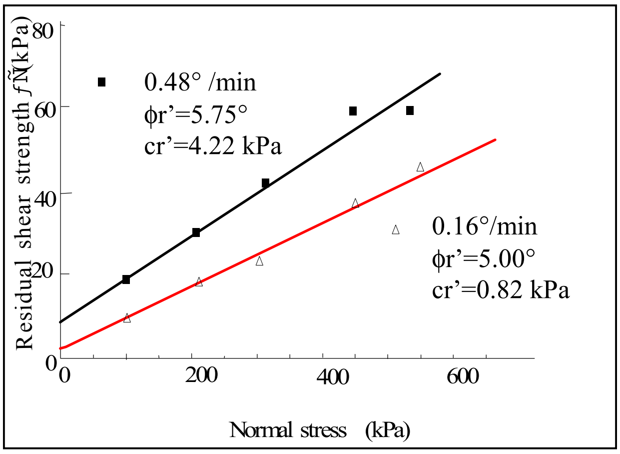


Figure 4.2: Effect of rate of displacement on residual strength parameters

The average displacement D is calculated as follows:

$$D = R\omega t\,(\pi/180) \qquad (6)$$

Where R is the mean radius of the specimen defined as

$$R = \frac{R_1 + R_2}{2} \qquad (7)$$

ω is the rate of displacement (deg /min) and t is the elapsed time in minutes.

$$D = \frac{(R_1 + R_2)}{360}\,\omega t \quad (8)$$

Preliminary tests were conducted on the same sample at the same condition of consolidation under 100 kPa during 48 hours to determine the shearing rate corresponding to the lowest residual strength which was chosen for the future tests. The results of these preliminary tests, shown in Figure 4.1, indicate that the slower the sample is sheared, the lower the residual strength becomes. Iwasaki (1998) has also shown that a lower displacement rate gives lower strength parameters (Figure 4.2).

Therefore the rate of 0.032°/minute giving the minimum residual strength was chosen for the test to be under the most critical state. Six tests were then conducted on each specimen under normal effective stress of 25, 50, 75, 100, 150, 200 kPa. The horizontal shear displacement was plotted against the shearing stress as shown in Figure 5 to find the residual strength.

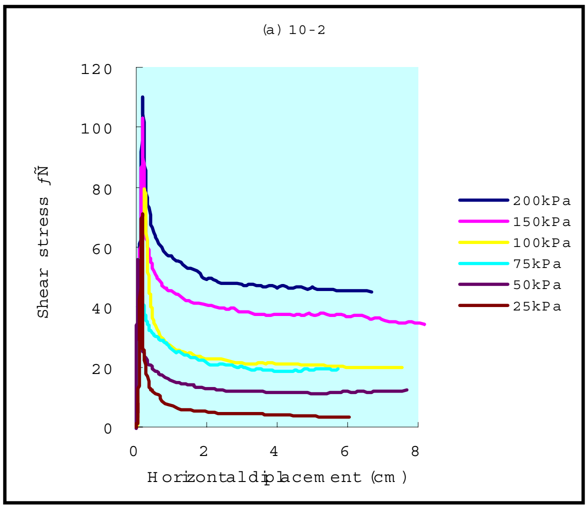


Figure.5: Shear stress versus horizontal displacement

TESTS RESULTS

Figure 5 shows an example of the results (Specimen 10-2) of shearing stress and horizontal displacement curves. It can be seen clearly that the stress after the peak value had been reached, decreases to a residual value. It could also be noticed that the deformation to the peak value is significantly small and the residual strength is reached at a relatively small shear displacement of nearly 40 mm. This residual strength value depends on the degree of consolidation. By plotting the residual shear strength versus the normal stress, the failure envelope of each sample could be determined and the cohesion and internal friction angle be derived as illustrated in Figure 6 and Table 2. It could be seen that Specimens 10-2 and 10-5 show the same behavior. On the other hand, Specimen 10-4 shows a high internal friction angle. All the samples tested presents very low cohesion intercepts (Figure 6).

Table 2: Tests results

Sample Speciemn	Plasticity Index	Residual Friction angle •r’ (^{o})	Residual friction coefficient cr’ (kPa)
10-2	28.5%	12.56	0.00
10-4	21.5%	19.09	.66
10-5	15%	10.61	2.21

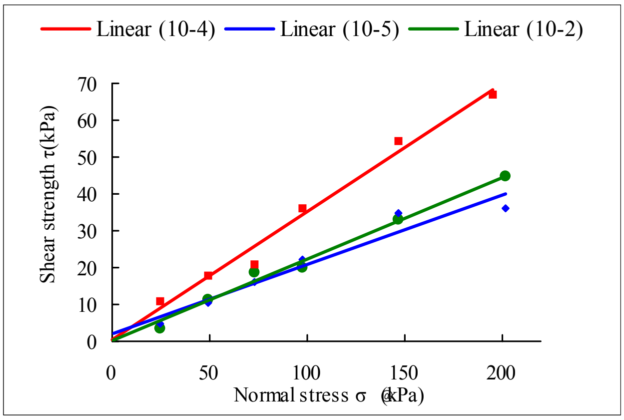
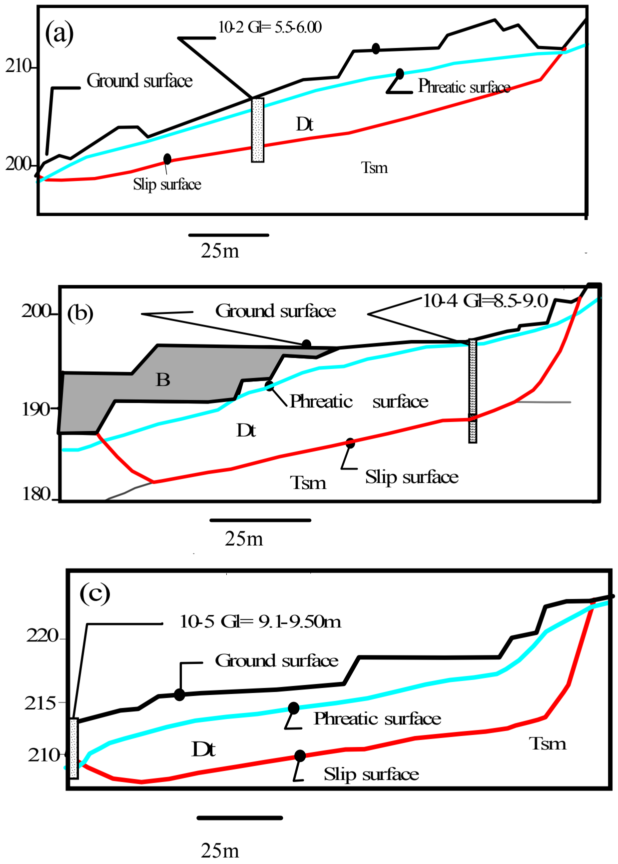


Figure 6: Shear strength versus normal Stress

SLOPE STABILITY ANALYSIS

An evaluation of slope stability using the notion of safety factor was curried out for each slope (Figure 7) considering the actual ground water level condition and then considering the case of the fully saturated slope. The limit equilibrium approach was used. This method involves making an analysis of the forces that act in the slope.

In the limit equilibrium analysis methods, strain considerations are of no consequence and therefore these methods are more appealing to engineers as the uncertainty of material properties is confined to shear strength parameters. These methods commonly use the Coulomb's approach, which assesses the stability and assumed shear surface.



B = Fill material Dt = Colluviums
Tsm = Tufficious Mudstone

Figure 7: Investigated slope profiles

The criterion for strength in Mohr- Coulomb limit equilibrium condition for effective stress analysis is given by:

$$\tau = \sigma' \tan \phi' + c' \qquad (9)$$

where τ = shear strength, σ'=effective normal stress, c' and ϕ' are the effective shear strength parameters measured by shear tests.

The Coulomb approach sums forces and moments related to an assumed slip surface passing through a soil mass as related in Fredlund et al. (1981). A factor of safety (Fs) is defined as the ratio of available shear strength to the shear stress mobilized along the shear surface to maintain equilibrium. Limit equilibrium methods of analysis have proven to be a widely used and successful method for the assessment of stability of slopes. The critical slip surface of each slope analysed were determined by inclinometers installed inside the respective slopes.

Calculations of stability were made based on the assumption that the slope will slip on the detected shear surface. Three different methods were used to see the incidence of each method on the calculation result: the standard slice method, the simplified Bishop method proposed by

Bishop (1955) (these two methods assume a slip surface to be circular) and the simplified Janbu method (1973) applied to non-circular slip surface. Based on the critical slip surface obtained by inclinometer, calculations were made and the results are shown in Table 3.

Table 3: Factor of safety by the three different methods

Profiles	Ground water lev.	Factor of safety (Fs) Standard Slice	Simplified Bishop	Simplified Janbu
10-2	Case 1	1.78	1.78	1.75
	Case 2	1.28	1.29	1.27
10-4 BC	Case 1	2.07	2.20	2.13
	Case 2	1.69	1.82	1.75
10-4 AC	Case 1	6.6	7.28	9
	Case 2	2.79	3.09	3.18
10-5	Case 1	1.44	1.52	1.34
	Case 2	1.05	1.13	1.00

Case1 = Actual ground water level Case2 = Slope fully saturated
BC=without fill material AC=with fill material

It can be seen that all the slopes gave a factor of safety higher than 1.2 with the exception of block A-4-1 (10-5) that gave a factor of safety of 1.00 when fully saturated (by simplified Janbu Method). For block A-7-2 (10-4), other calculation was done to see the effect of the fill material at the toe of the slope. The results obtained show that it has improved the stability condition to more than 3 times in the case of actual ground water condition and about 2 times the fully saturated case in on one hand. On the other hand a considerable decrease of the factor of safety is noticed (square in Figure 8).

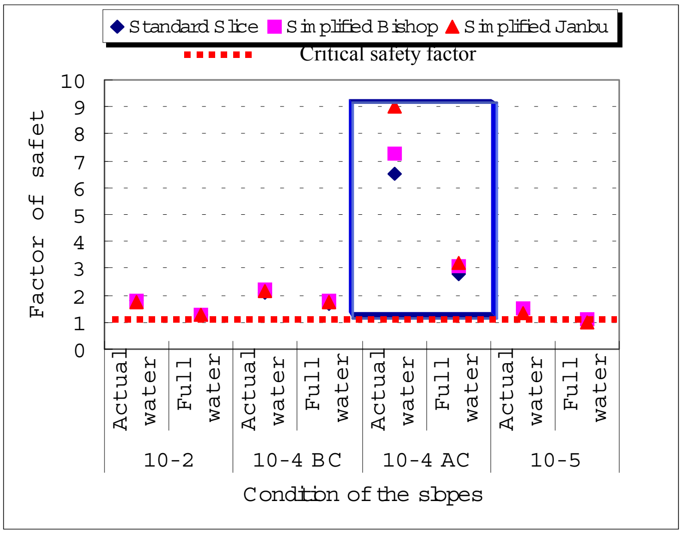


Figure 8: Variation of the factor of safety Fs

CONCLUSIONS

Residual strength parameters were obtained by drained shear test performed on remolded specimen from the Ichihara landslide project. The results indicated that the lower the rate of displacement is, the lower the residual shear stress is, and the lower the residual strength parameters become.

Parameters obtained from tests conducted at a rate of displacement of 0.032 degrees per minute were used in the limit equilibrium slope stability analysis. The factors of safety obtained by the three methods used showed that all the slopes analyzed presented a good condition of stability at the actual ground water level. These results indicated also that the stability condition could change considerably with the degree of saturation and Block A-4-1 could become instable and fail if, for some reasons (intensive irrigation, heavy rain) the ground water level increases to the ground surface. As all paddy rice fields in Japan are irrigated by flooding even in terrace fields, an increase in the ground water level will inevitably be observed during the cropping period and that will cause the instability. Therefore for this specific slope, mitigation works, such as under ground drainage facilities, are necessary to maintain the ground water level condition as lower as possible.

The results indicates also that the fill material at the toe of block A-7-2 has improved considerably its safety condition but that when the ground water level increases, a considerable decrease in the safety condition is observed. Consequently attention must be paid on such an analysis when using fill material for amelioration of the safety condition of the slope.

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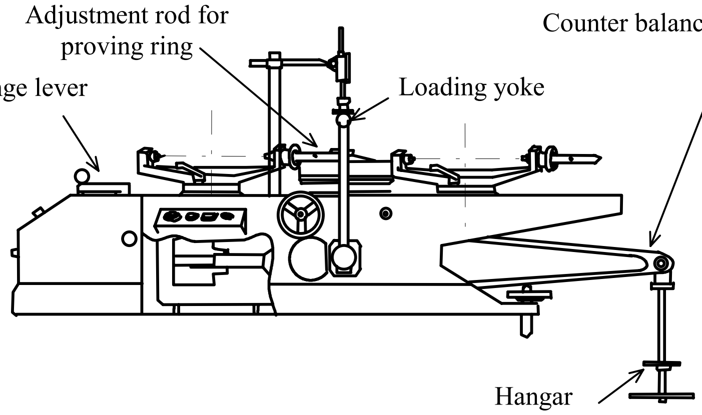
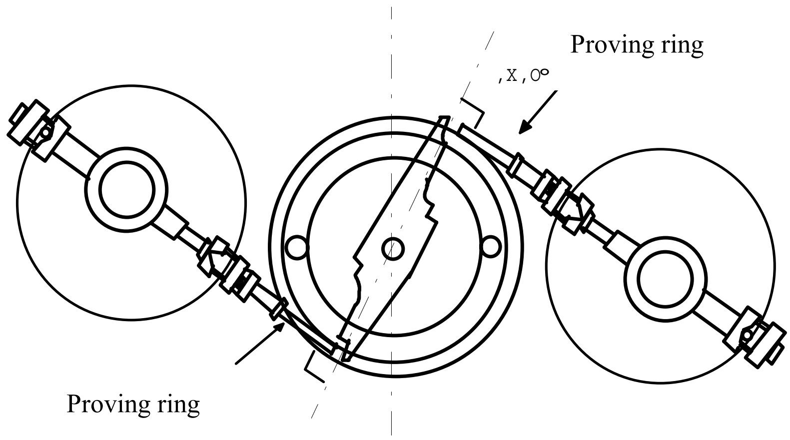
APPENDIX:
THE BROMHEAD RING SHEAR APPARATUS



Side view of the Bromhead Ring
Shear Apparatus



Aerial view of the specimen
container ready for shearing