CHAPTER 3

EXPERIMENT

3.1 Apparatus

3.1.1 Boundary potential supply instruments.

The circuit diagram for the boundary potential supplied instruments is shown in fig.8(a). The resistor R_1 was used for setting voltage supply. It consisted of two 0-50k variable resistors connected in parallel. From R_1 the supply was fed to $1^{\underline{st}}$ voltage vary board which was composed of several sets of resistors (R_2,R_3, R_4,R_5), t hese sets of resistors were called"Controller". The controllers supplied the boundary potentials to different points on the specimen.

The resistor R_2 was used to drop the potentials at the intermediate points where potentials were not so high. The resistor R_2 would be any value but it was convenient to use 30 k resistor for each controller. The potential of the points near the corner were high. The potentials dropped by 30 k resistors were too high, so the resistors R_x of suitable values were connected in parallel to the resistors R_2 to reduce the resistance. A number of resistors range from 1 k to 100 k should be prepared.

R_3,R_4 were variable resistor 0-5 k and 0-10 k. They were used for adjusting the boundary potential at each point individually. R_5 was 1M resistor connected to the negative terminal. The $1^{\underline{st}}$ voltage vary board($1^{\underline{st}}$VVB) was used for supplying high poteneial.

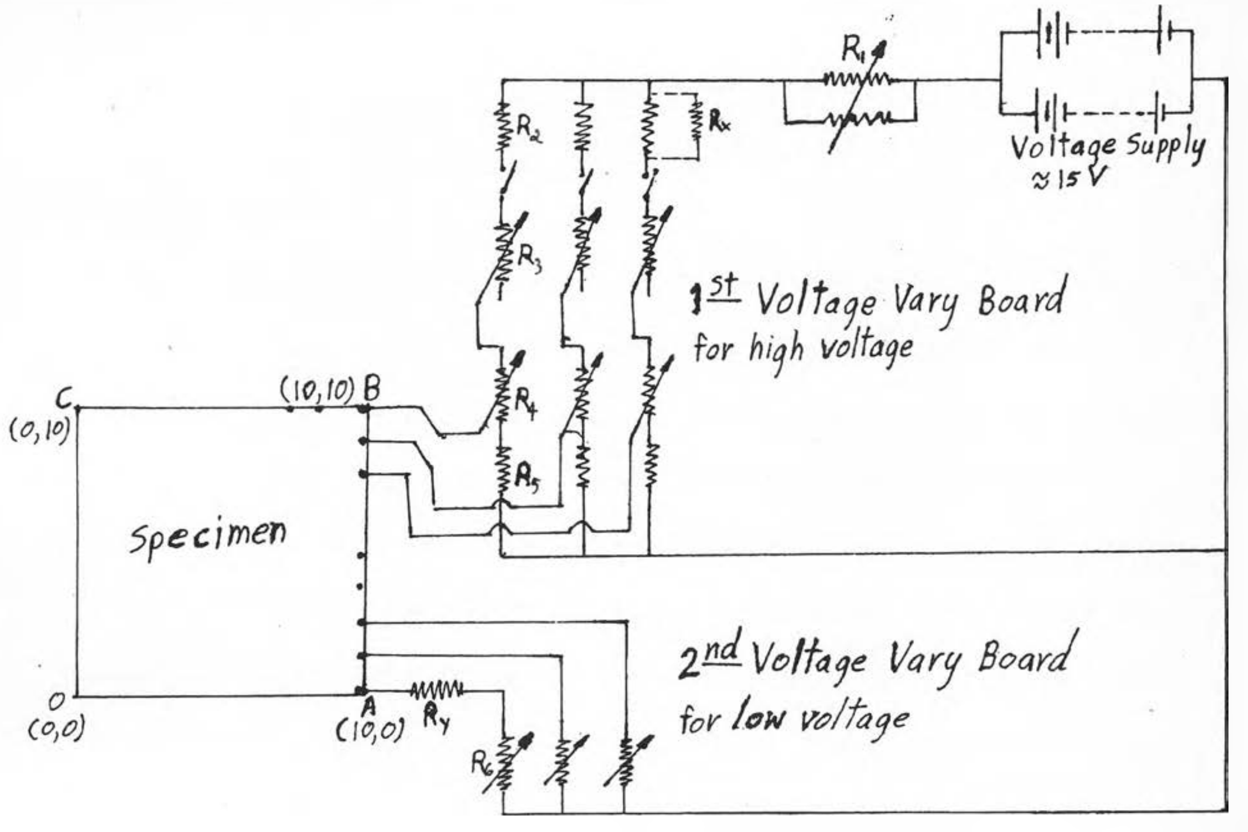

Fig.8 (a) Circuit diagram for the boundary potential supply instruments

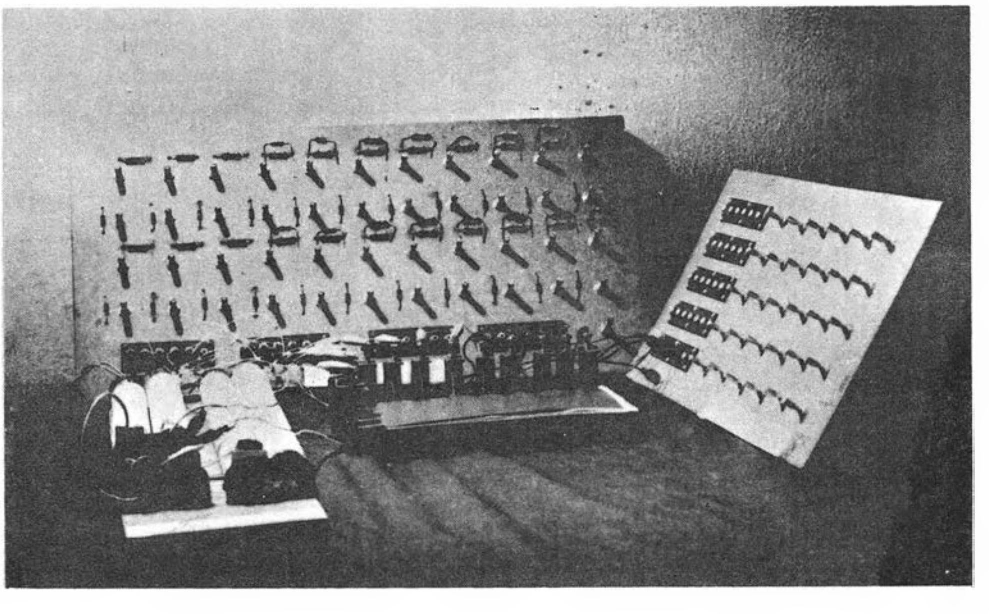

Fig.8 (b) The boundary potential supply instruments

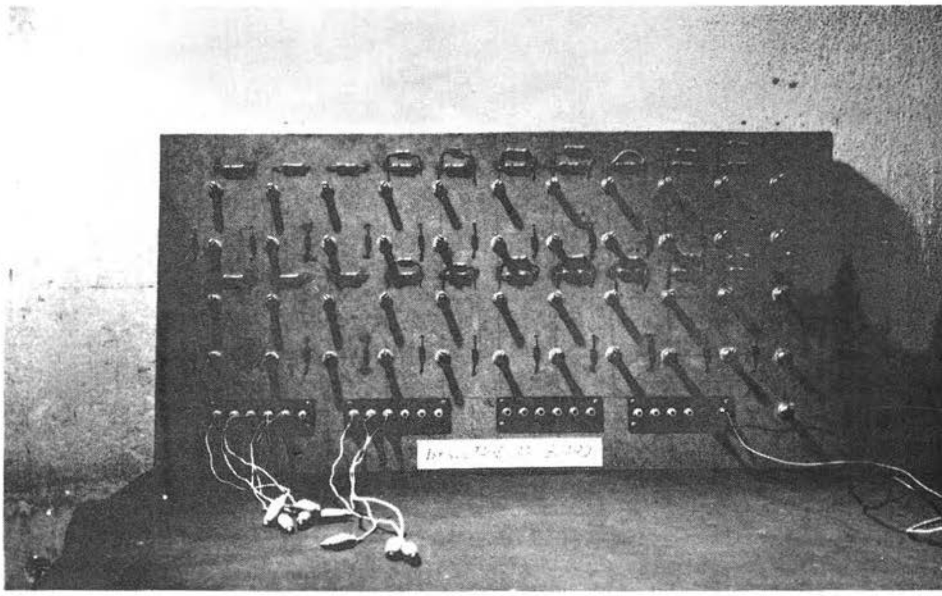

Fig.8(c) 1st Voltage vary board

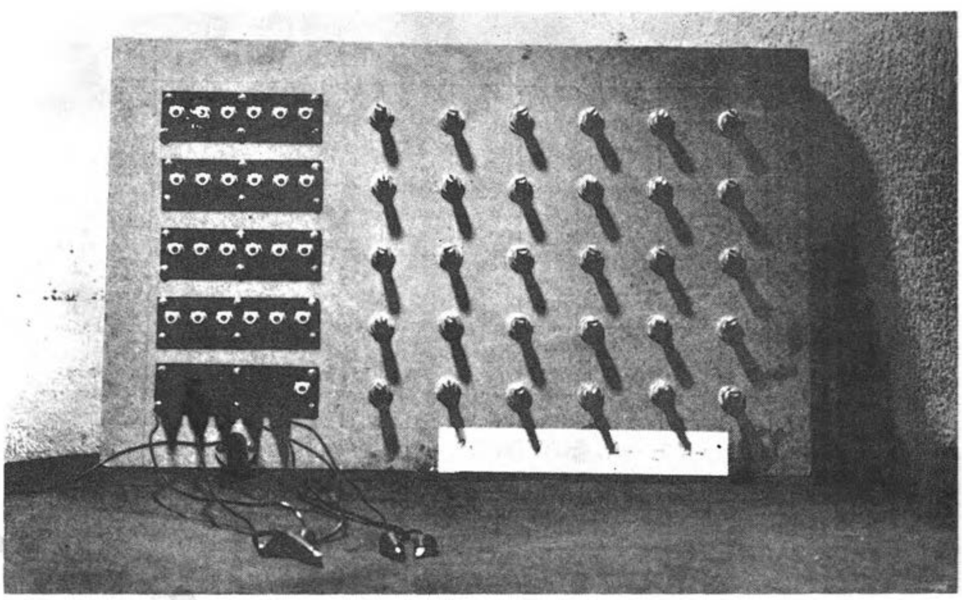

Fig.8(d) 2nd Voltage vary board

The low potentials were supplied by several 0-25 k variable resistors R_6 in the 2^{nd} voltage vary board (2^{nd} VVB). These variable resistors were connected to the negative terminal of the source. The resistor R_y was put in series with R_6 if potential supply was too low.

3.1.2 Measuring instrument

The potentials were measured by a digital voltmeter. The values which were measured by this digital voltmeter were either three or four figures. The small value could be measured to 4 figures while the high value was measured to 3 figures only. There were several scales such as 20 mV,200mV,2V,20V,etc. Since the smallest scale was up to 20mV, so the highest accuracy of the instrument was 0.01 mV. In this experiment, the accuracy of 1.0 mV was enough. The highest number which could be measured before changing the scale was 2300.

3.1.3 Specimen

The specimen was Teledesto's recording paper of resistivity approximately 2500 ohms per square grid. This paper was provided in the form of a sheet of 12 in. wide and 24 in. long.

The conducting paper was cut into 3 diffirent shapes representing the cross-sections of shafts, as shown in fig.9.

Both the geometry of the cross-section and the boundary potential are symmetry about the co-ordinate axes. It follows, first, that the potential distribution is the same in any quadrants, and second, that no currents flow across x and y axes. Therefore the experiments can be carried out on any of the quadrants of the cross-section of shafts. The specimens shown in fig. 9 represent only a quarter of the cross-section of shafts.

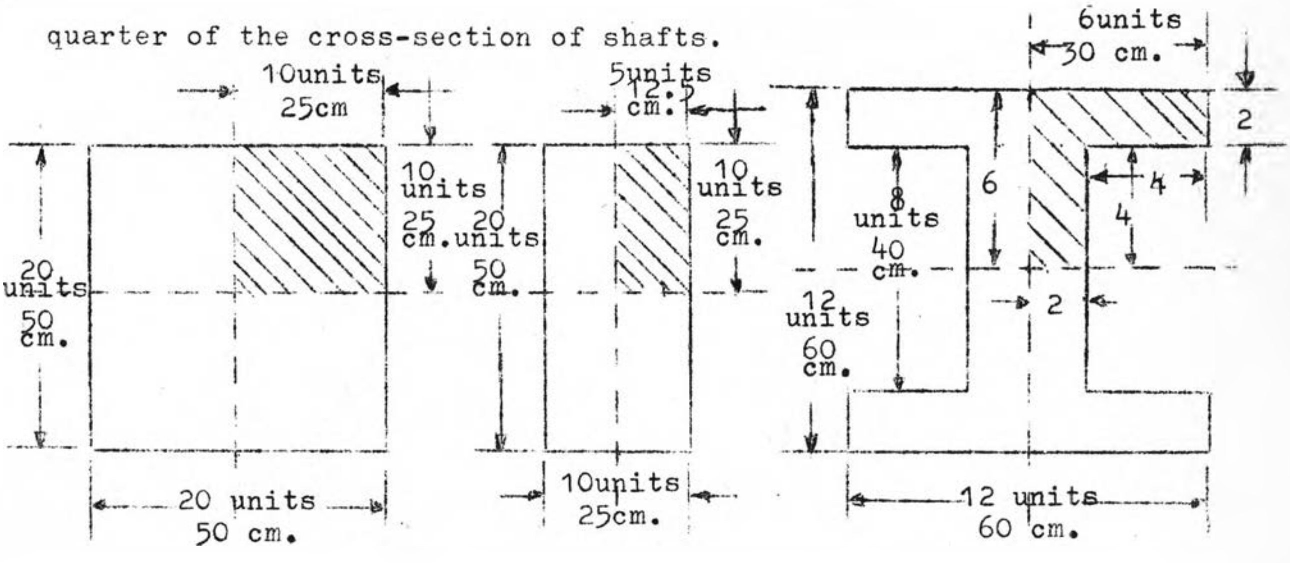

Fig.9 The cross-sections under investigation, the shade areas are the specimens which represent a quarter of a section.

a. The square cross-section

b. The rectangular cross-section

c. The I cross-section

The specimen was fixed on a card board with a graph paper inserted between them to show the co-ordinates. Then it was fixed tightly to a wooden board by clamps. External boundary potentials were supplied through these clamps. Fig.10 show how the specimen was prepared.

Practically, the resistivity of the Teledesto's recording paper measured along the length of the original paper is not equal to those measured along its width. According to the method of Ross and Qureshi,[1] the result was corrected by multiplying all dimensions along x-direction by the factor $(\rho_x/\rho_y)^{\frac{1}{2}}$. In this thesis, the resistivity of both directions could not be specified exactly because the resistivity measured in either direction varied widely, so the average values were preferred.

For the rectangular and the I cross-sections 2 specimens were prepared. One was cut so that the length was along the length of the original paper whereas the other was along its width. They were called "L-specimen" and "W-specimen," respectively.

For the square specimen , there is symmetry on diagonal line, it is necessary to measure the potential on one side of the diagonal line only, then, it is automatically the potential of the other points on the other side, such as point P and P' in figure 11. When the potential of the whole sheet are measured, the average value of the pairs of the corresponding points will cancel the effect of unequal resistivity. Thus for the square specimen, it was necessary to use only one specimen in stead of two as in the case of the rectangular and the I specimen. It should be noted that:-

$$\tau_{yz} \text{ at } P = \tau_{xz} \text{ at } P'$$
$$\tau_{xz} \text{ at } P = \tau_{yz} \text{ at } P'$$

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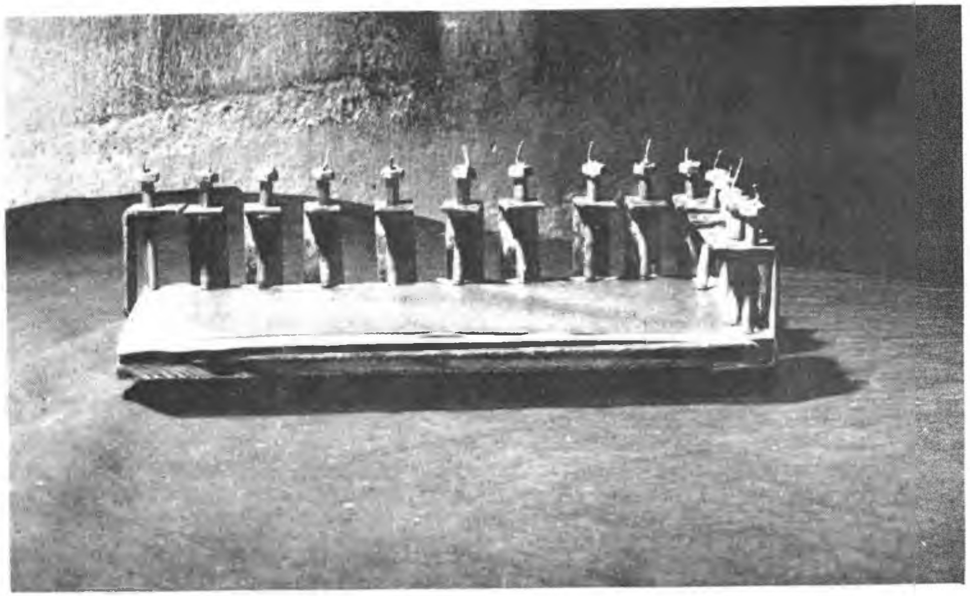
[1] Ross,D.S.and Qureshi,I.H. "Boundary Value Problem in Two Dimension Elasticity by Conducting Paper Analogue." Journal of Scientific Instruments. Vol.40(1963):P.513-517.

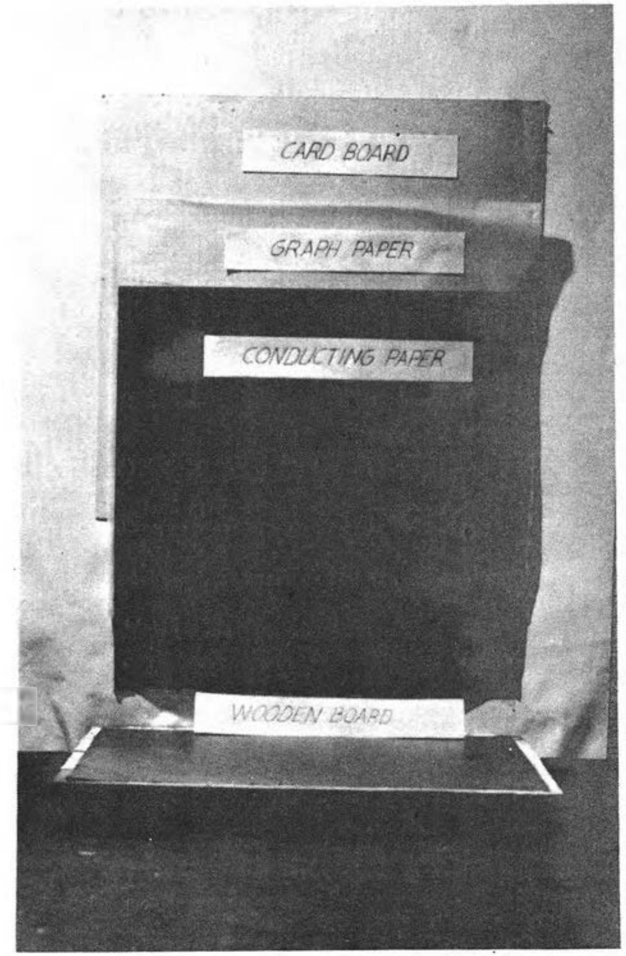


(b)

Fig.10 show how to prepare the specimen

(a) the components of the specimen

(b) the ready prepared specimen



(a)

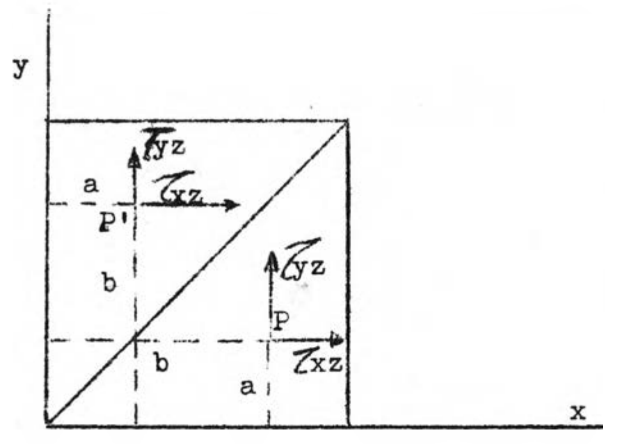


Fig. 11 The symmetry of the square shaft on the diagonal line

3.2 Procedure

When the specimen was clamped on the wooden board, care should be taken that every point was pressed tightly and not torn. These clamps are used as external potential supply. These points were called "the controlled points." The controlled points near the end should be closer than the middle.[1]

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[1] The potential at the points between the controlled point deviated from those required to satisfy the boundary condition. During the experiment, it was found that the deviation was less as the controlled points are closer, and if the distance between the controlled points were equal, the points nearer to both ends had more deviation, too high at the lower end and too low at the higher end. This was the reason why the controlled point should be selected closer near the end.

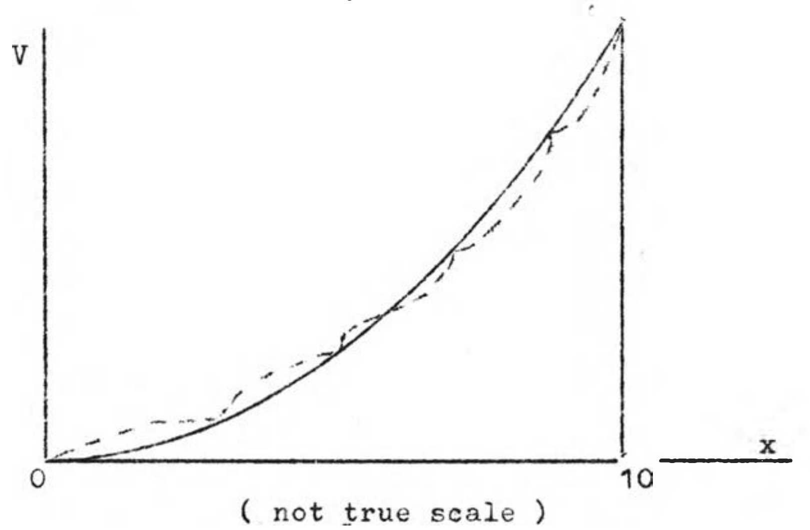
After the specimen had been carefully prepared, clamps were connected to the voltage vary board. The controlled points which the potential were under 3 V, were connected to the 2^{nd}VVB and those over 3 V to the 1^{st}VVB.

It was rather difficult to set the boundary potential, since when one controller was adjusted, not only the potential of the controlled point corresponding to it was changed but also the others because the entire circuit was interconnected. So it was necessary to repeat the process several times.

After the circuit shown in fig.8(a) had already been connected, the variable resistor R_1 was adjusted to supply potential about 11-12 V. All switches S_1 corresponding to the controlled points were on. The point having the highest potential on the boundary was the first to be set. The potential was measured by inserting the negative probe to the negative terminal of source and pointing the positive probe on the conducting sheet as close to the clamp as possible. R_3 and R_4 were adjusted to get the potential as close to the correct potential as possible. If the highest potential that can be adjusted was lower than the potential required, a resistor R_x of proper value was connected in parallel to R_2 to reduce the resistance. The resistor R_2 was removed if the corresponding potential at that point was high. It was easily done by putting an electrical wire parallel to the resistor R_2. Normally, the first 2-3 points, the resistor R_2 had to be removed. After getting the correct value, the second point was adjusted. The adjustments were gradually done from high potential points to low potential points. It was advisable to adjust both side alternatively.

Sometime, it happened that the adjustable potential was higher than the potential required. This controlled point was thus altered to connect to the controller in 2$\underline{\text{nd}}$VVB. The resistor R_6 was adjusted to obtain the correct value. It was also possible that the adjustable potential of the controlled point corresponding to the 2$\underline{\text{nd}}$VVB was lower than the required potential, then the controlled point was altered to connect to the 1$\underline{\text{st}}$VVB or a resistor R_y of proper value was added in serie with R_6.

As the potential adjustment at one point gave rise to changes of the potential at other points. After completing one round, the adjustment had to be repeated several times, until each potentials was close to the correct value.



(not true scale)

____________ Boundary potential required

------------ Boundary potential obtained

Fig.12 The deviation of the actual boundary potential.

The potential between two controlled points deviated from the correct potential, Figure12. This deviation could be reduced by increasing the potential of the controlled point a little higher than the correct value where the potential was low, and decreasing where the potential was high.

Another problem was when the potential of the controlled point was very low the observed potential was alway higher than the correct one although it was connected directly to the negative terminal of the source. It was because there was a very thin air gap between the specimen and the clamps. The air gap behaved like a resistance connected in series between the controlled point and the negative terminal of source. When the current flowed through them, there was potential diffirence between negative terminal of the source and the controlled point. Thus the potential of the controlled point could not be set lower than this potential.

It was possible to be corrected by increasing the minimum potential of the conducting sheet, then the potential of the other points were increased by the same value. This was just to change the constant of equation. But practically the potential difference was not constant, it varied as the potential of other points. So it was better to leave them at the smallest value.

When the most suitable potential was found, the potential supply was recorded and the boundary potential was measured at every 0.1 or 0.2 unit interval. It was left with no further adjustment for at least one hour since the potential supply might gradually decrease. If the potential supply decreased,it was reset to the original value by setting the resistor R_1. The boundary potentials were checked for any changes and a little adjustment might be necessary. After this step was repeated for a few times, the potential supply should be almost constant. If not, the capacity of the source had to be increased. After everything was ready, the potential supply and boundary potential were recorded. These values were checked against the required potentials by the method in section A1 appendix A.

To plot the equipotential line, points on the conducting sheet of which potential are 0.4,0.8,1.2,----,9.6 were located. Then the scale of the digital voltmeter was altered to 200 mV-scale. One probe of the digital voltmeter was fixed at the point located above, another probe was moved on the specimen to find the other points having the same potential. The digital voltmeter was now used as a null indicator. These points formed an equipotential line. The other equipotential lines were constructed in the same way. There were some region where the distance between two equipotential lines were too far, then an intermediate line should be plotted.

When the experiment was completed, the specimen was removed. The potentials were transformed to conjugate functions by means of eq.(2.29) or (2.32) or (2.35). The shear stress lines could be constructed by means of eq.(2.15) and the method shown in section A-3 appendix A. The value of the integral part of the twisting moment as shown in eq.(2.21) could be approximately determined by dividing the area of the specimen into squares. The value of the shearing stress function ϕ at the center of squares were determined by interpolation. Then the area of each square was multiplied by the shearing stress function at its center and summed up, thus the value of the integral part of the twisting moment was obtained.