MEASURING GROUND MOVEMENT BY

PRECISE SURVEY

A Thesis

Submitted to the Faculty of Graduate Studies and Research

in Partial Fulfilment of the Requirements

For the Degree of

Master of Science

in the

Department of Civil Engineering

by

Roy Wayne Chursinoff

Saskatoon, Saskatchewan

January, 1980

U N I V E R S I T Y   O F   S A S K A T C H E W A N

PERMISSION TO USE POSTGRADUATE THESES

TITLE OF THESIS: Measuring Ground Movement by Precise Survey

NAME OF AUTHOR: Roy Wayne Chursinoff

DEPARTMENT OR COLLEGE: Department of Civil Engineering
College of Engineering

DEGREE: Master of Science

In presenting this thesis in partial fulfilment of the requirements for a postgraduate degree from the University of Saskatchewan, I agree that the Libraries of this University may make it freely available for inspection. I further agree that permission for extensive copying of this thesis for scholarly purposes may be granted by the professor or professors who supervised my thesis work or, in their absence, by the Head of the Department or the Dean of the College in which my thesis work was done. It is understood that any copying or publication or use of this thesis or parts thereof for financial gain shall not be allowed without my written permission. It is also understood that due recognition shall be given to me and to the University of Saskatchewan in any sholarly use which may be made of any material in my thesis.

Signature Roy W Chursinoff

414B Gardiner Place
SASKATOON, Saskatchewan

January, 1980

ABSTRACT

The three dimensional surface movements of the retrogressive landslides at Beaver Creek were monitored from May, 1978 to August, 1979 using precise surveying techniques. A comprehensive, parametric, least squares adjustment computer program was developed to assist in the determination of the limit of accuracy, selection of the most desirable configuration and field procedure given the equipment available at the University of Saskatchewan, Saskatoon, Saskatchewan. The computer program was also used in the subsequent analysis of the field results, calculation of statistical accuracies and checking the reliability of the data.

The study indicated that the rate of horizontal surface movement of the landslides increased from the scarp to the toe, with as much as 100 mm of surface movement occurring from May, 1978 to August, 1979. This observed movement agrees with the current retrogressive slide model. Vertical surface movement was as much as 30 mm downward in the same time period. Slide blocks near the scarp exhibited predominantly rotational movement whereas slide blocks near the toe exhibited predominantly translational movement. This observed behavior also agreed with the current retrogressive slide model. A seasonal trend in the rates of movement was also apparent suggesting a correlation between slide movement and environmental effects such as freeze-thaw, rainfall or river level.

Surveying accuracies expressed in the form of 95 percent error elliptical cylinders were in the order of 7 mm horizontally and 2 mm vertically at distances of 150 metres. This accuracy was more than adequate considering the relatively large amount of slide movement. The techniques and procedures set forth in this study should be used as guidelines when employing surveying techniques in future geotechnical field investigations.

ACKNOWLEDGEMENTS

This project was financially supported by the National Research Council. The Geodetic Survey of Canada also provided considerable assistance in the installation of vertical control bench marks near the study area. This support is gratefully acknowledged.

Special gratitude is extended to Dr. M. D. Haug and Dr. D. G. Fredlund for their guidance and assistance to this research project. Their contributions of freely given time, knowledge and interest in the project were invaluable.

The generous assistance of the faculty, staff and fellow graduate students was much welcomed and appreciated.

Special thanks are also extended to the typist, Mrs. Pat Arthurs, and Mr. Alex Kozlow, who performed the drafting.

TABLE OF CONTENTS

Page

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

1.1 The Study of Retrogressive Landslides

Retrogressive landslides have played a destructive role in the construction and performance of civil engineering works for centuries. In recent years significant advances have been made in understanding the mechanisms of the retrogressive landslides occurring at the confluence of Beaver Creek with the South Saskatchewan River (Haug, 1976). However many uncertainties still remain.

Haug (1976) states: "In order for this type (i.e., retrogressive) of failure to occur, it must be assumed that the rate of lateral movement increases toward the river." It is necessary to verify this assumption in order to enhance confidence in present and future slope stability analyses of the landslides at Beaver Creek.

Terzaghi (1950) stated that "if a landslide comes as a surprise to the eyewitness, it would be more accurate to say the observers failed to detect the phenomena which preceded the slide." The implication is that the smallest movements possible should be measured at the earliest possible time.

The availability of a wide range of precise survey equipment at the University of Saskatchewan set the stage for the systematic monitoring of the three dimensional surface movements of the retrogressive landslides at Beaver Creek.

1.2 Ground Surveys

Ground surveys are necessary to establish a frame of reference against which movements of the ground surface can be compared. Dearinger (1974), in outlining survey procedures for measuring the magnitude and direction of terrain movements, states: "the standard error propagated in the measurement and computation processes must be less than the smallest significant movement."

Since a technically sound analysis can be derived only from technically sound data, it is necessary to employ statistical-geodetic techniques to determine the standard error propagated in the measurement process. Once the standard error is known, the accuracy and reliability of the results can be determined. This establishes the need for a computer program to perform statistical survey adjustments for complex survey networks.

1.3 Location

The study area is located near the confluence of Beaver Creek with the South Saskatchewan River, 30 kilometers south of Saskatoon (Figure 1.1), extending north from the mouth of Beaver Creek for 1/2 km along the east bank of the river. The legal description of the area is the North-west Quarter of Section 16, Township 35, Range 6, West of the Third Meridian. The National Topographic System map designation is 72 0/15 g and the 1000 meter grid reference is 820-605.

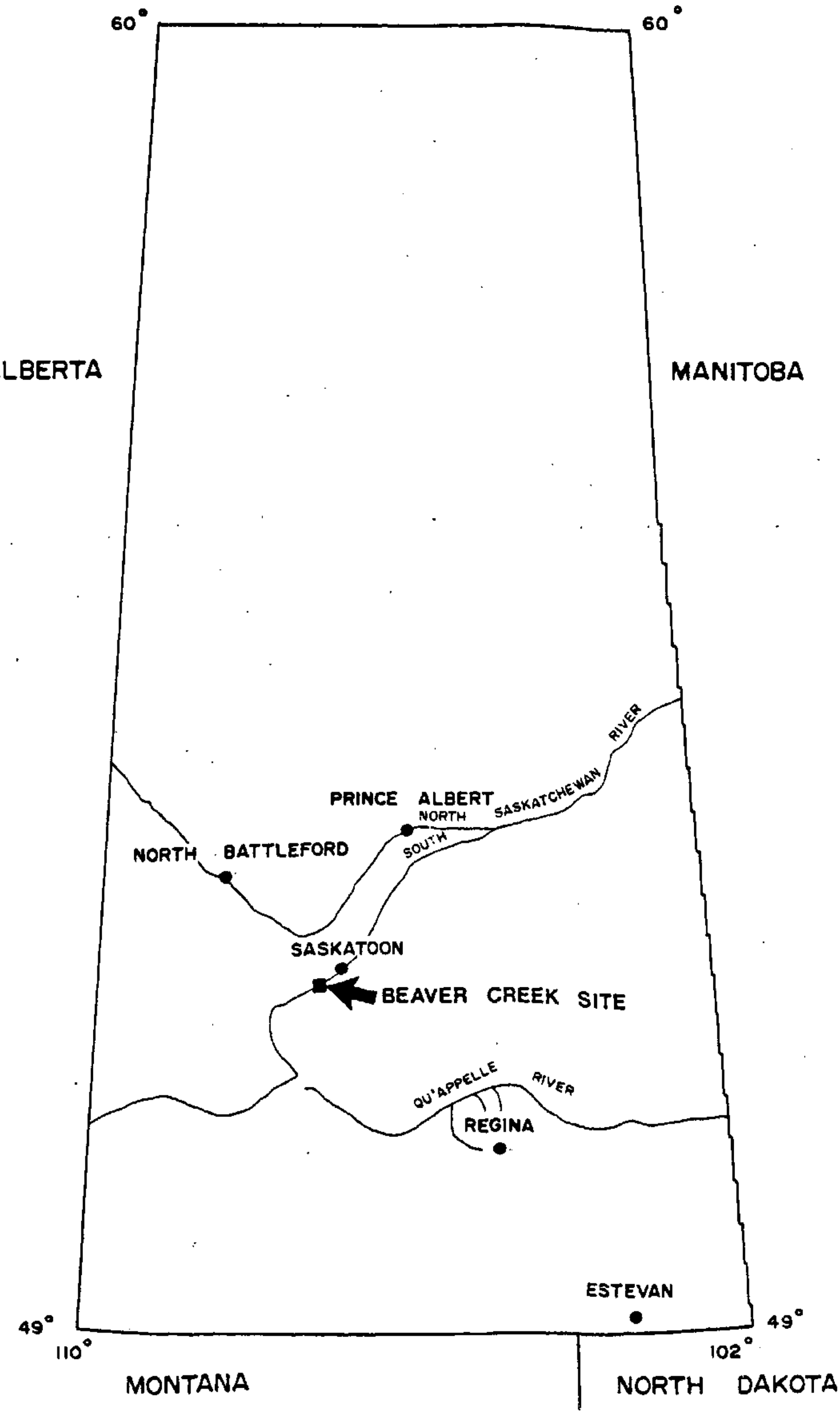


FIGURE 1.1 BEAVER CREEK STUDY SITE

1.4 Object

The principal objectives of this thesis were:

(i) to establish a survey network to monitor the three dimensional surface movements of the retrogressive landslides at Beaver Creek as accurately as possible with the available equipment,

(ii) to develop a computer program to perform statistical survey adjustments and thus determine the accuracy and reliability of the results,

(iii) to determine the rates of the surface movements and compare them with the current retrogressive slide model.

CHAPTER II

LITERATURE REVIEW

2.1 Introduction

A review of the literature was carried out to determine the state-of-the-art with respect to precise surveying as an aid in measuring surface ground movements. The findings show that the work which has been performed to date has lacked a sound basis with respect to determination of the reliability of the results and statistical prediction of accuracies. The literature review was concentrated in two specific areas: 1) the use of precise survey techniques for the detection of movement and 2) the analysis of the surface movements of retrogressive landslides.

2.2 Literature Search

Richardson (1964) discussed the development of a precise survey network to monitor the structural deformations of the Glen Canyon concrete arch dam. The author stated that a systematic program is essential, in which each of the several factors can be separated from the total and an evaluation made of the part contributed by each to the total. Measurements must be made from the beginning with as high a degree of accuracy as possible so that their reliability is unquestionnable.

The author discussed the establishment of a horizontal coordinate system over the whole study area. The network consisted of a set of stable reference piers around the perimeter of the study area and permanently mounted targets inside the study area. The coordinates of the reference piers were established by precise horizontal angle and distance measurements from a known baseline. The coordinates of the targets were established by angle measurements made from the reference piers. If the target points in the study area inaccessible, a remote measuring system such as this is imperative.

The reference piers employed permanently mounted brass base plates with forced centering instrument mounts. These base plates enabled any instrument to be mounted over the exact same point without any need for centering. This process minimizes the source of error due to setup.

Richardson (1968) discussed the usefulness of precise survey techniques in the monitoring of the Glen Canyon arch dam. It was concluded that surveying methods offered a "convenient and reasonably accurate means" of determining the structural deformation.

The author indicated that a least squares survey adjustment was performed but that "low orders of magnitude of deformation (i.e., 0.1 inch) may be an indication that measurable deformation is beyond the limits of the specific measurements." No comment was made on the statistical accuracies attained and the degree of confidence in the results.

The monumentation used in the study (described by Richardson (1964)) had performed extremely well. The author states that the procedures and monumentation used at the Glen Canyon arch dam were being used at other dam locations with a great deal of success.

Wilson (1970) discussed the usefulness of observational data on ground movements related to slope instability. Several case histories are briefly mentioned in which optical survey techniques were used to reinforce the measurements taken by slope indicators. The general concensus was that survey techniques were applicable and useful in areas of large deformations. Much more study is needed to establish the usefulness of survey techniques in slides of low deformation (e.g., 2 to 3 cm per year).

Wilson (1970) states: "Once a failure has occurred it is always possible to make a stability analysis and arrive at a balance between the driving forces and resistance of the clay, such that the failure can be explained. It is one thing to do this yet quite another to predict in advance the performance of such an excavation or embankment. It is only by studying the progressive movement of landslides that we can understand their mechanism and thus hopefully arrive at improved methods of stability analyses."

Gould and Dunnicliff (1971) discussed the accuracy of field deformation measurements. The authors define accuracy as "the closeness of approach of a measurement to the true value of the quantity measured, i.e., degree of correctness." Verification of accuracy can be achieved in one of two ways: (i) acquisition of data by at least two independent measuring systems and (ii) use of instruments which can be removed at any time in order to check if they are operating properly.

The authors emphasize the need to establish the accuracy attained during the measuring process. The sensitivity of a device or technique must be appropriate to the needs of a particular field problem. It may be more significant to determine the increment of movement over a short time interval rather than the absolute position of a point at one given time.

Penman and Charles (1972) discussed the use of optical survey techniques to measure the movement points on the surface of an embankment dam. The authors emphasized the use of stable reference piers fitted with forced centering baseplates for horizontal control. The study utilized a Tellurometer MA-100, a Kern DKM-2A one second theodilte and a Wild N3 precise level.

The movements were calculated by three independent methods: 3 dimensional trilateration, 2 dimensional trilateration and 3 dimensional triangulation. The three methods achieved differences in calculated coordinates of the same point of 5 mm horizontally and 10 mm vertically when compared. No discussion is presented with respect to the degree of confidence in the data or the statistical prediction of accuracies.

Uotila (1973) emphasizes the use of statistical techniques in surveying. The author clearly states: "when surveyors are called upon to be expert witnesses in court, they must be able to attest as to the integrity of their results. Statistics and least squares adjustments give data that can be used to convey information to a third party in a professional manner."

Chrzanowski (1974) strongly suggests the use of a statistical analysis for a surveying network to lend credibility to those results. The author states that errors in surveying always arise and "these errors should always be determined unless the surveyor is not interested in the accuracy of his work."

It is also emphasized that "the information supplied by the surveyor is practically useless because any measurements and results of calculations in surveying projects are meaningless if they are not accompanied by a good estimation of their accuracy."

Durr (1974) discussed the case history of an embankment saved by instrumentation. Conventional survey techniques were used in conjunction with slope indicators to monitor the movements of the embankment and thus aid in its redesign. The amount of ground movement was large (e.g., 1 m) and thus an evaluation of errors and accuracy attained was deemed unnecessary. The network consisted of "survey lines" across the embankment.

Reynolds and Dearinger (1974) discussed the measurement of building movement by precise survey. The authors claimed "an accuracy of ±0.3 mm to ±0.5 mm" was obtained. The results were analyzed using a least square adjustment and the most probable locations of the targets were established using "error triangles."

The plots of movement of the targets on the building show an unreasonable scatter in the results, far above the stated accuracy of ±0.5 mm. No attempt was made at calculating the statistical accuracies, the degree of confidence in the results, or determining whether the movement measured was realistic.

Tice and Sams (1974) discussed their experiences with landslide instrumentation in the southeastern United States. It was concluded that surveying grids are an effective means of defining slide limits and patterns of movement, measuring growth of the area involved in movement, determining areas of bulge and subsidence, and providing a base grid for mapping of scarps, ground cracks and seeps. Survey techniques are best suited to slow, creep movements; rapid failures that stabilize after initial movement are not subjects for survey grid measurement.

The authors state that for maximum effectiveness the grid should be established so that surface movements can be measured in two directions and so that elevation data can be obtained. Elevation data are not always amenable to interpretation, particularly at a given grid point, but a pattern can sometimes be deduced from all the data considered together.

The preferred method of presenting the results of survey grid monitoring depends on having grid movements measured in two directions so that a vector representing the resultant movement of the grid point can be drawn to scale. Instrumentation to monitor surface and subsurface movement is a necessity for any landslide investigation.

McKenna and Roy (1975) used survey techniques as a part of the total instrumentation to monitor the movement of a highway embankment built of soft ground. The external survey instrumentation consisted of "pegs controlled by survey lines 30 m offset from the embankments." At each reading, the 30 m offset was checked and a theodolite was used to determine the lateral movements of the pegs. Levels were also taken. The authors conclude "the measurements were not sufficiently accurate to allow the ground movements to be measured." No discussion is made concerning the magnitudes of the movements or errors in the surveying.

Thomson and Hayley (1975) used survey techniques to monitor the surface movements of the Little Smoky landslide. The process consisted of accurately locating a series of control points consisting of steel rods, 3 metres long, driven at intervals from the river to beyond the scarp.

The results indicated that the entire area from the scarp to the river was moving. Horizontal displacements were stated to be larger than the survey error. The results also indicated that the amount of movement of the ground surface increases from a minimum at the scarp to a maximum near the river.

There is no mention of the type of equipment used to perform the surveying. The authors have not discussed the reliability of the results nor the amount and sources of survey error. However, the results seem to indicate that there probably are differing rates of movement in the slide. The authors state that the assumption of differing rates of movement is essential in the analysis of a retrogressive landslide.

Haug (1976) investigated the landslides at Beaver Creek, south of Saskatoon, Sask., and determined they were best described as retrogressive in behavior. His detailed analysis of the landslides led to the statement: "Acceptance of retrogressive failure mechanisms requires that more work be carried out to pinpoint the dimensions and rate of movement of the process involved."

Haug (1976) determined the assumption that rate of movement increases toward the river was essential for the simulation of a retrogressive landslide. The author recommends "the installation of precise surface surveys and monumentation" to determine whether the assumption is valid."

Chrzanowski and Steeves (1977) discussed the accuracy requirements of horizontal control networks. The authors recommend the use of a parametric least squares adjustment method and expression of accuracies in terms of 95% error ellipses. The error ellipse is merely a statistical representation of the maximum and minimum standard deviations of the coordinates at a station. Ninety-five per cent error ellipses in the order of 10 mm can be obtained using a Wild T-2 1 second theodolite and a laser AGA-76 Electronic Distance meter with a stated accuracy of ±5 mm for distances up to 5 km.

Sowers and Royster (1978) discussed the field investigation of landslides and landslide prone areas. They determined that ground surveys are necessary to (a) establish the ground control for photogrammetric mapping and instrumentation, (b) obtain topographic details where ground surface is obscured by vegetation and (c) establish a frame of reference against which movements of the ground surface can be compared.

The first requirement is a system of local bench marks that will remain stable during the course of the investigation and as far into the future as movements will be observed. The bench marks should be tied together by triangulation and precise leveling loops. The continuing movement of a landslide can be measured by a system of traverses or grids across the landslide area. The authors also emphasize that the mathematical analysis of a landslide is based on the field investigations and obviously can be no more accurate than the data obtained from the field work.

Wilson and Mikkelson (1978) discussed field instrumentation of landslides. Adequate planning is required before a specific landslide is instrumented. The steps are: (a) determine what types of measurements are required, (b) select the specific types of instruments best suited to make the required measurements, (c) plan the location, number, and depth of instrumentation and (d) develop the recording techniques.

Landslides, by definition, involve movement, and the magnitude, rate, and distribution of this movement is generally the most important measurement required. Vertical and horizontal measurements of movement of the ground surface at various locations within the slide area should be obtained. When direct measurements are not possible, a remote monitoring technique such as triangulation should be used. Triangulation requires precise measurement of base distances and angles from good reference monuments. The authors state that accuracies from ±0.6 mm to ±12 mm are attainable with precise triangulation and ±0.6 mm to ±12 mm with precise leveling.

In the monumentation of a landslide it is imperative to establish, beyond a reasonable doubt, the magnitude of the movements taking place. Only then can a definite observation be made and a reasonable analysis performed. The retrogressive slides at Beaver Creek are ideal for this type of investigation.

CHAPTER III

THEORY OF STATISTICAL-GEODETIC ANALYSIS

3.1 Introduction

The remote observation and systematic monitoring of spatial deformations by geodetic methods involves the measurement of horizontal and vertical theodolite angles and of distances to a series of light reflecting targets. These mixed angle and range observations are usually processed on a computer by well established statistical-geodetic methods (Chrzanowski, 1974). This provides not only the most probable absolute and instantaneous three dimensional positions of the target points, but also an estimate of the accuracy of their determination, which is essential for the correct interpretation of the results.

3.2 Errors

It is impossible to obtain a result which is absolutely correct. The measurement of any quantity can only be made to a certain degree of accuracy, which is governed by the instruments used, the external conditions and the individual who makes the observation. Hence, it follows that no matter how good the instruments may be and how careful the observer, there will always be present small discrepancies between repeated observations of the same quantity.

It is necessary first to consider in a general way the various kinds of error which occur in practice; they may be roughly divided into four categories (Hirvonen, 1971):

(1) blunders

(2) constant errors

(3) systematic errors

(4) accidental or random errors.

Blunders or mistakes are a definite misreading of whatever scale is being used. All observing procedures are designed to show up this form of mistake by a sufficient number of repetitions, in which the conditions such as the initial reading are changed for each repetition.

Blunders can also be checked for by providing extra degrees of freedom. In the case of calculating X-Y coordinates for the apex of a triangle from two interior angles and a known baseline, a unique answer results. It is possible, however, that one of the angles was consistently misread. This yields a wrong answer for the coordinates, but there is no way to check it. In this case there are zero degrees of freedom, i.e., no redundant information. If an additional quantity such as the third angle or a side was measured, two unique answers for the coordinates can be calculated. In this case there is one degree of freedom. Degrees of freedom are calculated by subtracting the unknowns (e.g., X-Y coordinates) from the knowns (e.g., angle and side measurements). If the two answers did not agree, then a blunder exists in one of the measurements.

Constant errors are those which do not vary throughout the particular work concerned. These errors are always of the same sign. If a tape is not standardized, and is used for measuring a distance, it introduces a constant error (i.e., assuming no alternation in tape length during the survey). Constant errors are usually associated with

EDM equipment. Reflector constants, zero constants and instrument constants must be evaluated on a known baseline prior to use in the field.

Systematic errors are those which follow some fixed law (i.e., possibly unknown) dependent on the local circumstances. If a temperature correction is neglected in traverse work a systematic error is introduced. Most EDM equipment requires that a temperature correction be applied to the measured distance. These corrections should be made in the field to avoid their omission. Since some systematic errors are impossible to detect, it is advisable to use the same procedures in setting up, etc., to duplicate the field conditions of the last measurement. Using this procedure the successive measurements are relative to the same set of conditions because the systematic errors will remain approximately constant.

Accidental or random errors are the remaining small errors after all the others just mentioned have been eliminated. They are due to imperfections of the instruments, the fallibility of the observer, the changing conditions, set up error, pointing error, etc., all of which affect the quality of the observation. It has been hypothesized that random errors are usually small, can be either positive or negative and follow a normal distribution (Rainsford, 1957).

3.3 Least Square Adjustments

The question most often surrounding survey adjustments is what is to be adjusted? The short answer is that an adjustment of errors is required.

The least squares theory is based upon the theoretical normal distribution of random errors, and is the best presently known method of determining the most probable value. In general, the object of least squares is:

(1) to produce unique values for the unknown,

(2) which will be of maximum probability and,

(3) to indicate the precision with which the unknowns have been determined.

To illustrate, let us consider the example discussed earlier. The X-Y coordinates of the apex in a triangle are to be determined knowing the base line distance, two interior angles and one side. There is one degree of freedom, hence, two unique answers can be calculated using various combinations of angle and side relationships. Using a least square adjustment, only one unique answer results and it is the most probable answer.

3.3.1 Application of Least Squares Theory

For n observed values x, the mean $\overline{x}$ can be defined as,

$$\overline{x} = (x_1 + x_2 + \ldots + x_n)/n$$

The residual v can then be defined as:

$$v_i = \overline{x} - x_i \qquad (1)$$

On the assumption that the mean is the best value for a set of observations, it can then be shown that:

$$[vv] = \text{minimum} \qquad (2)$$

The square brackets denote summation, and equation (2) is called the Gaussian condition of least squares: the sum of the squares of the residuals will be a minimum on the assumption that the mean is the best value.

Recalling (1) and expanding,

$$v_i = \overline{x} - x_i \qquad (1)$$

$$\therefore v_1 = \bar{x} - x_1$$

$$v_2 = \bar{x} - x_2$$

$$\cdot$$

$$\cdot$$

$$v_n = \bar{x} - x_n \qquad (3)$$

Equations (3) are called observation equations. The residuals, v_i, are expressed as functions of the measurements themselves, x_i, and the mean $\bar{x}$. The condition of least squares is applied by differentiating with respect to the mean and setting the result equal to zero.

$$\therefore \frac{d[vv]}{d\bar{x}} = \bar{x} - x_1 + \bar{x} - x_2 + \ldots \bar{x} - x_n$$

$$= n\bar{x} - x_1 - x_2 - \ldots x_n = 0 \qquad (4)$$

Equation (4) is known as a normal equation. For a complex series of measurements (i.e., a triangulation - trilateration network), the observation equations must be formed, and the normal equations then developed by differentiation of [vv] with respect to each parameter on the right hand side of the observation equations and setting equal to zero. These are solved simultaneously in order to arrive at the best set of parameters that will make [vv] a minimum. However, certain systematic procedures tend to simplify the operations, as will be shown later.

3.3.2 Direct and Indirect Observations

The least squares condition can be applied to a set of measurements by two different methods. The first method is called the method of direct observations (i.e., method of conditions or correlates). This method takes advantage of a priori conditions which must be imposed on the residuals. Such an a priori condition is the prior knowledge that the sum of three angles in a plane triangle must be 180 degrees. The second method is the method of indirect observations. This might be a case in which the coordinates of a point are not measured directly, but are functions of observed angles and distances.

In general, the method of condition equations is best used for adjustments of simple networks, i.e., quadrilaterals. For more complicated networks, this method becomes extremely complex and difficult to use, and is not easily applicable to a computer program. As a result, a more convenient method which is based on the method of indirect observations will be used. This method is called variation of coordinates or variation of parameters.

3.4 Formulation of Observation Equations

3.4.1 Variation of Coordinates for X-Y Coordinate Systems

In the adjustment of a triangulation (or trilateration) network by observation equations, a set of approximate X and Y coordinates is first computed for each new station. These approximate coordinates are then allowed to vary by small amounts, ΔX and ΔY, in such a way that the computed values of the ΔX's and ΔY's make the weighted sum of the squares of the corrections to the measurements a minimum. (The concept of weighting will be discussed later).

Each measured angle in a triangulation net involves three points in the net. These are the 'at' station designated A, the 'from' station designated F, and the 'to' station designated T (see Figure 3.1). The form of the observation equation that expresses the correction "v" to a measured angle as a function of the variations ΔX and ΔY of the triangulation stations can be developed in a number of different ways.

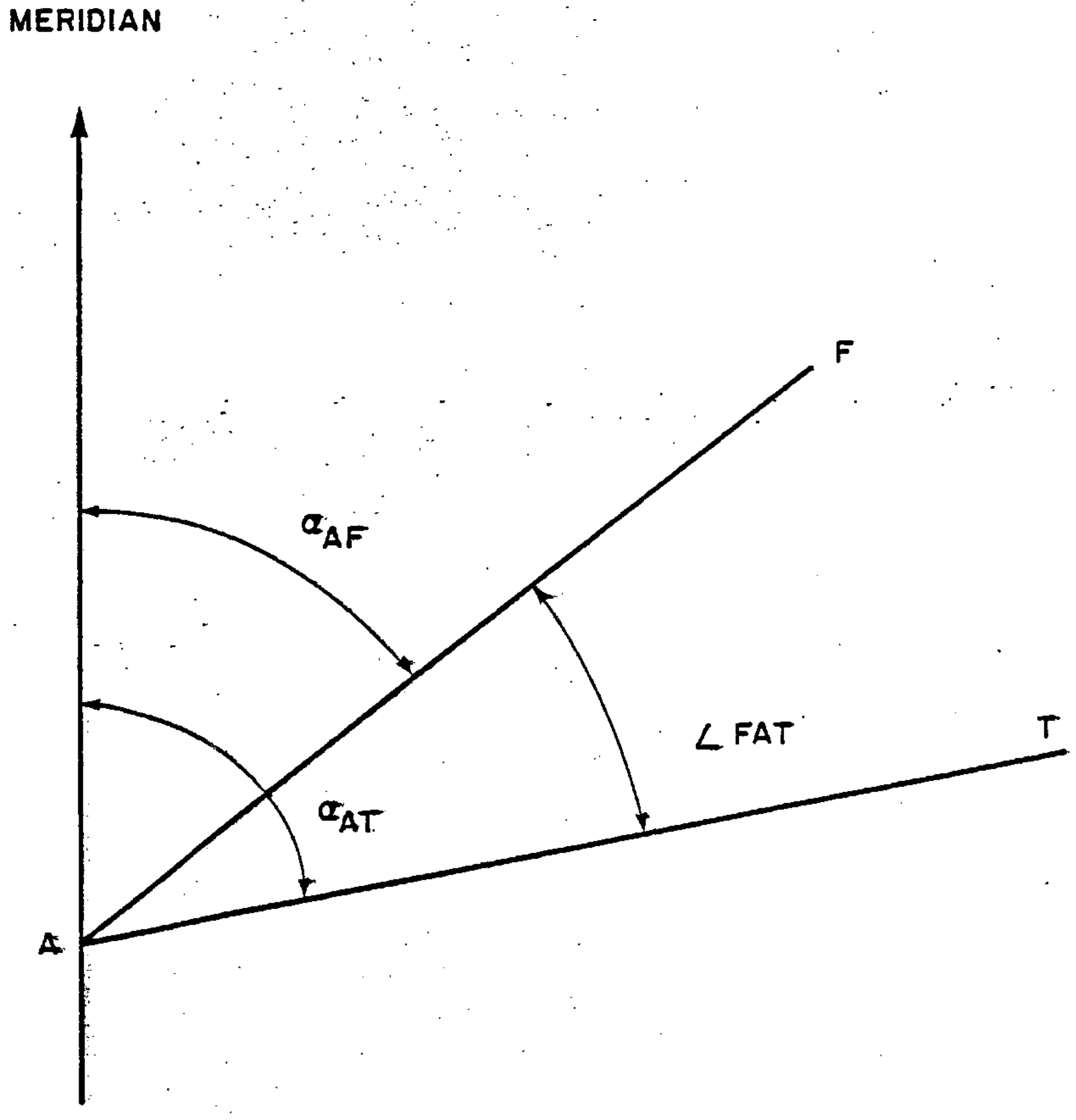


FIGURE 3.1 ANGLE AS DIFFERENCE IN AZIMUTHS

The development presented here is trignometric in nature, (Moffitt and Bouchard, 1975).

The angle ∠FAT in Figure 3.1 is equal to the azimuth of the line AT minus the azimuth of the line AF.

Stated as an observation equation,

$$\angle FAT + v_A = \alpha_{AT} - \alpha_{AF} \tag{5}$$

where:

∠FAT is the measured angle at A from F to T. (clockwise)

v_A = correction to the angle at A. (residual)

α_{AF} = adjusted azimuth of AF.

α_{AT} = adjusted azimuth of AT.

The adjusted azimuths are obtained by applying corrections $\Delta\alpha_{AF}$ and $\Delta\alpha_{AT}$ to preliminary azimuths obtained from the approximate coordinates of the stations.

Thus:

$$\alpha_{AF} = \alpha'_{AF} + \Delta\alpha_{AF} \tag{6}$$

and (5) can be written,

$$v_A = \Delta\alpha_{AT} - \Delta\alpha_{AF} + [\alpha'_{AT} - \alpha'_{AF} - \angle FAT]$$

$$\therefore v_A = \Delta\alpha_{AT} - \Delta\alpha_{AF} + K_A \tag{7}$$

where

$$K_A = [\alpha'_{AT} - \alpha'_{AF} - \angle FAT] = \text{(calculated)} - \text{(observed)} \tag{7.1}$$

Expressions for $\Delta\alpha_{AT}$ and $\Delta\alpha_{AF}$ can be developed geometrically from Figure 3.2 and Figure 3.3.

From Figure 3.2, the small distance ρ_A between the preliminary line A'F' and the final line AF is expressed as:

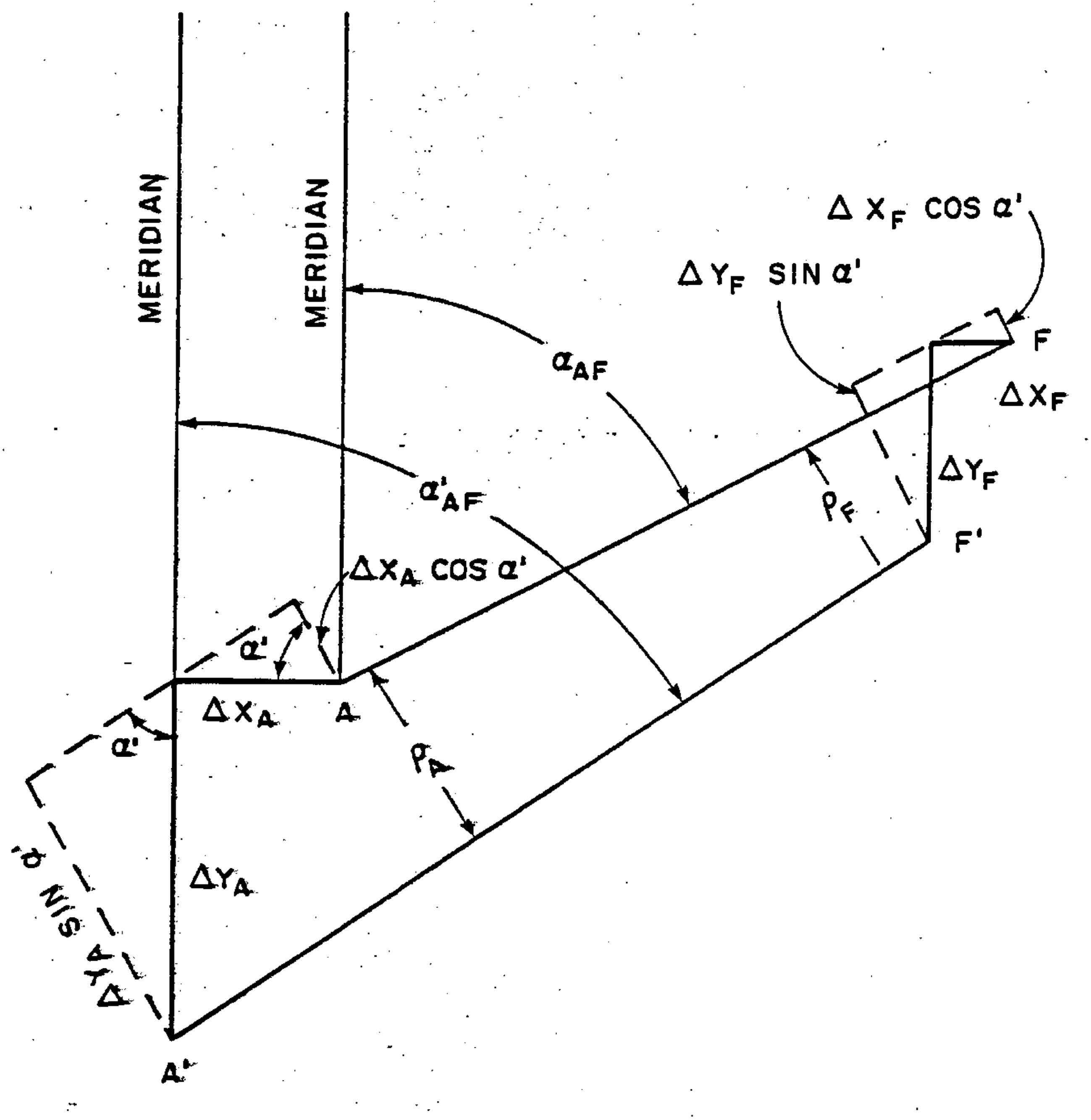


FIGURE 3.2 CHANGE IN AZIMUTH AS FUNCTION OF CHANGE IN COORDINATES

$$\rho_A = \Delta Y_A \sin \alpha'_{AF} - \Delta X_A \cos \alpha'_{AF} \tag{8}$$

and the small distance ρ_F at the other end of the line is

$$\rho_F = \Delta Y_F \sin \alpha'_{AF} - \Delta X_F \cos \alpha'_{AF} \tag{9}$$

If the line AF is imagined to be moved parallel with itself to make A coincide with A', the results are shown in Figure 3.3. Thus the small angle $\Delta\alpha_{AF}$ can be expressed as:

$$\Delta\alpha_{AF} = \frac{\rho_A - \rho_F}{AF \text{ arc } 1''} \tag{10}$$

Letting

$$P = \frac{1}{\text{arc } 1''} = 206264.8 \text{ seconds/radian}$$

$$\Delta\alpha_{AF} = \frac{P}{AF} (\rho_A - \rho_F) \tag{11}$$

Substituting equations (8) and (9) into (11),

$$\Delta\alpha''_{AF} = \frac{-P \cos \alpha'_{AF}}{AF} \Delta X_A + \frac{P \sin \alpha'_{AF}}{AF} \Delta Y_A$$

$$+ \frac{P \cos \alpha'_{AF}}{AF} \Delta X_F - \frac{P \sin \alpha'_{AF}}{AF} \Delta Y_F \tag{12}$$

By the same geometrical analysis an expression for $\Delta\alpha_{AT}$ can be developed in terms of the variation of the coordinates of A and T, giving

$$\Delta\alpha''_{AT} = \frac{-P \cos \alpha'_{AT}}{AT} \Delta X_A + \frac{P \sin \alpha'_{AT}}{AT} \Delta Y_A$$

$$+ \frac{P \cos \alpha'_{AT}}{AT} \Delta X_T - \frac{P \sin \alpha'_{AT}}{} \Delta Y_T \tag{13}$$

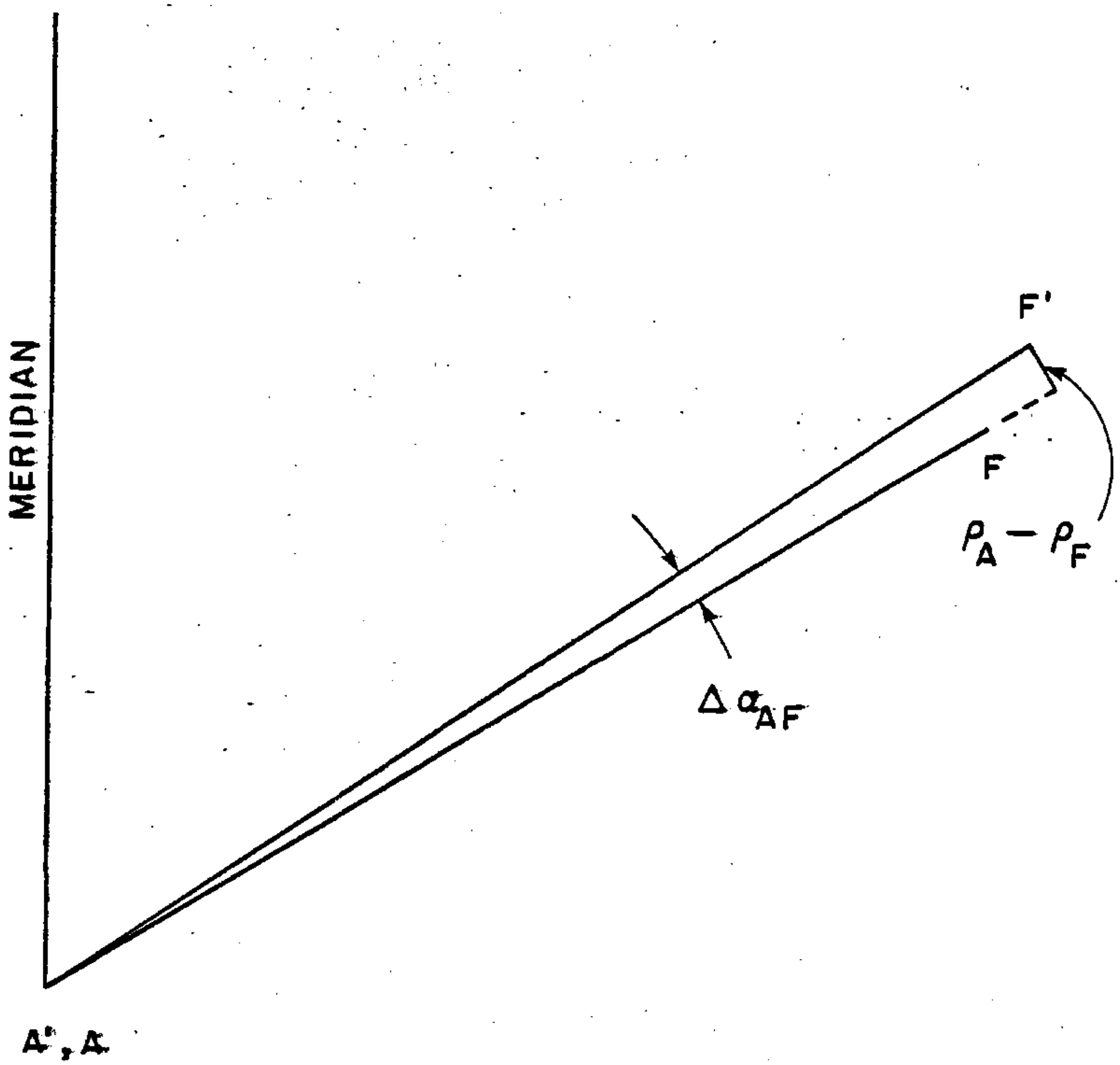


FIGURE 3.3 CHANGE IN PRELIMINARY AZIMUTH

The observation equation for angle FAT is obtained in its final form by substituting the value of $\Delta\alpha_{AF}$ from equation (12) and $\Delta\alpha_{AT}$ from equation (13) into equation (7), giving

$$v_A = \frac{P \cos \alpha'_{AF}}{AF} \Delta X_A - \frac{P \sin \alpha'_{AF}}{AF} \Delta Y_A - \frac{P \cos \alpha'_{AF}}{AF} \Delta X_F$$

$$+ \frac{P \sin \alpha'_{AF}}{AF} \Delta Y_F - \frac{P \cos \alpha'_{AT}}{AT} \Delta X_A + \frac{P \sin \alpha'_{AT}}{AT} \Delta Y_A$$

$$+ \frac{P \sin \alpha'_{AT}}{AT} \Delta Y_A + \frac{P \cos \alpha'_{AT}}{AT} \Delta X_T - \frac{P \sin \alpha'_{AT}}{AT} \Delta Y_T + K_A \tag{14}$$

By applying the same principles, an observation equation can be found for distance measurements:

$$v_A = - \sin \alpha'_{AT} \Delta X_A - \cos \alpha'_{AT} \Delta Y_A + \sin\alpha'_{AT} \Delta X_T$$

$$+ \cos \alpha'_{AT} \Delta Y_T + K_A \tag{15}$$

Each independent measured angle or side will introduce an observation equation of the form given by equations (14) and (15). These are then reduced by special methods in order to make the weighted sum of squares of the residuals a minimum. It should be noted that if a station is fixed (i.e., errorless), the respective ΔX's and ΔY's will be zero.

3.4.2 Level Networks - Z Coordinate Systems

In the adjustment of a leveling network by observation equations, a set of approximate Z coordinates is first computed for each new station. These approximate coordinates are then allowed to vary by small amounts, Δz, in such a way that the computed values of the Δz's make the weighted sum of the squares of the corrections to the measurements a minimum.

Each measured link in a level net involves two stations in the net. These are the "from" station designated F, and the "to" station designated T, (see Figure 3.4). The form of the observation equation that expresses the correction "v" to a measured link as a function of the variations, Δz, of the stations can be developed using a trigonometric approach, (Moffitt and Bouchard, 1975). Stated as an observation equation:

$$DE_{FT} + V_{FT} \doteq \text{Adj. elev. T} - \text{Adj. elev. F} \qquad (16)$$

where

DE_{FT} = observed difference in elevation from F to T.

V_{FT} = correction to DE_{FT}.

The adjusted elevations are obtained by applying corrections, Δz, to the preliminary elevations. Thus:

$$\text{Adj. elev. F} = \text{Preliminary elev. F} + \Delta Z_F$$

$$\text{Adj. elev. T} = \text{Preliminary elev. T} + \Delta Z_T$$

Equation (16) can now be rewritten

$$V_{FT} = (\text{Prelim. elev.}_T + \Delta Z_T) - (\text{Prelim. elev. F} + \Delta Z_F) - DE_{FT}$$

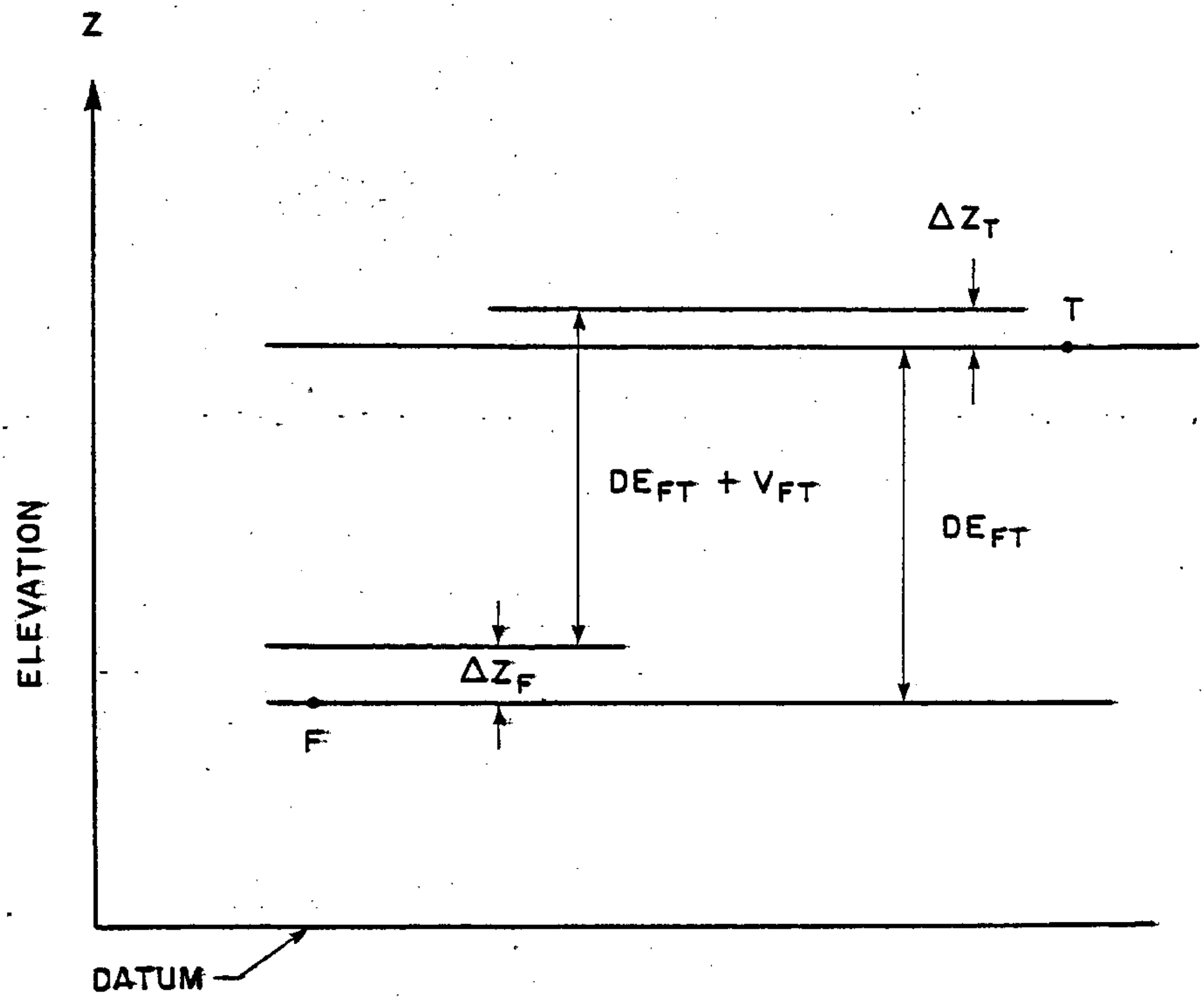


FIGURE 3.4 CHANGE IN DIFFERENCE IN ELEVATION AS A FUNCTION OF CHANGE IN ELEVATION

or $$V_{FT} = \Delta Z_T - \Delta Z_F + K_{FT} \qquad (17)$$

where

$$K_{FT} = \text{Prelim. elev. T} - \text{Prelim. elev. F} - DE_{FT} \qquad (18)$$

Each independent measured link will introduce an observation equation of the form given by equation (17). It should be noted that if the elevation of a station is fixed (i.e., errorless), the respective ΔZ will be zero.

3.5 Weights

The weight of a measurement can be thought of as the value or worth of that measurement relative to any other measurement. By definition, the weight "p" is taken to be inversely proportional to the variance, σ^2,

$$p = K/\sigma^2 \qquad (19)$$

where σ is the standard deviation (or standard error) of the respective measurement and K is any convenient constant. σ can be 1) approximated, (i.e., knowing that a theodolite reads with a 10 second accuracy) or 2) actually calculated from a series of measurements by the well known statistical formula:

$$\sigma = \sqrt{\frac{([\bar{x} - x_i])^2}{n - 1}} \qquad (20)$$

In an actual network, σ for angles is expressed in seconds and σ for sides in ppm (parts per million). To ensure compatability between the two different units, a special relationship is required. Figure 3.5 shows the relationship between an angle and two adjacent sides. From $s = r\theta$; let θ equal 1 second expressed in radians.

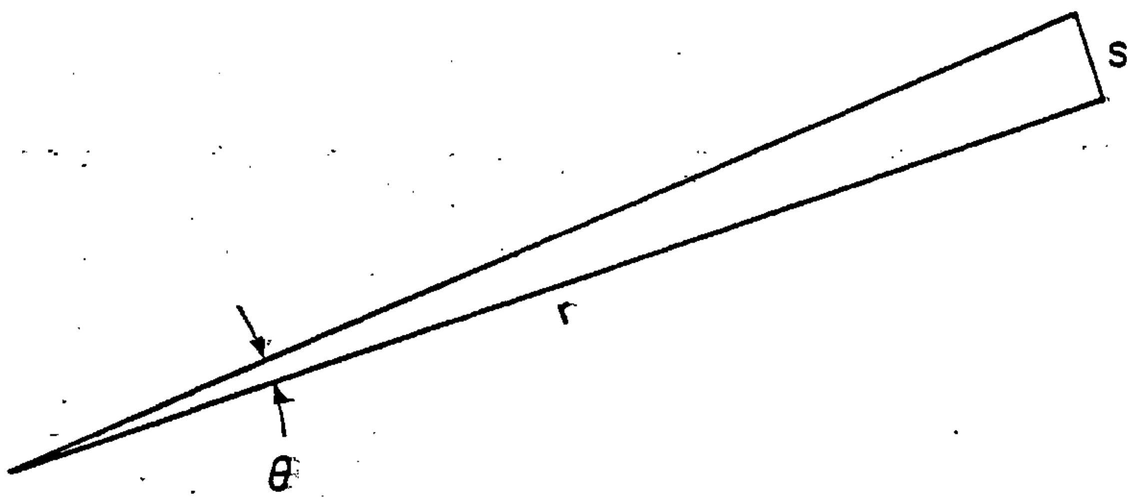


FIGURE 3.5 INCLUDED ANGLE

$$\therefore \; s = r(\frac{1''}{60 \times 60} \times \frac{\pi}{180}) = 4.848 \times 10^{-6} \, r$$

Thus for an angle of 1 second, the arc s equals 4.848 ppm of r. It can then be found that for angles, (McLellan, Peterson and Katinas, 1970):

$$P_a = (K/\sigma)^2; \; \sigma \text{ in seconds} \qquad (21)$$

and for sides

$$P_s = (4.848 \; K/\sigma)^2; \; \sigma \text{ in ppm} \qquad (22)$$

For measurements in which σ is calculated from equation (2), K equals 1. For measurements in which σ is estimated, K has to be determined by the surveyor. For example, if a network consists of 2 angles, one measured 2 times and the other measured 4 times (i.e. both with the same instrument), K would be 2 and 4 respectively. If such a clear cut relationship does not exist, K should be set equal to 1. In other words, K is just a relative weighting factor.

The weights for links in level networks can also be taken as:

$$P_L = K/\sigma_L^{\,2}$$

where:

σ_L = standard deviation of observed difference in elevation.

If σ_L cannot be determined, an estimate such as:

P_L = 1/# of setups

or P_L = 1/distance between stations (23)

can be used.

The weights for direction measurements are much more complex and will be discussed later.

3.6 Matrix Methods

For a complex network, the large number of simultaneous equations that have to be solved are best handled in a systematic manner with matrices.

The observation equations (14) and (15) can be written in matrix form as,

$$V = AX + K \tag{24}$$

The least squares condition from equation (2) can also be shown to apply if the weighting system of section 3.5 is considered. Thus,

$$[pvv] = \text{minimum}$$

or in matrix form

$$V^T PV = \text{minimum} \tag{25}$$

By substituting for V from equation (24) into equation (25), differentiating, and setting equal to zero,

$$X = -A^T PK\ (A^T PA)^{-1} \tag{26}$$

The values of X are the corrections ΔX and ΔY to the preliminary coordinates, the A matrix is the matrix of coefficients from the elements of the observation equations (14), (15) and (17). There is one equation for each independent measurement. The P matrix is a square diagonal weight matrix, and K is a column matrix of the K values from equations (14), (15) and (17).

For n observations and m unknowns, A will be of the order n x m, P will be of the order n x n, K is a column matrix n x 1 and X is a column matrix m x 1.

3.7 Error Ellipses

At each station in the network we will have a standard deviation in the X and Y direction after adjustment, (see Figure 3.6).

The standard errors can be said to describe a rectangle:

$$X_A - \sigma_X < X < X_A + \sigma_X$$

$$Y_A - \sigma_Y < Y < Y_A + \sigma_Y$$

around this point. In this way we have a rough illustration about the two dimensional dispersion of the possible locations for our point.

In a mathematical idealization, however, the rectangle is replaced by an ellipse to which the sides of the rectangle are tangents. In fact, there are several possible ellipses inside such a rectangle, each having different directions as main axes.

To find the error ellipse which is a maximum, the basics of error propagation can be used.

Let x,y be a two dimensional stochastic variable and u=f(x,y) a mathematical function representing a one dimensional variable:

$$U_t = f(X_t, Y_t)$$

From the basic principle of error propagation we can write, (Hirvonen, 1971):

$$\delta_u = \varepsilon_x \frac{\partial u}{\partial x} + \varepsilon_y \frac{\partial u}{\partial y} \qquad (27)$$

where

δu = errors of u

and ε = errors of x and y (i.e. $\varepsilon_i = x_i - \bar{x}$)

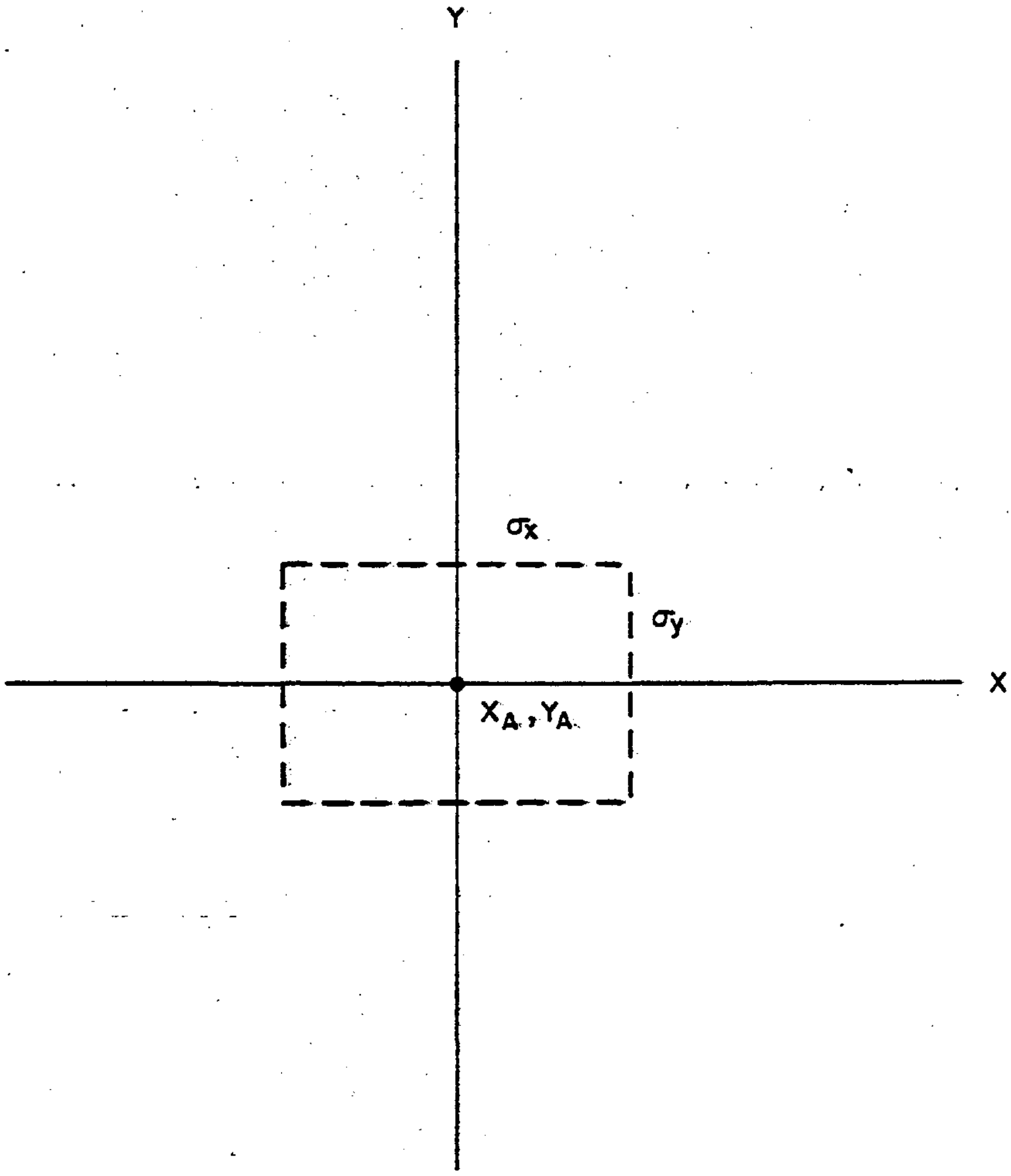


FIGURE 3.6 ERROR RECTANGLE ABOUT A POINT

Squaring equation (27) yields:

$$\delta u_i^{\,2} = \varepsilon_{x_i}\varepsilon_{x_i}(\frac{\partial u}{\partial x_i})^2 + 2\varepsilon_{x_i}\varepsilon_{x_i}\frac{\partial u}{\partial x_i}\frac{\partial u}{\partial y_i}$$

$$+ \varepsilon_{y_i}\varepsilon_{y_i}(\frac{\partial u}{\partial y_i})^2 \tag{28}$$

Also by definition:

$$\sigma_x^{\,2} = \lim_{n \to \infty} \frac{[\varepsilon_x \varepsilon_x]}{n}; \quad \sigma_y^{\,2} = \lim_{n \to \infty} \frac{[\varepsilon_y \varepsilon_y]}{n}$$

where

σ^2 = variance

and $\sigma_{xy} = \lim\limits_{n \to \infty} \frac{[\varepsilon_x \varepsilon_y]}{n}$

where σxy = covariance.

If equation (28) is summed from i=1 to n, and substituting for the variance and covariance:

$$\sigma_u^{\,2} = \sigma_x^{\,2}(\frac{\partial u}{\partial x})^2 + \sigma_y^{\,2}(\frac{\partial u}{\partial y})^2 + 2\sigma_{xy}\frac{\partial u}{\partial x}\frac{\partial u}{\partial x} \tag{29}$$

Equation (29) is referred to as the error propagation equation.

The next step is to perform an orthogonal transformation of the parameters (i.e., rotation of coordinate axes). For a 2-D case we have simply:

$$u = x \cos t + y \sin t \tag{30}$$

$$v = y \cos t + x \sin t \tag{31}$$

where t = the direction angle of the u-axis in the x-y system measured from the x-axis.

Applying the error propagation equation (29) to the transformation equation (30), we can write

$$\sigma_u^2 = \sigma_x^2 \cos^2 t + \sigma_y^2 \sin^2 t + 2\sigma_{xy} \sin t \cos t$$

recalling

$$\sin 2t = 2\sin t \cos t$$
$$\cos 2t = \cos^2 t - \sin^2 t$$
$$1 = \cos^2 t + \sin^2 t$$

$$\sigma_u^2 = \sigma_x^2 \cos^2 t + \sigma_y^2 \sin^2 t + \sigma_{xy} \sin 2t$$
$$= \frac{\sigma_x^2}{2}(1 + \cos 2t) + \frac{\sigma_y^2}{2}(1 - \cos 2t) + \sigma_{xy} \sin 2t$$

$$\therefore \quad \sigma_u^2 = \frac{1}{2}(\sigma_x^2 + \sigma_y^2) + \frac{1}{2}(\sigma_x^2 - \sigma_y^2)\cos 2t + \sigma_{xy} \sin 2t \quad (32)$$

The maximum σ^2 occurs when the first derivative equals zero. Thus,

$$\frac{2\sigma_u^2}{\partial_t} = (\tfrac{1}{2})(\sigma_x^2 - \sigma_y^2)(2)(-\sin 2t) + 2\sigma_{xy}\cos 2t = 0$$

$$\therefore \quad 2\sigma_{xy}\cos 2t = (\sigma_x^2 - \sigma_y^2)\sin 2t$$

$$\therefore \quad \tan 2t = \frac{\sin 2t}{\cos 2t} = \frac{2\sigma_{xy}}{(\sigma_x^2 - \sigma_y^2)} \quad (33)$$

By definition

$$\tan 2t = \frac{y}{x} = \frac{2\sigma_{xy}}{(\sigma_x^2 - \sigma_y^2)}$$

$$r = \sqrt{x^2 + y^2} = \sqrt{(\sigma_x^2 - \sigma_y^2)^2 + 4\sigma_{xy}}$$

Therefore

$$\sin 2t = \frac{y}{r} = \frac{2\sigma_{xy}}{r} \quad (34)$$

$$\cos 2t = \frac{x}{r} = \frac{(\sigma_x^2 - \sigma_y^2)}{r} \quad (35)$$

Substituting (34) and (35) into (32) yields

$$\sigma_u^2 = \frac{1}{2}(\sigma_x^2+\sigma_y^2) + \frac{\frac{1}{2}(\sigma_x^2-\sigma_y^2)(\sigma_x^2-\sigma_y^2)}{r} + \frac{2\sigma_{xy}2\sigma_{xy}}{r}$$

and substituting for r

$$\sigma_u^2 = \frac{1}{2}(\sigma_x^2+\sigma_y^2) + \frac{1}{2}\frac{(\sigma_x^2-\sigma_y^2)^2 + 4\sigma_{xy}^2}{\sqrt{(\sigma_x^2-\sigma_y^2)^2 + 4\sigma_{xy}^2}}$$

$$\therefore \quad \sigma_u^2 = \frac{1}{2}\left(\sigma_x^2+\sigma_y^2+\sqrt{(\sigma_x^2-\sigma_y^2)^2 + 4\sigma_{xy}^2}\right) \qquad (36)$$

and similarly

$$\sigma_v^2 = \frac{1}{2}\left(\sigma_x^2+\sigma_y^2-\sqrt{(\sigma_x^2-\sigma_y^2)^2 + 4\sigma_{xy}^2}\right) \qquad (37)$$

where

σ_u = semi major axis

σ_v = semi minor axis

t = orientation of major axis

Equations (33), (36) and (37) can be used to find the maximum error ellipse relative to fixed points in the net. The error ellipse relative to a fixed (i.e., errorless) point is called an absolute error ellipse. Error ellipses between any two points in the net are called relative error ellipses because the standard deviations of both stations are considered in the calculations.

In summary:

for absolute error ellipses, relative to fixed points in the net:

$$\text{Tan } 2t = \frac{2\sigma_{xy}}{\sigma_y^2 - \sigma_x^2} \tag{33}$$

$$\sigma^2_{max} = \frac{1}{2} [\sigma_x^2 + \sigma_y^2 + \sqrt{(\sigma_y^2 - \sigma_x^2)^2 + 4\sigma_{xy}^2}] \tag{36}$$

$$\sigma^2_{min} = \frac{1}{2} [\sigma_x^2 + \sigma_y^2 - \sqrt{(\sigma_y^2 - \sigma_x^2)^2 + 4\sigma_{xy}^2}] \tag{37}$$

and for relative error ellipses, between any two points in the net:

$$\text{Tan } 2t = \frac{2\sigma_{\Delta X \Delta Y}}{\sigma_{\Delta Y \Delta Y} - \sigma_{\Delta X \Delta X}} \tag{38}$$

$$\sigma^2_{max} = \frac{1}{2} [\sigma_{\Delta X \Delta X} + \sigma_{\Delta Y \Delta Y} + \sqrt{(\sigma_{\Delta Y \Delta Y} - \sigma_{\Delta X \Delta X})^2 + 4\sigma^2_{\Delta X \Delta Y}}] \tag{39}$$

$$\sigma^2_{min} = \frac{1}{2} [\sigma_{\Delta X \Delta X} + \sigma_{\Delta Y \Delta Y} - \sqrt{(\sigma_{\Delta Y \Delta Y} - \sigma_{\Delta X \Delta X})^2 + 4\sigma^2_{\Delta X \Delta Y}}] \tag{40}$$

where

$$\sigma_{\Delta X \Delta X} = \sigma_{x_j x_j} - 2\sigma_{x_i x_j} + \sigma_{x_i x_i}$$

$$\sigma_{\Delta Y \Delta Y} = \sigma_{y_j y_j} - 2\sigma_{y_i y_i} + \sigma_{y_i y_i}$$

$$\sigma_{\Delta X \Delta Y} = \sigma_{x_j y_j} - \sigma_{x_j y_i} - \sigma_{x_i y_j} + \sigma_{x_i y_i}$$

The probability of a point falling within the error ellipse is 39%. In order to obtain other probabilities, the major and minor axes of the error ellipse have to be multiplied by the factor C presented in Table 3.1, (Uotila, 1973).

Table 3.1: Probability Factors for Error Ellipses

Probability	C
25%	0.76
39%	1.00
50%	1.18
75%	1.66
90%	2.15
95%	2.45
99%	3.03

A sketch of the error ellipse is presented in Figure 3.7. The "ideal" two dimensional error ellipse is a circle in which $\sigma_{max} = \sigma_{min}$.

When the third dimension (i.e., Z-coordinate) is established by leveling, the standard deviations of the adjusted elevations can be combined with the two dimensional error ellipse to form an error elliptical cylinder. This volume results because the Z-coordinate is independent from the determination of the X and Y coordinates. If the X-Y-Z coordinates are interdependent (e.g., elevation determined by vertical angle measurement) the resultant volume would be an error ellipsoid. This thesis will deal with the mathematics of the error elliptical cylinder.

The specifications put forth by the Horizontal Control Section are based on the 95% error ellipse. The two dimensional error

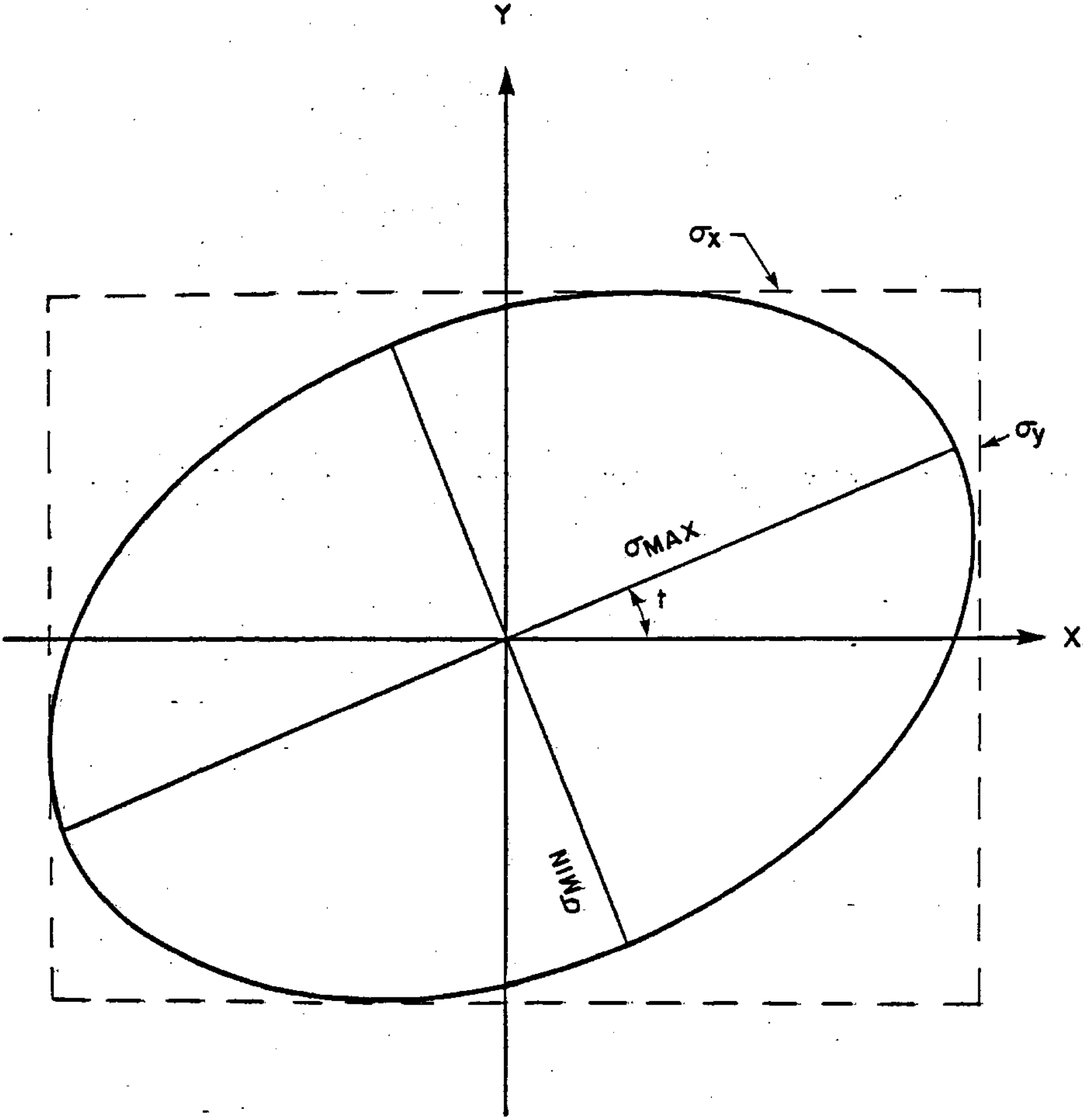


FIGURE 3.7 ERROR ELLIPSE

ellipse for 95% probability is obtained by multiplying the major and minor axes by 2.45 (see Table 3.1). To obtain the 95% probability interval for the Z-coordinates, we multiply σ_z by 1.96 (Aguilar, 1973). This results in an error elliptical cylinder for 95% probability as shown in Figure 3.8.

Of interest at this point is the resultant matrix $(A^TPA)^{-1}$ from equation (26). This resultant matrix is known as the weight coefficient matrix:

$$(A^TPA)^{-1} = \begin{bmatrix} Q^2_{X1} & Q_{X1Y1} & Q_{X1X2} & Q_{X1Y2} & \cdots \\ Q_{X1Y1} & Q^2_{Y1} & Q_{Y1X2} & Q_{Y1Y2} & \cdots \\ Q_{X1X2} & Q_{Y1X2} & Q^2_{X2} & Q_{X2Y2} & \cdots \\ Q_{X1Y2} & Q_{Y1Y2} & Q_{X2Y2} & Q^2_{Y2} & \cdots \\ \vdots & \vdots & \vdots & \vdots & \end{bmatrix}$$

Hirvonen, 1971, has shown that the variance-covariance matrix can be found by multiplying the weight coefficient matrix by the variance of unit weight, σ_o^2:

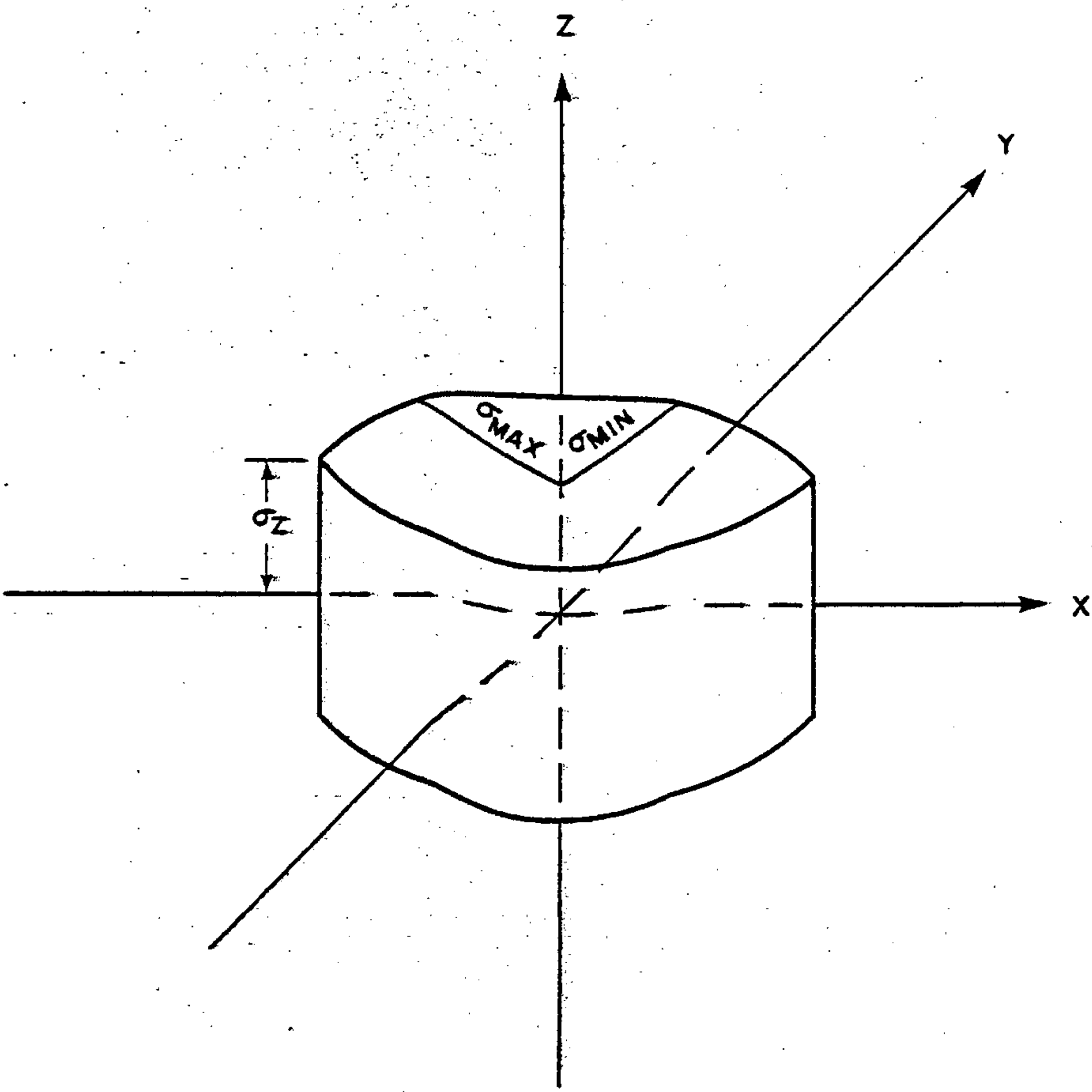


FIGURE 3.8 ERROR ELLIPTICAL CYLINDER

$$\sigma_o^2(A^TPA)^{-1} = \begin{bmatrix} \sigma_{X1}^2 & \sigma_{X1Y1} & \sigma_{X1X2} & \sigma_{X1Y2} & \cdots \\ \sigma_{X1Y1} & \sigma_{Y1}^2 & \sigma_{Y1X2} & \sigma_{Y1Y2} & \cdots \\ \sigma_{X2X1} & \sigma_{X2Y1} & \sigma_{X2}^2 & \sigma_{X2Y2} & \cdots \\ \sigma_{Y2X1} & \sigma_{Y2Y1} & \sigma_{Y2X2} & \sigma_{Y2}^2 & \cdots \\ \vdots & \vdots & \vdots & \vdots & \end{bmatrix}$$

where

$$\sigma_o^2 = \frac{V^TPV}{n-u} = \frac{[PVV]}{n-u}$$

and n = # of observations
u = # of unknowns

hence n-u = degrees of freedom.

The standard error of unit weight, σo, is simply the standard error of an observation that has a weight of unity (i.e., one).

The diagonal elements of the matrix are the variances, σ^2, of the coordinates after their adjustment, and the remaining elements are covariances, which are a measure of the correlations between the adjusted coordinates. From the elements of the variance - covariance matrix, the error ellipse at a station can be found using equations (33), (36) and (37) or (38), (39) and (40).

By examining $(A^TPA)^{-1}$, it can be seen that the error ellipse depends on the A matrix and P matrix only. Thus approximate error ellipses for a station can be found by using approximate values for coordinates and reasonable estimates of the standard errors for the measurements, (McLennan, Peterson and Katinas, 1970).

3.8 Centering Error

Centering error refers to the error arising when setting up an instrument over a point. For example, Chrzanowski (1977), estimates centering error for optical plummets as ±0.5 mm/m. For example, if the height of a plummet is 2.0 metres above a point, the centering error is ±1.0 mm.

In terms of surveying adjustments, the effect of centering error is to increase the standard deviation of an observed angle, direction or side measurement.

The relationship between the actual standard deviation and the additional effect due to centering error can be derived from the equation of error propagation:

$$\sigma_u^2 = \left(\frac{\partial u}{\partial x}\right)^2 \sigma_x^2 + \left(\frac{\partial u}{\partial y}\right)^2 \sigma_y^2 + \left(\frac{\partial u}{\partial x}\right)\left(\frac{\partial u}{\partial y}\right)\sigma_{xy} \qquad (29)$$

We can assume that all $\sigma xy = 0$, since the centering errors at different stations are independent.

For the angle shown in Figure 3.9 we can write:

$$\theta = \alpha_{AY} - \alpha_{AF}$$

where a_{AT} = azimuth of line AT

and a_{AF} = azimuth of line AF

By definition:

$$\alpha_{AF} = \tan^{-1}\left(\frac{X_F - X_A}{Y_F - Y_A}\right)$$

and

$$\alpha_{AT} = \tan^{-1}\left(\frac{X_T - X_A}{Y_T - Y_A}\right)$$

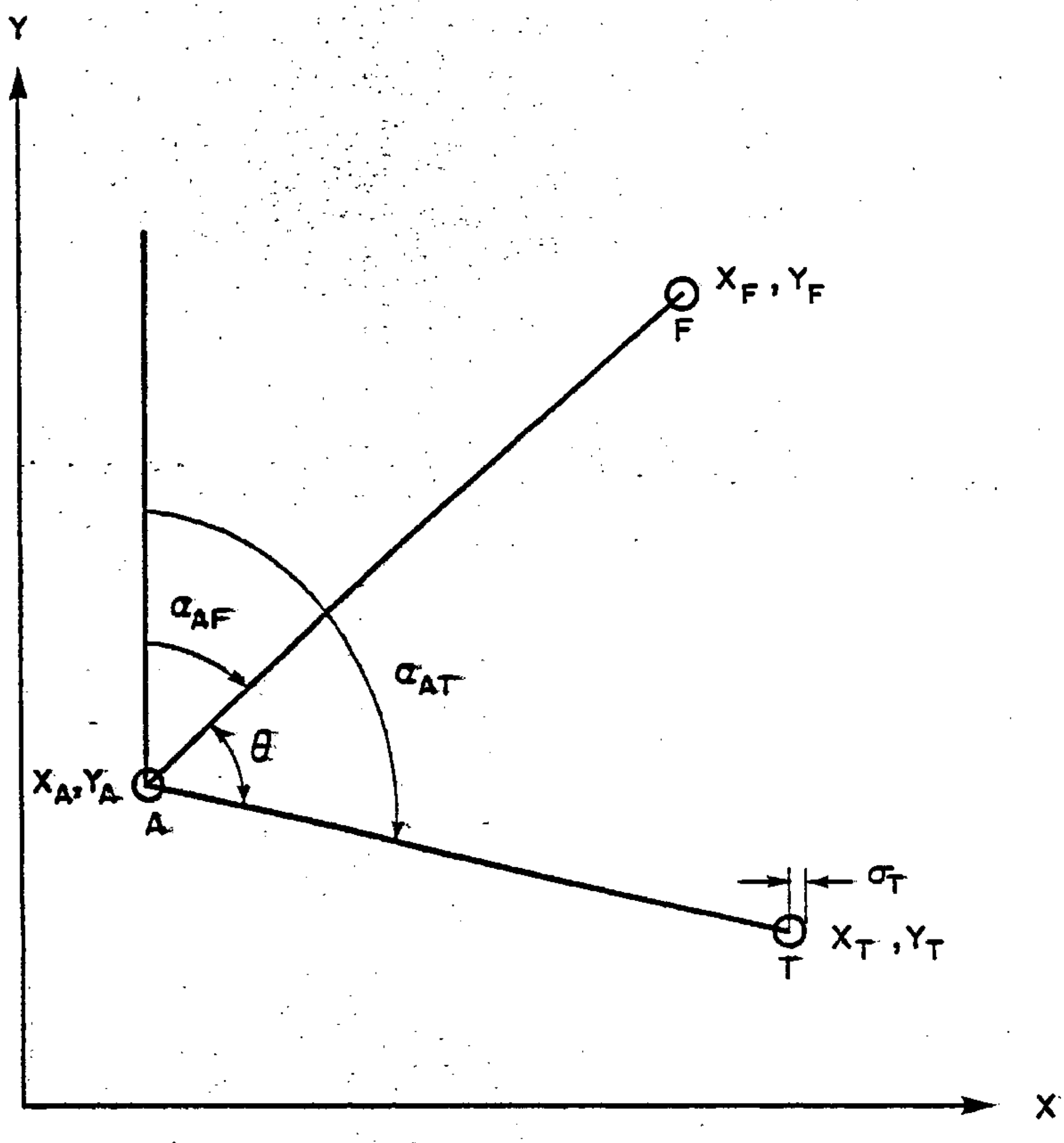


FIGURE 3.9 CENTERING ERROR FOR ANGLES

where X and Y are the horizontal cartesian coordinates of A, F and T. Substituting:

$$\theta = \tan^{-1} \left(\frac{X_T - X_A}{Y_T - Y_A}\right) - \tan^{-1} \left(\frac{X_F - X_A}{Y_F - Y_A}\right) \tag{41}$$

Applying the error propagation equation to equation (41) yields:

$$\therefore \sigma_{\theta_c}^2 = \left(\frac{\partial\theta}{\partial X_F}\right)^2 \sigma_{X_F}^2 + \left(\frac{\partial\theta}{\partial X_A}\right)^2 \sigma_{X_A}^2 + \left(\frac{\partial\theta}{\partial X_T}\right)^2 \sigma_{X_T}^2 + \left(\frac{\partial\theta}{\partial Y_F}\right)^2 \sigma_{Y_F}^2 + \left(\frac{\partial\theta}{\partial Y_A}\right)^2 \sigma_{Y_A}^2 + \left(\frac{\partial\Theta}{\partial Y_T}\right)^2 \sigma_{Y_T}^2 \tag{42}$$

where σ_{θ_C} = standard deviation due to centering error

σ_{X_F} = standard deviation of centering error

We can assume that the centering error is the same in all directions at each station:

$$\therefore \sigma_{X_F} = \sigma_{Y_F} = \sigma_F$$

$$\sigma_{X_T} = \sigma_{Y_T} = \sigma_T$$

$$\sigma_{X_A} = \sigma_{Y_A} = \sigma_A$$

Using the chain rule for differentiation and various trignometric identities, it can be shown that:

$$\sigma\theta_C^2 = \frac{\sigma_F^2 + \sigma_A^2}{AF^2} + \frac{\sigma_T^2 + \sigma_A^2}{AT^2} - \frac{2\sigma_A^2}{ATAF} \cos\theta$$

Applying the basics of error propagation again, it can be found for angles:

$$\sigma_\theta^2 = \sigma_{\theta_C}^2 + \sigma_A^2$$

where σ_A = original standard deviation of angle

and σ_θ = standard deviation of angle corrected for centering error.

Using the same rigorous approach for directions and sides it can be found that:

for directions

$$\sigma_\alpha^2 = \sigma_{\alpha_C}^2 + \sigma_D^2 \tag{43}$$

where $\sigma_{\alpha_C}^2 = \dfrac{\sigma_F^2 + \sigma_A^2}{AF^2}$ = standard deviation due to centering error

σ_D = original standard deviation of direction

σ_α = standard deviation of direction corrected for centering error

and for sides

$$\sigma_S^2 = \sigma_{AF}^2 + \sigma_L^2 \tag{44}$$

where $\sigma_{AF}^2 = \sigma_F^2 + \sigma_A^2$ = standard deviation due to centering error

σ_L = original standard deviation of side

σ_S = standard deviation of side corrected for centering error

The effects of centering error affect only the weights, thus the size of the error ellipses will increase. Stations with large centering errors will therefore play a less important role in the adjustment.

3.9 Weight Matrix for Directions

If [R] is the matrix to transform directions to angles and if $[S_d]$ and $[S_a]$ are respectively the a priori covariance matrices for a set of directions [D] and their corresponding angles [A], then

$[A] = [R][D]$

and

$$[S_a] = [R][S_d][R]^T$$

In terms of weights:

where $P = \frac{K}{S_a}$

$$[Pa] = K[Sa]^{-1}$$

$$\therefore [Pa] = ([R][P_d]^{-1}[R]^T)^{-1}$$

For a set of four directions at a station, [Pa] would be:

$$\text{Pa = inverse of } [R][Pd]^{-1}[R]^T = \overset{[R]}{\begin{bmatrix} -1 & 1 & 0 & 0 \\ 0 & -1 & 1 & 0 \\ 0 & 0 & -1 & 1 \end{bmatrix}} \overset{[Pd]^{-1}}{\begin{bmatrix} \frac{1}{P1} & 0 & 0 & 0 \\ 0 & \frac{1}{P2} & 0 & 0 \\ 0 & 0 & \frac{1}{P3} & 0 \\ 0 & 0 & 0 & \frac{1}{P4} \end{bmatrix}} \overset{[R]^T}{\begin{bmatrix} -1 & 0 & 0 \\ 1 & -1 & 0 \\ 0 & 1 & -1 \\ 0 & 0 & 1 \end{bmatrix}}$$

$$\therefore Pa = ([R][Pd]^{-1}[R]^T)^{-1} = \begin{bmatrix} (\frac{1}{P1})+(\frac{1}{P2}) & -(\frac{1}{P2}) & 0 \\ -(\frac{1}{P2}) & (\frac{1}{P2})+(\frac{1}{P3}) & -(\frac{1}{P3}) \\ 0 & -(\frac{1}{P3}) & (\frac{1}{P3})+(\frac{1}{P4}) \end{bmatrix}^{-1} \quad (45)$$

where P1, P2, P3 and P4 are weights of the independent directions. [Pa] then is the weight matrix developed for the 3 angle equations.

3.10 Reliability of Results

Since the statistical accuracy of the results depends only on the geometry and standard deviations, it is independent of the actual measurements. Thus, some way of checking the reliability of the results is required. This is accomplished by checking the magnitude of the residuals after the adjustment calculations.

During the adjustment, a unique set of coordinates is calculated for each station in the network. Based on these unique coordinates, calculated values can be obtained for all angles and sides in the network. These calculated values are the values the angles and sides have to take in order to yield the most probable coordinates. The differences between the calculated and the actual values are called the residuals. The magnitude of the residuals is checked using the well known tolerance test for 99 percent probability (Chrzanowski, 1976). If the residual is less than three times the standard deviation of the respective measurement, the measurement is reliable. If the residual is greater, the respective observation is classed as unreliable and should be deleted unless it can be determined why it is unreliable and consequently corrected. The residuals are in essence a check on how good the data fit the new adjusted coordinates.

3.11 Computer Program

A computer program to perform least squares survey adjustments was developed by Chursinoff (1978). The program was called LSQADJ, (Least SQuares survey ADJustments) and was written in Fortran IV. This original program was rewritten and greatly expanded as part of this thesis.

The revised program, LSQADJ, can compute and analyse a least squares survey adjustment on any type of horizontal or vertical survey network, real or ficticious, given adequate datum (i.e., fixed position and orientation) and enough observations to determine all points. The configuration may be a simple traverse or an intricately connected network. Observed data may be lengths, directions, angles or differences in elevation. Observations are assumed to be reduced to a cartesian X-Y coordinate system for horizontal networks or a Z-coordinate system for leveling networks.

The observation equation method derived earlier is used in LSQADJ. This method is also referred to as the variation of coordinates or parametric method, hence the phrase: parametric least squares adjustment. The user must provide fixed or preliminary coordinates for all points. The solution will pass several times, if necessary, to obtain better preliminary values for the final solution. The criterion is that the solution cycles until all corrections to coordinates are less than a preset value. The user controls both the preset value and the maximum number of passes.

LSQADJ is designed not only for adjustment and analyses of actual networks, but also for testing the strength of proposed networks by simulation. The user need only supply coordinates and ficticious data appropriately weighted. Observation values can be omitted.

LSQADJ allows for centering error corrections, relative weighting factors, calculates error ellipses at any desired station, calculates the final residuals, checks reliability of the final results and can print out any desired matrix on request. A brief flow chart of the program is presented in Figure 3.10. A complete listing of the program will be published in the CD Transportation and Geotechnical Group series at the University of Saskatchewan in early 1980.

The reliability of the program has been checked against hand calculated adjustments and various published adjustment calculations. The program LSQADJ has been found to give nearly identical answers in all cases (see Appendix F). Any discrepancy is most probably due to the fact that LSQADJ uses Fortran IV Double Precision (16 significant figures) and a minimum of two passes in its solution. The majority of published adjustments have used only one pass at solution and from 3 to 7 significant figures in the calculations. This is especially critical in the inversion of the A^TPA matrix.

Obviously the test of a program's reliability can be made by examining the final answers. In all adjustments performed in this report and outside of it, the author is convinced that the program LSQADJ does not have any apparent or significant malfunctions.

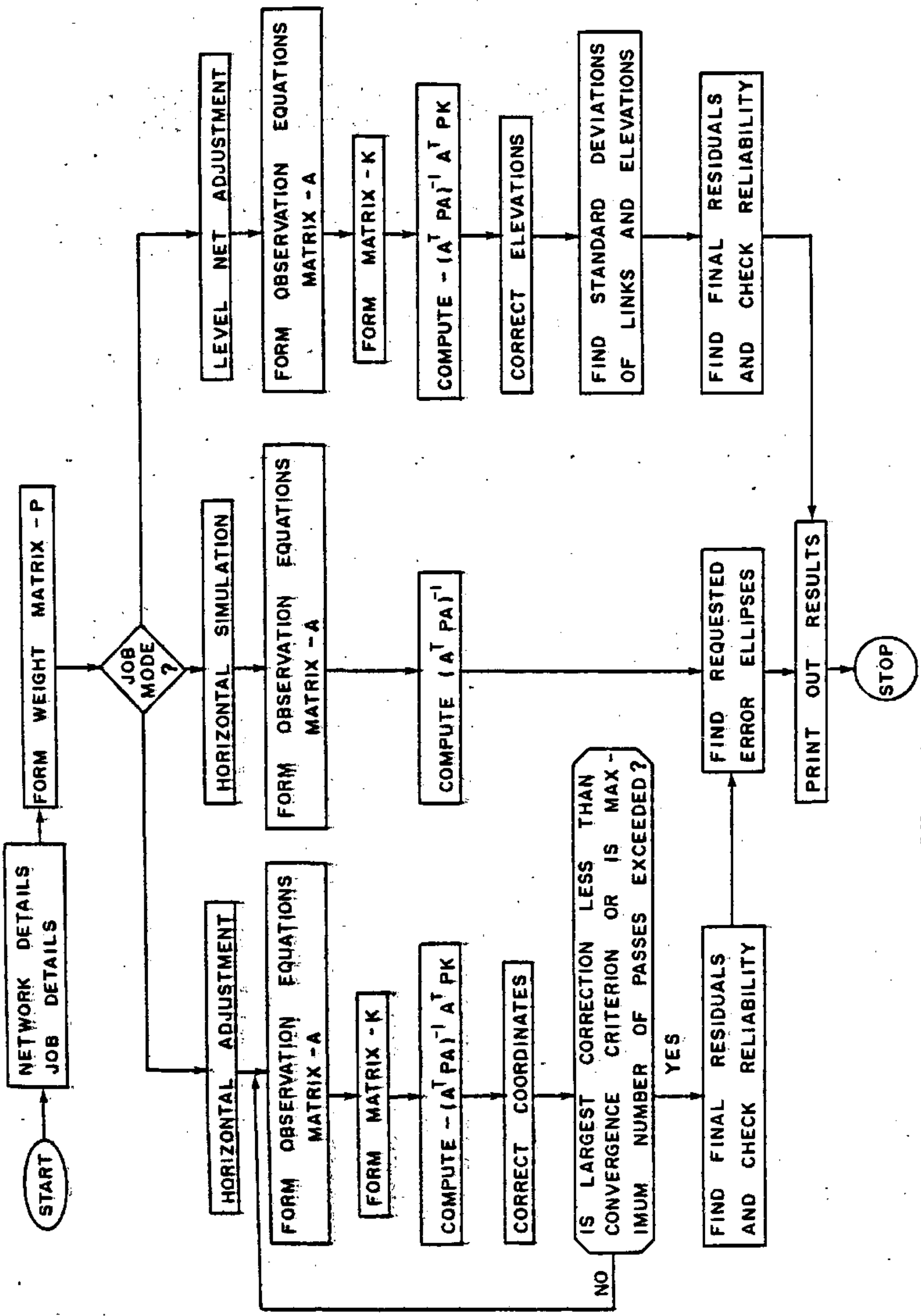


FIGURE 3.10 FLOW CHART

CHAPTER IV

MEASUREMENT OF SPATIAL DEFORMATIONS BY GEODETIC METHODS

4.1 Introduction

The monumentation of a retrogressive landslide using precise survey techniques involves a combination of the principles of surveying and geotechnical engineering. A proper approach to the problem requires a thorough analysis of the requirements of instrumentation in geotechnical engineering and an in depth understanding of state-of-the-art statistical-geodetic techniques. Once a sound basis has been established, the problem can be treated in an ordinary engineering manner.

4.2 Principles of Measurement

The systematic monitoring of three dimensional deformations of a retrogressive landslide by geodetic methods is a measurement process. Thus we must consider the fundamental attributes of a measuring system, (Arthur, 1973). They are:

(1) The variables to be measured.

(2) The physical phenomena employed in the measuring instrument.

(3) Robustness: the intrinsic ability to survive in its chosen environment, standing up to impact, prolonged submergence, corrosive substances, temperature variations, etc.

(4) Sensitivity: the smallest change in the variable being measured which the instrument will consistently detect.

(5) Response time: the time the measuring system takes to complete a single reading of the variable or a set of variables.

(6) Range: the difference between the maximum and minimum quantities that can be measured by the same instrument without going under any alteration.

(7) Stability: the variation with time of the tolerance within which any measurement of the variable by the given instrument will lie in relation to the actual value of the variable.

(8) Environmental Calibration: the relationship between the actual measurement and the ideal measurement. The ideal measurement is the value the measured variable would have had if the presence of the instrument would have been miraculously avoided.

(9) Accuracy: the tolerance within which any measurement of the variable by the given instrument will lie in relation to the ideal measurement.

(10) Data Reliability: this comprises the accuracy under normal working conditions, together with the ability to check for erroneous readings.

(11) Data Presentation Chain: the component chain through which a reading of the variable passes before it is read by a responsible person capable of interpreting the meaning of the data.

The significance of each principle can now be assessed with respect to the monumentation of a retrogressive landslide using precise surveying techniques.

4.2.1 Variables

The variables to be determined in the monitoring of spatial deformations of a landslide are the instantaneous three dimensional coordinates of a point in the slide. The coordinates are determined by the measurement of:

i) horizontal and vertical theodolite angles to the station;

ii) distances to the station by taping or electronic distance measurement and;

iii) elevations by leveling.

4.2.2 Physical Phenomena

Horizontal and vertical angles are measured using optical survey techniques. High quality theodolites are available that can read angles manually and electronically. Distances are measured with modern EDM (electronic distance meter) equipment, which utilize infrared light and special light reflecting targets. Differences in elevation are measured using optical leveling techniques.

The physical process of angle, distance, and elevation measurement is performed by a surveyor. This adds human error into the measurement process. Since we are dealing with optical survey techniques, errors due to atmospheric conditions, pointing and set up will also occur. These add unknown and unmeasurable variables to the system.

4.2.3 Robustness

The quality of the measurement process is significantly affected by the quality of the monumentation. Monumentation refers to the monuments or markers that are placed in the slide and observed for movement. In a retrogressive slide, monuments must be installed such that they will reflect the actual surface movement of the slide. Those monuments must be able to last for a selected time interval and withstand environmental changes.

A permanent fixed frame of reference is also required. This is termed "control" and can be established by installing geodetic bench marks far removed from the study area. If the reference points move, the detected movements of the monuments in the slide will not be the true surface movement.

4.2.4 Sensitivity

It is essential for the surveyor to know whether he is measuring actual movements of the monuments in the landslide or whether he is picking up "noise" in the system. "Noise" is described as the accumulation of miscellaneous errors in the system due to misreading the instrument, pointing, set up, temperature variation and other unmeasurable or unknown sources. The level of noise is called "sensitivity" and is determined from the error ellipses calculated after a least squares survey adjustment.

4.2.5 Response time

The measurement of a set of angles, distances or elevations may take anywhere from a few minutes to a few hours, depending on the equipment and field conditions. Since most retrogressive landslides are not instantaneous, it is safe to assume that no discernable movement will take place during the measuring process.

4.2.6 Range

Surveying equipment is not significantly limited in the maximum value that can be read. All theodolites can measure angles from 0 to 360 degrees, and EDM equipment can accurately measure distances from 4 metres to 1 kilometer or more.

4.2.7 Stability

The variation with time of a surveying instrument is significant in the short term. Temperature and atmospheric changes can affect the stability of an instrument and hence the measurement. Monuments can contract and expand thermally and two measurements taken minutes apart may be slightly different. The effects ultimately affect the accuracy of the measurements and increase the "noise" in the system.

4.2.8 Environmental Calibration

The presence of a monument should certainly not affect the movement of the landslide. However, it should be pointed out that the movement of the monument in the slide might not necessarily be representative of the true surface movement of the slide. Effects due to freeze-thaw, consolidation, tilt, etc., add to the difficulty in establishing the amount of true surface movement.

4.2.9 Accuracy

The accuracy of the measurement will determine the sensitivity as defined earlier. The accuracy is comprised of how accurate an instrument can be read and how accurate a person can consistently read it. All surveying measurements should be repeated and the standard deviations of the measurements determined. The standard deviation of a measurement is essential in performing a least square survey adjustment.

4.2.10 Data Reliability

The reliability of the data is best determined by examining the residuals after performing a least squares survey adjustment, and comparing them with the standard deviations of the observations. In measurement of slide movement it is sometimes hard to accept that movement in a certain direction has taken place. The only way to be sure is to have a high degree of confidence in the data.

4.2.11 Data Presentation Chain

Movement of a landslide as measured with optical survey techniques is three dimensional surface movement only. Thus the analysis of the results must be realistic. Only the surface kinematics of the slide are known (i.e., direction and rate of movement). Enough data must be available to establish a definite pattern of movement. This movement can then be checked against a model of a retrogressive landslide. The whole process of data presentation and analysis is enhanced once the sensitivity of the variables is known and the data has proved to be reliable.

The principles of measurement just discussed break down the measuring process into two broad areas:

i) obtaining data in the field and,

ii) reducing and analyzing the data.

The task of obtaining the data in the field, the selection of monumentation, etc., varies from project to project. However, the task of reducing and analyzing the data is the same. The process can be confusing and complex unless handled in a systematic and comprehensive manner with the aid of a computer program.

4.3 Pre-analysis

Before any attempt is made to set up a network to measure slide movement, it is necessary to establish the limit of accuracy attainable based on the equipment available and the various field procedures employed. Pre-analysis is necessary to establish how small a movement can be detected. This will determine the type of network to select, the type of monumentation required, and the sensitivity of the results to be expected.

4.3.1 Equipment Available

The surveying equipment available at the University of Saskatchewan that was applicable to the study is as follows:

(1) Wild T-3 Theodolite: reads directions direct to 0.2 seconds. Based on specifications put forth by the Horizontal Control Section of the Geodetic Survey of Canada, the standard deviation of a set of six independent pointings can be taken to be 1.2 seconds, (Figure 4.1).

(2) MA-100 Tellurometer: an electronic distance meter which is capable of measuring distances up to two kilometers within an established accuracy of 1.5 mm, (Figure 4.2).

(3) Sokkisha targets with optical plummets: the stated accuracy in setting up over a point is 0.5 mm/m, (Figure 4.3).

(4) Wild NA-2 Automatic Level: a precise level equipped with a parallel plate micrometer and an invar rod. The accuracy is stated as 0.5 mm/km, (Figure 4.4).

4.3.2 Pre-analysis of Error Ellipses

Using the a priori standard deviations, a number of trials using different procedures were analyzed for the triangle shown in Figure 4.5. The analysis was performed using the LSQADJ program in the simulation mode. The results show that for distances under 250 metres mixed observations (e.g., two angles and two sides measured) resulted in the smallest error ellipses. Pure triangulation (i.e., angle

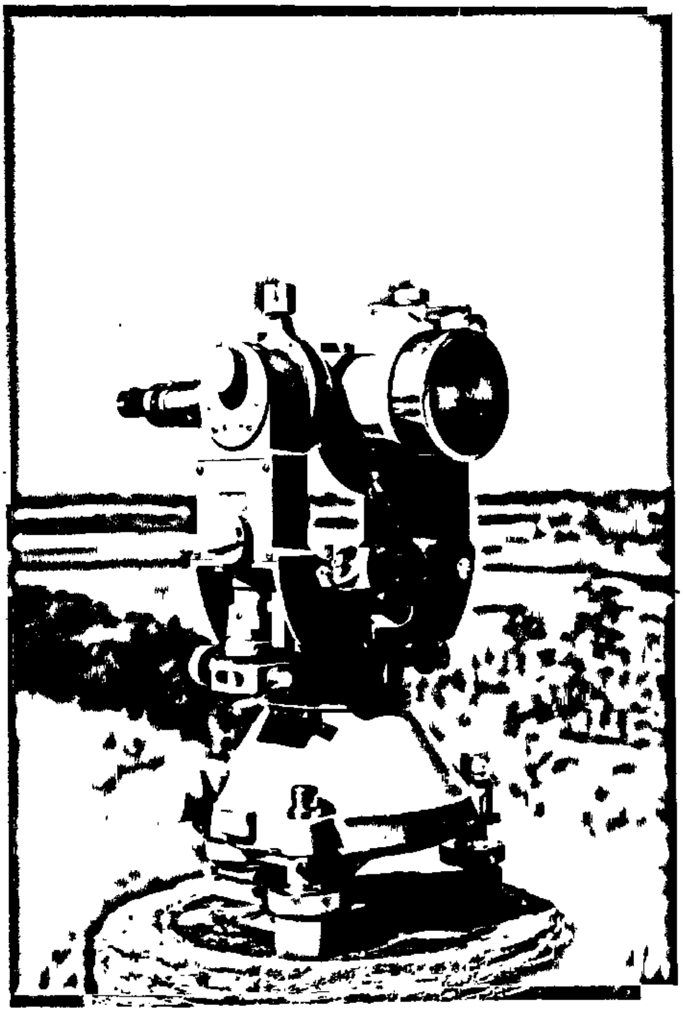


FIGURE 4.1: WILD T-3 THEODOLITE

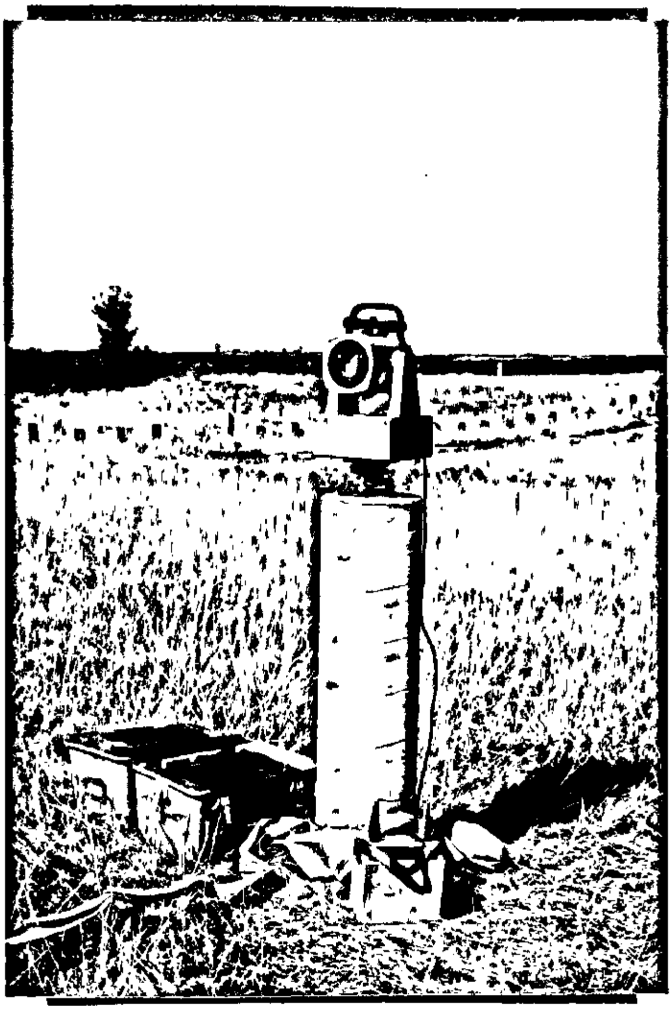


FIGURE 4.2: MA-100 TELLUROMETER

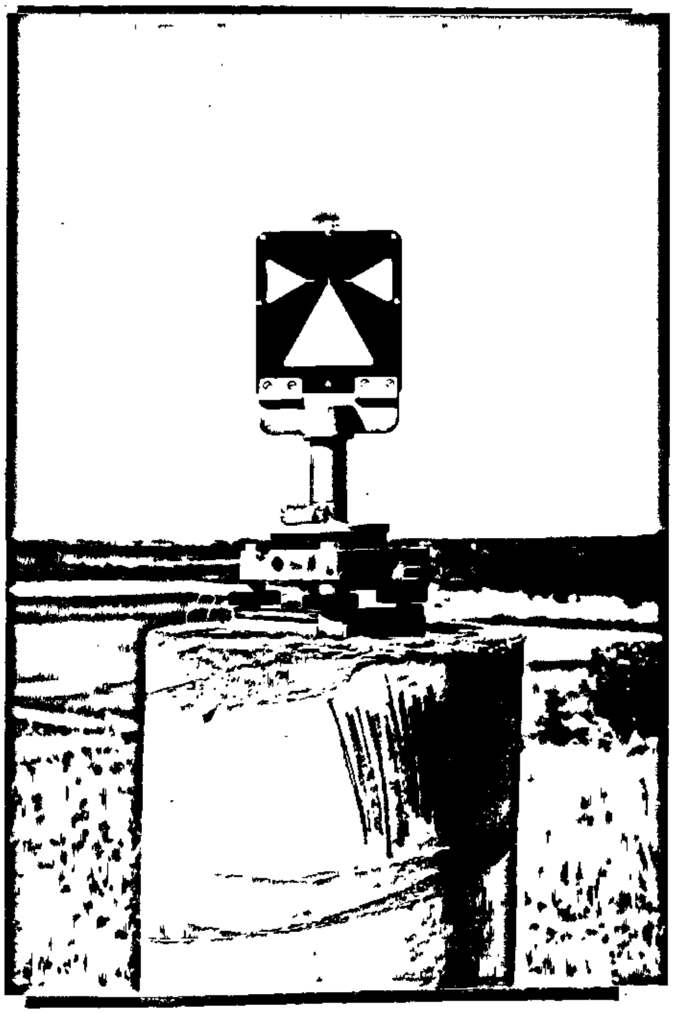


FIGURE 4.3: SOKKISHA TARGETS

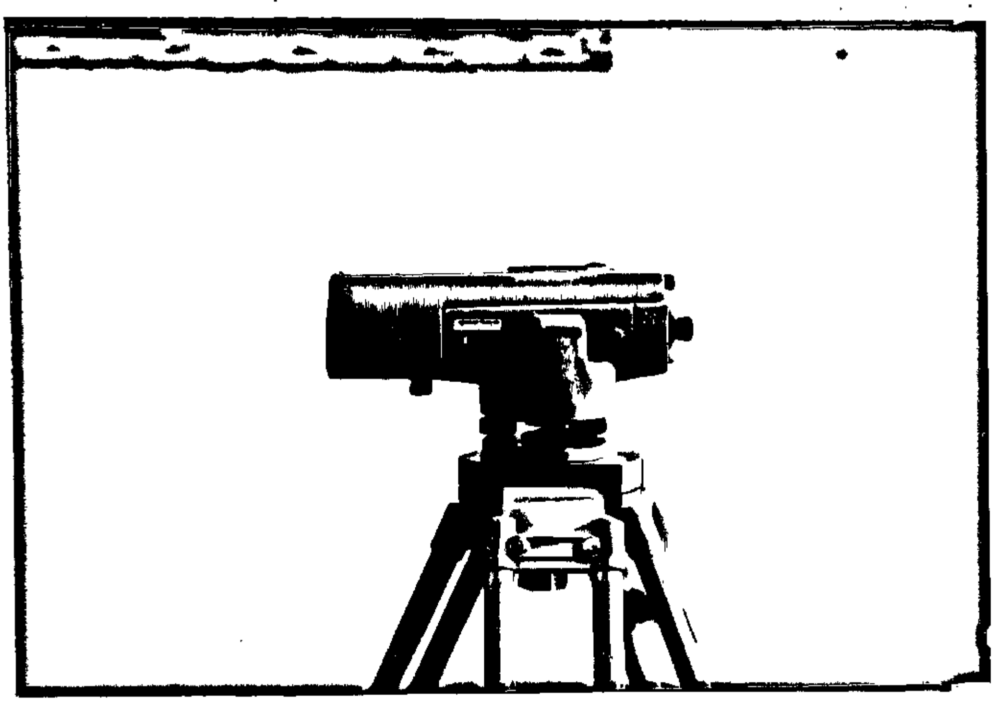


FIGURE 4.4: WILD NA-2 AUTOMATIC LEVEL

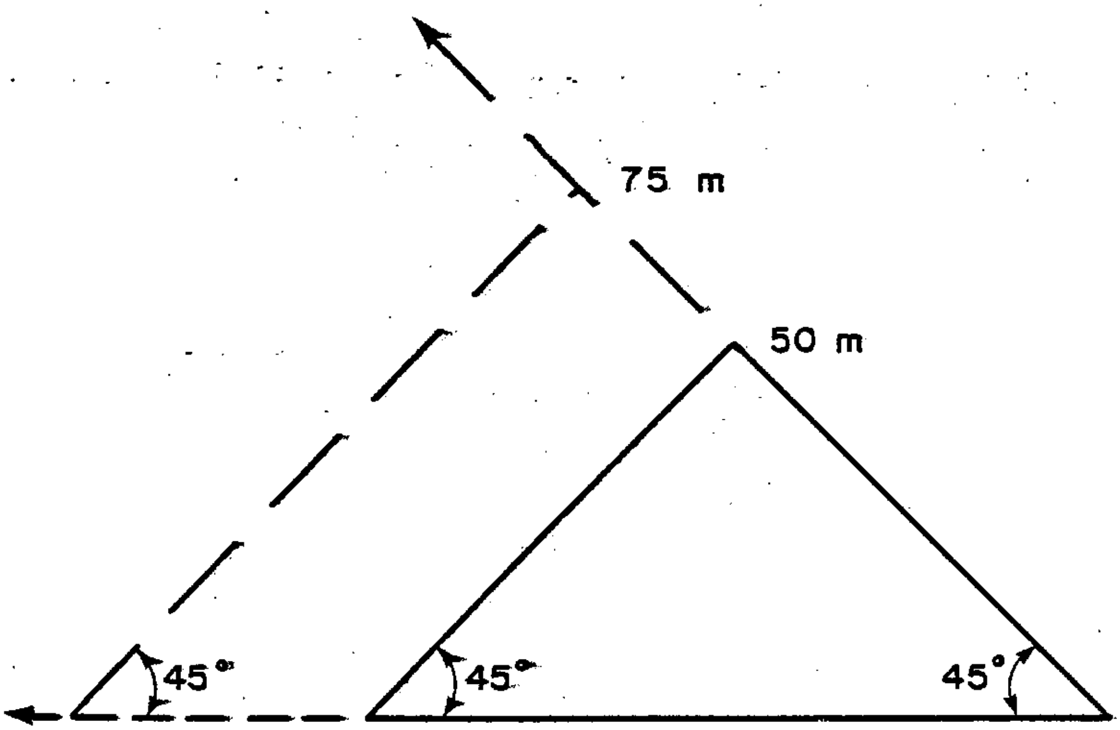


FIGURE 4.5 TRIANGLE USED FOR PREANALYSIS

measurement only) resulted in just slightly larger error ellipses. Pure trilateration (i.e., side measurements only) resulted in a constant sized error ellipse which was larger than the ones for pure triangulation at distances less than 250 metres. The results are shown graphically in Figure 4.6. The results agree very well with the work by Wolf and Johnson (1974).

The pre-analysis results showed that pure triangulation provided better sensitivity at close range than pure trilateration. This suggested that no distance measurements other than base line calibration are necessary at less than 250 metres. Using mixed measurements at close range does not significantly affect the error ellipses leaving pure triangulation as the best alternative.

4.3.3 Spherical Excess and Curvature

The theory of least square adjustments developed in Chapter III dealt with the plane surveying case. No attempt was made to expand the theory to encompass geodetic surveying (i.e., accounting for the curvature of the earth). It is necessary now to establish at what point the curvature of the earth becomes significant.

Since the earth is approximately spherical in shape, any triangle described on its surface will be a spherical triangle. Moffit and Bouchard (1975), calculated the amount of spherical excess (i.e., the amount by which the sum of the three interior angles of a triangle will be greater than 180 degrees) as 1 second per 200 square kilometers. This means that a triangle must be 200 square kilometers in area in order to introduce a spherical excess correction of 1 second. The area of any triangle used in monitoring the landslides at Beaver Creek will be much less than 1 square kilometer. Hence any error due to

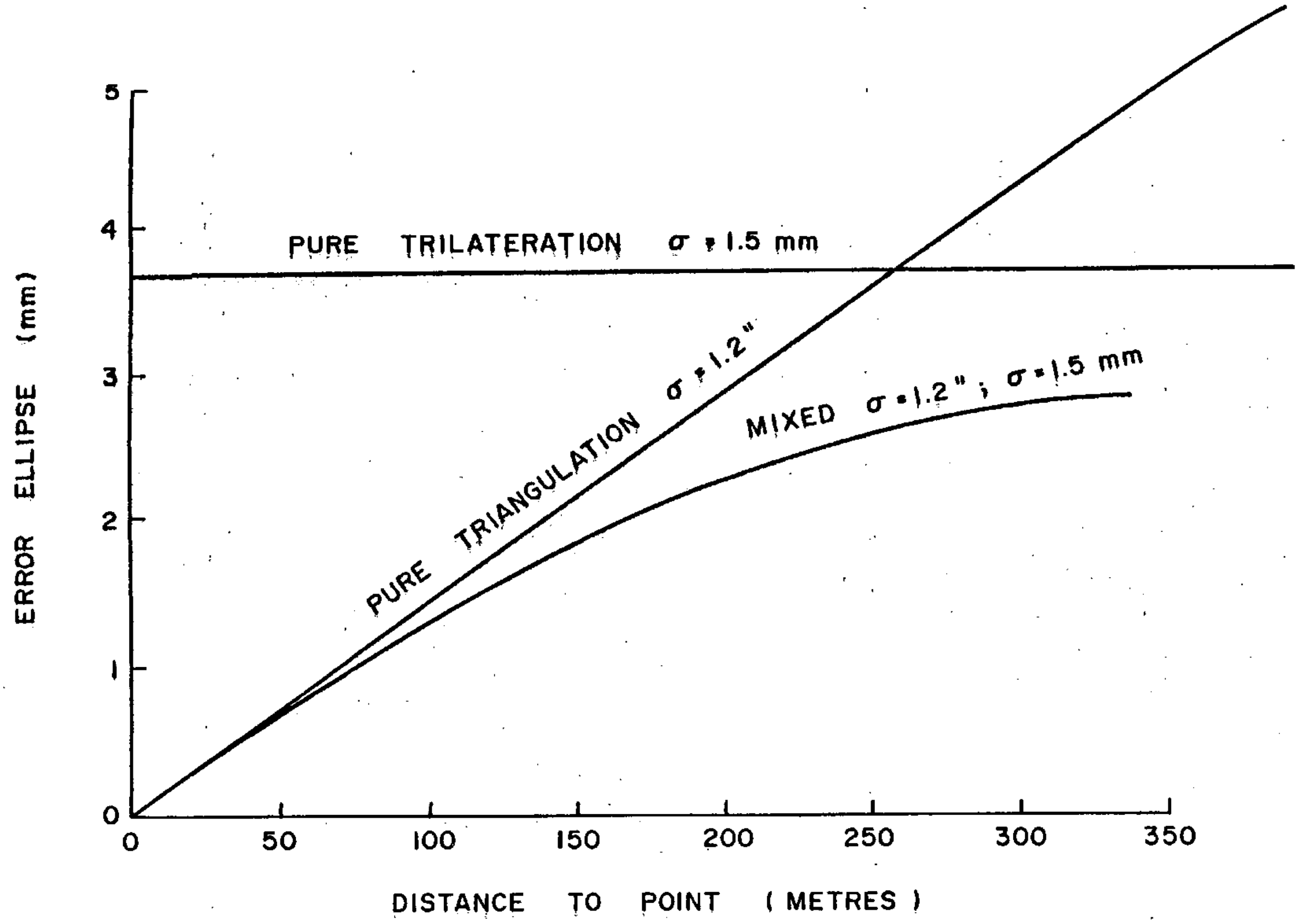


FIGURE 4.6 RESULTS OF PREANALYSIS

spherical excess will be less than 1/200 of a second, i.e., negligible.

It is also necessary to determine if all coordinates should be reduced to an equivalent sea level coordinate system. The correction to sea level can be given by the equation (Moffit and Bouchard, 1975):

$$C_{SL} = C_{sea\ level\ (metres)} = -1.57 \times 10^{-7} h\ell_h$$

where h = elevation above sea level

ℓ_h = length of line at elevation h

The sea level distance is then:

$$\ell_{SL} = \ell_h + C_{SL}$$

If the difference in elevation between two points in the network is 20 metres, not converting to sea level (or any common datum) will introduce an error of:

$$C_{SL} = -1.57 \times 10^{-7}(20)\ell = 3 \text{ ppm of } \ell.$$

For a 300 metre distance this is an error of 0.9 mm. This error will not occur in this study if pure triangulation (i.e., horizontal angle measurement and base line calibration) is used. As a result, all coordinates calculated will be with respect to the geodetic elevation of the baseline. If distance measurements were employed, it would be necessary to convert all distance measurements and hence coordinates to a common datum, preferably sea level.

4.4 Limits of Accuracy

In monitoring deformations using survey techniques it is necessary to establish the limits of accuracy, i.e., how much movement of a point can occur before it can be consistently detected? For example, in Figure 4.7, point A has appeared to move to point A' in

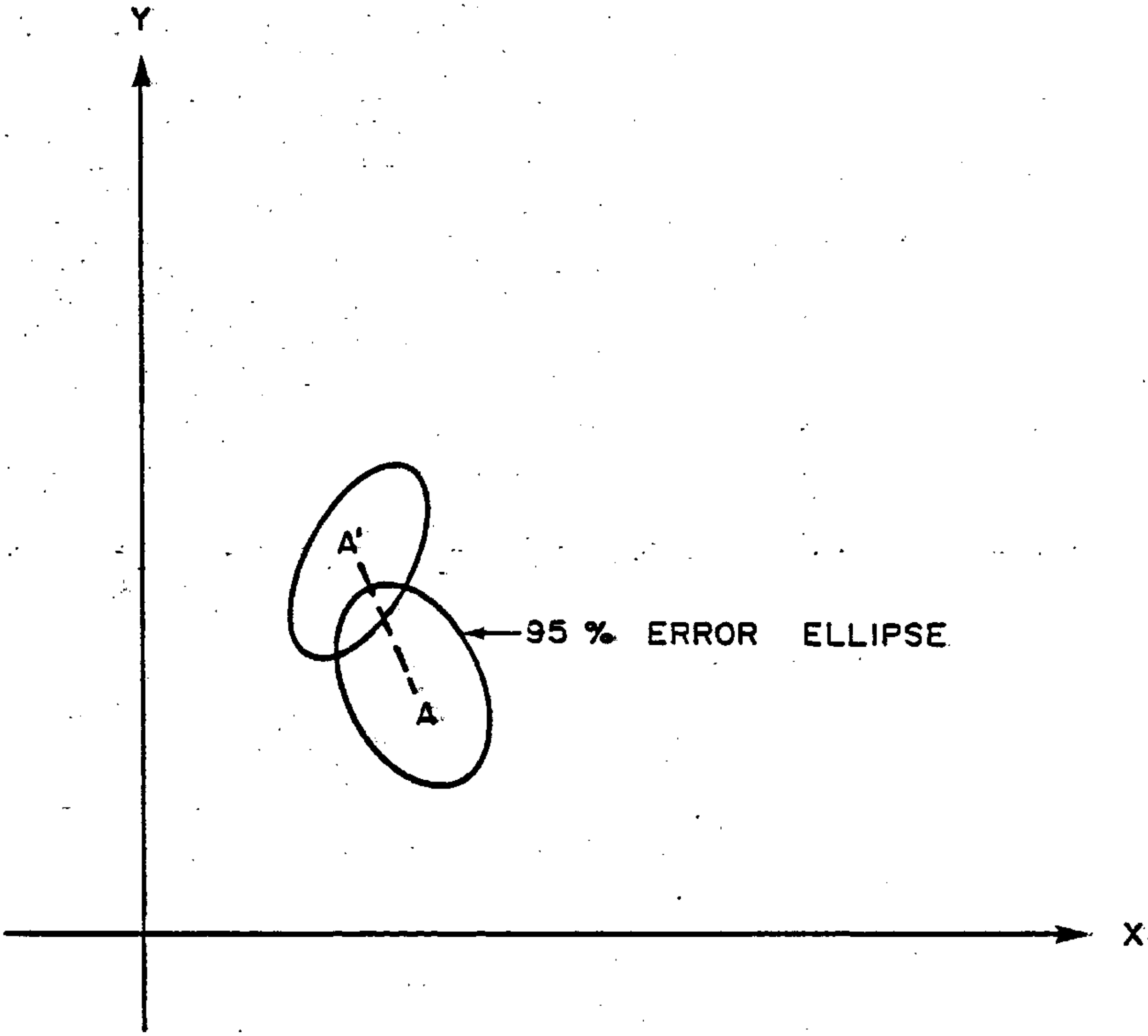


FIGURE 4.7 APPARENT MOVEMENT

a certain period. The 95% error ellipses overlap in this case. The question is how much movement has taken place and how confident are we that any movement has taken place? The determination of the limits of accuracy will establish the smallest movement that can be consistently detected, based on the equipment available.

4.4.1 Determination of Limit of Accuracy

The magnitude of the 95% error ellipse at 100 metres using pure triangulation is approximately 3 mm. This is reasonable when one realizes that an angle of 1.2 seconds subtends an arc of 0.6 mm at 100 metres. 0.6 mm is the approximate thickness of a pencil lead. At 100 metres, distance measurements have an accuracy of 1.5 mm hence, the larger ellipse of 4 mm.

Quan (1978), has performed field tests to establish a statistical test to determine confidences levels in movement. The surveying equipment consisted of a Wild T-3 Theodolite, MA-100 Tellurometer and a movable reflector. The field tests were performed on a baseline calibrated by the Geodetic Survey of Canada in 1978. The network used is shown in Figure 4.8. The test consisted of measuring the two interior base angles and two sides of a triangle and determining the coordinates of the target at the apex. The target was then moved distances of 2 mm, 5 mm, and 10 mm with the respective measurements being taken each time. The results show that a movement of 3 mm can be detected at 100 metres with 95% confidence. The results also show that no movement takes place at the 95% confidence level when resetting up over a point using a Sokkisha target. The standard deviations obtained in the field were considerably lower than the a priori standard deviations, but the

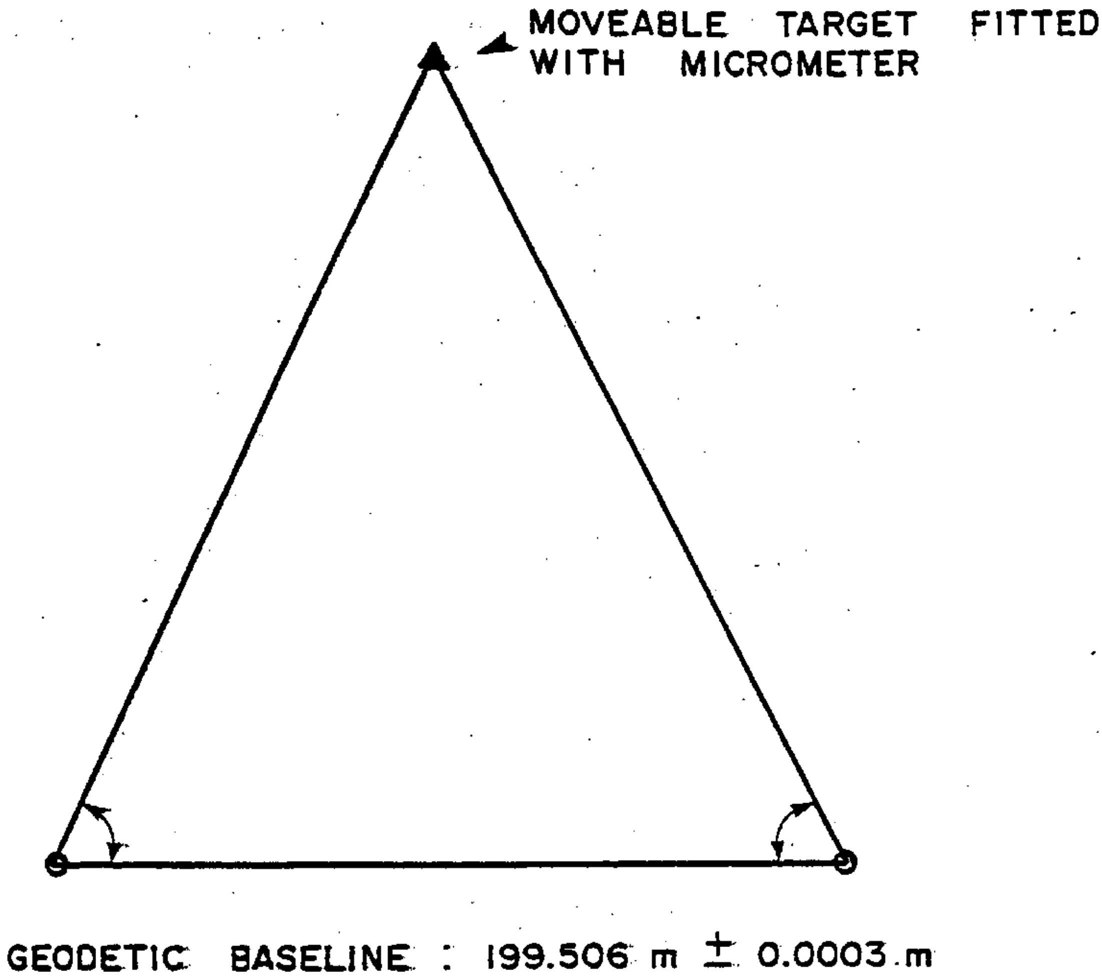


FIGURE 4.8 TEST NETWORK

specified a priori standard deviations (1.2 seconds, 1.5 mm) were used in the analysis.

The statistical test proposed by Quan (1978) is based on the comparison of two means:

$$(\bar{X}_1 - \bar{X}_2) - Z_{\frac{\alpha}{2}} \sqrt{\frac{\sigma_1^{\ 2}}{n_1} + \frac{\sigma_2^{\ 2}}{n_2}} < u_1 - u_2 < \bar{X}_1 - \bar{X}_2) + Z_{\frac{\alpha}{2}} \sqrt{\frac{\sigma_1^{\ 2}}{n_1} + \frac{\sigma_2^{\ 2}}{n_2}} \qquad (46)$$

where $\bar{X}_1$ and $\bar{X}_2$ are the means of independent random samples of size n_1 and n_2 from populations with known variances $\sigma_1^{\ 2}$ and $\sigma_2^{\ 2}$. $Z_{\frac{\alpha}{2}}$ is the value of the standard normal curve leaving an area of $\frac{\alpha}{2}$ to the right. This test applies to large samples (e.g., $n \geq 30$) which are normally distributed. Since the standard deviations calculated in surveying are based on small samples (e.g., $n \geq 6$), the distribution is no longer a standard normal distribution but is better described with a t-distribution, (Walpole and Myers, 1972). Applying students t-test:

$$t = \frac{X_1 - X_2}{\sqrt{Sx^2}}$$

where

$$Sx^2 = \frac{n_1 Sx_1^{\ 2} + n_2 Sx_2^2}{n_1 + n_2} \qquad (47)$$

Sx_1, Sx_2 = calculated standard deviations in the X direction

n_1, n_2 = degress of freedom

Walpole and Myers (1972) have published tables for the value of t for different levels of significance. The value of t calculated compared with the value of t from the tables will determine if the Null hypothesis is satisfied at a desired level of significance. The Null hypothesis assumes that there is no difference between X_1 and X_2 (i.e., $X_1-X_2=0$). If the value of t calculated is greater than the value of t from the tables at a given level of significance, then the Null hypothesis is not satisfied and the difference, X_1-X_2, is significant at that level.

Students t-test can now be used to determine the theoretical limit of accuracy. Consider a point whose X-Y coordinates are calculated using a least square adjustment with 2 degrees of freedom (e.g., 2 angle and 2 side measurements to the point) for 2 different time periods. Assume the error ellipses for 68% probability have been calculated for the point at time A and time A' as shown in Figure 4.9. For simplicity sake, let us assume the error ellipses are very nearly circular and very nearly equal for both time periods. We can now calculate the amount of movement, ΔX, that is significant at the 5% level:

$$t = \frac{\Delta X}{\sqrt{\dfrac{n_1\sigma_A^{\,2} + n_2\sigma_{A^1}^{\,2}}{n_1 + n_2}}} \tag{48}$$

but $\sigma_A \doteq \sigma_{A^1}$ and $n_1=n_2=2$.

For 95% probability (i.e., 5% level of significance) and a total of 4 degrees of freedom: t=2.132 (Walpole and Myers, 1972).

$$\therefore\ t=2.132 = \frac{\Delta X}{\sqrt{\dfrac{2\sigma^2 + 2\sigma^2}{4}}} = \frac{\Delta X}{\sqrt{2\sigma^2}}$$

$$\Delta X = 3\sigma \tag{49}$$

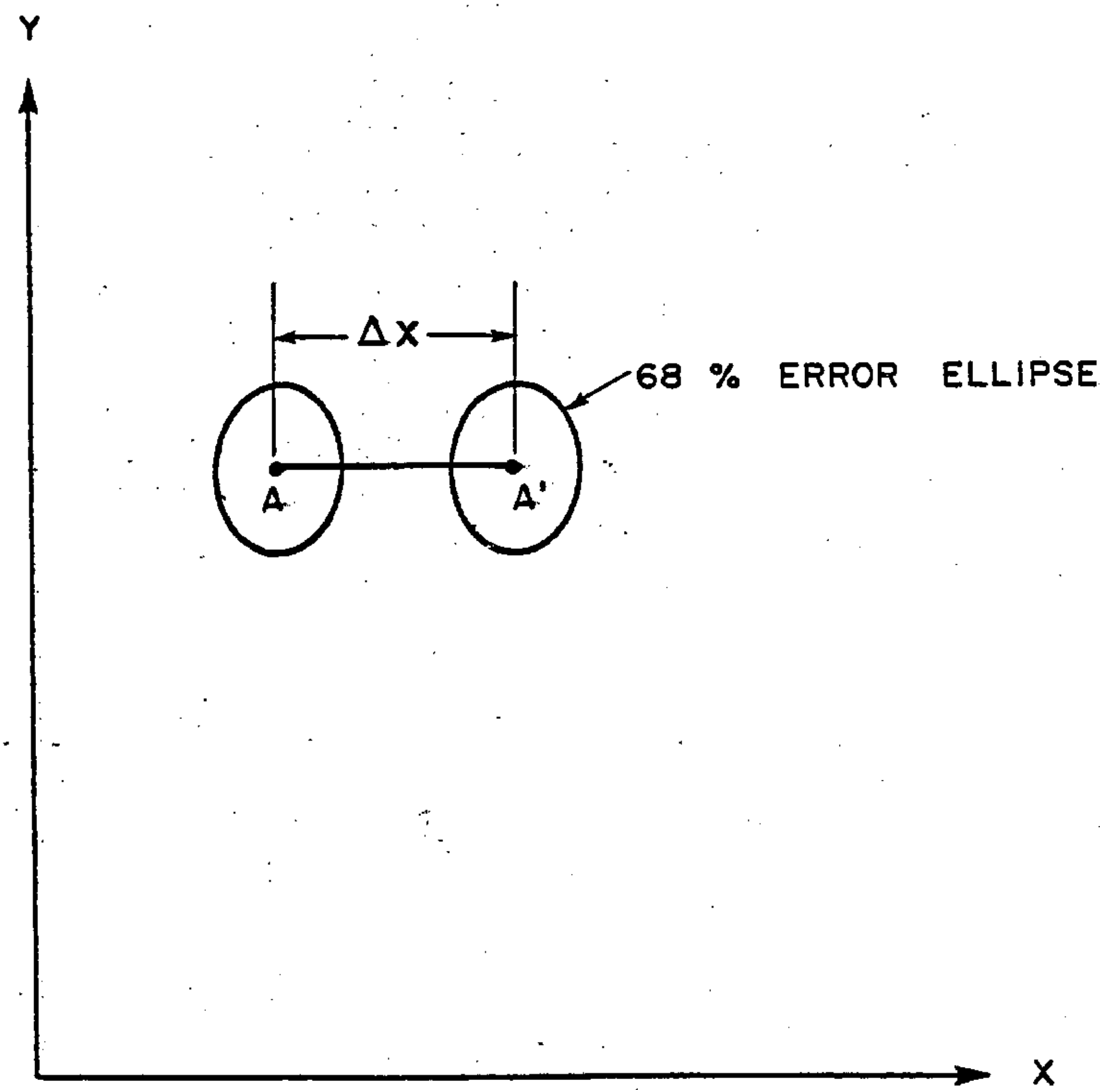


FIGURE 4.9 DETERMINATION OF MOVEMENT

If we substitute the values for the 95% error ellipse, where $\sigma_{95\%} = 1.61\sigma_{68\%}$ (Table 3.1):

$$\Delta X = 1.9\sigma_{95\%} \doteq 2\sigma_{95\%}$$

This indicates that movement is significant at the 5% level if the total movement is approximately equal to the major axis of the 95% error ellipse. As a general guideline we can then say that movement is significant at the 5% level if the 95% error ellipses do not overlap.

The results from Figure 4.6 show that the semi-major axes of the 95% error ellipses are approximately 1.5 mm using pure triangulation over a 100 metre distance. This would indicate that movement of 3 mm could be detected at the 95% confidence level. This agrees exactly with results by Quan (loc cit), where it was determined experimentally that 3 mm of movement could be detected at the 95% confidence level over a distance of 100 metres, using the same available equipment.

The limit of accuracy (i.e., the smallest amount of movement that can be consistently detected) is in the order of 3 mm using the available equipment. This is based on the assumption that 2 degrees of freedom are provided at each point. To achieve this accuracy in the monumentation of the landslides at Beaver Creek, it became apparent that special monuments, techniques, and procedures were required.

CHAPTER V

MONUMENTATION OF LANDSLIDES AT BEAVER CREEK

5.1 Introduction

Optical surveying techniques were used to monitor the surface movement of a retrogressive landslide. Emphasis was placed on using the results to describe retrogressive landslide behavior as well as establishing a rigorous approach in reducing the data and predicting the accuracies of the results.

5.5.1 Selection of the Study Area

The selection of the site was based primarily on the presence of active slides and the fact that Beaver Creek has been the subject of intensive investigation in recent years.

5.2 Selection of Instrumentation

The selection of instrumentation was based on the results of the pre-analysis. The pre-analysis determined that 95 percent error ellipses in the order of 3 mm at 100 metres could be obtained using the equipment available at the University of Saskatchewan, Saskatoon, Sask. It also showed that at distances of less than 250 metres pure triangulation provided error ellipses of smaller magnitude than those obtained with pure trilateration.

5.2.1 Configuration

Once it had been established that pure triangulation was the best alternative, the layout of the monuments was selected accordingly.

The configuration that was selected is shown in Figure 5.1. Angles are measured to each of the slide monuments from the monuments at the edge of the scarp. Since the scarp monuments are not in a stable area, it is expected they would also move. A fixed frame of reference (i.e., control) was ensured by establishing a base line far back from the scarp. These inner monuments would establish the origin of coordinates and provide horizontal control. Vertical control would be established by installing geodetic vertical control bench marks far removed from the study area.

5.2.2 Procedures

The origin of coordinates is fixed by the INNER monuments. The SCARP monuments are referenced to this coordinate system by a triangulation network consisting of the INNER and SCARP monuments (Figure 5.1). The coordinates of the monuments in the slide are determined by reading angles to the SLIDE monuments from the SCARP monuments. The coordinates of the SLIDE monuments are calculated with respect to the INNER monuments. Thus, any movement of the SCARP monuments will not affect the final coordinates of the SLIDE monuments.

The derivation of the statistical test to determine confidence intervals in movement presented earlier was based on the assumption that two degrees of freedom were provided at the station in question. To accomplish the objective of measuring the smallest movement possible, it was necessary to provide at least two degrees of freedom at each monument. This meant that four independent angles would have to be measured to each SLIDE monument. This would also provide a means of checking the reliability of the data and greatly enhance the confidence in the final results.

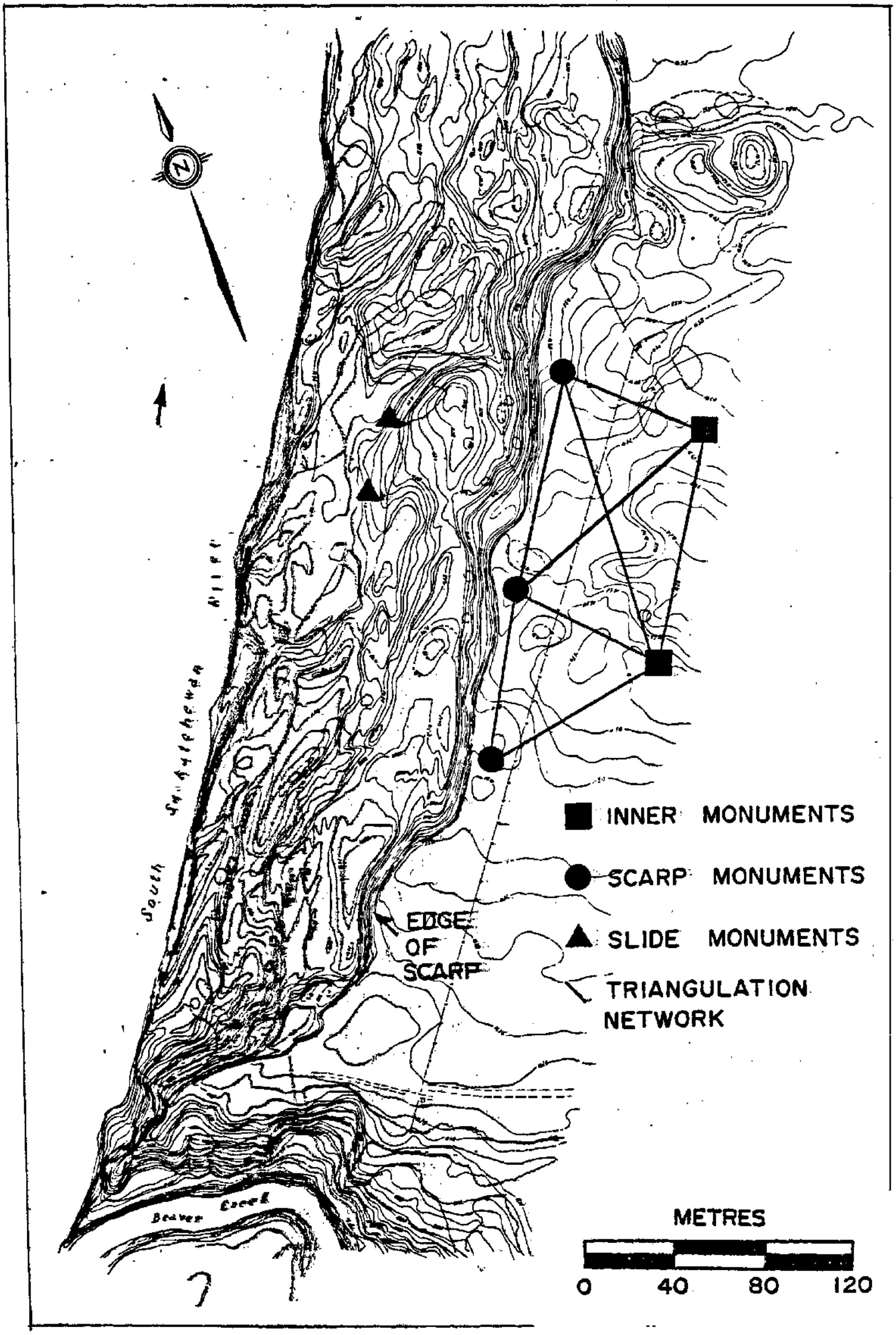


FIGURE 5.1 SELECTED CONFIGURATION

5.2.3 Monument Location

Once the configuration was established, it was necessary to establish the exact locations of the monuments in the field.

The location of the INNER monuments was chosen to be in a relatively flat area back of the scarp, where it was believed that slide movement would have no effect for many years.

The selection of the location of the SCARP and SLIDE monuments was more difficult. The site was restricted in the sense that it had to be in the same area where previous research had been carried on. The selection of the final locations was made by Professor Moir D. Haug* based on intervisibility to the scarp and placement at desirable locations on the major slide blocks (Figure 5.2 and Figure 5.3). Sixteen points in the slide were selected. This number was chosen to presumably get a good representation of the surface movements.

5.2.4 Monument Types

It was established during the pre-analysis that 95 percent error ellipses in the order of 3 mm were attainable. Since this is so small, the type of monumentation had to be selected to ensure that other errors did not jeopardise this accuracy.

It was decided to use concrete monuments with forced centering baseplates for the INNER and SCARP monuments. The concrete monuments are 12 feet in length with 4 feet exposed above ground (Figure 5.4). The base plates were manufactured by Central Shops,

---

* Assistant Professor of Civil Engineering, University of Saskatchewan, Saskatoon, Sask.

FIGURE 5.3: VIEW DOWN TO THE RIVER

FIGURE 5.2: VIEW UP TO THE SCARP

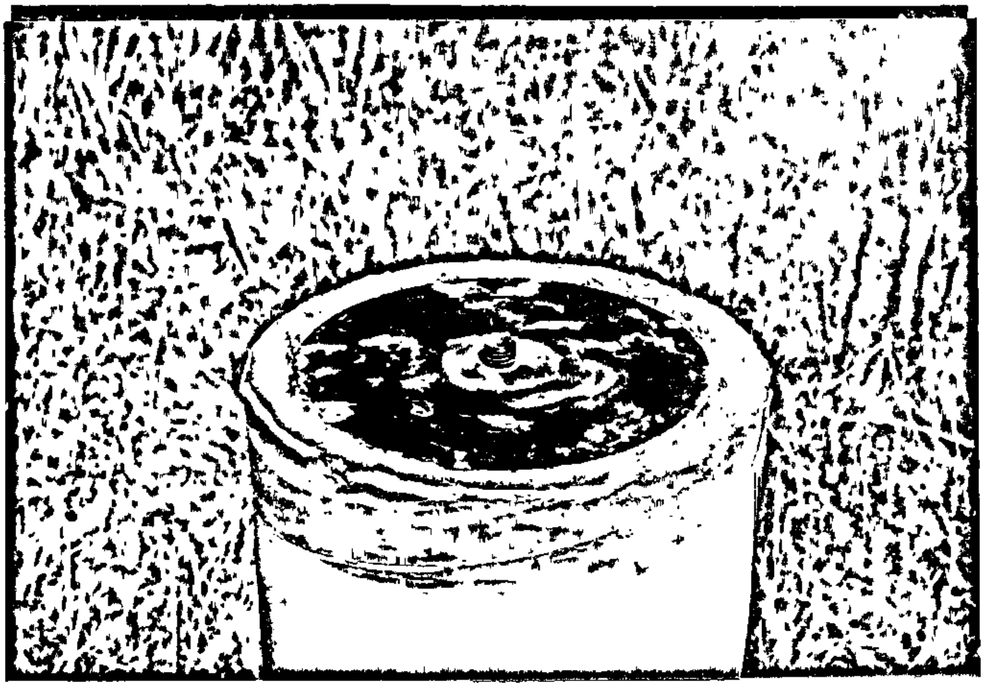


FIGURE 5.5: FORCED CENTERING BASEPLATES

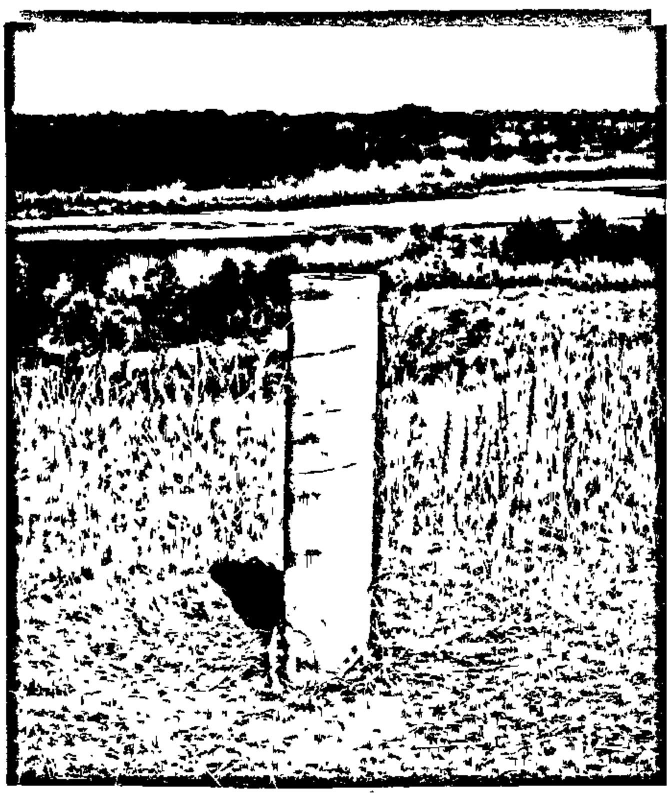
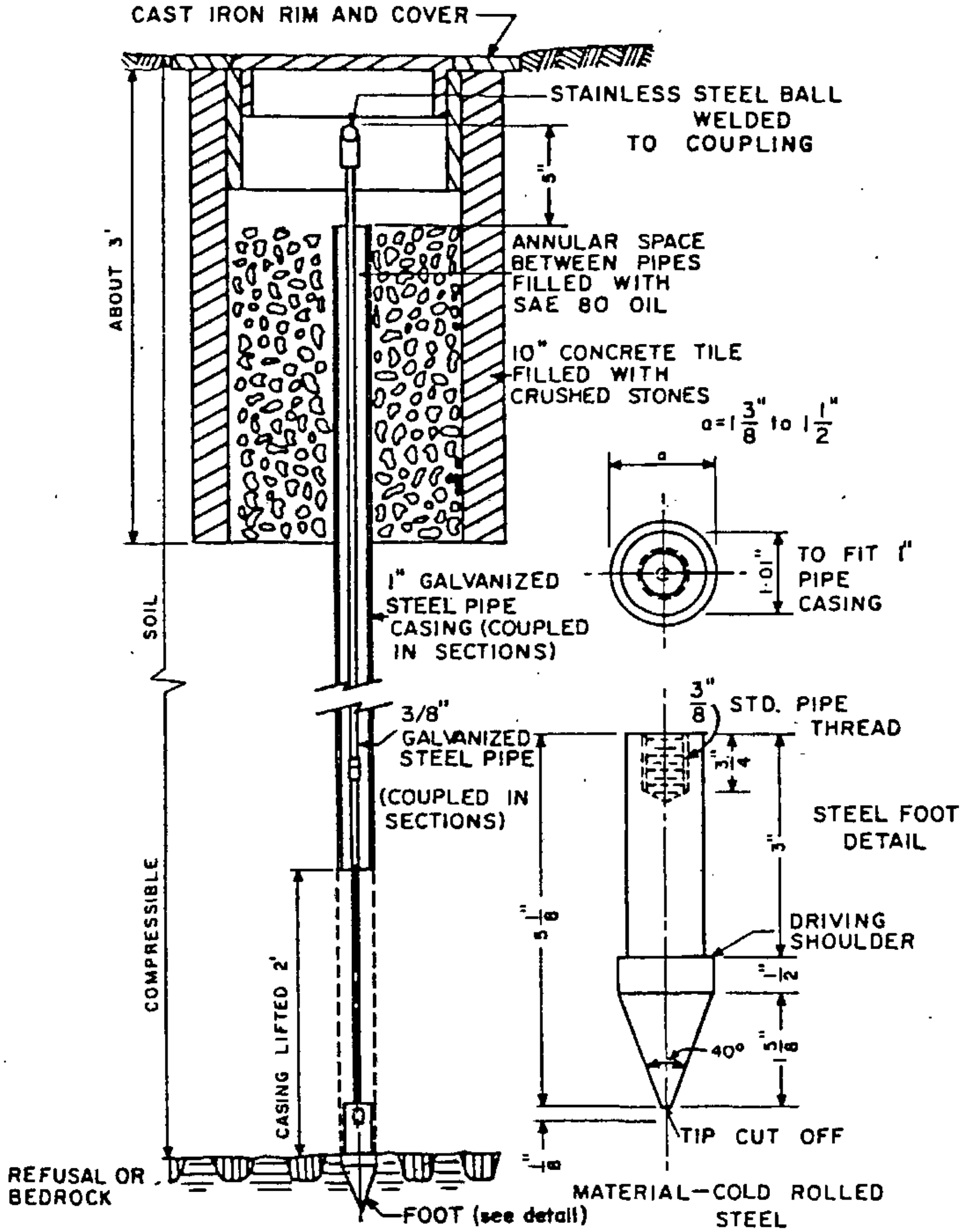


FIGURE 5.4: CONCRETE MONUMENTS FOR HORIZONTAL CONTROL



* National Research Council

FIGURE 5.6 N.R.C.* TYPE DEEP BENCH MARK

protect the steel pipe from frost heave. The annular space was filled with vermiculite. The centering head has a curved surface and a precise center punched hole (Figure 5.7). The monuments can be concealed with a cap fitting into the PVC pipe (Figure 5.8 and Figure 5.9). This protects the monuments from weather and vandalism.

5.3 Field Measuring Procedure

The final layout of the monumentation is shown in Figure 5.10. The field measurement procedure involves: 1) baseline calibration, 2) horizontal angle measurement and 3) precise leveling.

5.3.1 Baseline Calibration

The baseline was chosen to be between monuments INNER-2 and INNER-3. These monuments were selected because the land between them is relatively flat and they are far removed from the study area.

The distance between INNER-2 and INNER-3 was measured with the MA-100 Tellurometer and a Wild light reflecting target. The slope angle was measured with the Wild T-3 Theodolite. All the surveying instruments mount directly on the forced centering baseplates, minimizing any errors due to set up.

The procedure consisted of measuring the baseline distance 9 times in each direction and calculating a mean distance.

The MA-100 Tellurometer has been calibrated on a yearly basis using a baseline established in Saskatoon by the Geodetic Survey of Canada.

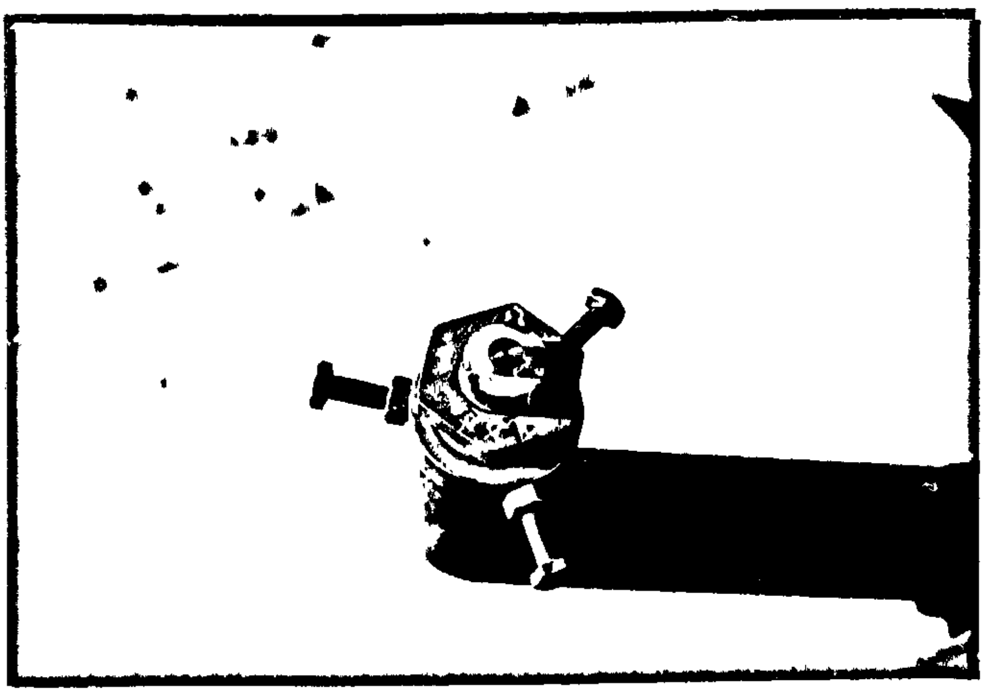


FIGURE 5.7: CENTERING HEAD

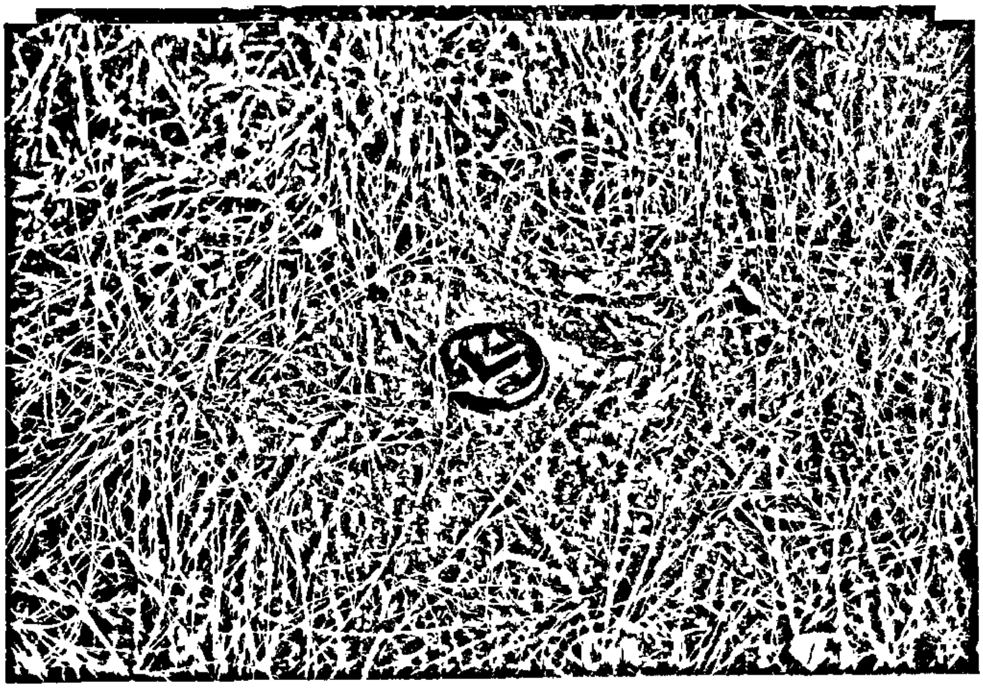


FIGURE 5.9: SLIDE MONUMENT CONCEALED

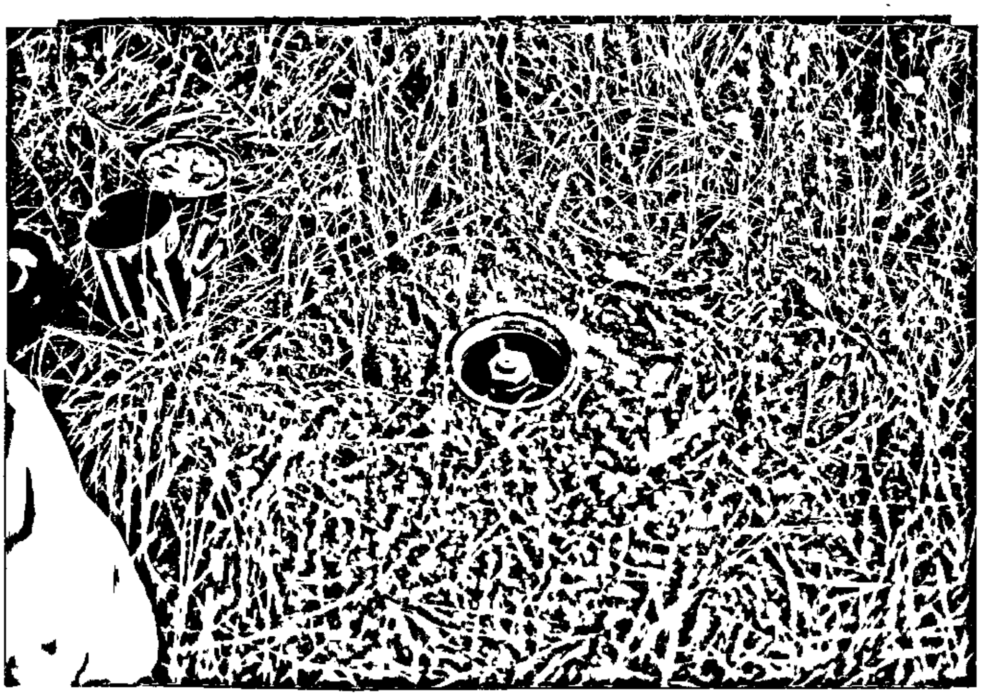


FIGURE 5.8: SLIDE MONUMENT IN PLACE

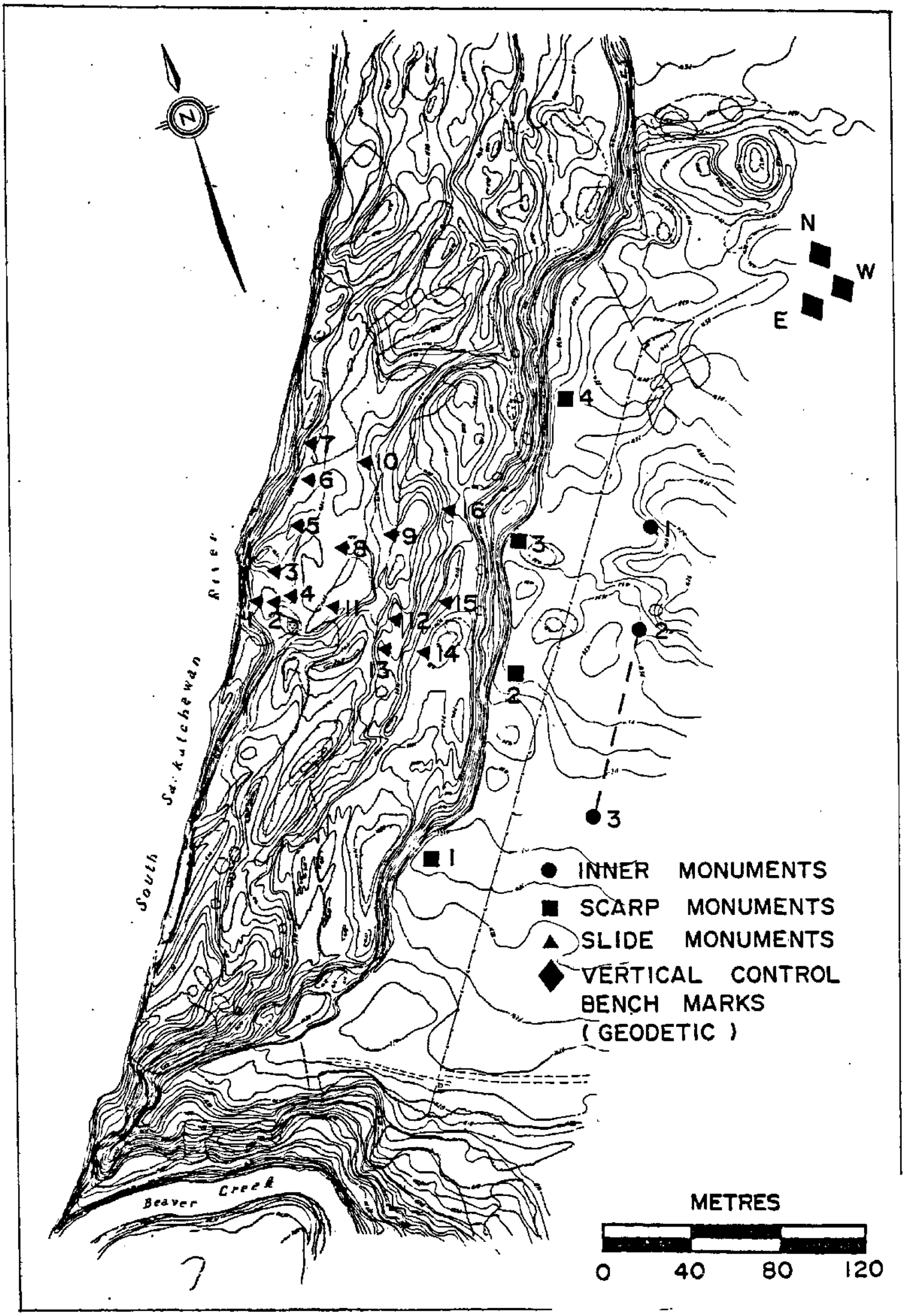


FIGURE 5.10 FINAL LOCATION OF MONUMENTATION

The baseline bewteen INNER-2 and INNER-3 has also been calibrated on a yearly basis. The results indicate that no discernable horizontal movement has taken place. The results of the calibrations are given in Appendix A.

5.3.2 Horizontal Angle Measurement

To minimize the effects of systematic error, it was decided to measure the same sets of angles during each survey. This keeps the systematic errors approximately constant and aids in checking the reliability of the data during successive measurements. The angles were read with the aid of Sokkisha targets (employing optical plummets accurate to 0.5 mm/m) set up over each SLIDE monument. The targets were set up directly over the center punched hole in the centering head of the SLIDE monuments. The height of the targets is at most 2.0 metres which introduces a centering error of 1.0 mm due to set up, (Chrzanowski, 1977). The accuracy and adjustment of the targets is checked regularily against the Wild Nadir Plummet (accuracy of 0.5 mm/100 metres) which is the most precise optical plummet available today (Figure 5.11). This ensured that the targets were accurate to their specifications and in perfect adjustment.

The field procedure using the Wild T-3 was according to the specifications set forth by the Horizontal Control Section, Geodetic Survey of Canada. It specifies 6 independent pointings at a target to justify a minimum standard deviation of 1.2 seconds. This involved 3 individual pointings in a circle right position and 3 individual pointings in a circle left position.

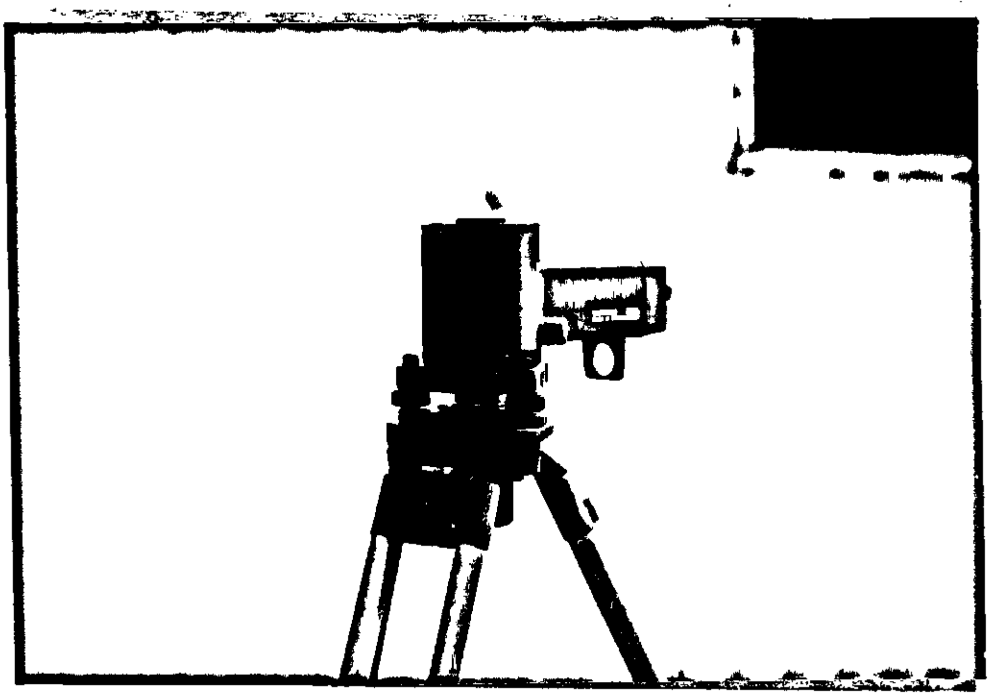


FIGURE 5.11: WILD NADIR PLUMMET

The procedure involved setting up the targets in groups of four in the slide area, and two targets on the SCARP monuments. The Horizontal angles were then read from the SLIDE monuments to the SCARP monuments. Four independent sets of angles were measured to each SLIDE monument (Figure 5.12). Appendix A presents the angle measurement procedure that was used throughout the study.

The triangulation network between the SCARP monuments and INNER monuments was performed by reading all visible interior angles (Figure 5.13). This resulted in a minimum of 5 degrees of freedom at each concrete monument.

The field results indicate that standard deviations in the order of 0.2 to 1.0 seconds were easily and consistently attained in the field regardless of weather conditions. This is well below the minimum specified by the Horizontal Control Section, Geodetic Survey of Canada, and indicates a high degree of accuracy was being obtained. It also indicates that the Wild T-3 is an extremely precise and dependable instrument when used properly.

5.3.3 Precise Leveling

The precise leveling was performed with the Wild NA-2 automatic Level in conjunction with a metric invar level rod. The procedure used for leveling is the one for first order leveling set forth by the Vertical Control Section, Geodetic Survey of Canada. This requires an accuracy of 5 mm/km.

The precise leveling circuit was carried from the geodetic bench marks to all other monuments in a series of interlocking loops (Figure 5.14). The three geodetic bench marks were also leveled to

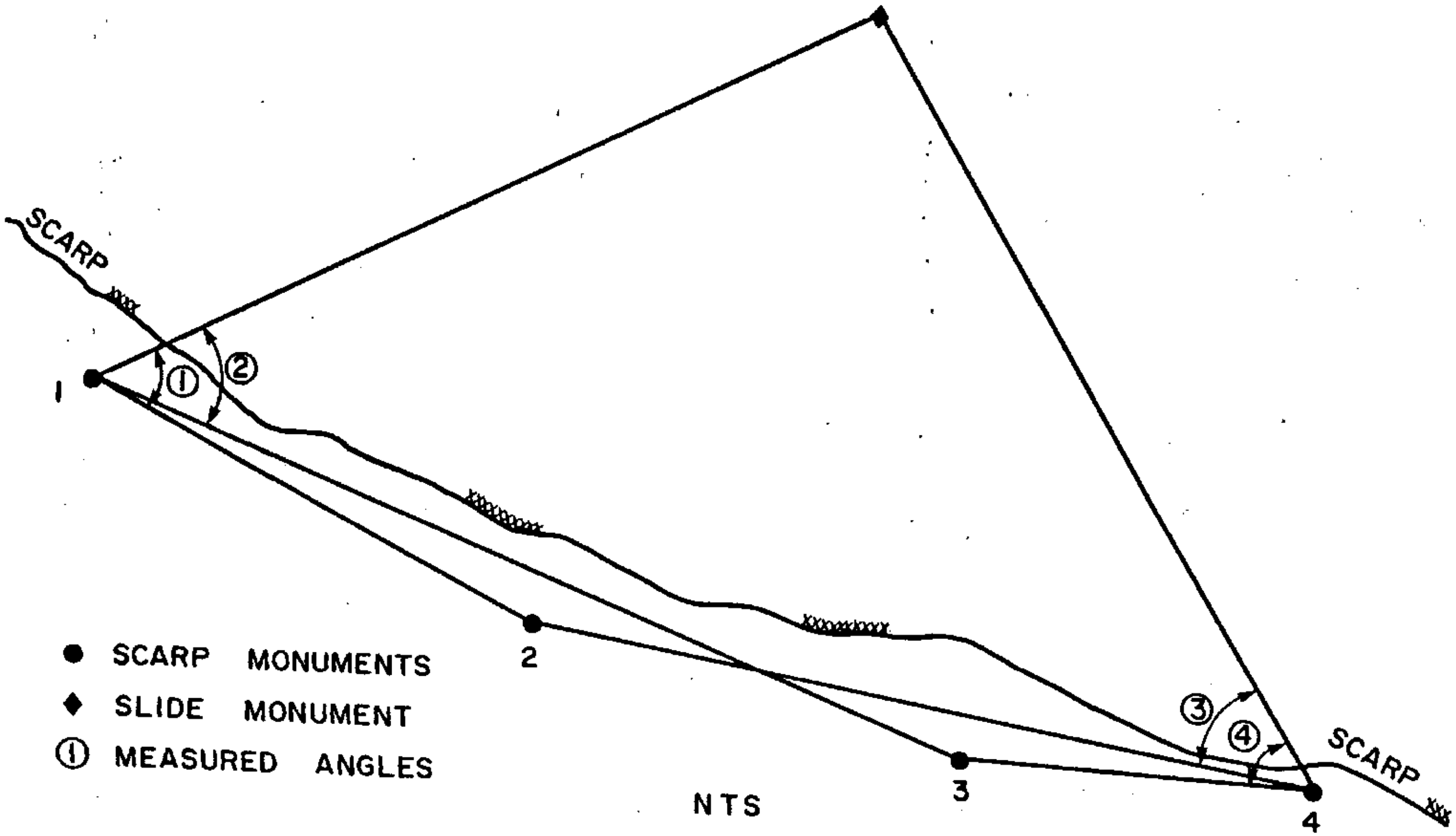


FIGURE 5.12 MEASUREMENT OF 4 INDEPENDENT ANGLES TO EACH SLIDE MONUMENT

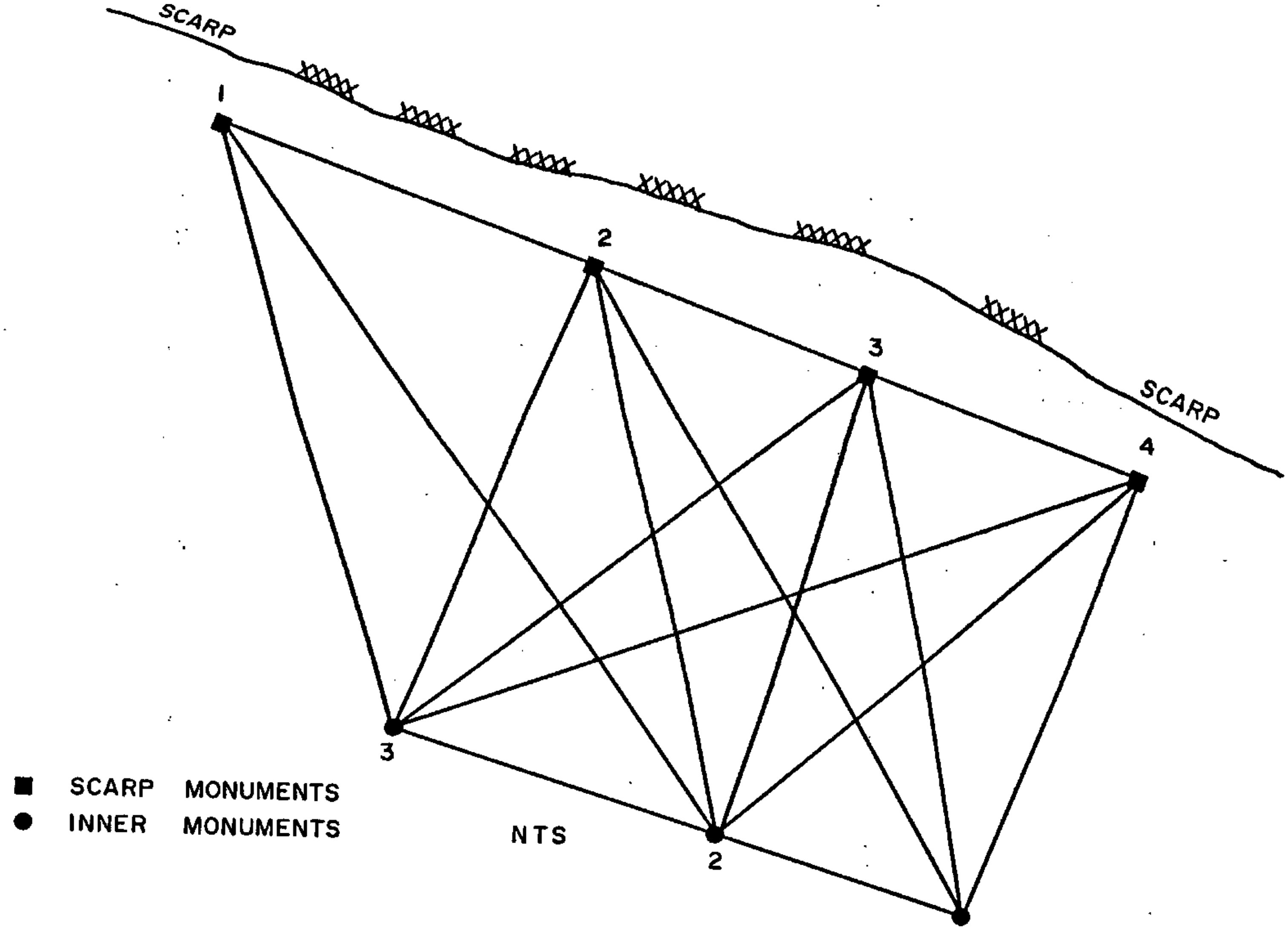


FIGURE 5.13 TRIANGULATION NETWORK

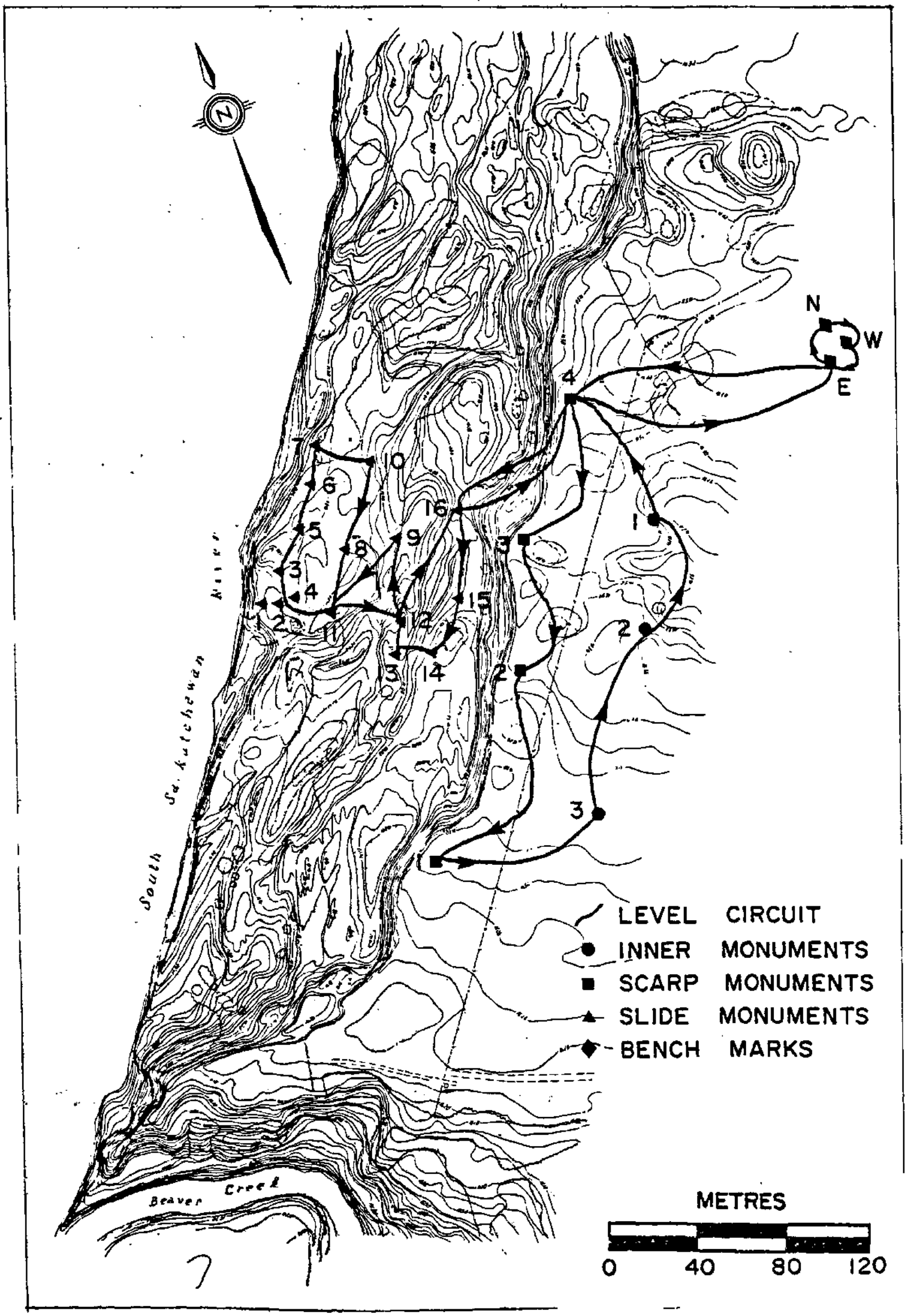


FIGURE 5.14 LEVEL CIRCUIT

regularly to ensure that no differential movements were taking place.

The field results indicate that standard deviations in the order of 0.3 mm to 1.5 mm were obtained for all the elevations. This is well within the requirements for first order leveling and indicates a high degree of accuracy was being obtained.

5.3.4 Frequency of Measurement

All the monuments were installed in October, 1977. The first survey took place in November, 1977 and consisted of horizontal angle measurements to the SLIDE monuments and assorted distance measurements between the SCARP and INNER monuments.

The second survey was performed in May, 1978. This survey consisted of horizontal angle measurement to the SLIDE monuments, triangulation-trileration between the concrete monuments on top of the scarp and precise leveling to all monuments.

The third survey in August, 1978, the fourth survey in May, 1979, and the fifth survey in August, 1979, consisted of horizontal angle measurements to the SLIDE monuments, triangulation between the concrete monuments on top of the scarp, baseline calibration and precise leveling to all monuments.

Special field sheets for angle measurement and leveling were developed to keep the large amount of data recorded organized. The field data for each survey is presented in Appendix B.

5.4 Adjustment and Reduction of Field Data

The entire network consists of 23 stations. The triangulation network between all the monuments consists of approximately 90 angle measurements. Handling the large amount of data was made simple by establishing a rigorous procedure to reduce and analyze the results.

This procedure consisted of:

1. Reducing the data and calculating standard deviations in the field. This ensures that no blunders are made and the required accuracy of 1.2 seconds is being attained.
2. Comparing horizontal angle measurements of the current survey with that of the last survey to ensure no blunders occurred.
3. Adjusting the data using program LSQADJ.
4. Checking the reliability of the results and eliminating any unreliable data.
5. Using a statistical test to find the confidence regions for movement between respective time periods, if necessary.

5.4.1 Calculation of Initial Coordinates

The first step was to establish an origin for the X-Y-Z coordinate system. The baseline was chosen to be from INNER-2 to INNER-3. The coordinates of INNER-3 were arbitrarily chosen as X=100.0000 metres; Y=100.0000 metres. The baseline was also assumed to be the X-axis. This baseline is roughly parallel with the South Saskatchewan River (Figure 5.10). Any resulting slide movement will be towards the river, i.e., almost entirely in the Y-direction. The baseline distance was measured to be 83.7176 metres, yielding coordinates of INNER-2: X=183.7176 metres; Y=100.0000 metres.

The East Geodetic Vertical Control Bench Mark (Figure 5.10) was assumed to be at an elevation of 100.0000 metres. At the time of writing, the Geodetic Survey of Canada had not yet processed the final geodetic elevations.

The coordinates of the remaining monuments were determined once the base line coordinates had been established. There was insufficient data available from the November, 1977, survey to establish the coordinates of all the concrete monuments and the results of the May, 1978, survey had to be used for this purpose. As a result, the data from the November, 1977, survey was used for checking purposes only and was not used for any movement calculations.

The preliminary coordinates of the SCARP and INNER monuments were calculated by using various trignometric relationships since the program LSQADJ requires only approximate coordinates prior to performing and adjustment. The preliminary coordinates of the SLIDE monuments were then calculated knowing the coordinates of the SCARP monuments.

After all the preliminary coordinates were found, the entire network was adjusted using the May, 1978, measurements. This adjustment was performed using INNER-2 and INNER-3 as fixed stations with centering error equal to 0.5 mm at all concrete monuments and 1.0 mm at all SLIDE monuments. The reliability of the results was checked using the tolerance test. All the measurements were found to be reliable with the mean, absolute, unweighted residual being 0.41 seconds for angle measurements. The results of the adjustment calculations are presented in Appendix C.

The initial coordinates of the May, 1978, survey were used as the basis for calculating movements in all the other surveys. The final adjusted coordinates for May, 1978, are presented in Appendix D.

The angles to the SLIDE monuments in November, 1977 and May, 1978 agree very closely. This indicates that no blunders were made, but the results were not used to determine if any movement had taken place.

5.4.2 Adjustment of Subsequent Surveys

The initial coordinates from the May, 1978 survey were used as the preliminary coordinates for the adjustment of all other surveys. This eliminated the recalculating of coordinates and extra punching of data cards.

The same procedure for reduction and analysis of the data was followed in all subsequent surveys. The results of the adjustments using LSQADJ is presented in Appendix C. The final coordinates of the monuments for each subsequent survey are presented in Appendix D.

5.4.3 Statistical Accuracies and Reliability of Results

The reliability of the results for the August, 1978, survey was checked with the tolerance test for residuals. For the 92 resultant angles (i.e., obtained from the 119 measured directions) the mean, absolute, unweighted residual was 1.1 seconds, with all the measurements passing the tolerance test. This indicated that all the data was reliable.

The reliability of the results was checked for the May, 1979, survey. For the 95 resultant angles (i.e., obtained from 123 measured directions) the mean, absolute, unweighted residual was 1.0 seconds and all the data was reliable. The results for the August, 1979, survey were also found to be reliable. For the 89 resultant angles (i.e., obtained from 114 measured directions) the mean, absolute, unweighted residual was 1.1 seconds.

Comparison of angles from the August, 1978, and the August, 1979, surveys differed by as much as 100 seconds which indicated that movement was definitely taking place.

The maximum error ellipses occurred at SLIDE monuments farthest away from the scarp. For example, at SLIDE-7 in August, 1979, the major axis of the 95 percent error ellipse was 6.5 mm. The 95 percent interval for elevation was 2.1 mm. The resultant 95 percent error elliptical cylinder at SLIDE-7 for the August, 1979, survey is shown in Figure 5.15. The 95 percent error elliptical cylinders will be used to determine the levels of significance with respect to movement in the next chapter.

In general, the results of all the surveys were found to be highly reliable. This should serve to greatly enhance our confidence in the final analysis.

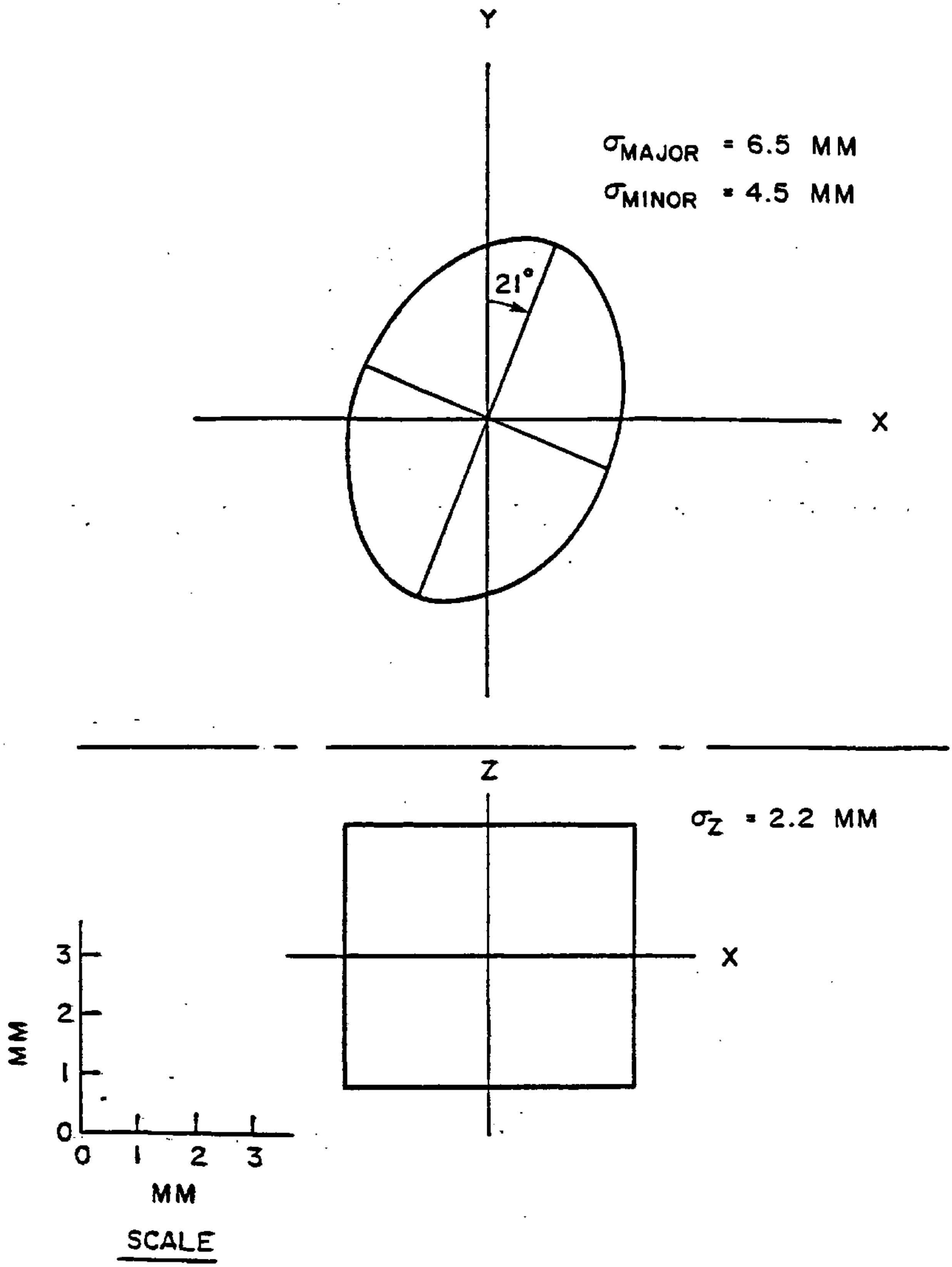


FIGURE 5.15 95 % ERROR ELLIPTICAL CYLINDER AT SLIDE -7 FOR AUGUST, 1979

CHAPTER VI

ANALYSIS OF RESULTS

6.1 Introduction

The surface movements of the landslides at Beaver Creek were studied and compared to the current retrogressive slide model. Emphasis was also placed on analyzing the survey techniques employed.

6.2 Retrogressive Slide Model

The slides occurring at Beaver Creek have been described as retrogressive in behavior. Figures 6.1 and 6.2 show the landslides at present. They are composed of numerous slide blocks, a clearly discernable scarp and an eroded toe. A detailed description and geotechnical analysis of the landslides is presented by Haug (1976)

The nature of a retrogressive mechanism suggests the slide is triggered by movement at the toe. The movement of the slide then works its way up the slide in a series of failures. The simulation of this type of failure requires that the slide be broken into a series of slide blocks.

A graphical illustration of how the different portions of the slide travel at different speeds, and end up with configurations similar to those described in the slide, is shown in Figure 6.3. This figure shows a sequence of failures of a previously unfailed 2 to 1 slope. The movements are indicated by vectors and a material balance is maintained in the slide at all times.

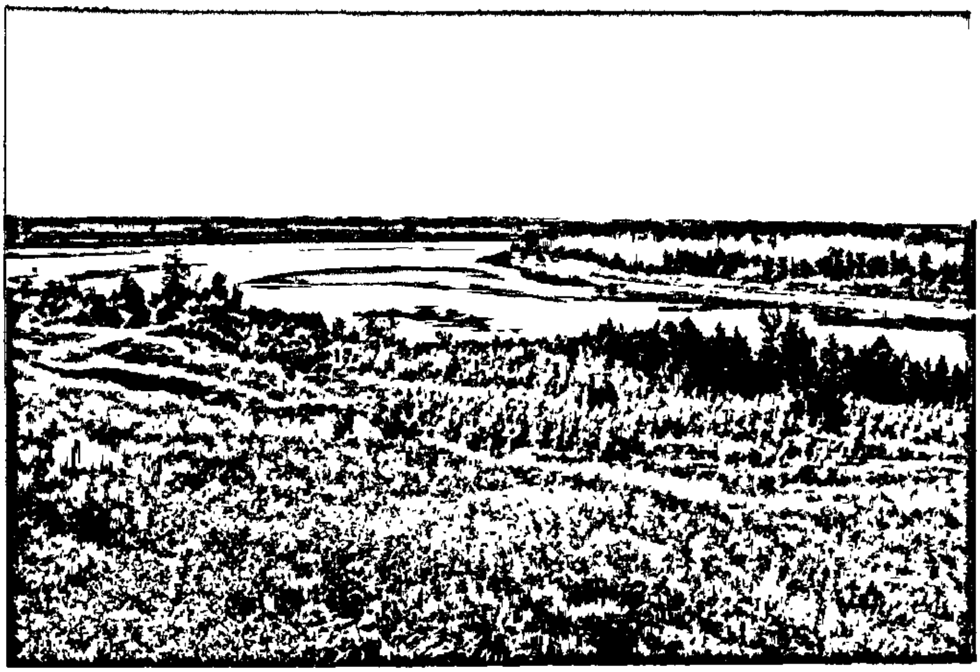


FIGURE 6.2: LANDSLIDES AT PRESENT

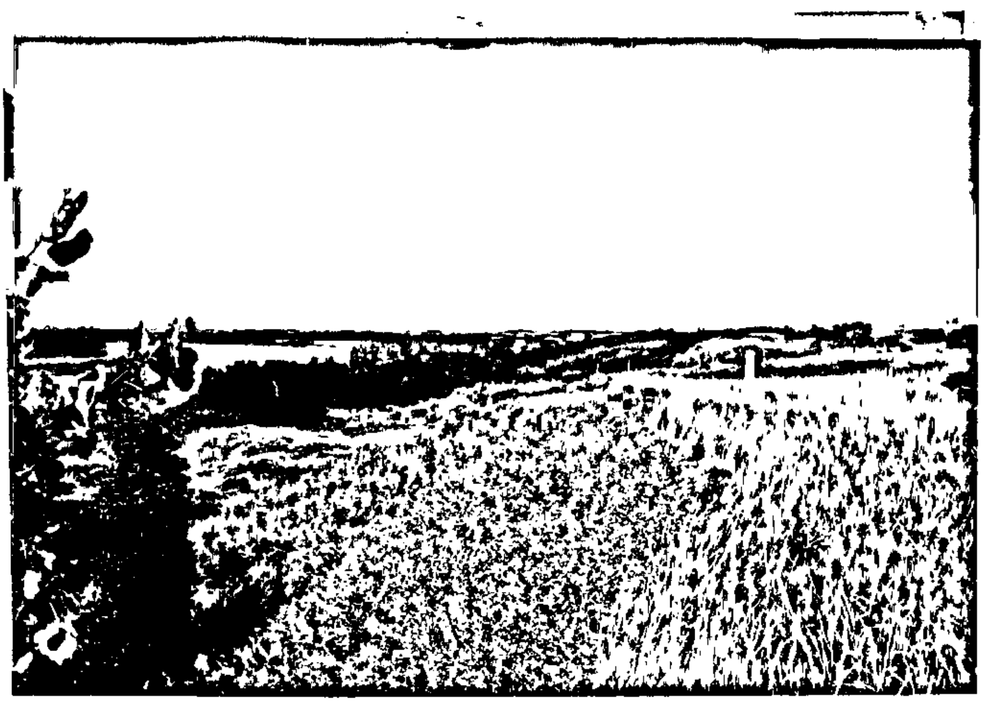
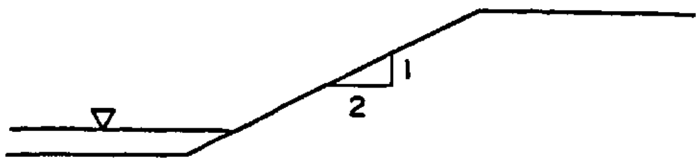
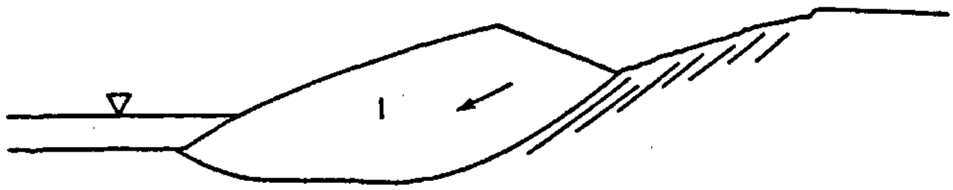


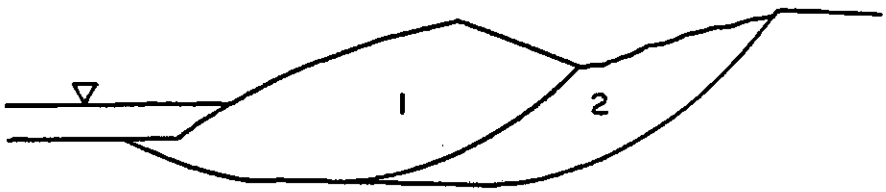
FIGURE 6.1: LANDSLIDES AT PRESENT



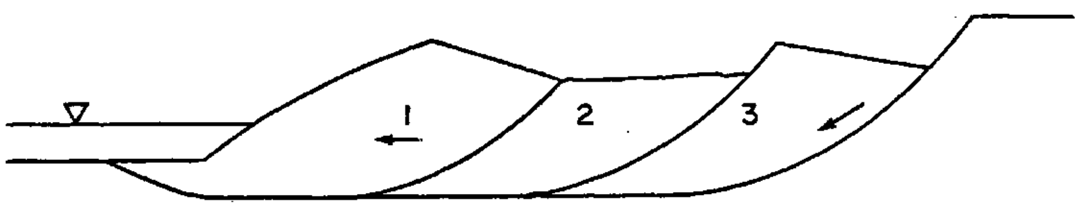
a UNFAILED SLOPE



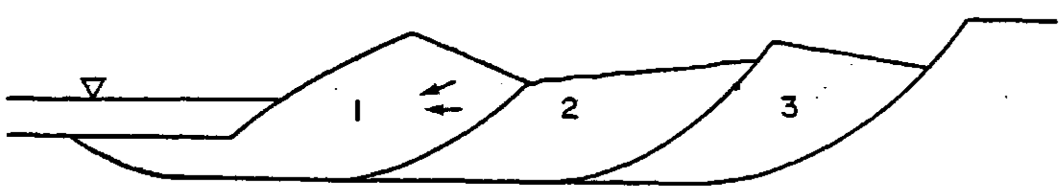
b ROTATIONAL FAILURE AND PULLING DOWN OF THE SCARP



c ROTATIONAL FAILURE OF BLOCK 2



d HORIZONTAL MOVEMENT OF BLOCK 1 ALLOWING BLOCK 2 TO SETTLE AND BLOCK 3 TO FAIL



e ROTATION AND TRANSLATION OF BLOCK 1 ALLOWING BLOCK 2 TO SETTLE MORE

FIGURE 6.3 RETROGRESSIVE SLIDE MODEL, HAUG (1976)

In order for this type of failure to occur, it must be assumed that the rate of movement increases towards the river. Blocks nearer the river should tend to have a predominantly horizontal movement while blocks near the scarp should have predominantly rotating movement. This type of model also requires that each slide block move as a coherent mass.

6.3 Observed Surface Kinematics

The amount of surface movement was calculated from the X-Y-Z coordinates of the slide monuments during successive time periods. Once the degree of confidence in the movements was determined, an analysis of the results was made.

6.3.1 Calculation of Surface Movement

The coordinates of the Scarp and Inner monuments could not be determined from the November, 1977 survey due to a lack of field information. Hence no movement calculations were performed for the time period from November, 1977 to May, 1978.

As a result, the coordinates of the monuments in May, 1978 were used as the initial or starting coordinates for the remainder of the study. The three time periods studied are from May, 1978 to August, 1978; May, 1978 to May, 1979; and May, 1978 to August, 1979.

The horizontal and vertical coordinates were determined independently, but could be combined to find the resultant three dimensional movement. The movement calculations performed were the calculation of the resultant horizontal and vertical movements and their respective rates. The results of the movement calculations are presented in Appendix E.

6.3.2 Reliability of Results

To assist in interpreting the results, the horizontal and vertical vectors for surface movement were plotted on a map of the slide area. The plot of surface movement for the May, 1978 to August, 1978 period is shown in Figure 6.4, for the May, 1978 to May, 1979 time period in Figure 6.5, and for the May, 1978 to August, 1979 time period in Figure 6.6. The 95 percent error elliptical cylinders have been plotted for monuments SLIDE-7 and SCARP-4 on Figures 6.7 and 6.8 respectively.

6.3.2.1 May, 1978 to August, 1978 Time Period

The horizontal surface movements for the May, 1978 to August, 1978 time interval, (Figure 6.4), indicate that the majority of the SLIDE monuments have moved a distance of 10 mm towards the river. All the movements appear to be in the expected direction with the exception of SLIDE-1. The fact that allof the movement is in the same general direction and of the same magnitude implies that some significant movement is occurring. The plots of the 95 percent error elliptical cylinders for SLIDE-7 and SCARP-4 (Figures 6.7 and 6.8) reveal that the error ellipses do not overlap for this time period. Based on the statistical test derived earlier, this would indicate that movement is occurring at the 5 percent level of significance.

Movement in the vertical direction is small (e.g., 3 mm) at all monuments and all are in a downward direction. This movement was

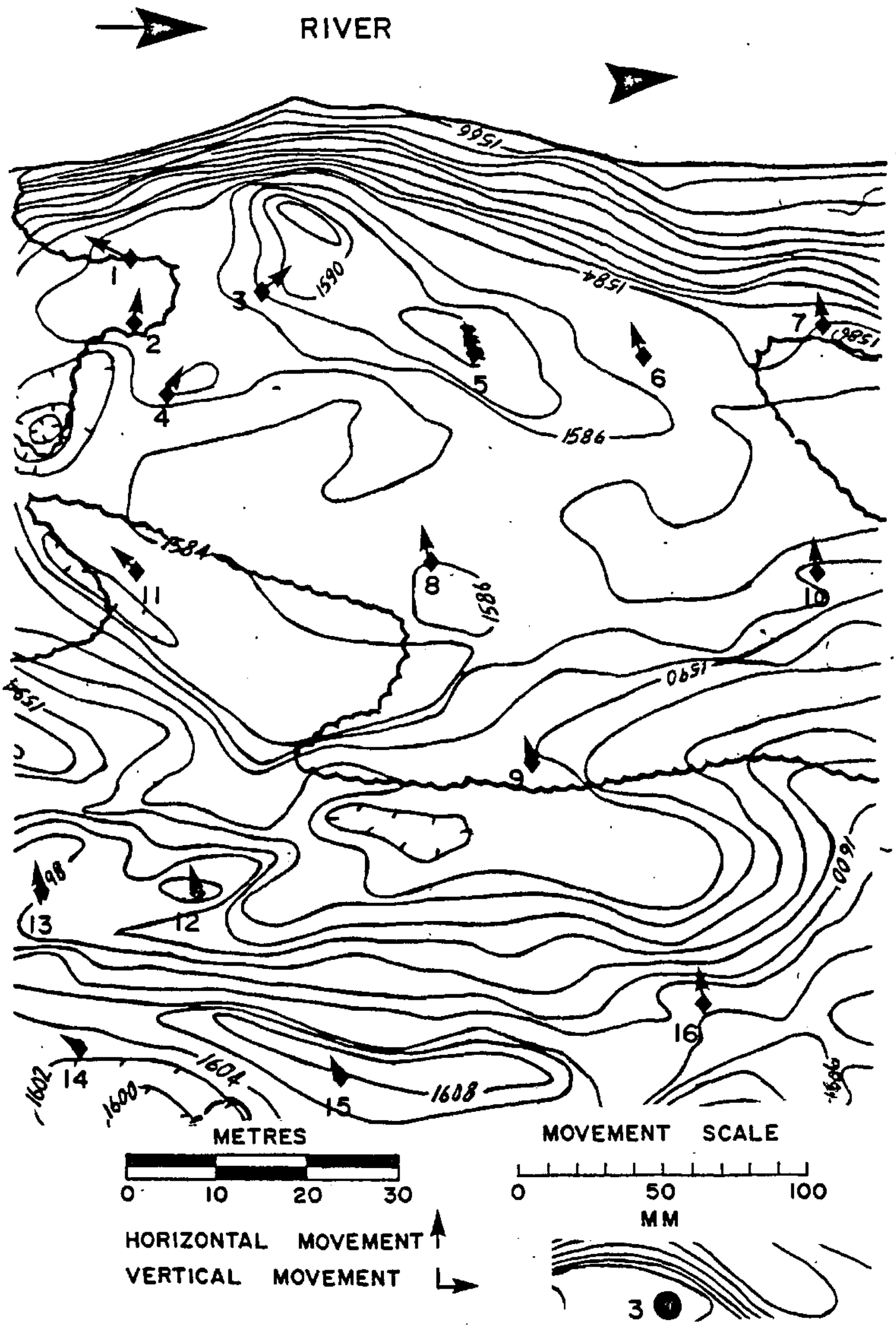


FIGURE 6.4 MOVEMENT FROM MAY, 1978 TO AUGUST, 1978

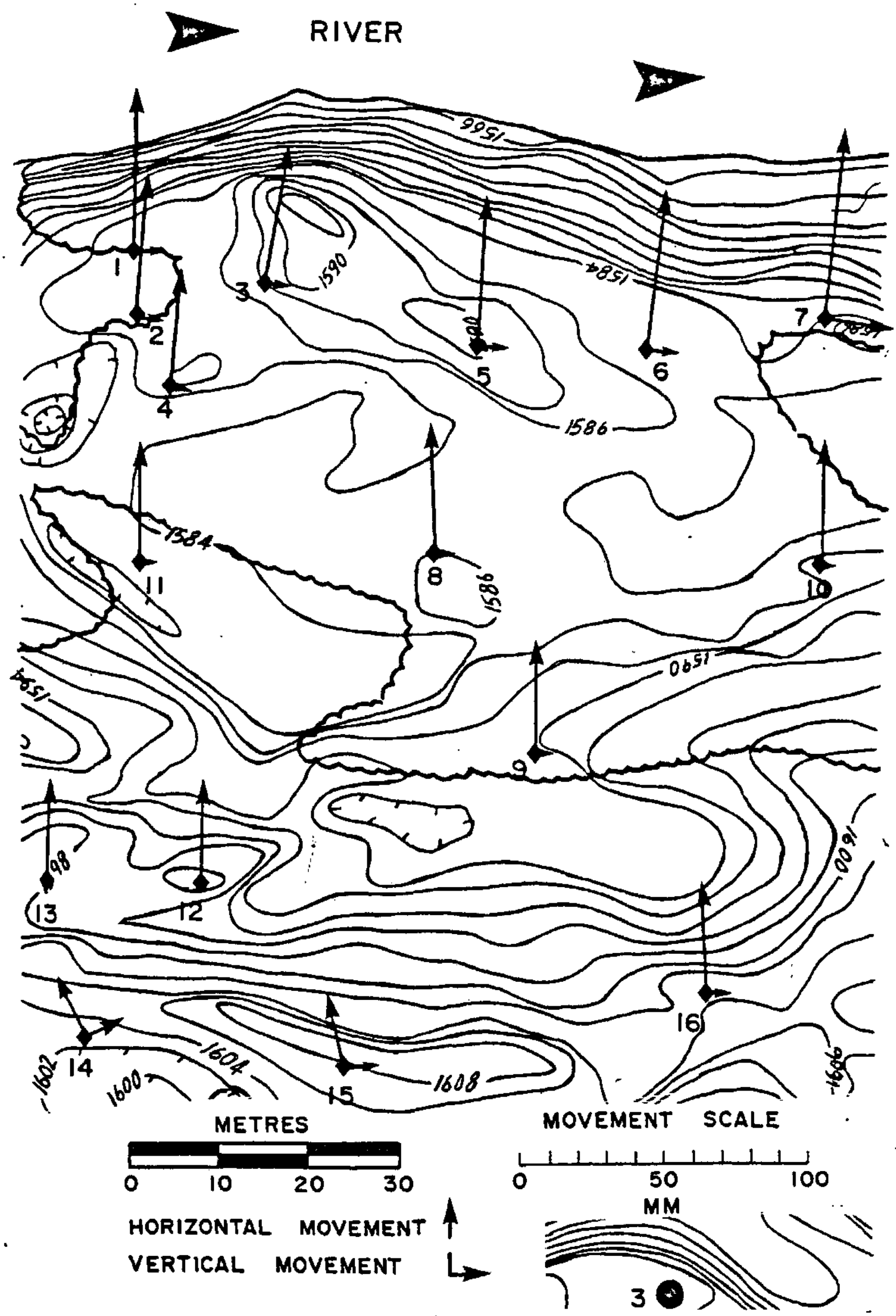


FIGURE 6.5 MOVEMENT FROM MAY, 1978 TO MAY, 1979

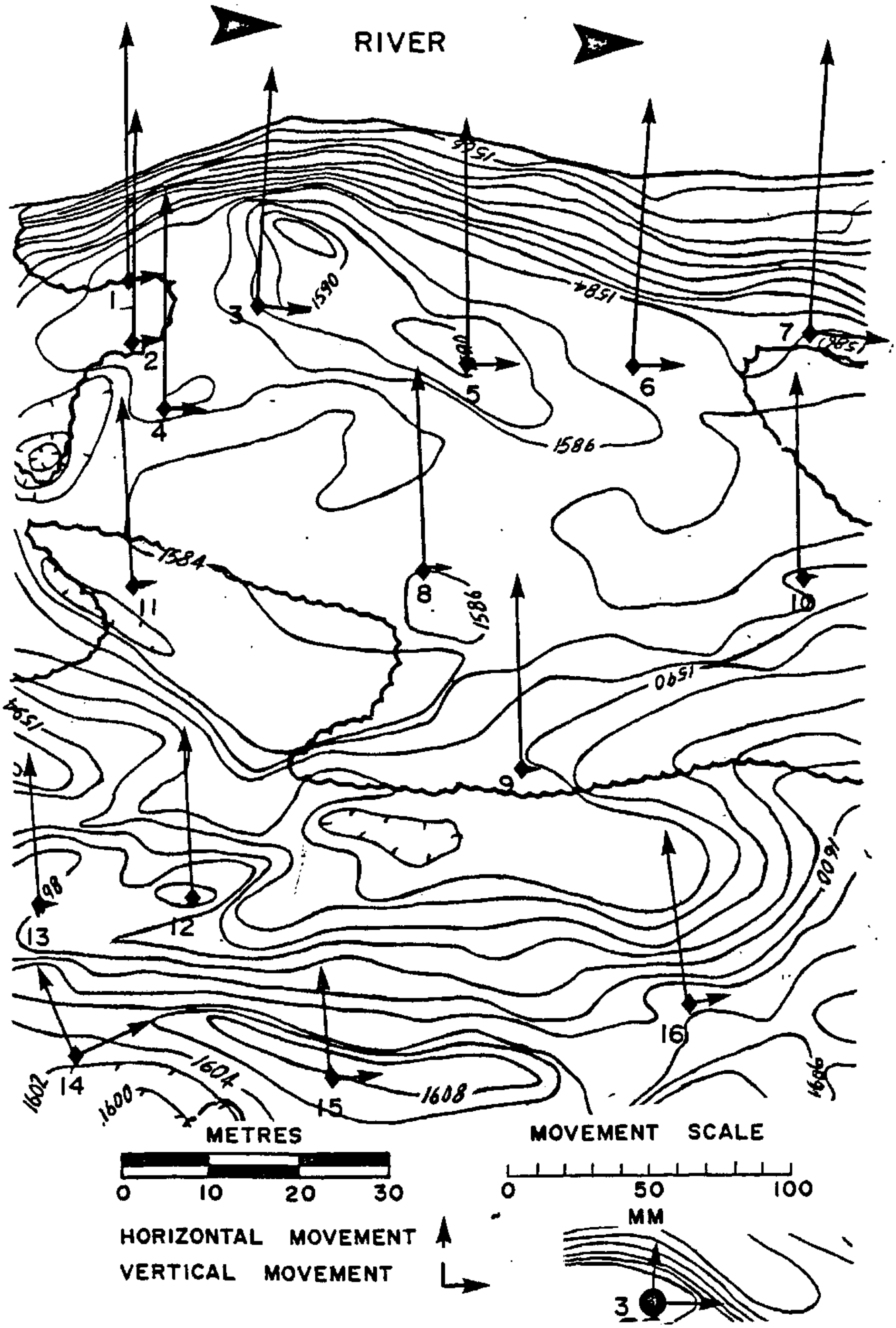


FIGURE 6.6 MOVEMENT FROM MAY, 1978 TO AUGUST, 1979

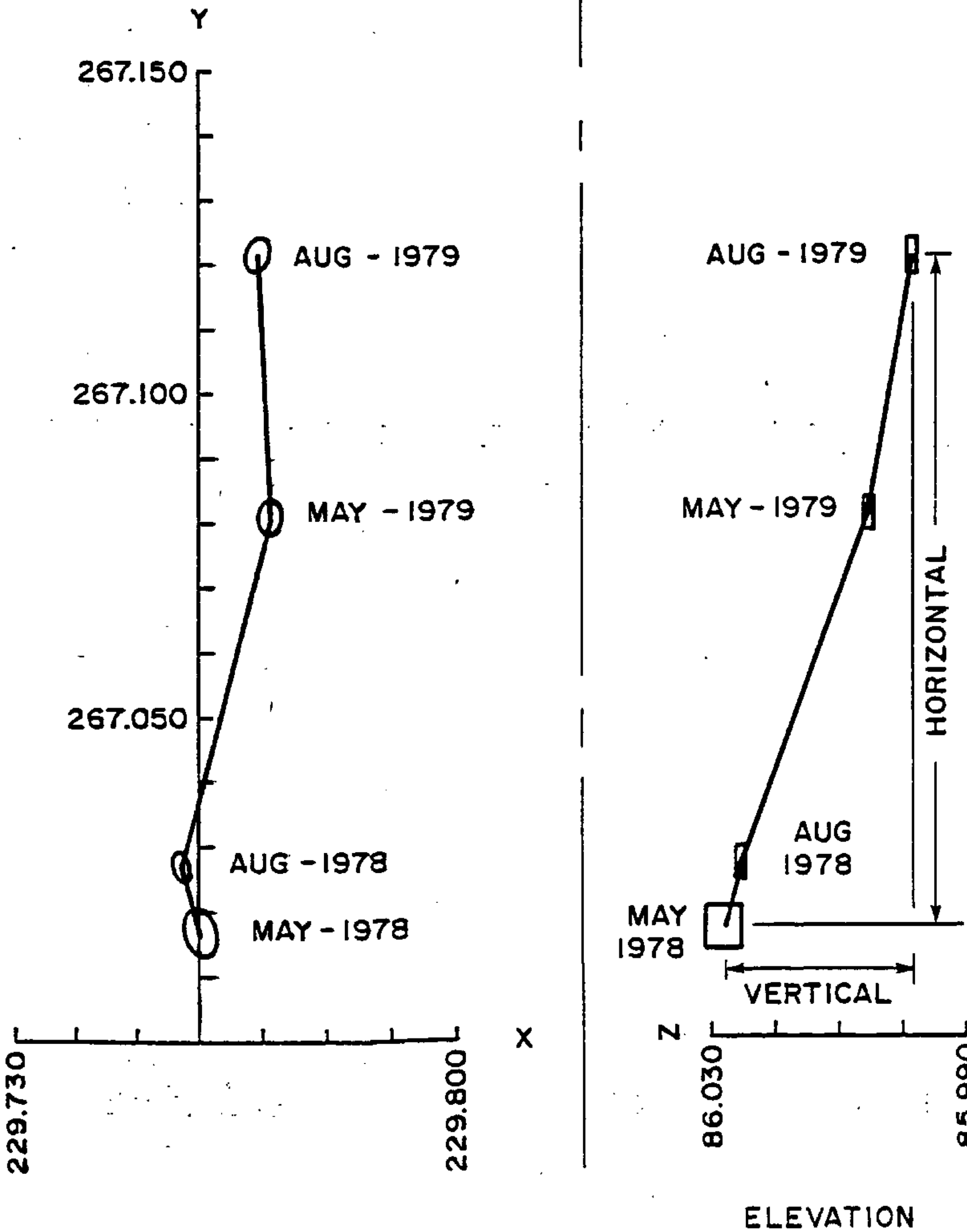


FIGURE 6.7 ERROR ELLIPTICAL CYLINDERS AT SLIDE - 7

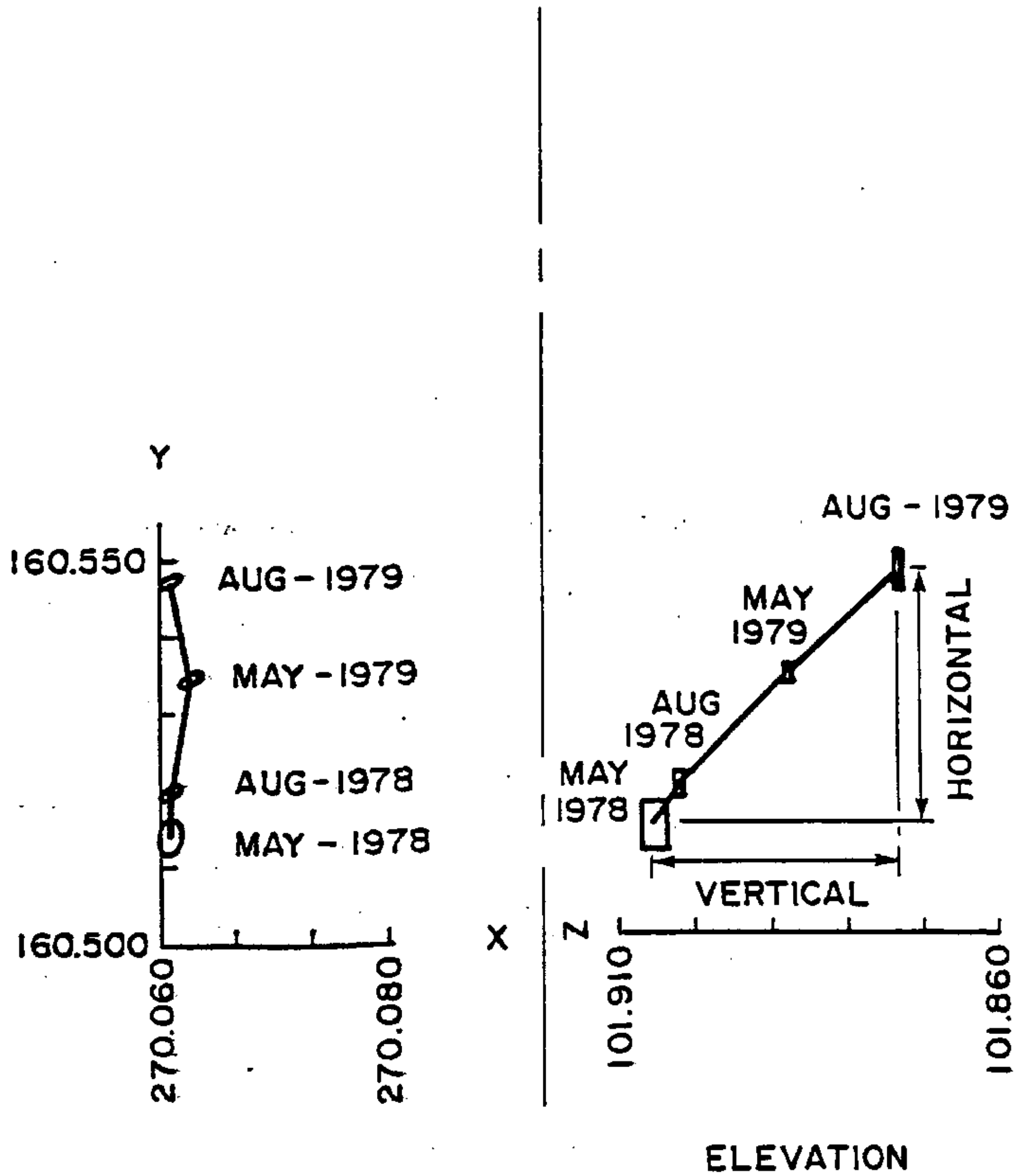


FIGURE 6.8 95 % ERROR ELLIPTICAL CYLINDERS FOR SCARP - 4

too small to plot on Figure 6.4. The plot of the 95 percent error elliptical cylinder for SLIDE-7 reveals that the 95 percent confidence intervals for elevation do overlap which would suggest that the vertical movement is not highly significant.

A more detailed statistical analysis of the movements was not performed since a consistent pattern of movement was readily apparent, i.e., horizontal movement was towards the river and vertical movement was downwards. This consistency together with the results of the least square adjustment suggested that statistically significant movement was occurring.

Since the movement is very small (e.g., 10 mm horizontally and 3 mm vertically), it was difficult to establish how much of this was true surface slide movement. This period was the first time the monuments have been exposed to summer conditions. It is entirely possible that setttlement, climatic changes and even the effects of the first initiating movement may have taken up any "slack" and resulted in tilt of the monuments. It is feasible that this could account for at least 5 mm of movement in a horizontal direction and 3 mm of movement in a vertical direction. Any attempt at analyzing the movement of the slide based on the results of May, 1978 to August, 1978 time period was therefore disregarded.

6.3.2.2 May, 1978 to May, 1979 Time Period

The horizontal movements for the May, 1978 to May, 1979 time period, (Figure 6.5), indicate that all movements are in the order of 30 mm to 60 mm and all are towards the river. Vertical movement ranges from 6 mm to 20 mm in a downward direction. The 95 percent error elliptical cylinders for SLIDE-7 and SCARP-4 (Figures 6.7 and 6.8) between May, 1978 and May, 1979 are so far apart that any statistical test on the significance of the movement was deemed unnecessary. The consistent pattern of movement together with the results of the least square adjustment indicated that movement of the SLIDE monuments was indeed occurring.

The amount of movement was large relative to the May, 1978 to August, 1978 time period. The observed 30 mm to 60 mm of movement must be due to true surface movement of the slide. It would be unreasonable to attribute the movement solely to the effects of environmental changes on the SLIDE monuments. The slide movement is undeniably towards the river, as was expected.

6.3.2.3 May, 1978 to August, 1979 Time Period

The horizontal movements for the May, 1978 to August, 1979 time period (Figure 6.6) indicate that all movements are in the order of 40 mm to 100 mm, and all follow the direction of movement that occurred in the previous time period. Vertical movement ranges from 10 mm to 30 mm in a downward direction. The 95 percent error elliptical cylinders for SLIDE-7 and SCARP-4 (Figures 6.7 and 6.8 respectively) begin to reveal an interesting pattern. SCARP-4, which is at the edge of the scarp, appears to move the same amount horizontally and vertically. SLIDE-7, which is near the river, appears to move in a predominantly horizontal direction. This pattern is consistent for all three time periods. At this stage, there is no doubt whatsoever that significant surface slide movement is occurring.

The results of the movement calculations for the three time periods indicate that surface movement of the slide follows a definite pattern. The accuracy of the surveying was such that this movement (e.g., 40 mm to 100 mm horizontally and 10 mm to 30 mm vertically) could be used to analyze the pattern of movement in the slide with a high degree of confidence. The results of the May, 1978 to August, 1979 time period will be used for this purpose.

6.4 Analysis of Surface Movements

Prior to an analysis of surface kinematics using the results of the May, 1978 to August, 1979 time period, it is necessary to know on what part of the slide the monuments are located. Using air photos and ground surveillance, the major slide blocks in the area have been outlined, (see Figure 6.9). This shows SLIDE monuments 1 to 11 are on a major slide block near the river, (Figure 6.10). SLIDE monuments 14 and 15 are on the edge of a slide block adjacent to the scarp, (Figure 6.11). SLIDE monuments 12, 13 and 16 are in interblock zones between the two major slide blocks, (Figure 6.12). SCARP-4 is adjacent to a new slide block forming to the northeast, (Figure 6.13).

The analysis first considers the movement of the whole study area. From Figure 6.6., it is apparent that the horizontal movement is predominantly towards the river. The rate of horizontal movement varies from 1 mm/month on top of the scarp to 7 mm/month near the river. This is shown in contour form in Figure 6.14. This supports the model of a retrogressive slide which states that the rate of

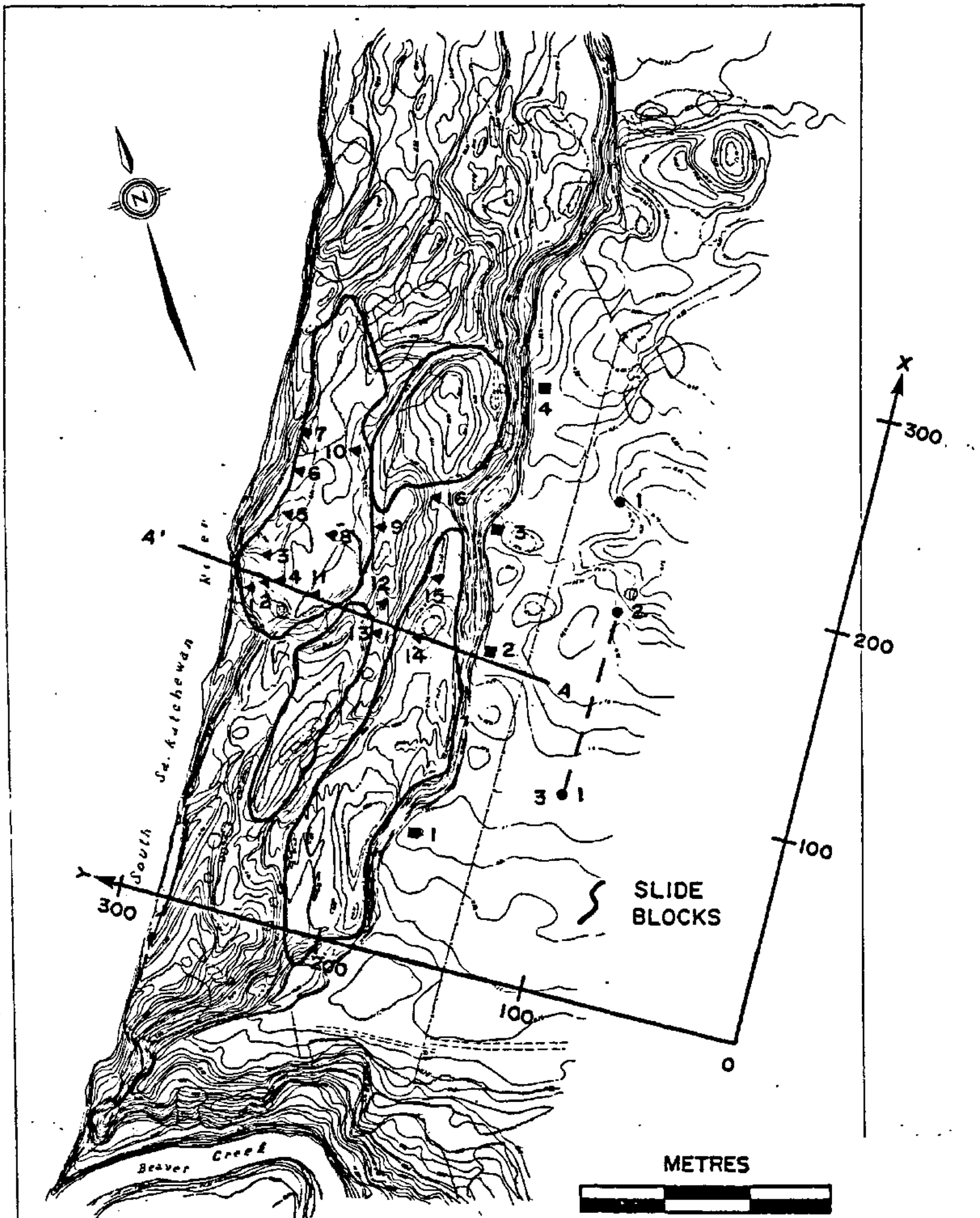


FIGURE 6.9 MAJOR BLOCKS

FIGURE 6.11: SLIDE BLOCK NEAR SCARP

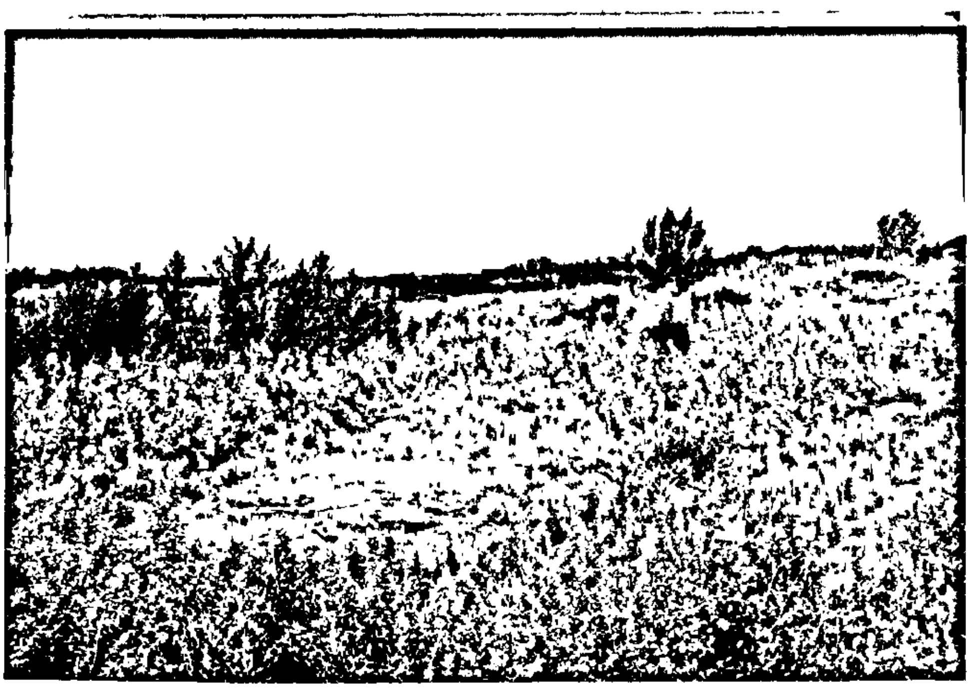


FIGURE 6.10: MAJOR SLIDE BLOCK NEAR RIVER

FIGURE 6.13: FORMATION OF NEW SLIDE BLOCK ADJACENT TO STUDY AREA

FIGURE 6.12: INTERBLOCK ZONE

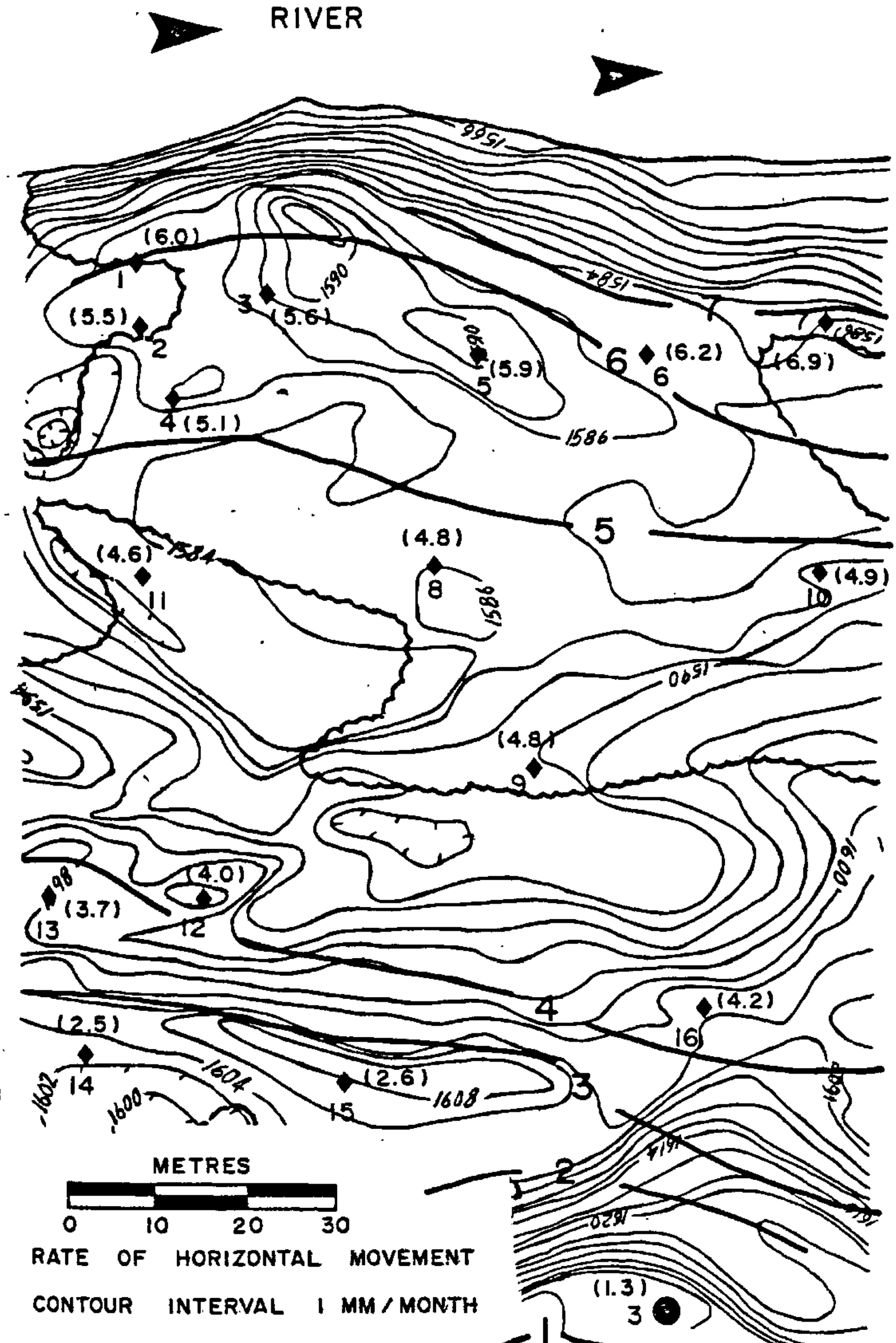


FIGURE 6.14 RATE OF HORIZONTAL MOVEMENT FROM MAY, 1978 TO AUGUST, 1979

horizontal movement increases from the scarp to the toe. The contour map shows that the movement is relatively constant in the middle of the slide at 4 mm/month to 5 mm/month, with sharper changes in rates near the toe and near the scarp.

The vertical surface movement rates have been plotted in contour form on Figure 6.15. This plot shows downward vertical movement near the scarp and near the toe of 1.5 mm/month. There is downward movement of 0.5 mm/month in the middle of the slide. This indicates that the material near the toe is sloughing into the river and the area near the scarp is dropping down at a slightly faster rate than the material in the middle of the slide.

A cross section was drawn across the study area to better illustrate the surface movement. The cross section chosen was $A\text{-}A^1$ in Figure 6.9. The rates of movement were then plotted on Figure 6.16. The plot clearly shows the increase in movement towards the toe. The area near the top of the scarp moves horizontally and vertically at the same rate suggesting a rotational type of motion. The downward movement becomes less pronounced with increasing distance from the scarp. Near the river, the movement is predominantly horizontal.

This observed behavior agrees well with the expected model. Movement near the top of the scarp is primarily rotation. The amount of rotation decreases as the blocks near the toe.

The movements of the slide monuments on the large slide block near the river indicate that it is moving as one coherent mass. The rates of movement are very similar as is the direction of movement. There is a noticeable effect of sloughing near the leading edge of the

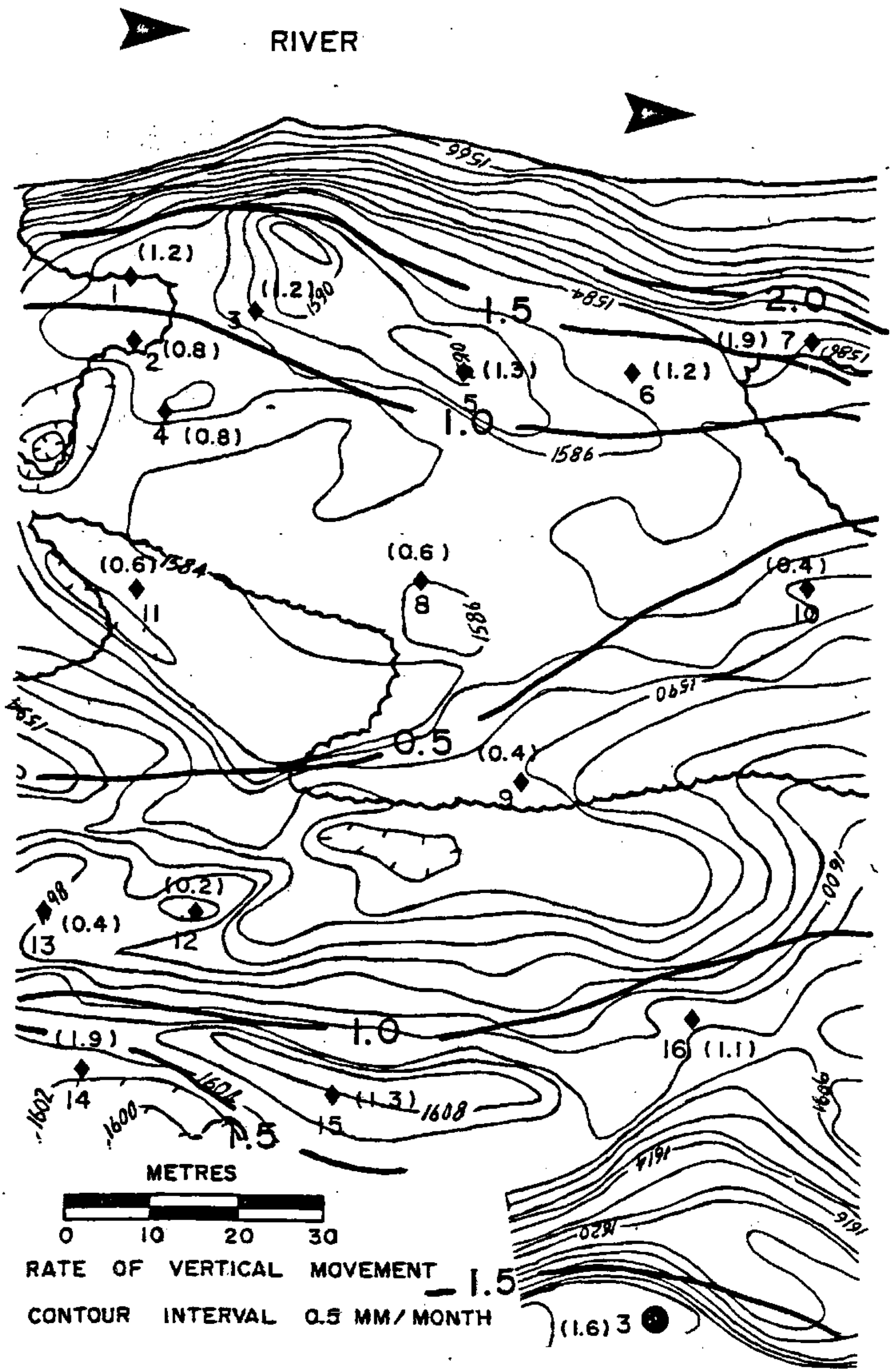


FIGURE 6.15 RATE OF DOWNWARD VERTICAL MOVEMENT FROM MAY, 1978 TO AUGUST, 1979

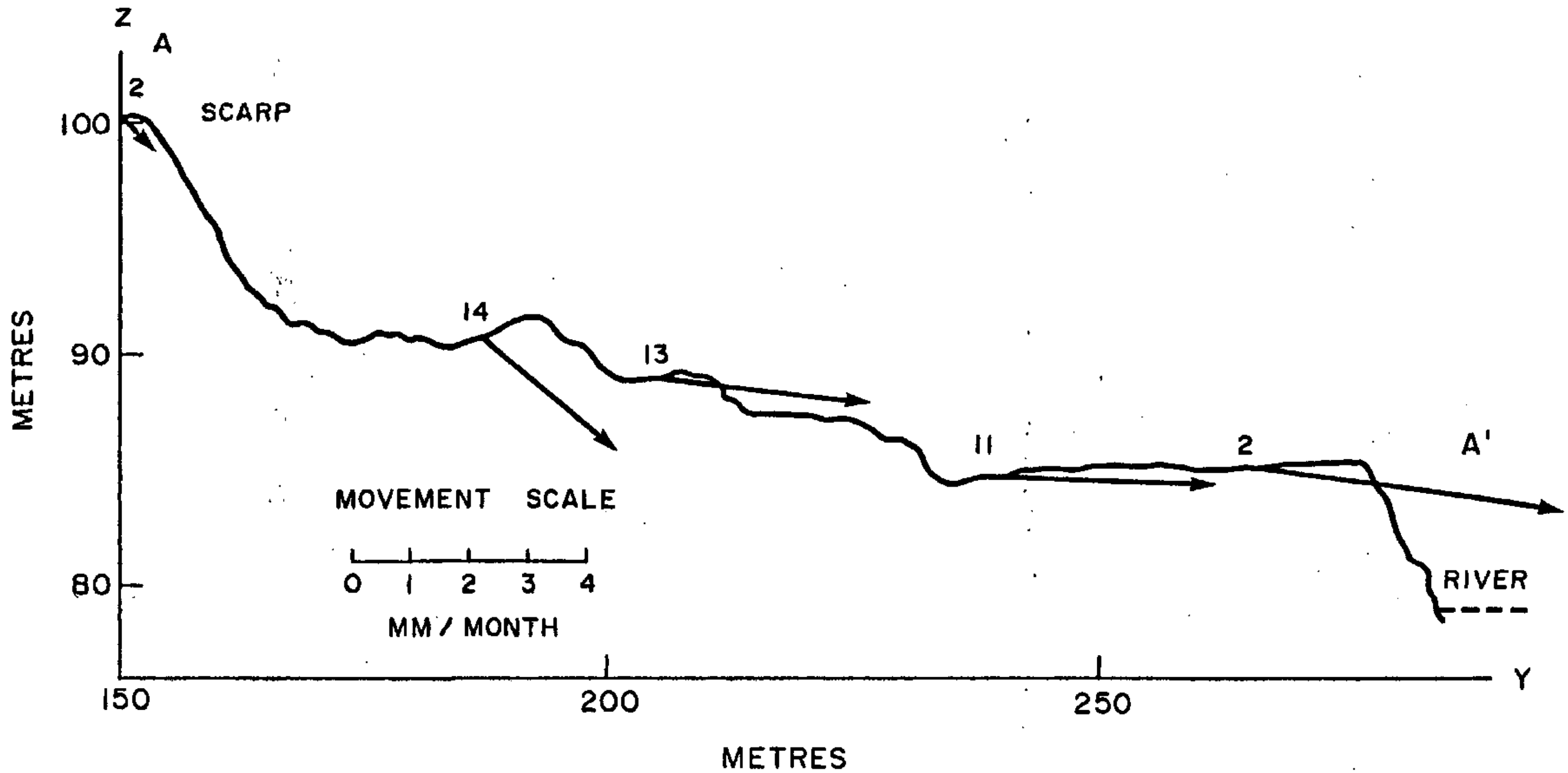


FIGURE 6.16 CROSS SECTION A - A' THROUGH LANDSLIDE SHOWING RATES OF MOVEMENT

block as SLIDE-1 and SLIDE-7 experience more movement. The vertical drop for SLIDE-7 indicates that it is in the process of falling into the river (Figure 6.17).

There does not appear to be any significant rotation of the slide block, but it appears to move in a constant, slightly downward rate. This might indicate that the failure surface is not horizontal but slightly sloping towards the river.

SCARP-4 is located near to a new slide block that is forming to the northeast. The resultant movement is probably strictly rotation. The resultant movement is inclined at a 45 degree angle to the horizontal.

The movement of the three INNER monuments is very small. In fact, no significant movement of the INNER monuments has taken place in the horizontal direction or the vertical direction, at least no movement outside of the original 95 percent error elliptical cylinder. This ensures that the baseline is stable and that no undue movement has taken place due to tilt, consolidation of the monuments, freeze-thaw, etc.

A close look at the plots of the 95 percent error elliptical cylinders for SLIDE-7 and SCARP-4 (Figures 6.7 and 6.8 respectively) reveals a seasonal trend. The movement from May, 1979 to August, 1979 is much larger than the movement from May, 1978 to August, 1978. In other words, the slide appears to have moved more during the summer of 1979 than during the summer of 1978. This trend suggests that monitoring of the slide should continue into the future to establish if there is indeed some correlation between surface movement and

FIGURE 6.17: SLIDE-7 IN PROCESS OF SLOUGHING INTO RIVER.

environmental factors (e.g., water table, rainfall, river level, etc.). The slide has also appeared to move more during the August, 1978 to May, 1979 period than during either summer. This might suggest that spring thaw affects the movement of the slide. Much more data than is currently available is necessary to establish any seasonal trend, however it definitely does warrant further investigation.

6.5 Analysis of Survey Techniques

The integral parts of the instrumentation are the monument type, monument location, measuring technique and surveying equipment available.

6.5.1 Monument Type

The concrete monuments (SCARP and INNER) with the forced centering baseplates were found to be very reliable. They simplified the measuring process by enabling the surveyor to mount the equipment quickly and consistently each time. They have not experienced any deterioration or significant movement due to environmental changes. They provide a reliable means of horizontal control which enhances confidence in the results.

The SCARP monuments have experienced some horizontal and vertical movement but this has not affected their usefulness.

The SLIDE monuments have withstood all the environmental conditions considerably well. After the initial movement, they seem to be firmly mounted in the slide surface and capable of reflecting true surface movement.

The geodetic vertical control bench marks have not moved and provide the most reliable means of vertical control.

6.5.2 Monument Location

The study area should have been located 50 metres to the southwest. This would have allowed for the monumentation of two clearly discernible slide blocks, (Figure 6.9). The location of the present study area is in a complex area which made interpretation of the results more difficult.

An important consideration is to determine exactly how many monuments are necessary to adequately monitor the landslide. For example, SLIDE monuments 1 to 11 have all moved essentially the same amount in the same direction. This is because they were on one slide block. One monument at each corner should have been sufficient to adequately describe the slide block movement with respect to rate and tilt. The monuments should be placed far enough back of the leading edge so they do not begin to slough into the river as evidenced by SLIDE-1 and SLIDE-7. Monuments placed in interblock zones such as SLIDE-12, 13 and 16 do not add any pertinent information, and should be avoided. The SCARP monuments are in a good location in the sense that the study area in the slide can be shifted and all SCARP monuments will still be in desirable locations. It might have been possible to dispense with monument INNER-1 since it only served to reinforce the triangulation net on top of the scarp. However, a high order of horizontal control was needed and was obtained utilizing INNER-1.

6.5.3 Measuring Techniques

The measuring technique consisted of having two degrees of freedom at each SLIDE monument. This resulted in highly reliable results and a great deal of confidence in the calculations. Using one degree of freedom would increase the size of the error ellipses and ultimately affect the statistical test for movement. Two degrees of freedom should continue to be used.

It is interesting to note that the pattern of movement established during the May, 1978 to August, 1978 time period was followed throughout. This indicates that some true surface movement must have been detected during this time period. This lends credibility to the statistical test which states that significant movement has occurred if the two 95 percent error ellipses do not overlap. It is perhaps unfortunate that such a large amount of slide movement occurred relative to the 95 percent error ellipses and the use of the statistical test was deemed unnecessary in the latter time periods. It will eventually be necessary to establish exactly how small a movement can be consistently detected if surveying techniques continue to be used in geotechnical engineering. A detailed verification of the statistical test was determined to be beyond the principal objectives of this thesis once it had been established that the test did not in any way affect the final analysis of the surface movements of the slide.

6.5.4 Equipment

Each survey consisted of approximately 115 direction measurements. Using a theodolite that is not as precise as the Wild T-3 would not reduce the measurement time by a significant amount. However, a total station instrument such as the K & E Vectron, which can calculate the coordinates in the field, would greatly reduce the measuring time. Its applicability has yet to be determined.

The total measuring time took 3 full days with 1 person and just slightly shorter with 2 persons. The surveying time consists mainly of angle measurement and leveling. Consequently, the implementation of more points would increase the surveying time in a linear fashion, (Figure 6.18). The use of the more points would also increase the data reduction time in a linear fashion. This amounts to about 1 day to reduce and code the data, run the LSQADJ program, check and plot the results.

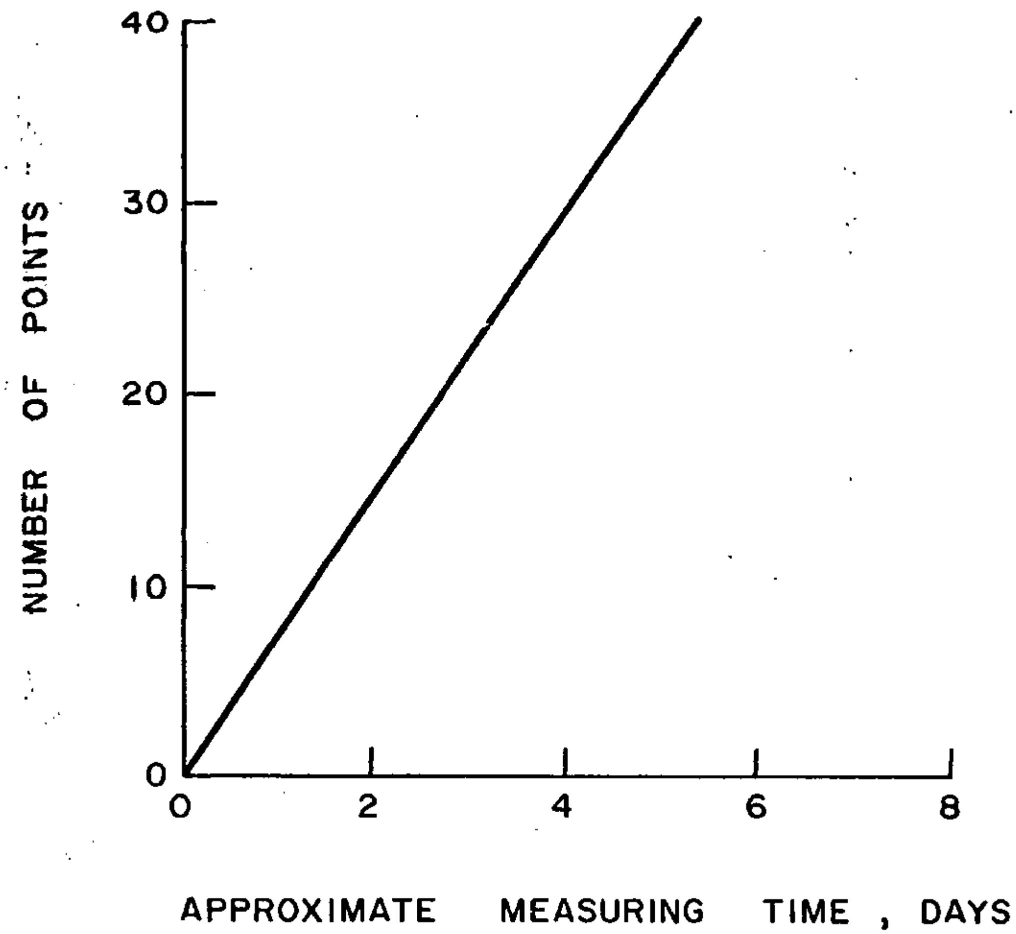


FIGURE 6.18 PLOT OF APPROXIMATE MEASURING TIME VERSUS NUMBER OF POINTS

CHAPTER VII

CONCLUSION

7.1 Retrogressive Slide Model

The principal conclusion of this study is that the rate of lateral movement of a retrogressive landslide increases from the scarp to the toe. The results also suggest that movement near the scarp is predominantly rotation, and near the toe movement is predominantly translation.

The vertical movement of the slide was downward throughout the study period. This might indicate that the failure surface is sloping slightly downwards from the scarp to the toe.

A seasonal trend in the movement of the slide is apparent. The slide moved more during the summer of 1979 than during the summer of 1978. Also, the slide appeared to move more during the winter of 1978-79 than during either summer. This suggests that some correlation exists between slide movement and environmental changes, (e.g., river level, rainfall, freeze-thaw).

The analysis of the movements was hampered because the study area contained only one clearly discernable slide block. Relocation of the study area might have yielded better information on the movement of slide blocks near the scarp.

The observed rate of movement of the landslide was 7 mm/month near the river and 1 mm/month near the scarp. 7 mm/month corresponds to approximately 1 x 10^{-9} ft/sec, which would classify the landslide as extremely slow (Schuster and Krizek, 1978).

7.2 Survey Technique

The survey techniques used in this study gave very reliable results. This is because a comprehensive preanalysis was made to determine the optimum type of network and to determine the expected statistical accuracies. The analysis was greatly enhanced with the use of the computer program LSQADJ which was used to perform the least squares adjustments, calculate the statistical accuracies and check the reliability of the results.

The study was aided considerably by the availability of precise surveying equipment: the Wild T-3 Theodolite, MA-100 Tellurometer and the Wild NA-2 precise level. However, this equipment is readily available from various companies and is not unique to this particular study.

The results indicated that the smallest movement that can be measured at the 95 percent confidence level using the available network and equipment was in the order of 7 mm at 150 metres. This accuracy was more than adequate since movement in the order of 40 mm to 100 mm occurred in the slide.

This study indicates that surveying techniques can be used to measure small deformations with a high degree of confidence. It is recommended that the methods of preanalysis, selection of configuration, selection of type of monumentation and final analysis employed herein be utilized when employing survey techniques as part of the total instrumentation in future geotechnical investigations.

7.3 Further Study

The present study should be carried on into the future. This would yield more results concerning the rates of movement, types of movement and possible seasonal trends in movement. This information is necessary if we are to analyze retrogressive landslides in the future with a reasonably degree of confidence.

The whole process of least squares survey adjustments, with respect to statistical accuracies and detection of movement, should be further investigated. A possible field test to investigate the statistical test for detection of movement presented in this thesis would be similar to that proposed by Quan, (1978). However, the concrete monuments present at the Beaver Creek site would provide a much more reliable means of control. More measurements with varying degrees of freedom should be taken to determine exactly when movement can be consistently detected and compared to the results of the statistical test. It is necessary to establish this threshold limit if surveying techniques are to be accepted as a useful measuring technique in geotechnical engineering.

This survey network at Beaver Creek is just one part of the total instrumentation. Slope indicators had been installed in the slide in 1977. An interesting project would be to compare the movements of the slope indicators with the movement of the SLIDE monuments. It is hoped that the surface movements obtained from survey measurements would assist in interpretation of the results from the slope indicators and vice versa. A study such as this should reveal that surveying techniques are indeed an essential component of the total instrumentation of a landslide, or in fact, in any geotechnical investigation.

SELECTED REFERENCES

AGUILAR, A.M. (1973), "Principals of Survey Error Analysis and Adjustment", Journal of the Survey and Mapping Division, ASCE, Vol. 99, No. SU1, pp. 107-121.

ARTHUR, J.R.F. (1974), "Field Instrumentation in Geotechnical Engineering", The British Geotechnical Society, John Wiley and Sons Inc., New York.

CHRZANOWSKI, A. (1974), "Pre-analysis and Design of Survey Projects", Part I, Northpoint No. 1, Journal of the Association of Certified Survey Technicians and Technologists of Ontario, pp. 22-30.

CHRZANOWSKI, A. (1976), "Pre-analysis and Design of Survey Projects", Part VII, Northpoint No. 1, Journal of the Association of Certified Survey Technicians and Technologists of Ontario, pp. 19-25.

CHRZANOWSKI, A. and STEEVES, P. (1977), "Control Networks with Wall Monumentation: A Basis for Integrated Survey Systems in Urban Areas", The Canadian Surveyor, The Canadian Institute of Surveying, Vol. 31, No. 1, pp. 211-223.

CHRZANOWSKI, A. (1977), "Pre-analysis and Design of Survey Projects", Part IV, Northpoint No. 4, Journal of the Association of Certified Survey Technicians and Technologists of Ontario, pp. 6-12.

CHURSINOFF, R.W. (1978), "Least Square Adjustments by Variation of Coordinates: A Computer Program", Unpublished B.Sc. Thesis, Dept. of Civil Engineering, University of Saskatchewan, Saskatoon, Saskatchewan.

DEARINGER, R.A. (1974), "Structural and Terrain Movements", Journal of the Surveying and Mapping Division, ASCE, Vol. 101, No. SU2, pp. 123-141.

DURR, D.L. (1974), "An Embankment Saved by Instrumentation", Transportation Research Board, Transportation Research Record 482, pp. 43-50.

GOULD, J.P. and DUNNICLIFF, C.J. (1971), "Accuracy of Field Deformation Measurements", Proc., 4th Pan-American Conference on Soil Mechanics and Foundation Engineering, San Juan, ASCE, New York, Vol. 1, pp. 313-366.

HAUG, M.D. (1976), "Retrogressive Slope Failure at Beaver Creek", Unpublished M.Sc. Thesis, Dept. of Civil Engineering, University of Saskatchewan, Saskatoon, Saskatchewan.

HIRVONEN, R.A. (1971), "Adjustment by Lease Squares in Geodesy and Photogrammetry", Frederick Ungar Publishing Co., New York.

McKENNA, J.M. and ROY, M. (1975), "Performance of the Instrumentation used to Monitor the M5 Motorway Embankments Built on Soft Ground Between Edithmead and Huntworth", Field Instrumentation in Geotechnical Engineering, John Wiley and Sons Inc., New York, pp. 225-287.

McLELLAN, C.D., PETERSON, A.E. and KATINAS, G.E. (1970), "GALS: Geographic Adjustment by Least Squares", Unpublished Documentation, Geodetic Survey of Canada, Ottawa, Ontario.

MOFFITT, F.H. and BOUCHARD, H. (1975), "Surveying", Sixth Edition, Intext Educational Publishers, New York.

PENMAN, A.D.M. and CHARLES, J.A. (1973), "Measuring Movements of Embankment Dams", Field Instrumentation in Geotechnical Engineering, John Wiley and Sons Inc., New York, pp. 341-359.

PETERSON, A.E. (1966), "Program Levelob", Technical Report No. 70-2, Geodetic Survey of Canada, Ottawa, Ontario.

QUAN, Y.P. (1978), "The Analysis of Set Up Error in Surveying Equipment", Unpublished B.Sc. Thesis, Dept. of Civil Engineering, University of Saskatchewan, Saskatoon, Saskatchewan.

RAINSFORD, H.F. (1957), "Survey Adjustments and Least Squares", Constable and Company Ltd., London, England.

REYNOLDS, J.D. and DEARINGER, J.A. (1974), "Measuring the Movement of Tall Buildings by Precise Survey", Journal of the Surveying and Mapping Division, ASCE, Vol. 96, No. SU1, pp. 87-96.

RICHARDSON, J.T. (1964), "Measuring Structural Behavior of Glen Canyon Dam", Journal of the Surveying and Mapping Division, ASCE, Vol. 90, No. SU2, pp. 133-152.

RICHARDSON, J.T. (1968), "Measured Deformation Behavior of Glen Canyon Dam", Journal of the Surveying and Mapping Division, ASCE, Vol. 94, No. SU4, pp. 149-168.

SCHUSTER, R.L. and KRIZEK, F.J. (1978), "Landslides: Analysis and Control", Transportation Research Board, Special Report 176, Chapter 2.

SOWERS, G.F. and ROYSTER, D.L. (1978), "Landslides: Analysis and Control", Transportation Research Board, Special Report 176, Chapter 4.

TERZAGHI, K. (1950), "Mechanism of Landslides", Application of Geology to Engineering Practice, Geological Society of America, Berkey Vol., pp. 83-123.

THOMSON, S. and HAYLEY, D.M. (1975), "The Little Smoky Landslide", Canadian Geotechnical Journal, Vol. 23, No. 3, pp. 379-392.

TICE, J.A. and SAMS, C.E. (1974), "Experiences with Landslide Instrumentation in the Southeast", Transportation Research Board, Transportation Research Record 482, pp. 18-29.

UOTILA, U.A. (1973), "Useful Statistics for Land Surveyors", Journal of the Surveying and Mapping Division, ASCE, Vol. 98, No. SU1, pp. 67-77.

WALPOLE, R.E. and MYERS, R.H. (1972), "Probability and Statistics for Engineers and Scientists", MacMillan Publishing Co., Inc., New York.

WILSON, S.D. (1970), "Observational Data on Ground Movements Related to Slope Instability", Journal of Soil Mechanics and Foundations Division, ASCE, Vol. 96, No. SM5, pp. 1521-1544.

WILSON, S.D. and MIKKELSON, P.E. (1978), "Landslides: Analysis and Control", Transportation Reserach Board, Special Report 176, Chapter 5.

WOLF, P.R. and JOHNSON, S.D. (1974), "Trilateration with Short Range EDM Equipment and Comparison with Triangulation", Journal of Surveying and Mapping, ACSM, Vol. 34, No. 4, pp. 337-347.

Field Manual for First Order Horizontal Control Surveys, Geodetic Survey of Canada, Surveys and Mapping Branch, Dept. of Energy, Mines and Resources, Ottawa, Ontario.

Vertical Control Manual, Geodetic Survey of Canada, Surveys and Mapping Branch, Dept. of Energy, Mines and Resources, Ottawa, Ontario.

Standards for Cadastral Surveys, Unpublished Report, Division of Continuing Education, University of Calgary, Calgary, Alberta May, 1974.

APPENDIX A

Baseline Calibration and Angle Measurement Procedure

A.1 BASELINE CALIBRATION

The baseline was chosen to be between monuments INNER-2 and INNER-3. The line was calibrated on October 29,1977; May 15,1978; and August 13,1979.

Sample Calculation for October 29,1977

Field data

Indicated slope distance:

83.8265	83.8270
83.8267	83.8266
83.8272	83.8268
83.8264	83.8262
83.8268	83.8269

mean= 83.8267 meters; standard deviation = 0.0003 m

Dry bulb temperature = 14.8°C
Wet bulb temperature = 9.3°C
Barometric pressure = 27"Hg = 915 millibar

elevation INNER-2 baseplate = 99.9692 metres
elevation INNER-3 baseplate = 98.0216 metres

height to center of MA-100 = 0.400 metres
height to center of Wild reflector = 0.240 metres

reflector constant = -0.086 metres = zero correction

from Table A.1
barometric pressure = 915 mb
Td = 14.8°C
thus c =+22.7 ppm

from Table A.2
Tw = 9.3°C
ΔT = 5.5°C
thus c =+0.3 ppm

Total correction = 22.7 + 0.3 =+23.0 ppm

Therefore corrected slope distance:

$$S = 83.8267 - 0.086 + 83.8267(1 + 23.0 \text{ ppm})$$

$$S = 83.7426 \text{ metres}$$

Ddfference in elevation:

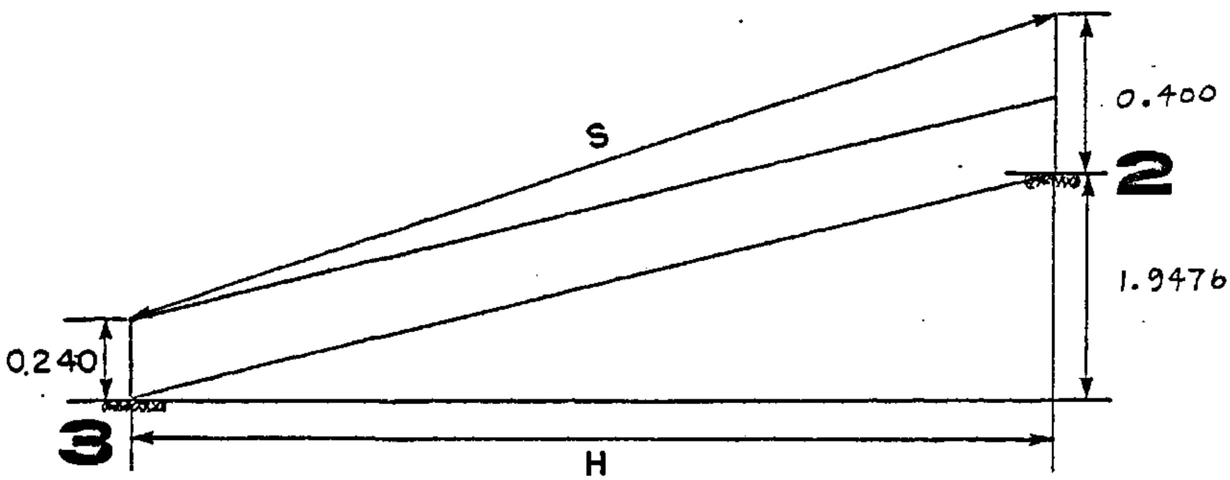
$$h = 99.9692 - 98.0216 + 0.400 - 0.240$$

$$h = 2.108 \text{ metres}$$

Therefore corrected horizontal distance:

$$H = (83.7426^2 - 2.108^2)^{1/2}$$

$$H = 83.7171$$



SUMMARY OF CALIBRATIONS

November, 1977 = 83.7171 $\pm$ 0.0015 metres

May, 1978 = 83.7176 $\pm$ 0.0015 metres

August, 1979 = 83.7166 $\pm$ 0.0015 metres

TABLE A.1

TEMP. C°	PRESSURE IN MILLIBARS 896	898	900	902	904	906	908	910	912	914	916	918
−20	− 6·1	− 6·7	− 7·4	− 8·0	− 8·6	− 9·2	− 9·9	−10·5	−11·1	−11·7	−12·4	−13·0
−19	− 5·0	− 5·6	− 6·3	− 6·9	− 7·5	− 8·1	− 8·8	− 9·4	−10·0	−10·6	−11·2	−11·9
−18	− 3·9	− 4·5	− 5·2	− 5·8	− 6·4	− 7·0	− 7·6	− 8·3	− 8·9	− 9·5	−10·1	−10·7
−17	− 2·8	− 3·5	− 4·1	− 4·7	− 5·3	− 5·9	− 6·5	− 7·2	− 7·8	− 8·4	− 9·0	− 9·6
−16	− 1·8	− 2·4	− 3·0	− 3·6	− 4·2	− 4·8	− 5·5	− 6·1	− 6·7	− 7·3	− 7·9	− 8·5
−15	− 0·7	− 1·3	− 1·9	− 2·5	− 3·1	− 3·8	− 4·4	− 5·0	− 5·6	− 6·2	− 6·8	− 7·4
−14	0·3	− 0·2	− 0·9	− 1·5	− 2·1	− 2·7	− 3·3	− 3·9	− 4·5	− 5·1	− 5·7	− 6·4
−13	1·3	0·7	0·1	− 0·4	− 1·0	− 1·6	− 2·2	− 2·8	− 3·4	− 4·1	− 4·7	− 5·3
−12	2·4	1·8	1·1	0·5	0·0	− 0·6	− 1·2	− 1·8	− 2·4	− 3·0	− 3·6	− 4·2
−11	3·4	2·8	2·2	1·6	1·0	0·4	− 0·1	− 0·7	− 1·3	− 1·9	− 2·5	− 3·1
−10	4·4	3·8	3·2	2·6	2·0	1·4	0·8	0·2	− 0·3	− 0·9	− 1·5	− 2·1
− 9	5·4	4·8	4·2	3·6	3·0	2·4	1·9	1·3	0·7	0·1	− 0·4	− 1·0
− 8	6·5	5·9	5·3	4·7	4·1	3·5	2·9	2·3	1·7	1·1	0·5	− 0·0
− 7	7·5	6·9	6·3	5·7	5·1	4·5	3·9	3·3	2·7	2·1	1·5	0·9
− 6	8·5	7·9	7·3	6·7	6·1	5·5	4·9	4·3	3·7	3·1	2·5	1·9
− 5	9·4	8·9	8·3	7·7	7·1	6·5	5·9	5·3	4·7	4·1	3·5	3·0
− 4	10·4	9·8	9·3	8·7	8·1	7·5	6·9	6·3	5·7	5·1	4·5	4·0
− 3	11·4	10·8	10·2	9·6	9·1	8·5	7·9	7·3	6·7	6·1	5·5	5·0
− 2	12·4	11·8	11·2	10·6	10·0	9·5	8·9	8·3	7·7	7·1	6·5	6·0
− 1	13·3	12·8	12·2	11·6	11·0	10·4	9·8	9·3	8·7	8·1	7·5	6·9
0	14·3	13·7	13·1	12·6	12·0	11·4	10·8	10·2	9·7	9·1	8·5	7·9
1	15·2	14·7	14·1	13·5	12·9	12·3	11·8	11·2	10·6	10·0	9·5	8·9
2	16·2	15·6	15·0	14·4	13·9	13·3	12·7	12·1	11·6	11·0	10·4	9·8
3	17·1	16·5	16·0	15·4	14·8	14·2	13·7	13·1	12·5	12·0	11·4	10·8
4	18·0	17·5	16·9	16·3	15·8	15·2	14·6	14·0	13·5	12·9	12·3	11·8
5	19·0	18·4	17·8	17·2	16·7	16·1	15·5	15·0	14·4	13·8	13·3	12·7
6	19·9	19·3	18·7	18·2	17·6	17·0	16·5	15·9	15·3	14·8	14·2	13·6
7	20·8	20·2	19·6	19·1	18·5	17·9	17·4	16·8	16·3	15·7	15·1	14·6
8	21·7	21·1	20·5	20·0	19·4	18·9	18·3	17·7	17·2	16·6	16·0	15·5
9	22·6	22·0	21·4	20·9	20·3	19·8	19·2	18·6	18·1	17·5	17·0	16·4
10	23·5	22·9	22·3	21·8	21·2	20·7	20·1	19·5	19·0	18·4	17·9	17·3
11	24·3	23·8	23·2	22·7	22·1	21·6	21·0	20·4	19·9	19·3	18·8	18·2
12	25·2	24·7	24·1	23·5	23·0	22·4	21·9	21·3	20·8	20·2	19·7	19·1
13	26·1	25·5	25·0	24·4	23·9	23·3	22·8	22·2	21·7	21·1	20·5	20·0
14	26·9	26·4	25·8	25·3	24·7	24·2	23·6	23·1	22·5	22·0	21·4	20·9
15	27·8	27·3	26·7	26·2	25·6	25·1	24·5	24·0	23·4	22·9	22·3	21·8
16	28·7	28·1	27·6	27·0	26·5	25·9	25·4	24·8	24·3	23·7	23·2	22·6
17	29·5	29·0	28·4	27·9	27·3	26·8	26·2	25·7	25·1	24·6	24·0	23·5
18	30·3	29·8	29·2	28·7	28·2	27·6	27·1	26·5	26·0	25·4	24·9	24·4
19	31·2	30·6	30·1	29·5	29·0	28·5	27·9	27·4	26·8	26·3	25·8	25·2
20	32·0	31·5	30·9	30·4	29·8	29·3	28·8	28·2	27·7	27·1	26·6	26·1
21	32·8	32·3	31·7	31·2	30·7	30·1	29·6	29·1	28·5	28·0	27·4	26·9
22	33·6	33·1	32·6	32·0	31·5	31·0	30·4	29·9	29·3	28·8	28·3	27·7
23	34·4	33·9	33·4	32·8	32·3	31·8	31·2	30·7	30·2	29·6	29·1	28·6
24	35·3	34·7	34·2	33·7	33·1	32·6	32·1	31·5	31·0	30·5	29·9	29·4
25	36·1	35·5	35·0	34·5	33·9	33·4	32·9	32·3	31·8	31·3	30·7	30·2
26	36·8	36·3	35·8	35·3	34·7	34·2	33·7	33·1	32·6	32·1	31·6	31·0
27	37·6	37·1	36·6	36·1	35·5	35·0	34·5	33·9	33·4	32·9	32·4	31·8
28	38·4	37·9	37·4	36·8	36·3	35·8	35·3	34·7	34·2	33·7	33·2	32·6
29	39·2	38·7	38·2	37·6	37·1	36·6	36·1	35·5	35·0	34·5	34·0	33·4
30	40·0	39·5	38·9	38·4	37·9	37·4	36·8	36·3	35·8	35·3	34·8	34·2
31	40·7	40·2	39·7	39·2	38·7	38·1	37·6	37·1	36·6	36·1	35·5	35·0
32	41·5	41·0	40·5	40·0	39·4	38·9	38·4	37·9	37·4	36·8	36·3	35·8
33	42·3	41·7	41·2	40·7	40·2	39·7	39·2	38·6	38·1	37·6	37·1	36·6
34	43·0	42·5	42·0	41·5	41·0	40·4	39·9	39·4	38·9	38·4	37·9	37·4
35	43·8	43·3	42·7	42·2	41·7	41·2	40·7	40·2	39·7	39·1	38·6	38·1
36	44·5	44·0	43·5	43·0	42·5	42·0	41·4	40·9	40·4	39·9	39·4	38·9
37	45·3	44·7	44·2	43·7	43·2	42·7	42·2	41·7	41·2	40·7	40·1	39·6
38	46·0	45·5	45·0	44·5	44·0	43·4	42·9	42·4	41·9	41·4	40·9	40·4
39	46·7	46·2	45·7	45·2	44·7	44·2	43·7	43·2	42·7	42·2	41·6	41·1
40	47·4	46·9	46·4	45·9	45·4	44·9	44·4	43·9	43·4	42·9	42·4	41·9
41	48·2	47·7	47·2	46·7	46·1	45·6	45·1	44·6	44·1	43·6	43·1	42·6
42	48·9	48·4	47·9	47·4	46·9	46·4	45·9	45·4	44·9	44·4	43·9	43·4
43	49·6	49·1	48·6	48·1	47·6	47·1	46·6	46·1	45·6	45·1	44·6	44·1
44	50·3	49·8	49·3	48·8	48·3	47·8	47·3	46·8	46·3	45·8	45·3	44·8
45	51·0	50·5	50·0	49·5	49·0	48·5	48·0	47·5	47·0	46·5	46·0	45·5
46	51·7	51·2	50·7	50·2	49·7	49·2	48·7	48·2	47·7	47·2	46·7	46·2
47	52·4	51·9	51·4	50·9	50·4	49·9	49·4	48·9	48·4	47·9	47·4	47·0
48	53·1	52·6	52·1	51·6	51·1	50·6	50·1	49·6	49·1	48·6	48·2	47·7
49	53·8	53·3	52·8	52·3	51·8	51·3	50·8	50·3	49·8	49·3	48·9	48·4
50	54·4	54·0	53·5	53·0	52·5	52·0	51·5	51·0	50·5	50·0	49·6	49·1

TABLE A.2

TABLE 2

Correction for water vapour ΔK

Dry Bulb Temp. °C	Wet Bulb Depression (°C) 0	5	10	15	20	25
—10	0.1					
— 5	0.2					
0	0.3					
5	0.4	0.1				
10	0.5	0.2				
15	0.7	0.3	0.1			
20	0.9	0.5	0.2			
25	1.2	0.8	0.4	0.1		
30	1.6	1.1	0.6	0.3		
35	2.1	1.5	0.9	0.5	0.1	
40	2.6	1.7	1.3	0.8	0.4	0.1
45	3.4	1.9	1.7	1.1	0.6	0.2
50	4.3	3.2	2.3	1.6	1.0	0.5

N.B. All the above values are positive

Above values calculated from $15.02 \frac{e}{T}$

where T = air temp. °K

e = partial press. H_2O (mmHg) from NPL tables.

MA100 FIELD SHEET

FROM INNER-2 TO INNER-3 DATE Oct 29/77

OPERATOR	D. Stuart		WEATHER	Sunny, cool
INSTRUMENT #	MA-100	HI 0.400m	TEMPERATURE	Td = 14.8°C; Tw: 5.5°C
REFLECTOR(S)	Wild	HI 0.240	BAROMETER	27 "Hg
EXTERNAL SIGNAL			~~MET.~~ reflector CORR.	-0.086m

MX10									
M		0	8						
MMX100			8	3					
MMX10				3	8				
MM					8	2	6	5	F
					8	2	7	0	R
INDICATED DISTANCE			8	3	8	2	7	0	F/R MEAN
				−	0	8	6	0	ZERO CORRECTION
					(1+23 ppm)				MET. CORRECTION
SLOPE DISTANCE			8	3	7	4	2	6	

.8267	.8262
.8272	.8266
.8264	.8268
.8268	.8269

$\Delta h: 1.948 + 0.400 - 0.240$

$= 2.108$

$\therefore H = (83.7426^2 - 2.108^2)^{1/2}$

$= 83.7171$

MA100 FIELD SHEET

FROM	INNER-2	TO	INNER-3	DATE	May 15/78

OPERATOR	G. Stamatinos		WEATHER	Sunny, warm
INSTRUMENT #	MA-100	0.400 m	TEMPERATURE	Td = 15°C ; Tw = 10°C
REFLECTOR(S)	Wild	0.240 m	BAROMETER	27.5 " Hg
EXTERNAL SIGNAL			~~MET~~ reflector CORR.	−0.086 m

MX10									
M		0	8						
MMX100			8.	3.					
MMX10				3.	8				
MM				.	8	3	0	2	F
				.	8	2	6	7	R
INDICATED DISTANCE			8	3.	8	2	7	6	F/R MEAN
				− .	0	8	6	0	ZERO CORRECTION
				.	(1	+ 18	.5 p	pm)	MET. CORRECTION
SLOPE DISTANCE			8	3.	7	4	3	1	

.8267	.8280
.8277	.8274
.8280	.8278
.8273	.8266
.8275	.8276

$\Delta h = 1.948 + 0.400 - 0.240$

$= 2.108$

$\therefore H = (83.7431^2 - 2.108^2)^{1/2}$

$= 83.7176$

MA100 FIELD SHEET

FROM	INNER-2	TO	INNER-3	DATE	Aug 13/79

OPERATOR	R. Chursinoff		WEATHER	Sunny, hot
INSTRUMENT #	MA-100	~~HI~~ 0.400m	TEMPERATURE	Td = 30.5°C ; Tw = 17.6°C
REFLECTOR(S)	ZC-1	~~HI~~ 0.120	BAROMETER	28.9 "Hg
EXTERNAL SIGNAL			reflector ~~MET~~. CORR.	−0.0130 m

MX10	0	1							
M		0	8						
MMX100			8.	3.					
MMX10				3.	7				
MM				.	7	5	7	8	F
				.	7	5	8	0	R
INDICATED DISTANCE			8	3.	7	5	7	6	F/R MEAN
				− .	0	1	3	0	ZERO CORRECTION
				.	(1+	19.5	ppm)		MET. CORRECTION
SLOPE DISTANCE			8	3.	7	4	6	2	

.7576	.7577
.7568	.7570
.7575	.7577
.7573	.7578
.7581	.7577

$\Delta h = 1.948 + 0.400 - 0.120$

$= 2.238$

$\therefore H = (83.7462^2 - 2.238^2)^{\frac{1}{2}}$

$= 83.7166$

A.2 Direction Measurement Procedure

Slide Monuments - 2 degrees of freedom

Wild T-3 at:	Targets at:
SCARP-1	SLIDE-5,6,7,10,SCARP-2 SLIDE-5,6,7,10,SCARP-3
SCARP-4	SCARP-2,SLIDE-5,6,10,7 SCARP-3,SLIDE-5,6,10,7
SCARP-1	SLIDE-1,2,3,4,SCARP-2 SLIDE-1,2,3,4,SCARP-3
SCARP-4	SCARP-2,SLIDE-4,2,1,3 SCARP-3,SLIDE-4,2,1,3
SCARP-3	SCARP-2,SLIDE-13,12,11,9 SCARP-1,SLIDE-13,12,11,9
SCARP-2	SLIDE-13,11,12,9,SCARP-3
SCARP-1	SLIDE-11,13,12,9,SCARP-3
SCARP-2	SLIDE-14,8,15,16,SCARP-4 SLIDE-14,8,15,16,SCARP-3
SCARP-4	SCARP-2,SLIDE-16,8 SCARP-3,SLIDE-16,8
SCARP-3	SCARP-2,SLIDE-14,15 SCARP-1,SLIDE-14,15

Triangulation Network on Top

INNER-1	INNER-2,SCARP-2,3,4
INNER-2	INNER-3,SCARP-1,2,3,4,INNER-1
INNER-3	SCARP-1,2,3,INNER-2
SCARP-1	SCARP-3,4,2,INNER-2,3
SCARP-2	SCARP-3,4,INNER-1,2,3,SCARP-1
SCARP-3	SCARP-4,INNER-1,2,3,SCARP-2,1
SCARP-4	INNER-1,2,SCARP-1,2,3

APPENDIX B

Field Results

B.1 May, 1978 Survey

B.1.1 Angle Measurements

HORIZONTAL ADJUSTMENT - JCODE=111

TOTAL NUMBER OF STATIONS IN NETWORK	CODE 0=ANGLES 1=DIRECTIONS	NUMBER OF OBSERVED ANGLES *OR* SETS OF DIRECTIONS	NUMBER OF OBSERVED SIDES	NUMBER OF CALLS FOR ERROR ELLIPSES
23	0	58	0	21

CONVERGENCE CRITERION= 0.0020

MAXIMUM NUMBER OF ITERATIONS= 6

ERROR ELLIPSE PROBABILITY= 95 PERCENT. L-FACTOR= 2.4477

BEAVER CREEK - MAY,1976 - MONUMENTATION OF LANDSLIDES -- SET-#1

HORIZONTAL ADJUSTMENT - JMODL=111

STATION NUMBER	STATION NAME	STATION TYPE (1=FIXED,0=FREE)	X-COORDINATE	Y-COORDINATE	CENTERING ERROR
1	INNER-1	0	232.9106	107.0104	0.0005
2	INNER-2	1	183.7180	100.0000	0.0005
3	INNER-3	1	100.0000	100.0000	0.0005
4	SCARP-1	0	58.5863	167.7215	0.0005
5	SCARP-2	0	152.0199	153.2088	0.0005
6	SCARP-3	0	210.2494	164.8048	0.0005
7	SCARP-4	0	277.0616	160.5146	0.0005
8	SLIDE-1	0	156.7343	274.6724	0.0010
9	SLIDE-2	0	157.5601	268.0054	0.0010
10	SLIDE-3	0	170.4231	270.0040	0.0010
11	SLIDE-4	0	161.1390	259.5858	0.0010
12	SLIDE-5	0	192.3850	265.3753	0.0010

HORIZONTAL ADJUSTMENT - JMODL=111

STATION NUMBER	STATION NAME	STATION TYPE (1=FIXED;0=FREE)	X-COORDINATE	Y-COORDINATE	CENTERING ERROR
13	SLIDE-6	0	211.7071	264.8253	0.0010
14	SLIDE-7	0	229.7600	267.0170	0.0010
15	SLIDE-8	0	187.4055	242.0612	0.0010
16	SLIDE-9	0	198.5795	221.1124	0.0010
17	SLIDE-10	0	229.1826	241.0701	0.0010
18	SLIDE-11	0	157.3737	241.4471	0.0010
19	SLIDE-12	0	162.9380	208.2445	0.0010
20	SLIDE-13	0	146.1042	208.8130	0.0010
21	SLIDE-14	0	151.5985	191.6860	0.0010
22	SLIDE-15	0	177.2279	188.7450	0.0010
23	SLIDE-16	0	217.0463	196.3338	0.0010

NUMBER OF FREE STATIONS= 21 NUMBER OF FIXED STATIONS= 2

HORIZONTAL ADJUSTMENT - JMODE=111

AT STATION	FROM STATION	TO STATION	STANDARD DEVIATION (SECONDS)	OBSERVED ANGLE DEGREES	MINUTES	SECONDS	RELATIVE WEIGHTING FACTOR (1 IF DEFAULT)
INNER-1	INNER-2	SCARP-2	1.54	37	50	32.91	1
INNER-1	SCARP-2	SCARP-3	1.42	38	51	28.76	1
INNER-1	SCARP-3	SCARP-4	1.44	60	56	20.47	1
INNER-2	INNER-3	SCARP-1	1.79	28	25	19.65	1
INNER-2	SCARP-1	SCARP-2	2.02	30	47	38.42	1
INNER-2	SCARP-2	SCARP-3	1.91	53	2	50.41	1
INNER-2	SCARP-3	SCARP-4	2.32	34	46	48.17	1
INNER-2	SCARP-4	INNER-1	2.25	24	50	41.59	1
INNER-3	SCARP-1	SCARP-2	2.97	75	47	55.80	1
INNER-3	SCARP-2	INNER-2	2.90	45	38	50.18	1
SCARP-1	SCARP-3	SCARP-2	2.09	7	43	38.12	1
SCARP-1	SCARP-2	INNER-2	2.24	19	35	35.90	1

HORIZONTAL ADJUSTMENT - JMODE=111

AT STATION	FROM STATION	TO STATION	STANDARD DEVIATION (SECONDS)	OBSERVED ANGLE DEGREES	MINUTES	SECONDS	RELATIVE WEIGHTING FACTOR (1 IF DEFAULT)
SCARP-1	SCARP-2	INNER-3	2.09	49	43	24.92	1
SCARP-2	SCARP-3	SCARP-4	1.78	7	55	8.60	1
SCARP-2	SCARP-4	INNER-1	1.84	33	4	32.00	1
SCARP-2	INNER-2	INNER-3	2.02	75	8	12.44	1
SCARP-2	INNER-3	SCARP-1	1.86	54	28	33.86	1
SCARP-2	SCARP-4	INNER-2	1.28	62	33	35.87	1
SCARP-3	SCARP-4	INNER-1	2.01	64	54	56.24	1
SCARP-3	INNER-1	INNER-2	0.92	43	40	28.80	1
SCARP-3	INNER-2	INNER-3	2.91	37	17	13.91	1
SCARP-3	INNER-2	SCARP-2	0.76	56	28	22.43	1
SCARP-3	INNER-3	SCARP-1	2.03	31	32	55.74	1
SCARP-4	INNER-1	INNER-2	1.67	17	30	55.91	1

HORIZONTAL ADJUSTMENT - JMODE=111

AT STATION	FROM STATION	TO STATION	STANDARD DEVIATION (SECONDS)	OBSERVED ANGLE DEGREES	MINUTES	SECONDS	RELATIVE WEIGHTING FACTOR (1 IF DEFAULT)
SCARP-4	INNER-2	SCARP-2	1.59	29	36	41.58	1
SCARP-4	INNER-2	SCARP-3	1.15	36	37	45.39	1
SCARP-4	SCARP-1	SLIDE-3	1.34	43	51	59.05	1
SCARP-4	SCARP-1	SLIDE-5	2.20	49	11	21.35	1
SCARP-4	SCARP-1	SLIDE-6	1.66	56	2	31.13	1
SCARP-4	SCARP-1	SLIDE-7	1.25	64	9	46.40	1
SCARP-3	SCARP-1	SLIDE-14	2.06	23	31	17.18	1
SCARP-3	SCARP-1	SLIDE-13	2.15	33	21	4.24	1
SCARP-3	SCARP-1	SLIDE-15	2.06	34	50	23.91	1
SCARP-3	SCARP-1	SLIDE-12	1.98	41	27	19.39	1
SCARP-1	SLIDE-7	SCARP-4	2.00	32	0	24.52	1
SCARP-1	SLIDE-5	SCARP-4	1.45	38	0	48.49	1

HORIZONTAL ADJUSTMENT - MODEL=111

AT STATION	FROM STATION	TO STATION	STANDARD DEVIATION (SECONDS)	OBSERVED ANGLE DEGREES	MINUTES	SECONDS	RELATIVE WEIGHTING FACTOR (1 IF DEFAULT)
SCARP-1	SLIDE-15	SCARP-3	0.65	11	9	1.52	1
SCARP-1	SLIDE-14	SCARP-3	0.79	15	32	59.09	1
SCARP-1	SLIDE-12	SCARP-3	1.43	22	19	28.36	1
SCARP-1	SLIDE-13	SCARP-3	1.53	26	15	10.14	1
SCARP-1	SLIDE-11	SCARP-4	1.48	38	37	24.84	1
SCARP-1	SLIDE-4	SCARP-4	1.41	43	44	33.46	1
SCARP-1	SLIDE-2	SCARP-4	2.15	47	15	57.97	1
SCARP-1	SLIDE-1	SCARP-4	1.62	49	20	49.26	1
SCARP-4	SCARP-1	SLIDE-11	1.53	32	10	37.43	1
SCARP-4	SCARP-1	SLIDE-4	1.37	38	37	44.10	1
SCARP-4	SCARP-1	SLIDE-2	1.71	40	4	54.63	1
SCARP-4	SCARP-1	SLIDE-1	1.40	41	36	12.57	1

HORIZONTAL ADJUSTMENT - JMODE=111

AT STATION	FROM STATION	TO STATION	STANDARD DEVIATION (SECONDS)	OBSERVED ANGLE DEGREES	MINUTES	SECONDS	RELATIVE WEIGHTING FACTOR (1 IF DEFAULT)
SCARP-2	SLIDE-16	SCARP-4	0.78	30	12	29.43	1
SCARP-2	SLIDE-10	SCARP-4	1.81	45	21	55.63	1
SCARP-2	SLIDE-9	SCARP-4	1.24	52	13	7.71	1
SCARP-2	SLIDE-8	SCARP-4	1.24	64	56	28.05	1
SCARP-2	SLIDE-6	SCARP-4	1.12	58	31	13.40	1
SCARP-2	SLIDE-3	SCARP-4	1.15	77	42	6.38	1
SCARP-4	SCARP-2	SLIDE-16	1.66	34	10	26.64	1
SCARP-4	SCARP-2	SLIDE-9	1.70	41	0	58.98	1
SCARP-4	SCARP-2	SLIDE-8	1.84	45	37	54.99	1
SCARP-4	SCARP-2	SLIDE-10	1.86	62	37	5.87	1

B.1.2 Leveling

```
BEAVER CREEK - MAY,1978 - MONUMENTATION OF LANDSLIDES -- SET-#1                PAGE NO.   1
********************************************************************************************
LEVEL ADJUSTMENT - JMODE=444
********************************************************************************************
NUMBER OF STATIONS= 18          NUMBER OF LINKS= 26
********************************************************************************************
********************************************************************************************
```

BEAVER CREEK - MAY,1978 - MONUMENTATION OF LANDSLIDES -- SET-#1

LEVEL ADJUSTMENT - JMODE=444

STATION NUMBER	STATION NAME	STATION TYPE (1=FIXED;0=FREE)	ELEVATION
1	SCARP-4	0	101.9052
2	SLIDE-1	0	85.3215
3	SLIDE-2	0	85.8514
4	SLIDE-3	0	87.2168
5	SLIDE-4	0	86.3852
6	SLIDE-5	0	87.0505
7	SLIDE-6	0	85.4071
8	SLIDE-7	0	86.0278
9	SLIDE-8	0	85.9466
10	SLIDE-9	0	87.1444
11	SLIDE-10	0	86.3786
12	SLIDE-11	0	85.2342

LEVEL ADJUSTMENT - JMODE=444

STATION NUMBER	STATION NAME	STATION TYPE (1=FIXED;0=FREE)	ELEVATION
13	SLIDE-12	0	89.3357
14	SLIDE-13	0	89.7486
15	SLIDE-14	0	91.2505
16	SLIDE-15	0	92.7563
17	SLIDE-16	0	90.8732
18	EVCM-GEO	1	100.0000

NUMBER OF FREE STATIONS= 17 NUMBER OF FIXED STATIONS= 1

LINK NUMBER	FROM STATION	TO STATION	OBSERVED DIFFERENCE IN ELEVATION	LINK WEIGHT
1	SCARP-4	SLIDE-16	-11.0318	0.250
2	SLIDE-16	SLIDE-15	1.8820	1.000
3	SLIDE-15	SLIDE-14	-1.5060	1.000
4	SLIDE-14	SLIDE-13	-1.5021	1.000
5	SLIDE-13	SLIDE-12	-0.4132	1.000
6	SLIDE-12	SLIDE-16	1.5371	0.500
7	SLIDE-12	SLIDE-9	-2.1912	0.500
8	SLIDE-9	SLIDE-11	-1.9096	1.000
9	SLIDE-11	SLIDE-2	0.6169	1.000
10	SLIDE-2	SLIDE-1	-0.5299	1.000
11	SLIDE-2	SLIDE-4	0.5336	1.000
12	SLIDE-2	SLIDE-3	1.3651	1.000

LINK NUMBER	FROM STATION	TO STATION	OBSERVED DIFFERENCE IN ELEVATION	LINK WEIGHT
13	SLIDE-3	SLIDE-11	-1.9827	1.000
14	SLIDE-11	SLIDE-9	1.9109	1.000
15	SLIDE-9	SLIDE-12	2.1913	0.500
16	SLIDE-11	SLIDE-8	0.7127	1.000
17	SLIDE-8	SLIDE-10	0.4321	0.500
18	SLIDE-10	SLIDE-7	-0.3506	0.500
19	SLIDE-7	SLIDE-6	-0.6207	1.000
20	SLIDE-6	SLIDE-5	1.6435	1.000
21	SLIDE-5	SLIDE-3	0.1663	1.000
22	SLIDE-3	SLIDE-4	-0.8317	1.000
23	SLIDE-4	SLIDE-8	-0.4390	0.500
24	SLIDE-16	SCARP-4	11.0322	0.250

LINK NUMBER	FROM STATION	TO STATION	OBSERVED DIFFERENCE IN ELEVATION	LINK WEIGHT
25	SCARP-4	EVCH-GED	-1.9064	0.250
26	EVCH-GED	SCARP-4	1.9041	0.250

B.2 August, 1978 Survey

B.2.1 Direction Measurements

BEAVER CREEK - AUGUST,1978 - MONUMENTATION OF LANDSLIDES -- SET-#2 PAGE NO. 1

HORIZONTAL ADJUSTMENT - JMODE=111

TOTAL NUMBER OF STATIONS IN NETWORK	CODE 0=ANGLES 1=DIRECTIONS	NUMBER OF OBSERVED ANGLES *OR* SETS OF DIRECTIONS	NUMBER OF OBSERVED SIDES	NUMBER OF CALLS FOR ERROR ELLIPSES
23	1	28	0	21

CONVERGENCE CRITERION= 0.0020

MAXIMUM NUMBER OF ITERATIONS= 2

ERROR ELLIPSE PROBABILITY= 95 PERCENT, C-FACTOR= 2.4477

HORIZONTAL ADJUSTMENT - JMODE=111

STATION NUMBER	STATION NAME	STATION TYPE (1=FIXED;0=FREE)	X-COORDINATE	Y-COORDINATE	CENTERING ERROR
1	INNER-1	0	232.9106	107.0104	0.0005
2	INNER-2	1	183.7180	100.0000	0.0005
3	INNER-3	1	100.0000	100.0000	0.0005
4	SCARP-1	0	58.5863	167.7215	0.0005
5	SCARP-2	0	152.0199	153.2088	0.0005
6	SCARP-3	0	210.2494	164.8048	0.0005
7	SCARP-4	0	277.0616	160.5146	0.0005
8	SLIDE-1	0	156.7343	274.6724	0.0010
9	SLIDE-2	0	157.5601	268.0054	0.0010
10	SLIDE-3	0	170.4231	270.0040	0.0010
11	SLIDE-4	0	161.1390	259.5858	0.0010
12	SLIDE-5	0	192.3850	265.3753	0.0010

BEAVER CREEK - AUGUST,1978 - MONUMENTATION OF LANDSLIDES -- SET-#2

HORIZONTAL ADJUSTMENT - JMODE=111

STATION NUMBER	STATION NAME	STATION TYPE (1=FIXED;0=FREE)	X-COORDINATE	Y-COORDINATE	CENTERING ERROR
13	SLIDE-6	0	211.7071	264.8253	0.0010
14	SLIDE-7	0	229.7600	267.0170	0.0010
15	SLIDE-8	0	187.4055	242.0612	0.0010
16	SLIDE-9	0	198.5795	221.1124	0.0010
17	SLIDE-10	0	229.1826	241.0701	0.0010
18	SLIDE-11	0	157.3737	241.4471	0.0010
19	SLIDE-12	0	162.9380	208.2445	0.0010
20	SLIDE-13	0	146.1042	208.8130	0.0010
21	SLIDE-14	0	151.5985	191.6860	0.0010
22	SLIDE-15	0	177.2279	188.7450	0.0010
23	SLIDE-16	0	217.0463	196.3338	0.0010

NUMBER OF FREE STATIONS= 21   NUMBER OF FIXED STATIONS= 2

HORIZONTAL ADJUSTMENT - JMODE=111

SET NUMBER	DIRECTION NUMBER	TYPE	AT STATION	TO STATION	STANDARD DEVIATION (SECONDS)	OBSERVED DIRECTION DEGREES	MINUTES	SECONDS	RELATIVE WEIGHTING FACTOR (1 IF DEFAULT)
1	1	1	SCARP-3	SCARP-2	1.33	230	19	31.00	1
1	2	0	SCARP-3	SLIDE-14	0.89	266	12	38.45	1
1	3	0	SCARP-3	SLIDE-15	0.86	277	31	57.81	1
2	1	1	SCARP-3	SCARP-1	1.29	151	53	43.45	1
2	2	0	SCARP-3	SLIDE-14	0.86	175	24	57.13	1
2	3	0	SCARP-3	SLIDE-15	2.10	186	44	18.69	1
3	1	1	SCARP-2	SLIDE-14	0.69	133	49	13.62	1
3	2	1	SCARP-2	SLIDE-15	0.86	169	47	58.38	1
3	3	1	SCARP-2	SCARP-4	2.57	221	6	33.48	1
4	1	1	SCARP-2	SLIDE-14	2.00	133	49	15.00	1
4	2	1	SCARP-2	SLIDE-15	1.03	169	47	58.92	1

HORIZONTAL ADJUSTMENT - JMODE=111

SET NUMBER	DIRECTION NUMBER	TYPE	AT STATION	TO STATION	STANDARD DEVIATION (SECONDS)	OBSERVED DIRECTION DEGREES	MINUTES	SECONDS	RELATIVE WEIGHTING FACTOR (1 IF DEFAULT)
4	3	1	SCARP-2	SCARP-3	1.85	213	11	33.23	1
5	1	1	SCARP-2	SLIDE-8	0.87	124	57	29.28	1
5	2	1	SCARP-2	SLIDE-16	1.46	159	41	15.26	1
5	3	1	SCARP-2	SCARP-4	0.67	189	54	5.77	1
6	1	1	SCARP-2	SLIDE-8	0.65	169	34	27.18	1
6	2	1	SCARP-2	SLIDE-16	0.92	204	18	14.46	1
6	3	1	SCARP-2	SCARP-3	0.83	226	35	58.08	1
7	1	1	SCARP-4	SCARP-3	0.88	111	39	31.36	1
7	2	0	SCARP-4	SLIDE-16	0.37	138	49	12.37	1
7	3	0	SCARP-4	SLIDE-8	1.32	150	16	31.14	1
8	1	1	SCARP-4	SCARP-2	1.23	158	40	8.79	1

HORIZONTAL ADJUSTMENT - JMODE=111

SET NUMBER	DIRECTION NUMBER	TYPE	AT STATION	TO STATION	STANDARD DEVIATION (SECONDS)	OBSERVED DIRECTION DEGREES	MINUTES	SECONDS	RELATIVE WEIGHTING FACTOR (1 IF DEFAULT)
8	2	0	SCARP-4	SLIDE-16	1.28	192	50	54.55	1
8	3	0	SCARP-4	SLIDE-8	0.62	204	18	12.08	1
9	1	1	SCARP-2	SLIDE-13	0.33	108	54	24.57	1
9	2	1	SCARP-2	SLIDE-11	0.28	118	26	57.58	1
9	3	1	SCARP-2	SLIDE-12	0.72	126	11	55.44	1
9	4	1	SCARP-2	SLIDE-9	0.53	149	24	52.10	1
9	5	1	SCARP-2	SCARP-3	0.70	193	43	5.90	1
10	1	1	SCARP-1	SLIDE-11	0.97	28	33	16.22	1
10	2	1	SCARP-1	SLIDE-13	0.44	40	8	9.43	1
10	3	1	SCARP-1	SLIDE-12	0.70	44	3	55.70	1
10	4	1	SCARP-1	SLIDE-9	0.80	44	24	47.64	1

HORIZONTAL ADJUSTMENT - JMODE=111

SET NUMBER	DIRECTION NUMBER	TYPE	AT STATION	TO STATION	STANDARD DEVIATION (SECONDS)	OBSERVED DIRECTION DEGREES	MINUTES	SECONDS	RELATIVE WEIGHTING FACTOR (1 IF DEFAULT)
10	5	1	SCARP-1	SCARP-2	0.75	74	7	13.33	1
11	1	1	SCARP-3	SCARP-1	1.42	222	16	59.21	1
11	2	0	SCARP-3	SLIDE-13	0.95	255	38	16.03	1
11	3	0	SCARP-3	SLIDE-12	0.84	263	44	26.67	1
11	4	0	SCARP-3	SLIDE-11	1.30	276	34	42.11	1
12	1	1	SCARP-3	SCARP-2	0.90	29	55	4.42	1
12	2	0	SCARP-3	SLIDE-13	0.54	75	38	15.12	1
12	3	0	SCARP-3	SLIDE-12	0.44	83	44	27.96	1
12	4	0	SCARP-3	SLIDE-11	1.29	96	34	40.30	1
12	5	0	SCARP-3	SLIDE-9	0.94	119	28	18.09	1
13	1	1	SCARP-4	SCARP-2	0.89	243	49	32.88	1

HORIZONTAL ADJUSTMENT - JMODL=111

SET NUMBER	DIRECTION NUMBER	TYPE	AT STATION	TO STATION	STANDARD DEVIATION (SECONDS)	OBSERVED DIRECTION DEGREES	MINUTES	SECONDS	RELATIVE WEIGHTING FACTOR (1 IF DEFAULT)
13	2	0	SCARP-4	SLIDE-11	0.61	281	14	10.20	1
13	3	0	SCARP-4	SLIDE-9	0.35	284	50	37.55	1
14	1	1	SCARP-1	SLIDE-1	2.57	9	15	21.72	1
14	2	1	SCARP-1	SLIDE-2	0.83	11	20	12.55	1
14	3	1	SCARP-1	SLIDE-3	1.33	14	16	14.87	1
14	4	1	SCARP-1	SLIDE-4	1.06	14	51	42.96	1
14	5	1	SCARP-1	SCARP-3	0.83	57	48	58.69	1
15	1	1	SCARP-1	SLIDE-1	1.78	137	28	25.05	1
15	2	1	SCARP-1	SLIDE-2	1.37	139	33	15.14	1
15	3	1	SCARP-1	SLIDE-3	2.01	142	29	19.34	1
15	4	1	SCARP-1	SLIDE-4	0.74	143	4	47.47	1

HORIZONTAL ADJUSTMENT - JMODE=111

SET NUMBER	DIRECTION NUMBER	TYPE	AT STATION	TO STATION	STANDARD DEVIATION (SECONDS)	OBSERVED DIRECTION DEGREES	MINUTES	SECONDS	RELATIVE WEIGHTING FACTOR (1 IF DEFAULT)
15	5	1	SCARP-1	SCARP-2	1.51	193	45	38.04	1
16	1	1	SCARP-4	SCARP-2	0.82	9	43	14.60	1
16	2	0	SCARP-4	SLIDE-4	0.63	53	35	2.74	1
16	3	0	SCARP-4	SLIDE-2	0.78	55	2	17.14	1
16	4	0	SCARP-4	SLIDE-1	1.16	56	33	32.41	1
16	5	0	SCARP-4	SLIDE-3	0.90	58	49	26.95	1
17	1	1	SCARP-4	SCARP-3	1.87	236	58	25.16	1
17	2	0	SCARP-4	SLIDE-4	2.79	273	49	5.07	1
17	3	0	SCARP-4	SLIDE-2	1.25	275	16	17.53	1
17	4	0	SCARP-4	SLIDE-1	1.01	276	47	32.76	1
17	5	0	SCARP-4	SLIDE-3	1.80	279	3	24.68	1

HORIZONTAL ADJUSTMENT - JMODE=111

SET NUMBER	DIRECTION NUMBER	TYPE	AT STATION	TO STATION	STANDARD DEVIATION (SECONDS)	OBSERVED DIRECTION DEGREES	MINUTES	SECONDS	RELATIVE WEIGHTING FACTOR (1 IF DEFAULT)
18	1	1	SCARP-1	SLIDE-5	1.25	109	57	31.07	1
18	2	1	SCARP-1	SLIDE-6	1.59	113	42	2.97	1
18	3	1	SCARP-1	SLIDE-7	2.66	115	57	55.88	1
18	4	1	SCARP-1	SLIDE-10	0.61	122	49	0.05	1
18	5	1	SCARP-1	SCARP-2	0.64	154	54	48.63	1
19	1	1	SCARP-1	SLIDE-5	0.61	27	37	20.84	1
19	2	1	SCARP-1	SLIDE-6	0.35	31	21	52.79	1
19	3	1	SCARP-1	SLIDE-7	1.74	33	37	46.13	1
19	4	1	SCARP-1	SLIDE-10	1.42	40	28	51.73	1
19	5	1	SCARP-1	SCARP-3	1.06	64	51	2.21	1
20	1	1	SCARP-4	SCARP-3	0.80	230	58	31.48	1

HORIZONTAL ADJUSTMENT - JNODE=111

SET NUMBER	DIRECTION NUMBER	TYPE	AT STATION	TO STATION	STANDARD DEVIATION (SECONDS)	OBSERVED DIRECTION DEGREES	MINUTES	SECONDS	RELATIVE WEIGHTING FACTOR (1 IF DEFAULT)
20	2	0	SCARP-4	SLIDE-5	0.85	278	22	54.71	1
20	3	0	SCARP-4	SLIDE-6	1.04	285	14	3.46	1
20	4	0	SCARP-4	SLIDE-10	1.20	286	34	43.03	1
20	5	0	SCARP-4	SLIDE-7	0.93	293	21	18.00	1
21	1	1	SCARP-4	SCARP-2	1.61	75	32	46.53	1
21	2	0	SCARP-4	SLIDE-5	1.08	129	58	12.70	1
21	3	0	SCARP-4	SLIDE-6	0.36	136	49	19.18	1
21	4	0	SCARP-4	SLIDE-10	0.74	138	9	58.96	1
21	5	0	SCARP-4	SLIDE-7	1.16	144	56	34.89	1
22	1	1	INNER-1	INNER-2	1.05	4	57	26.11	1
22	2	1	INNER-1	SCARP-2	1.95	42	48	5.27	1

HORIZONTAL ADJUSTMENT - JMODE=111

SET NUMBER	DIRECTION NUMBER	TYPE	AT STATION	TO STATION	STANDARD DEVIATION (SECONDS)	OBSERVED DIRECTION DEGREES	MINUTES	SECONDS	RELATIVE WEIGHTING FACTOR (1 IF DEFAULT)
22	3	1	INNER-1	SCARP-3	0.53	81	39	32.04	1
22	4	0	INNER-1	SCARP-4	0.54	142	35	44.47	1
23	1	1	INNER-2	INNER-3	0.95	68	50	54.30	1
23	2	1	INNER-2	SCARP-1	0.79	97	16	14.99	1
23	3	1	INNER-2	SCARP-2	1.61	128	3	56.17	1
23	4	1	INNER-2	SCARP-3	0.83	181	6	39.84	1
23	5	1	INNER-2	SCARP-4	1.07	215	53	26.09	1
23	6	0	INNER-2	INNER-1	1.37	240	44	11.47	1
24	1	1	INNER-3	SCARP-1	0.62	167	27	47.32	1
24	2	1	INNER-3	SCARP-2	1.00	243	15	41.05	1
24	3	1	INNER-3	SCARP-3	0.95	258	27	43.28	1

HORIZONTAL ADJUSTMENT - JMODE=111

SET NUMBER	DIRECTION NUMBER	TYPE	AT STATION	TO STATION	STANDARD DEVIATION (SECONDS)	OBSERVED DIRECTION DEGREES	MINUTES	SECONDS	RELATIVE WEIGHTING FACTOR (1 IF DEFAULT)
24	4	0	INNER-3	INNER-2	0.49	288	54	37.32	1
25	1	1	SCARP-1	SCARP-3	1.36	219	9	37.29	1
25	2	0	SCARP-1	SCARP-2	0.84	226	53	16.31	1
25	3	1	SCARP-1	INNER-2	1.49	246	28	54.21	1
25	4	0	SCARP-1	INNER-3	1.52	276	36	45.02	1
26	1	1	SCARP-2	SCARP-3	1.22	162	44	24.02	1
26	2	1	SCARP-2	SCARP-4	2.29	170	39	30.50	1
26	3	1	SCARP-2	INNER-2	0.74	233	13	14.44	1
26	4	1	SCARP-2	INNER-3	0.57	308	21	15.99	1
26	5	0	SCARP-2	SCARP-1	1.13	362	49	52.39	1
27	1	1	SCARP-3	SCARP-4	0.79	2	39	59.39	1

HORIZONTAL ADJUSTMENT - JMODE=111

SET NUMBER	DIRECTION NUMBER	TYPE	AT STATION	TO STATION	STANDARD DEVIATION (SECONDS)	OBSERVED DIRECTION DEGREES	MINUTES	SECONDS	RELATIVE WEIGHTING FACTOR (1 IF DEFAULT)
27	2	1	SCARP-3	INNER-1	1.01	67	35	3.71	1
27	3	1	SCARP-3	INNER-2	0.46	111	15	23.84	1
27	4	1	SCARP-3	INNER-3	1.00	148	32	44.43	1
27	5	0	SCARP-3	SCARP-2	0.78	167	43	49.90	1
27	6	0	SCARP-3	SCARP-1	0.17	180	5	42.19	1
28	1	1	SCARP-4	INNER-1	0.77	156	57	7.46	1
28	2	1	SCARP-4	INNER-2	0.38	174	28	2.19	1
28	3	0	SCARP-4	SCARP-2	0.66	204	4	45.60	1
28	4	0	SCARP-4	SCARP-1	1.51	209	18	46.53	1
28	5	0	SCARP-4	SCARP-3	0.82	211	5	46.99	1

B.2.2 Leveling

```
BEAVER CREEK - AUGUST,1976 - MONUMENTATION OF LANDSLIDES -- SFI-#2                                PAGE NO.   1
*******************************************************************************************************
LEVEL ADJUSTMENT - JMODE=444
*******************************************************************************************************
NUMBER OF STATIONS= 24          NUMBER OF LINKS= 29
*******************************************************************************************************
*******************************************************************************************************
*******************************************************************************************************
```

BEAVER CREEK - AUGUST,1978 - MONUMENTATION OF LANDSLIDES -- SET-#2

LEVEL ADJUSTMENT - JMODE=444

STATION NUMBER	STATION NAME	STATION TYPE (1=FIXED;0=FREE)	ELEVATION
1	INNER-1	0	100.6639
2	INNER-2	0	101.9244
3	INNER-3	0	99.9768
4	SCARP-1	0	100.4044
5	SCARP-2	0	101.3489
6	SCARP-3	0	101.5452
7	SCARP-4	0	101.9052
8	SLIDE-1	0	85.3215
9	SLIDE-2	0	85.8514
10	SLIDE-3	0	87.2168
11	SLIDE-4	0	86.3852
12	SLIDE-5	0	87.0505

LEVEL ADJUSTMENT - JMODE=44

STATION NUMBER	STATION NAME	STATION TYPE (1=FIXED;0=FREE)	ELEVATION
13	SLIDE-6	0	85.4071
14	SLIDE-7	0	86.0278
15	SLIDE-8	0	85.9466
16	SLIDE-9	0	87.1444
17	SLIDE-10	0	86.3786
18	SLIDE-11	0	85.2342
19	SLIDE-12	0	89.3357
20	SLIDE-13	0	89.7486
21	SLIDE-14	0	91.2505
22	SLIDE-15	0	92.7563
23	SLIDE-16	0	90.8732
24	EVCM-GEO	1	100.0000

LINK NUMBER	FROM STATION	TO STATION	OBSERVED DIFFERENCE IN ELEVATION	LINK WEIGHT
1	SLIDE-9	SLIDE-8	-1.1986	0.500
2	SLIDE-8	SLIDE-11	-0.7122	1.000
3	SLIDE-11	SLIDE-12	4.1012	1.000
4	SLIDE-11	SLIDE-4	1.1510	1.000
5	SLIDE-11	SLIDE-1	0.0874	1.000
6	SLIDE-11	SLIDE-2	0.6173	1.000
7	SLIDE-2	SLIDE-3	1.3632	1.000
8	SLIDE-3	SLIDE-5	-0.1684	1.000
9	SLIDE-5	SLIDE-6	-1.6417	1.000
10	SLIDE-6	SLIDE-7	0.6228	1.000
11	SLIDE-7	SLIDE-10	0.3511	0.500
12	SLIDE-10	SLIDE-8	-0.4316	0.500

LINK NUMBER	FROM STATION	TO STATION	OBSERVED DIFFERENCE IN ELEVATION	LINK WEIGHT
13	SCARP-4	SLIDE-16	-11.0293	0.250
14	SLIDE-16	SCARP-4	11.0294	0.250
15	SCARP-4	SCARP-3	-0.3570	1.000
16	SCARP-3	SCARP-2	-0.1764	1.000
17	SCARP-2	SCARP-1	-0.9648	0.500
18	SCARP-1	INNER-3	-0.4277	1.000
19	INNER-3	INNER-2	1.9475	1.000
20	INNER-2	INNER-1	-1.2606	1.000
21	INNER-1	SCARP-4	1.2380	1.000
22	EVCH-GED	SCARP-4	1.9022	0.250
23	SCARP-4	EVCH-GED	-1.9019	0.250
24	SLIDE-16	SLIDE-15	1.8816	1.000

LINK NUMBER	FROM STATION	TO STATION	OBSERVED DIFFERENCE IN ELEVATION	LINK WEIGHT
25	SLIDE-15	SLIDE-14	-1.5074	1.000
26	SLIDE-14	SLIDE-13	-1.5020	1.000
27	SLIDE-13	SLIDE-12	-0.4111	1.000
28	SLIDE-12	SLIDE-16	1.5390	0.500
29	SLIDE-12	SLIDE-9	-2.1905	0.500

B.3 May, 1979 Survey

B.3.1 Direction Measurements

```
BEAVER CREEK - MAY,1979 - MONUMENTATION OF LANDSLIDES -- SET-#3                                PAGE NO.   1
**********************************************************************************************************
HORIZONTAL ADJUSTMENT - JMODE=111
**********************************************************************************************************
   TOTAL NUMBER          CODE                  NUMBER                  NUMBER               NUMBER
   OF STATIONS         0=ANGLES          OF OBSERVED ANGLES              OF                OF CALLS
   IN NETWORK         1=DIRECTIONS     *OR* SETS OF DIRECTIONS    OBSERVED SIDES     FOR ERROR ELLIPSES
**********************************************************************************************************
       23                  1                     28                      0                    21
**********************************************************************************************************
CONVERGENCE CRITERION= 0.0020
**********************************************************************************************************
MAXIMUM NUMBER OF ITERATIONS=  2
**********************************************************************************************************
ERROR ELLIPSE PROBABILITY= 95 PERCENT. C-FACTOR= 2.4477
**********************************************************************************************************
**********************************************************************************************************
```

HORIZONTAL ADJUSTMENT - JMODE=111

STATION NUMBER	STATION NAME	STATION TYPE (1=FIXED;0=FREE)	X-COORDINATE	Y-COORDINATE	CENTERING ERROR
1	INNER-1	0	232.9106	107.0104	0.0005
2	INNER-2	1	183.7180	100.0000	0.0005
3	INNER-3	1	100.0000	100.0000	0.0005
4	SCARP-1	0	58.5863	167.7215	0.0005
5	SCARP-2	0	152.0199	153.2088	0.0005
6	SCARP-3	0	210.2494	164.8048	0.0005
7	SCARP-4	0	277.0616	160.5146	0.0005
8	SLIDE-1	0	156.7343	274.6724	0.0010
9	SLIDE-2	0	157.5601	268.0054	0.0010
10	SLIDE-3	0	170.4231	270.0040	0.0010
11	SLIDE-4	0	161.1390	259.5858	0.0010
12	SLIDE-5	0	192.3850	265.3753	0.0010

HORIZONTAL ADJUSTMENT - JMODE=111

STATION NUMBER	STATION NAME	STATION TYPE (1=FIXED;0=FREE)	X-COORDINATE	Y-COORDINATE	CENTERING ERROR
13	SLIDE-6	0	211.7071	264.8253	0.0010
14	SLIDE-7	0	229.7600	267.0170	0.0010
15	SLIDE-8	0	187.4055	242.0612	0.0010
16	SLIDE-9	0	198.5795	221.1124	0.0010
17	SLIDE-10	0	229.1826	241.0701	0.0010
18	SLIDE-11	0	157.3737	241.4471	0.0010
19	SLIDE-12	0	162.9380	208.2445	0.0010
20	SLIDE-13	0	146.1042	208.8130	0.0010
21	SLIDE-14	0	151.5985	191.6860	0.0010
22	SLIDE-15	0	177.2279	188.7450	0.0010
23	SLIDE-16	0	217.0463	196.3338	0.0010

NUMBER OF FREE STATIONS= 21 NUMBER OF FIXED STATIONS= 2

BEAVER CREEK - MAY,1979 - MONUMENTATION OF LANDSLIDES -- SET-#3

HORIZONTAL ADJUSTMENT - JMODE=111

SET NUMBER	DIRECTION NUMBER	TYPE	AT STATION	TO STATION	STANDARD DEVIATION (SECONDS)	OBSERVED DIRECTION DEGREES	MINUTES	SECONDS	RELATIVE WEIGHTING FACTOR (1 IF DEFAULT)
1	1	1	SCARP-1	SLIDE-5	0.74	100	19	48.05	1
1	2	1	SCARP-1	SLIDE-6	1.31	104	4	21.98	1
1	3	1	SCARP-1	SLIDE-7	1.43	106	20	8.10	1
1	4	1	SCARP-1	SLIDE-10	2.00	113	11	23.68	1
1	5	1	SCARP-1	SCARP-2	0.64	145	17	34.50	1
2	1	1	SCARP-1	SLIDE-5	0.92	17	4	33.63	1
2	2	1	SCARP-1	SLIDE-6	0.92	20	49	7.66	1
2	3	1	SCARP-1	SLIDE-7	1.66	23	4	51.72	1
2	4	1	SCARP-1	SLIDE-10	1.24	29	56	8.00	1
2	5	1	SCARP-1	SCARP-3	0.54	54	18	38.96	1
3	1	1	SCARP-4	SCARP-3	0.98	155	58	38.04	1

HORIZONTAL ADJUSTMENT - JMODE-III

SET NUMBER	DIRECTION NUMBER	TYPE	AT STATION	TO STATION	STANDARD DEVIATION (SECONDS)	OBSERVED DIRECTION DEGREES	MINUTES	SECONDS	RELATIVE WEIGHTING FACTOR (1 IF DEFAULT)
3	2	0	SCARP-4	SLIDE-5	0.54	203	23	49.32	1
3	3	0	SCARP-4	SLIDE-6	1.40	210	15	7.90	1
3	4	0	SCARP-4	SLIDE-10	0.70	211	35	27.97	1
3	5	0	SCARP-4	SLIDE-7	1.29	218	22	27.70	1
4	1	1	SCARP-4	SCARP-2	1.30	261	54	48.76	1
4	2	0	SCARP-4	SLIDE-5	0.62	316	21	1.21	1
4	3	0	SCARP-4	SLIDE-6	0.78	323	12	20.37	1
4	4	0	SCARP-4	SLIDE-10	0.64	324	32	41.87	1
4	5	0	SCARP-4	SLIDE-7	0.39	331	19	39.60	1
5	1	1	SCARP-4	SCARP-2	0.61	90	24	26.59	1
5	2	0	SCARP-4	SLIDE-4	1.22	134	16	51.86	1

HORIZONTAL ADJUSTMENT - JMODE=111

SET NUMBER	DIRECTION NUMBER	TYPE	AT STATION	TO STATION	STANDARD DEVIATION (SECONDS)	OBSERVED DIRECTION DEGREES	MINUTES	SECONDS	RELATIVE WEIGHTING FACTOR (1 IF DEFAULT)
5	3	0	SCARP-4	SLIDE-2	0.60	135	44	6.12	1
5	4	0	SCARP-4	SLIDE-1	0.85	137	15	28.25	1
5	5	0	SCARP-4	SLIDE-3	0.74	139	31	14.37	1
6	1	1	SCARP-1	SLIDE-1	0.70	152	46	23.82	1
6	2	1	SCARP-1	SLIDE-2	1.12	154	51	22.62	1
6	3	1	SCARP-1	SLIDE-3	1.57	157	47	22.86	1
6	4	1	SCARP-1	SLIDE-4	0.78	158	22	49.48	1
6	5	1	SCARP-1	SCARP-2	1.18	209	4	14.07	1
7	1	1	SCARP-1	SLIDE-1	1.20	42	52	33.08	1
7	2	1	SCARP-1	SLIDE-2	1.50	44	57	32.83	1
7	3	1	SCARP-1	SLIDE-3	0.87	47	53	28.98	1

HORIZONTAL ADJUSTMENT - JMODE=111

SET NUMBER	DIRECTION NUMBER	TYPE	AT STATION	TO STATION	STANDARD DEVIATION (SECONDS)	OBSERVED DIRECTION DEGREES	MINUTES	SECONDS	RELATIVE WEIGHTING FACTOR (1 IF DEFAULT)
7	4	1	SCARP-1	SLIDE-4	0.71	48	28	57.21	1
7	5	1	SCARP-1	SCARP-3	1.40	91	26	38.17	1
8	1	1	SCARP-4	SCARP-2	1.62	6	4	48.58	1
8	2	0	SCARP-4	SLIDE-11	0.57	43	30	11.32	1
8	3	0	SCARP-4	SLIDE-9	0.58	47	6	37.32	1
9	1	1	SCARP-3	SCARP-2	0.85	8	12	27.62	1
9	2	0	SCARP-3	SLIDE-13	1.41	53	56	23.96	1
9	3	0	SCARP-3	SLIDE-12	0.60	62	2	40.10	1
9	4	0	SCARP-3	SLIDE-11	0.37	74	52	54.74	1
9	5	0	SCARP-3	SLIDE-9	0.55	97	46	8.39	1
10	1	1	SCARP-3	SCARP-1	0.44	90	33	30.48	1

HORIZONTAL ADJUSTMENT - JMODE=111

SET NUMBER	DIRECTION NUMBER	TYPE	AT STATION	TO STATION	STANDARD DEVIATION (SECONDS)	OBSERVED DIRECTION DEGREES	MINUTES	SECONDS	RELATIVE WEIGHTING FACTOR (1 IF DEFAULT)
10	2	0	SCARP-3	SLIDE-13	0.61	123	55	32.35	1
10	3	0	SCARP-3	SLIDE-12	1.64	132	1	48.65	1
10	4	0	SCARP-3	SLIDE-11	0.41	144	52	3.48	1
10	5	0	SCARP-3	SLIDE-9	1.42	167	45	18.38	1
11	1	1	SCARP-1	SLIDE-11	1.01	56	46	34.93	1
11	2	1	SCARP-1	SLIDE-13	0.61	68	21	23.70	1
11	3	1	SCARP-1	SLIDE-12	1.14	72	17	11.30	1
11	4	1	SCARP-1	SLIDE-9	0.86	72	38	8.32	1
11	5	1	SCARP-1	SCARP-2	1.06	102	21	3.03	1
12	1	1	SCARP-2	SLIDE-13	0.98	21	40	2.90	1
12	2	1	SCARP-2	SLIDE-11	1.00	31	12	27.88	1

HORIZONTAL ADJUSTMENT - JMODE=111

SET NUMBER	DIRECTION NUMBER	TYPE	AT STATION	TO STATION	STANDARD DEVIATION (SECONDS)	OBSERVED DIRECTION DEGREES	MINUTES	SECONDS	RELATIVE WEIGHTING FACTOR (1 IF DEFAULT)
12	3	1	SCARP-2	SLIDE-12	0.27	38	57	7.43	1
12	4	1	SCARP-2	SLIDE-9	0.40	62	9	42.10	1
12	5	1	SCARP-2	SCARP-3	1.36	106	28	10.23	1
13	1	1	SCARP-4	SCARP-2	1.73	90	8	27.93	1
13	2	0	SCARP-4	SLIDE-16	2.21	124	19	52.91	1
13	3	0	SCARP-4	SLIDE-8	0.86	135	47	10.99	1
14	1	1	SCARP-4	SCARP-3	1.20	45	20	33.73	1
14	2	0	SCARP-4	SLIDE-16	1.95	72	30	58.64	1
14	3	0	SCARP-4	SLIDE-8	1.40	83	58	17.41	1
15	1	1	SCARP-2	SLIDE-8	1.55	1	49	36.24	1
15	2	1	SCARP-2	SLIDE-16	0.45	36	32	53.93	1

HORIZONTAL ADJUSTMENT - JMODE=111

SET NUMBER	DIRECTION NUMBER	TYPE	AT STATION	TO STATION	STANDARD DEVIATION (SECONDS)	OBSERVED DIRECTION DEGREES	MINUTES	SECONDS	RELATIVE WEIGHTING FACTOR (1 IF DEFAULT)
15	3	1	SCARP-2	SCARP-3	1.32	58	51	9.60	1
16	1	1	SCARP-2	SLIDE-8	1.07	90	21	3.71	1
16	2	1	SCARP-2	SLIDE-16	1.35	125	4	23.43	1
16	3	1	SCARP-2	SCARP-4	0.73	155	17	42.96	1
17	1	1	SCARP-2	SLIDE-14	0.68	8	11	24.09	1
17	2	1	SCARP-2	SLIDE-15	0.62	44	9	51.17	1
17	3	1	SCARP-2	SCARP-3	0.63	87	33	58.06	1
18	1	1	SCARP-2	SLIDE-14	0.60	90	22	6.83	1
18	2	1	SCARP-2	SLIDE-15	1.07	126	20	33.00	1
18	3	1	SCARP-2	SCARP-4	1.90	177	39	45.25	1
19	1	1	SCARP-3	SCARP-1	1.39	0	24	35.40	1

HORIZONTAL ADJUSTMENT - JAMDE-III

SET NUMBER	DIRECTION NUMBER	TYPE	AT STATION	TO STATION	STANDARD DEVIATION (SECONDS)	OBSERVED DIRECTION DEGREES	MINUTES	SECONDS	RELATIVE WEIGHTING FACTOR (1 IF DEFAULT)
19	2	0	SCARP-3	SLIDE-14	0.86	23	56	10.08	1
19	3	0	SCARP-3	SLIDE-15	1.33	35	15	38.38	1
20	1	1	SCARP-3	SCARP-2	0.93	90	7	3.26	1
20	2	0	SCARP-3	SLIDE-14	0.87	126	0	30.80	1
20	3	0	SCARP-3	SLIDE-15	0.92	137	19	56.40	1
21	1	1	SCARP-4	SCARP-3	1.42	2	49	46.00	1
21	2	0	SCARP-4	SLIDE-4	0.67	39	41	13.98	1
21	3	0	SCARP-4	SLIDE-2	0.36	41	8	26.58	1
21	4	0	SCARP-4	SLIDE-1	1.80	42	39	49.34	1
21	5	0	SCARP-4	SLIDE-3	1.39	44	55	35.52	1
22	1	1	SCARP-2	SCARP-3	2.85	0	5	42.77	1

HORIZONTAL ADJUSTMENT - JMODE=111

SET NUMBER	DIRECTION NUMBER	TYPE	AT STATION	TO STATION	STANDARD DEVIATION (SECONDS)	OBSERVED DIRECTION DEGREES	MINUTES	SECONDS	RELATIVE WEIGHTING FACTOR (1 IF DEFAULT)
22	2	1	SCARP-2	SCARP-4	1.74	8	0	42.97	1
22	3	1	SCARP-2	INNER-1	1.18	41	5	45.36	1
22	4	1	SCARP-2	INNER-2	0.96	70	34	58.10	1
22	5	1	SCARP-2	INNER-3	1.67	145	42	37.33	1
22	6	0	SCARP-2	SCARP-1	2.17	200	11	15.82	1
23	1	1	SCARP-3	SCARP-4	1.29	0	3	32.39	1
23	2	1	SCARP-3	INNER-1	0.54	64	59	7.16	1
23	3	1	SCARP-3	INNER-2	1.08	108	39	13.73	1
23	4	1	SCARP-3	INNER-3	1.13	145	56	23.31	1
23	5	1	SCARP-3	SCARP-2	0.92	165	7	27.45	1
23	6	0	SCARP-3	SCARP-1	0.71	177	29	22.64	1

HORIZONTAL ADJUSTMENT - JAGUL-III

SET NUMBER	DIRECTION NUMBER	TYPE	AT STATION	TO STATION	STANDARD DEVIATION (SECONDS)	OBSERVED DIRECTION DEGREES	MINUTES	SECONDS	RELATIVE WEIGHTING FACTOR (1 IF DEFAULT)
24	1	1	SCARP-4	INNER-1	1.76	2	4	1.83	1
24	2	0	SCARP-4	INNER-2	1.09	19	35	2.22	1
24	3	0	SCARP-4	SCARP-2	0.89	49	11	51.55	1
24	4	0	SCARP-4	SCARP-1	1.01	54	25	55.34	1
24	5	0	SCARP-4	SCARP-3	0.31	56	12	52.91	1
25	1	1	SCARP-1	SCARP-3	1.73	0	8	48.80	1
25	2	0	SCARP-1	SCARP-4	0.96	0	56	2.25	1
25	3	0	SCARP-1	SCARP-2	1.28	7	52	29.51	1
25	4	0	SCARP-1	INNER-2	2.00	27	28	20.48	1
25	5	0	SCARP-1	INNER-3	0.91	57	36	12.17	1
26	1	1	INNER-3	SCARP-1	1.61	0	2	49.61	1

HORIZONTAL ADJUSTMENT - JMODE=111

SET NUMBER	DIRECTION NUMBER	TYPE	AT STATION	TO STATION	STANDARD DEVIATION (SECONDS)	OBSERVED DIRECTION DEGREES	MINUTES	SECONDS	RELATIVE WEIGHTING FACTOR (1 IF DEFAULT)
26	2	1	INNER-3	SCARP-2	1.52	75	50	28.99	1
26	3	1	INNER-3	SCARP-3	1.33	91	2	24.71	1
26	4	0	INNER-3	INNER-2	1.42	121	29	30.02	1
27	1	1	INNER-2	INNER-3	0.79	0	4	44.39	1
27	2	1	INNER-2	SCARP-1	1.17	28	30	10.83	1
27	3	1	INNER-2	SCARP-2	1.10	59	18	2.86	1
27	4	1	INNER-2	SCARP-3	0.57	112	20	31.43	1
27	5	1	INNER-2	SCARP-4	1.13	147	6	57.30	1
27	6	0	INNER-2	INNER-1	0.98	171	57	56.29	1
28	1	1	INNER-1	INNER-2	1.14	0	10	20.18	1
28	2	1	INNER-1	SCARP-2	1.23	38	1	12.56	1

HORIZONTAL ADJUSTMENT - JMODE=111

SET NUMBER	DIRECTION NUMBER	TYPE	AT STATION	TO STATION	STANDARD DEVIATION (SECONDS)	OBSERVED DIRECTION DEGREES	MINUTES	SECONDS	RELATIVE WEIGHTING FACTOR (1 IF DEFAULT)
28	3	1	INNER-1	SCARP-3	0.78	76	52	47.80	1
28	4	0	INNER-1	SCARP-4	1.05	137	48	16.87	1

B.3.2 Leveling

```
BEAVER CREEK - MAY,1976 - MONUMENTATION OF LANDSLIDES -- SET-#3                    PAGE NO.  1
*************************************************************************************************
LEVEL ADJUSTMENT - JMODE=444
*************************************************************************************************
NUMBER OF STATIONS= 24          NUMBER OF LINKS= 28
*************************************************************************************************
*************************************************************************************************
```

BEAVER CREEK - MAY,1975 - MONUMENTATION OF LANDSLIDES -- SET-#3

LEVEL ADJUSTMENT - JMODE=444

STATION NUMBER	STATION NAME	STATION TYPE (1=FIXED;0=FREE)	ELEVATION
1	INNER-1	0	100.6639
2	INNER-2	0	101.9244
3	INNER-3	0	99.9768
4	SCARP-1	0	100.4044
5	SCARP-2	0	101.3689
6	SCARP-3	0	101.5452
7	SCARP-4	0	101.9052
8	SLIDE-1	0	85.3215
9	SLIDE-2	0	85.8514
10	SLIDE-3	0	87.2168
11	SLIDE-4	0	86.3852
12	SLIDE-5	0	87.0505

BEAVER CREEK - MAY,1974 - MONUMENTATION OF LANDSLIDES -- SLT-#3

LEVEL ADJUSTMENT - JMODE=444

STATION NUMBER	STATION NAME	STATION TYPE (1=FIXED;0=FREE)	ELEVATION
13	SLIDE-6	0	85.4071
14	SLIDE-7	0	86.0278
15	SLIDE-8	0	85.9466
16	SLIDE-9	0	87.1444
17	SLIDE-10	0	86.3786
18	SLIDE-11	0	85.2342
19	SLIDE-12	0	89.3357
20	SLIDE-13	0	89.7486
21	SLIDE-14	0	91.2505
22	SLIDE-15	0	92.7563
23	SLIDE-16	0	90.8732
24	EVCM-GEO	1	100.0000

LINK NUMBER	FROM STATION	TO STATION	OBSERVED DIFFERENCE IN ELEVATION	LINK WEIGHT
1	EVCM-GED	SCARP-4	1.8876	0.250
2	SCARP-4	EVCM-GED	-1.8875	0.250
3	SCARP-4	SLIDE-16	-11.0230	0.125
4	SLIDE-16	SCARP-4	11.0233	0.125
5	SCARP-4	SCARP-3	-0.3557	0.500
6	SCARP-3	SCARP-2	-0.1695	0.500
7	SCARP-2	SCARP-1	-0.9609	0.500
8	SCARP-1	INNER-3	-0.4262	0.167
9	INNER-3	INNER-2	1.9479	0.250
10	INNER-2	INNER-1	-1.2584	0.250
11	INNER-1	SCARP-4	1.2240	0.500
12	SLIDE-16	SLIDE-15	1.8808	0.500

LINK NUMBER	FROM STATION	TO STATION	OBSERVED DIFFERENCE IN ELEVATION	LINK WEIGHT
13	SLIDE-15	SLIDE-14	-1.5108	0.500
14	SLIDE-14	SLIDE-13	-1.4892	1.000
15	SLIDE-13	SLIDE-12	-0.4109	1.000
16	SLIDE-12	SLIDE-16	1.5301	1.000
17	SLIDE-12	SLIDE-11	-4.1060	1.000
18	SLIDE-11	SLIDE-3	1.9795	0.500
19	SLIDE-11	SLIDE-2	0.6161	0.500
20	SLIDE-11	SLIDE-4	1.1503	0.500
21	SLIDE-11	SLIDE-1	0.0828	0.500
22	SLIDE-3	SLIDE-5	-0.1664	0.500
23	SLIDE-5	SLIDE-6	-1.6458	0.500
24	SLIDE-6	SLIDE-7	0.6093	1.000

LINK NUMBER	FROM STATION	TO STATION	OBSERVED DIFFERENCE IN ELEVATION	LINK WEIGHT
25	SLIDE-7	SLIDE-10	0.3688	0.500
26	SLIDE-10	SLIDE-8	-0.4341	0.250
27	SLIDE-10	SLIDE-9	0.7661	0.250
28	SLIDE-10	SLIDE-11	-1.1465	0.250

B.4 August, 1979 Survey

B.4.1 Direction Measurements

BEAVER CREEK - AUGUST,1979 - MONUMENTATION OF LANDSLIDES -- SET-#4 PAGE NO. 1

HORIZONTAL ADJUSTMENT - JMODE=111

TOTAL NUMBER OF STATIONS IN NETWORK	CODE 0=ANGLES 1=DIRECTIONS	NUMBER OF OBSERVED ANGLES *OR* SETS OF DIRECTIONS	NUMBER OF OBSERVED SIDES	NUMBER OF CALLS FOR ERROR ELLIPSES
23	1	25	0	21

CONVERGENCE CRITERION= 0.0020

MAXIMUM NUMBER OF ITERATIONS= 2

ERROR ELLIPSE PROBABILITY= 95 PERCENT. C-FACTOR= 2.4477

HORIZONTAL ADJUSTMENT - JMODE=111

STATION NUMBER	STATION NAME	STATION TYPE (1=FIXED;0=FREE)	X-COORDINATE	Y-COORDINATE	CENTERING ERROR
1	INNER-1	0	232.9106	107.0104	0.0005
2	INNER-2	1	183.7180	100.0000	0.0005
3	INNER-3	1	100.0000	100.0000	0.0005
4	SCARP-1	0	58.5863	167.7215	0.0005
5	SCARP-2	0	152.0199	153.2088	0.0005
6	SCARP-3	0	210.2494	164.8048	0.0005
7	SCARP-4	0	277.0616	160.5146	0.0005
8	SLIDE-1	0	156.7343	274.6724	0.0010
9	SLIDE-2	0	157.5601	268.0054	0.0010
10	SLIDE-3	0	170.4231	270.0040	0.0010
11	SLIDE-4	0	161.1390	259.5858	0.0010
12	SLIDE-5	0	192.3850	265.3753	0.0010

HORIZONTAL ADJUSTMENT - JMODE=111

STATION NUMBER	STATION NAME	STATION TYPE (1=FIXED;0=FREE)	X-COORDINATE	Y-COORDINATE	CENTERING ERROR
13	SLIDE-6	0	211.7071	264.8253	0.0010
14	SLIDE-7	0	229.7600	267.0170	0.0010
15	SLIDE-8	0	187.4055	242.0612	0.0010
16	SLIDE-9	0	198.5795	221.1124	0.0010
17	SLIDE-10	0	229.1826	241.0701	0.0010
18	SLIDE-11	0	157.3737	241.4471	0.0010
19	SLIDE-12	0	162.9360	208.2445	0.0010
20	SLIDE-13	0	146.1042	208.8130	0.0010
21	SLIDE-14	0	151.5985	191.6860	0.0010
22	SLIDE-15	0	177.2279	188.7450	0.0010
23	SLIDE-16	0	217.0463	196.3338	0.0010

NUMBER OF FREE STATIONS= 21 NUMBER OF FIXED STATIONS= 2

BEAVER CREEK - AUGUST,1979 - MONUMENTATION OF LANDSLIDES -- SET-#4

HORIZONTAL ADJUSTMENT - JMODE=111

SET NUMBER	DIRECTION NUMBER	TYPE	AT STATION	TO STATION	STANDARD DEVIATION (SECONDS)	OBSERVED DIRECTION DEGREES	MINUTES	SECONDS	RELATIVE WEIGHTING FACTOR (1 IF DEFAULT)
1	1	1	SCARP-2	SCARP-3	0.86	0	22	33.36	1
1	2	1	SCARP-2	SCARP-4	2.28	8	17	36.28	1
1	3	1	SCARP-2	INNER-1	1.49	41	22	57.82	1
1	4	1	SCARP-2	INNER-2	1.02	70	52	8.89	1
1	5	1	SCARP-2	INNER-3	1.70	145	59	38.21	1
1	6	0	SCARP-2	SCARP-1	1.35	200	28	14.27	1
2	1	1	SCARP-3	SCARP-4	0.92	0	35	19.23	1
2	2	1	SCARP-3	INNER-1	1.85	65	31	15.01	1
2	3	1	SCARP-3	INNER-2	0.75	109	11	5.03	1
2	4	1	SCARP-3	SCARP-2	2.29	165	39	15.80	1
2	5	0	SCARP-3	SCARP-1	1.82	178	1	13.87	1

HORIZONTAL ADJUSTMENT - JMODE=111

SET NUMBER	DIRECTION NUMBER	TYPE	AT STATION	TO STATION	STANDARD DEVIATION (SECONDS)	OBSERVED DIRECTION DEGREES	MINUTES	SECONDS	RELATIVE WEIGHTING FACTOR (1 IF DEFAULT)
3	1	1	SCARP-4	INNER-1	1.03	0	12	13.10	1
3	2	1	SCARP-4	INNER-2	0.37	17	43	11.55	1
3	3	0	SCARP-4	SCARP-2	1.58	47	20	8.12	1
3	4	0	SCARP-4	SCARP-3	1.19	54	21	10.71	1
4	1	1	SCARP-1	SCARP-3	0.56	0	15	27.20	1
4	2	1	SCARP-1	SCARP-2	1.97	7	59	10.27	1
4	3	1	SCARP-1	INNER-2	1.05	27	35	7.11	1
4	4	0	SCARP-1	INNER-3	1.79	57	42	57.48	1
5	1	1	INNER-3	SCARP-1	1.63	0	10	10.54	1
5	2	1	INNER-3	SCARP-2	1.72	75	57	45.45	1
5	3	0	INNER-3	INNER-2	2.67	121	36	51.58	1

HORIZONTAL ADJUSTMENT - JMODE=111

SET NUMBER	DIRECTION NUMBER	TYPE	AT STATION	TO STATION	STANDARD DEVIATION (SECONDS)	OBSERVED DIRECTION DEGREES	MINUTES	SECONDS	RELATIVE WEIGHTING FACTOR (1 IF DEFAULT)
6	1	1	INNER-2	INNER-3	1.61	0	9	19.10	1
6	2	1	INNER-2	SCARP-1	0.87	28	34	43.31	1
6	3	1	INNER-2	SCARP-2	2.38	59	22	38.41	1
6	4	1	INNER-2	SCARP-3	0.98	112	24	54.42	1
6	5	1	INNER-2	SCARP-4	1.81	147	11	6.10	1
6	6	0	INNER-2	INNER-1	0.64	172	2	22.95	1
7	1	1	INNER-1	INNER-2	0.59	0	7	36.69	1
7	2	1	INNER-1	SCARP-2	2.15	37	58	34.87	1
7	3	1	INNER-1	SCARP-3	1.20	76	50	12.18	1
7	4	0	INNER-1	SCARP-4	2.69	137	45	11.75	1
8	1	1	SCARP-1	SLIDE-11	2.96	0	46	31.17	1

HORIZONTAL ADJUSTMENT - JMODE=111

SET NUMBER	DIRECTION NUMBER	TYPE	AT STATION	TO STATION	STANDARD DEVIATION (SECONDS)	OBSERVED DIRECTION DEGREES	MINUTES	SECONDS	RELATIVE WEIGHTING FACTOR (1 IF DEFAULT)
8	2	1	SCARP-1	SLIDE-13	1.38	12	21	15.92	1
8	3	1	SCARP-1	SLIDE-12	0.99	16	16	59.48	1
8	4	1	SCARP-1	SLIDE-9	1.39	16	38	0.18	1
8	5	1	SCARP-1	SCARP-3	0.81	38	37	47.59	1
9	1	1	SCARP-3	SCARP-2	0.98	45	20	45.96	1
9	2	0	SCARP-3	SLIDE-14	1.04	81	14	51.60	1
9	3	0	SCARP-3	SLIDE-15	1.71	92	34	35.44	1
10	1	1	SCARP-3	SCARP-1	1.64	0	39	34.22	1
10	2	0	SCARP-3	SLIDE-14	1.25	24	11	42.35	1
10	3	0	SCARP-3	SLIDE-15	1.70	35	31	28.80	1
11	1	1	SCARP-2	SLIDE-14	1.06	45	15	27.15	1

BEAVER CREEK - AUGUST,1979 - MONUMENTATION OF LANDSLIDES -- SET-#4

HORIZONTAL ADJUSTMENT - JMODE=111

SET NUMBER	DIRECTION NUMBER	TYPE	AT STATION	TO STATION	STANDARD DEVIATION (SECONDS)	OBSERVED DIRECTION DEGREES	MINUTES	SECONDS	RELATIVE WEIGHTING FACTOR (1 IF DEFAULT)
11	2	1	SCARP-2	SLIDE-8	1.05	67	36	16.56	1
11	3	1	SCARP-2	SLIDE-15	0.56	81	13	44.88	1
11	4	1	SCARP-2	SLIDE-16	1.69	102	18	56.40	1
11	5	1	SCARP-2	SCARP-4	1.60	132	32	57.09	1
12	1	1	SCARP-2	SLIDE-14	0.39	0	10	42.43	1
12	2	1	SCARP-2	SLIDE-8	1.20	22	31	29.83	1
12	3	1	SCARP-2	SLIDE-15	1.07	36	8	56.80	1
12	4	1	SCARP-2	SLIDE-16	0.80	57	14	11.36	1
12	5	1	SCARP-2	SCARP-3	1.51	79	33	7.86	1
13	1	1	SCARP-4	SCARP-3	1.57	45	36	20.91	1
13	2	0	SCARP-4	SLIDE-16	1.16	72	47	31.38	1

HORIZONTAL ADJUSTMENT - JMODE=111

SET NUMBER	DIRECTION NUMBER	TYPE	AT STATION	TO STATION	STANDARD DEVIATION (SECONDS)	OBSERVED DIRECTION DEGREES	MINUTES	SECONDS	RELATIVE WEIGHTING FACTOR (1 IF DEFAULT)
13	3	0	SCARP-4	SLIDE-8	1.40	84	14	41.18	1
14	1	1	SCARP-4	SCARP-2	1.78	0	16	55.24	1
14	2	0	SCARP-4	SLIDE-16	0.92	34	29	9.45	1
14	3	0	SCARP-4	SLIDE-8	1.41	45	56	18.61	1
15	1	1	SCARP-2	SLIDE-13	1.19	0	36	49.29	1
15	2	1	SCARP-2	SLIDE-11	0.84	10	9	9.18	1
15	3	1	SCARP-2	SLIDE-12	1.08	17	53	36.56	1
15	4	1	SCARP-2	SLIDE-9	0.72	41	5	49.90	1
15	5	1	SCARP-2	SCARP-3	2.05	85	24	38.85	1
16	1	1	SCARP-3	SCARP-1	0.93	45	20	40.28	1
16	2	0	SCARP-3	SLIDE-13	1.29	78	43	23.81	1

HORIZONTAL ADJUSTMENT - JMODE=111

SET NUMBER	DIRECTION NUMBER	TYPE	AT STATION	TO STATION	STANDARD DEVIATION (SECONDS)	OBSERVED DIRECTION DEGREES	MINUTES	SECONDS	RELATIVE WEIGHTING FACTOR (1 IF DEFAULT)
16	3	0	SCARP-3	SLIDE-12	1.68	86	49	56.82	1
16	4	0	SCARP-3	SLIDE-11	0.75	99	39	50.82	1
16	5	0	SCARP-3	SLIDE-9	1.04	122	32	59.79	1
17	1	1	SCARP-3	SCARP-2	1.55	0	22	50.84	1
17	2	0	SCARP-3	SLIDE-13	1.61	46	7	30.95	1
17	3	0	SCARP-3	SLIDE-12	0.66	54	14	3.72	1
17	4	0	SCARP-3	SLIDE-11	0.43	67	3	58.60	1
17	5	0	SCARP-3	SLIDE-9	0.42	89	57	11.40	1
18	1	1	SCARP-4	SCARP-3	1.00	43	25	48.77	1
18	2	0	SCARP-4	SLIDE-4	0.83	80	17	59.39	1
18	3	0	SCARP-4	SLIDE-2	0.71	81	45	9.78	1

HORIZONTAL ADJUSTMENT - JMODE=111

SET NUMBER	DIRECTION NUMBER	TYPE	AT STATION	TO STATION	STANDARD DEVIATION (SECONDS)	OBSERVED DIRECTION DEGREES	MINUTES	SECONDS	RELATIVE WEIGHTING FACTOR (1 IF DEFAULT)
18	4	0	SCARP-4	SLIDE-1	0.67	83	16	33.02	1
18	5	0	SCARP-4	SLIDE-3	0.92	85	32	20.46	1
19	1	1	SCARP-1	SLIDE-1	1.27	45	24	20.78	1
19	2	1	SCARP-1	SLIDE-2	1.73	47	29	15.00	1
19	3	1	SCARP-1	SLIDE-3	0.72	50	25	15.10	1
19	4	1	SCARP-1	SLIDE-4	0.89	51	0	40.75	1
19	5	1	SCARP-1	SCARP-3	1.00	93	58	53.29	1
20	1	1	SCARP-1	SLIDE-1	1.03	0	32	13.86	1
20	2	1	SCARP-1	SLIDE-2	0.80	2	37	7.14	1
20	3	1	SCARP-1	SLIDE-3	0.81	5	33	7.00	1
20	4	1	SCARP-1	SLIDE-4	0.39	6	8	30.86	1

HORIZONTAL ADJUSTMENT - JMODE=111

SET NUMBER	DIRECTION NUMBER	TYPE	AT STATION	TO STATION	STANDARD DEVIATION (SECONDS)	OBSERVED DIRECTION DEGREES	MINUTES	SECONDS	RELATIVE WEIGHTING FACTOR (1 IF DEFAULT)
20	5	1	SCARP-1	SCARP-2	0.55	56	50	29.73	1
21	1	1	SCARP-4	SCARP-2	1.16	0	53	11.47	1
21	2	0	SCARP-4	SLIDE-4	0.75	44	46	21.66	1
21	3	0	SCARP-4	SLIDE-2	1.04	46	13	33.45	1
21	4	0	SCARP-4	SLIDE-1	0.51	47	44	55.89	1
21	5	0	SCARP-4	SLIDE-3	1.08	50	0	44.35	1
22	1	1	SCARP-4	SCARP-2	1.22	0	15	16.06	1
22	2	0	SCARP-4	SLIDE-5	1.00	54	42	13.33	1
22	3	0	SCARP-4	SLIDE-6	1.08	61	33	29.67	1
22	4	0	SCARP-4	SLIDE-10	1.92	62	53	47.97	1
22	5	0	SCARP-4	SLIDE-7	1.14	69	40	44.53	1

HORIZONTAL ADJUSTMENT - JMODE=111

SET NUMBER	DIRECTION NUMBER	TYPE	AT STATION	TO STATION	STANDARD DEVIATION (SECONDS)	OBSERVED DIRECTION DEGREES	MINUTES	SECONDS	RELATIVE WEIGHTING FACTOR (1 IF DEFAULT)
23	1	1	SCARP-4	SCARP-3	0.38	45	25	3.37	1
23	2	0	SCARP-4	SLIDE-5	0.54	92	50	57.69	1
23	3	0	SCARP-4	SLIDE-6	1.29	99	42	14.77	1
23	4	0	SCARP-4	SLIDE-10	1.27	101	2	33.84	1
23	5	0	SCARP-4	SLIDE-7	0.84	107	49	29.79	1
24	1	1	SCARP-1	SLIDE-5	0.96	45	24	50.82	1
24	2	1	SCARP-1	SLIDE-6	1.05	49	9	25.65	1
24	3	1	SCARP-1	SLIDE-7	1.05	51	25	11.05	1
24	4	1	SCARP-1	SLIDE-10	0.98	58	16	32.04	1
24	5	1	SCARP-1	SCARP-3	0.56	82	39	22.95	1
25	1	1	SCARP-1	SLIDE-5	1.05	0	10	23.99	1

BEAVER CREEK - AUGUST,1979 - MONUMENTATION OF LANDSLIDES -- SET-#4

HORIZONTAL ADJUSTMENT - JMODE=(1)

SET NUMBER	DIRECTION NUMBER	TYPE	AT STATION	TO STATION	STANDARD DEVIATION (SECONDS)	OBSERVED DIRECTION DEGREES	MINUTES	SECONDS	RELATIVE WEIGHTING FACTOR (1 IF DEFAULT)
25	2	1	SCARP-1	SLIDE-6	1.75	3	54	59.66	1
25	3	1	SCARP-1	SLIDE-7	1.08	6	10	44.28	1
25	4	1	SCARP-1	SLIDE-10	0.79	13	2	6.28	1
25	5	1	SCARP-1	SCARP-2	0.49	45	8	42.48	1

B.4.2 Leveling

```
BEAVER CREEK - AUGUST,1978 - MONUMENTATION OF LANDSLIDES -- SET-#4                    PAGE NO.   1
****************************************************************************************************
LEVEL ADJUSTMENT - JMODE=444
****************************************************************************************************
NUMBER OF STATIONS= 24          NUMBER OF LINKS= 28
****************************************************************************************************
****************************************************************************************************
```

LEVEL ADJUSTMENT - JHUDE-444

STATION NUMBER	STATION NAME	STATION TYPE (1=FIXED,0=FREE)	ELEVATION
1	INNER-1	0	100.6639
2	INNER-2	0	101.9244
3	INNER-3	0	99.9768
4	SCARP-1	0	100.4044
5	SCARP-2	0	101.3689
6	SCARP-3	0	101.5452
7	SCARP-4	0	101.9052
8	SLIDE-1	0	85.3215
9	SLIDE-2	0	85.8514
10	SLIDE-3	0	87.2168
11	SLIDE-4	0	86.3852
12	SLIDE-5	0	87.0505

LEVEL ADJUSTMENT - JMODE=444

STATION NUMBER	STATION NAME	STATION TYPE (1=FIXED;0=FREE)	ELEVATION
13	SLIDE-6	0	85.4071
14	SLIDE-7	0	86.0278
15	SLIDE-8	0	85.9466
16	SLIDE-9	0	87.1444
17	SLIDE-10	0	86.3786
18	SLIDE-11	0	85.2342
19	SLIDE-12	0	89.3357
20	SLIDE-13	0	89.7486
21	SLIDE-14	0	91.2505
22	SLIDE-15	0	92.7563
23	SLIDE-16	0	90.8732
24	EVCM-GED	1	100.0000

LINK NUMBER	FROM STATION	TO STATION	OBSERVED DIFFERENCE IN ELEVATION	LINK WEIGHT
1	EVCH-GEO	SCARP-4	1.8727	0.250
2	SCARP-4	EVCH-GEO	-1.8731	0.250
3	SCARP-4	SLIDE-16	-11.0147	0.250
4	SLIDE-16	SCARP-4	11.0152	0.250
5	SCARP-4	SCARP-3	-0.3525	0.500
6	SCARP-3	SCARP-2	-0.1614	0.500
7	SCARP-2	SCARP-1	-0.9595	0.250
8	SCARP-1	INNER-3	-0.4246	0.500
9	INNER-3	INNER-2	1.9480	0.500
10	INNER-2	INNER-1	-1.2605	0.500
11	INNER-1	SCARP-4	1.2101	0.500
12	SLIDE-16	SLIDE-15	1.8799	0.500

LINK NUMBER	FROM STATION	TO STATION	OBSERVED DIFFERENCE IN ELEVATION	LINK WEIGHT
13	SLIDE-15	SLIDE-14	-1.5159	1.000
14	SLIDE-14	SLIDE-13	-1.4785	1.000
15	SLIDE-13	SLIDE-12	-0.4097	1.000
16	SLIDE-12	SLIDE-16	1.5242	0.500
17	SLIDE-12	SLIDE-11	-4.1072	0.500
18	SLIDE-11	SLIDE-1	0.0781	0.500
19	SLIDE-11	SLIDE-2	0.6137	0.500
20	SLIDE-11	SLIDE-4	1.1482	0.500
21	SLIDE-11	SLIDE-3	1.9734	0.500
22	SLIDE-3	SLIDE-5	-0.1681	1.000
23	SLIDE-5	SLIDE-6	-1.6425	1.000
24	SLIDE-6	SLIDE-7	0.6094	1.000

LINK NUMBER	FROM STATION	TO STATION	OBSERVED DIFFERENCE IN ELEVATION	LINK WEIGHT
25	SLIDE-7	SLIDE-10	0.3742	1.000
26	SLIDE-10	SLIDE-8	-0.4364	0.500
27	SLIDE-8	SLIDE-9	1.2017	1.000
28	SLIDE-8	SLIDE-11	-0.7117	1.000

APPENDIX C

Results of Adjustment Calculations: Statistical Accuracies and Reliability of Data Checks

C.1 May, 1978 Survey

C.1.1 Horizontal Adjustment

BEAVER CREEK - MAY,1978 - MONUMENTATION OF LANDSLIDES -- SET-#1 PAGE NO. 18

HORIZONTAL ADJUSTMENT - JMODE=111

ANGLE NUMBER	AT STATION	FROM STATION	TO STATION	ADJUSTED ANGLE DEGREES	MINUTES	SECONDS	CORR.STD DEVIATION (SECONDS)	RESIDUAL (CALC-OBS) (SECONDS)	3-SIGMA TEST AT 99% PROB. (SECONDS)
1	INNER-1	INNER-2	SCARP-2	37	50	31.93	3.13	-0.98	9.40
2	INNER-1	SCARP-2	SCARP-3	38	51	29.51	2.67	0.75	8.01
3	INNER-1	SCARP-3	SCARP-4	60	56	20.93	3.10	0.46	9.30
4	INNER-2	INNER-3	SCARP-1	28	25	20.42	2.39	0.77	7.17
5	INNER-2	SCARP-1	SCARP-2	30	47	38.79	2.93	0.37	8.80
6	INNER-2	SCARP-2	SCARP-3	53	2	52.61	3.25	2.20	9.76
7	INNER-2	SCARP-3	SCARP-4	34	46	48.88	3.03	0.71	9.10
8	INNER-2	SCARP-4	INNER-1	24	50	41.18	3.45	-0.41	10.35
9	INNER-3	SCARP-1	SCARP-2	75	47	58.81	3.89	3.01	11.68
10	INNER-3	SCARP-2	INNER-2	45	38	50.44	3.59	0.26	10.77
11	SCARP-1	SCARP-3	SCARP-2	7	43	38.08	2.49	-0.04	7.47
12	SCARP-1	SCARP-2	INNER-2	19	35	36.04	2.64	0.14	7.91

HORIZONTAL ADJUSTMENT - JMODE=111

ANGLE NUMBER	AT STATION	FROM STATION	TO STATION	ADJUSTED ANGLE DEGREES	MINUTES	SECONDS	CORR.STD DEVIATION (SECONDS)	RESIDUAL (CALC-OBS) (SECONDS)	3-SIGMA TEST AT 99% PROB. (SECONDS)
13	SCARP-1	SCARP-2	INNER-3	49	43	26.37	2.88	1.45	8.64
14	SCARP-2	SCARP-3	SCARP-4	7	55	8.02	2.78	-0.58	8.34
15	SCARP-2	SCARP-4	INNER-1	33	4	31.70	2.38	-0.30	7.14
16	SCARP-2	INNER-2	INNER-3	75	8	10.35	3.50	-2.09	10.51
17	SCARP-2	INNER-3	SCARP-1	54	28	34.82	2.81	0.96	8.44
18	SCARP-2	SCARP-4	INNER-2	62	33	37.10	2.70	1.23	8.09
19	SCARP-3	SCARP-4	INNER-1	64	54	56.61	3.48	0.37	10.45
20	SCARP-3	INNER-1	INNER-2	43	40	28.49	2.68	-0.31	8.03
21	SCARP-3	INNER-2	INNER-3	37	17	18.53	3.50	4.62	10.49
22	SCARP-3	INNER-2	SCARP-2	56	28	22.26	2.85	-0.16	8.55
23	SCARP-3	INNER-3	SCARP-1	31	32	55.95	2.33	0.21	6.98
24	SCARP-4	INNER-1	INNER-2	17	30	56.44	2.51	0.53	7.53

BEAVER CREEK - MAY,1978 - MONUMENTATION OF LANDSLIDES -- SET-#1

HORIZONTAL ADJUSTMENT - JMODE=111

ANGLE NUMBER	AT STATION	FROM STATION	TO STATION	ADJUSTED ANGLE DEGREES	MINUTES	SECONDS	CORR.STD DEVIATION (SECONDS)	RESIDUAL (CALC-OBS) (SECONDS)	3-SIGMA TEST AT 99% PROB. (SECONDS)
25	SCARP-4	INNER-2	SCARP-2	29	36	41.41	2.07	-0.17	6.20
26	SCARP-4	INNER-2	SCARP-3	36	37	46.02	2.34	0.63	7.03
27	SCARP-4	SCARP-1	SLIDE-3	43	51	59.05	2.01	-0.00	6.04
28	SCARP-4	SCARP-1	SLIDE-5	49	11	21.35	2.78	0.0	8.35
29	SCARP-4	SCARP-1	SLIDE-6	56	2	31.13	2.50	0.00	7.51
30	SCARP-4	SCARP-1	SLIDE-7	64	9	46.40	2.36	-0.00	7.07
31	SCARP-3	SCARP-1	SLIDE-14	23	31	17.18	3.99	0.00	11.98
32	SCARP-3	SCARP-1	SLIDE-13	33	21	4.24	3.58	0.00	10.75
33	SCARP-3	SCARP-1	SLIDE-15	34	50	23.91	5.86	0.00	17.57
34	SCARP-3	SCARP-1	SLIDE-12	41	27	19.39	4.01	0.00	12.04
35	SCARP-1	SLIDE-7	SCARP-4	32	0	24.52	2.32	-0.00	6.96
36	SCARP-1	SLIDE-5	SCARP-4	38	0	48.49	2.01	-0.00	6.02

HORIZONTAL ADJUSTMENT - JADJE=111

ANGLE NUMBER	AT STATION	FROM STATION	TO STATION	ADJUSTED ANGLE DEGREES	MINUTES	SECONDS	CORR.STD DEVIATION (SECONDS)	RESIDUAL (CALC-OBS) (SECONDS)	3-SIGMA TEST AT 99% PROB. (SECONDS)
37	SCARP-1	SLIDE-15	SCARP-3	11	9	1.52	1.97	-0.00	5.90
38	SCARP-1	SLIDE-14	SCARP-3	15	32	59.09	2.43	-0.00	7.29
39	SCARP-1	SLIDE-12	SCARP-3	22	19	28.36	2.46	-0.00	7.38
40	SCARP-1	SLIDE-13	SCARP-3	26	15	10.14	2.77	-0.00	8.30
41	SCARP-1	SLIDE-11	SCARP-4	36	37	24.84	2.35	0.0	7.05
42	SCARP-1	SLIDE-4	SCARP-4	43	44	33.46	2.17	0.0	6.52
43	SCARP-1	SLIDE-2	SCARP-4	47	15	57.97	2.70	-0.00	8.09
44	SCARP-1	SLIDE-1	SCARP-4	49	20	49.26	2.27	-0.00	6.81
45	SCARP-4	SCARP-1	SLIDE-11	32	10	37.43	2.18	-0.00	6.55
46	SCARP-4	SCARP-1	SLIDE-4	38	37	44.10	2.03	0.00	6.08
47	SCARP-4	SCARP-1	SLIDE-2	40	4	54.63	2.23	-0.00	6.68
48	SCARP-4	SCARP-1	SLIDE-1	41	36	12.57	1.97	-0.00	5.92

HORIZONTAL ADJUSTMENT - JMODE-111

ANGLE NUMBER	AT STATION	FROM STATION	TO STATION	ADJUSTED ANGLE DEGREES	MINUTES	SECONDS	CORR.STD DEVIATION (SECONDS)	RESIDUAL (CALC-OBS) (SECONDS)	3-SIGMA TEST AT 99% PROB. (SECONDS)
49	SCARP-2	SLIDE-16	SCARP-4	30	12	29.43	2.97	0.00	8.91
50	SCARP-2	SLIDE-10	SCARP-4	45	21	55.63	2.74	0.0	8.22
51	SCARP-2	SLIDE-9	SCARP-4	52	13	7.71	3.08	-0.00	9.23
52	SCARP-2	SLIDE-8	SCARP-4	64	56	28.05	2.82	0.0	8.46
53	SCARP-2	SLIDE-6	SCARP-4	58	31	13.40	2.29	-0.00	6.86
54	SCARP-2	SLIDE-3	SCARP-4	77	42	6.38	2.49	-0.00	7.46
55	SCARP-4	SCARP-2	SLIDE-16	34	10	26.64	3.60	0.00	10.81
56	SCARP-4	SCARP-2	SLIDE-9	41	0.	58.98	2.89	0.00	8.68
57	SCARP-4	SCARP-2	SLIDE-8	45	37	54.99	2.72	0.00	8.15
58	SCARP-4	SCARP-2	SLIDE-10	62	37	5.87	3.17	0.00	9.50

MEAN RESIDUAL(ABSOLUTE,UNWEIGHTED)= 0.409

HORIZONTAL ADJUSTMENT - JADJE=111

ERROR ELLIPSES FOR 95 PERCENT PROBABILITY

STANDARD DEVIATION OF UNIT WEIGHT= 0.522

***** ERROR ELLIPSE AT ***** STATION NUMBER	STATION NAME	TYPE	******* RELATIVE TO ******* STATION NUMBER	STATION NAME	TYPE	DEGREES OF FREEDOM	MAJOR AXIS	MINOR AXIS	ORIENTATION OF MAJOR AXIS CW FROM Y-AXIS
1	INNER-1	0	2	INNER-2	1	6	0.0029	0.0021	39 DEGREES
4	SCARP-1	0	2	INNER-2	1	26	0.0035	0.0028	110 DEGREES
5	SCARP-2	0	2	INNER-2	1	24	0.0025	0.0016	109 DEGREES
6	SCARP-3	0	2	INNER-2	1	18	0.0033	0.0022	165 DEGREES
7	SCARP-4	0	2	INNER-2	1	12	0.0053	0.0041	24 DEGREES
8	SLIDE-1	0	2	INNER-2	1	0	0.0064	0.0056	144 DEGREES
9	SLIDE-2	0	2	INNER-2	1	0	0.0067	0.0058	137 DEGREES
10	SLIDE-3	0	2	INNER-2	1	0	0.0095	0.0052	147 DEGREES
11	SLIDE-4	0	2	INNER-2	1	0	0.0059	0.0053	131 DEGREES

HORIZONTAL ADJUSTMENT - JMODE=111

ERROR ELLIPSES FOR 95 PERCENT PROBABILITY

STANDARD DEVIATION OF UNIT WEIGHT= 0.522

***** ERROR ELLIPSE AT ***** STATION NUMBER	STATION NAME	TYPE	******* RELATIVE TO ******* STATION NUMBER	STATION NAME	TYPE	DEGREES OF FREEDOM	MAJOR AXIS	MINOR AXIS	ORIENTATION OF MAJOR AXIS CW FROM Y-AXIS
12	SLIDE-5	0	2	INNER-2	1	0	0.0065	0.0061	157 DEGREES
13	SLIDE-6	0	2	INNER-2	1	0	0.0090	0.0054	161 DEGREES
14	SLIDE-7	0	2	INNER-2	1	0	0.0081	0.0056	161 DEGREES
15	SLIDE-8	0	2	INNER-2	1	0	0.0075	0.0055	158 DEGREES
16	SLIDE-9	0	2	INNER-2	1	0	0.0062	0.0050	156 DEGREES
17	SLIDE-10	0	2	INNER-2	1	0	0.0079	0.0058	167 DEGREES
18	SLIDE-11	0	2	INNER-2	1	0	0.0057	0.0049	100 DEGREES
19	SLIDE-12	0	2	INNER-2	1	0	0.0054	0.0038	113 DEGREES
20	SLIDE-13	0	2	INNER-2	1	0	0.0056	0.0038	100 DEGREES

HORIZONTAL ADJUSTMENT - SHADE-III

ERROR ELLIPSES FOR 95 PERCENT PROBABILITY

STANDARD DEVIATION OF UNIT WEIGHT= 0.522

***** ERROR ELLIPSE AT ***** STATION NUMBER	STATION NAME	TYPE	******* RELATIVE TO ******* STATION NUMBER	STATION NAME	TYPE	DEGREES OF FREEDOM	MAJOR AXIS	MINOR AXIS	ORIENTATION OF MAJOR AXIS CW FROM Y-AXIS
21	SLIDE-14	0	2	INNER-2	1	0	0.0069	0.0033	96 DEGREES
22	SLIDE-15	0	2	INNER-2	1	0	0.0059	0.0034	108 DEGREES
23	SLIDE-16	0	2	INNER-2	1	0	0.0053	0.0049	120 DEGREES

C.1.2 Vertical Adjustment

BEAVER CREEK - MAY,1978 - MONUMENTATION OF LANDSLIDES -- SET-#1 PAGE NO. 9

LEVEL ADJUSTMENT - JMODE=444

LINK NUMBER	FROM STATION	TO STATION	CALCULATED DIFF. IN ELEV	OBSERVED DIFF. IN ELEV	RESIDUAL (CALC-OBS)	LINK WEIGHT	LINK STANDARD DEVIATION	3-SIGMA TEST AT 99% PROB.
1	SCARP-4	SLIDE-16	-11.0320	-11.0318	-0.0002	0.25	0.0007	0.0021
2	SLIDE-16	SLIDE-15	1.8830	1.8828	0.0002	1.00	0.0005	0.0014
3	SLIDE-15	SLIDE-14	-1.5058	-1.5060	0.0002	1.00	0.0005	0.0014
4	SLIDE-14	SLIDE-13	-1.5019	-1.5021	0.0002	1.00	0.0005	0.0014
5	SLIDE-13	SLIDE-12	-0.4130	-0.4132	0.0002	1.00	0.0005	0.0014
6	SLIDE-12	SLIDE-16	1.5376	1.5371	0.0005	0.50	0.0006	0.0018
7	SLIDE-12	SLIDE-9	-2.1913	-2.1912	-0.0001	0.50	0.0005	0.0015
8	SLIDE-9	SLIDE-11	-1.9102	-1.9096	-0.0006	1.00	0.0004	0.0011
9	SLIDE-11	SLIDE-2	0.6173	0.6169	0.0004	1.00	0.0004	0.0011
10	SLIDE-2	SLIDE-1	-0.5299	-0.5299	-0.0000	1.00	0.0005	0.0015
11	SLIDE-2	SLIDE-4	0.5337	0.5336	0.0001	1.00	0.0004	0.0011
12	SLIDE-2	SLIDE-3	1.3653	1.3651	0.0002	1.00	0.0004	0.0011

LEVEL ADJUSTMENT - JMODE=444

LINK NUMBER	FROM STATION	TO STATION	CALCULATED DIFF. IN ELEV	OBSERVED DIFF. IN ELEV	RESIDUAL (CALC-OBS)	LINK WEIGHT	LINK STANDARD DEVIATION	3-SIGMA TEST AT 99% PROB.
13	SLIDE-3	SLIDE-11	-1.9826	-1.9827	0.0001	1.00	0.0004	0.0011
14	SLIDE-11	SLIDE-9	1.9102	1.9109	-0.0007	1.00	0.0004	0.0011
15	SLIDE-9	SLIDE-12	2.1913	2.1913	-0.0000	0.50	0.0005	0.0015
16	SLIDE-11	SLIDE-8	0.7124	0.7127	-0.0003	1.00	0.0004	0.0013
17	SLIDE-8	SLIDE-10	0.4320	0.4321	-0.0001	0.50	0.0006	0.0019
18	SLIDE-10	SLIDE-7	-0.3507	-0.3506	-0.0001	0.50	0.0006	0.0019
19	SLIDE-7	SLIDE-6	-0.6208	-0.6207	-0.0001	1.00	0.0005	0.0014
20	SLIDE-6	SLIDE-5	1.6434	1.6435	-0.0001	1.00	0.0005	0.0014
21	SLIDE-5	SLIDE-3	0.1663	0.1663	-0.0001	1.00	0.0005	0.0014
22	SLIDE-3	SLIDE-4	-0.8316	-0.8317	0.0001	1.00	0.0004	0.0011
23	SLIDE-4	SLIDE-8	-0.4386	-0.4390	0.0004	0.50	0.0005	0.0015
24	SLIDE-16	SCARP-4	11.0320	11.0322	-0.0002	0.25	0.0007	0.0021

LEVEL ADJUSTMENT - JMODE-444

LINK NUMBER	FROM STATION	TO STATION	CALCULATED DIFF. IN ELEV	OBSERVED DIFF. IN ELEV	RESIDUAL (CALC-OBS)	LINK WEIGHT	LINK STANDARD DEVIATION	3-SIGMA TEST AT 99% PROB.
25	SCARP-4	EVCM-GEO	-1.9052	-1.9064	0.0012	0.25	0.0007	0.0021
26	EVCM-GEO	SCARP-4	1.9052	1.9041	0.0011	0.25	0.0007	0.0021

MEAN RESIDUAL= -0.0000

STD. ERROR OF OBS. OF UNIT WEIGHT= 0.0005

C.2 August, 1978 Survey

C.2.1 Horizontal Adjustment

BEAVER CREEK - AUGUST,1978 - MONUMENTATION OF LANDSLIDES -- SET-#2 PAGE NO. 24

HORIZONTAL ADJUSTMENT - JMODE=111

ANGLE NUMBER	AT STATION	FROM STATION	TO STATION	ADJUSTED ANGLE DEGREES	MINUTES	SECONDS	CURR.STD DEVIATION (SECONDS)	RESIDUAL (CALC-OBS) (SECONDS)	3-SIGMA TEST AT 99% PROB. (SECONDS)
1	SCARP-3	SCARP-2	SLIDE-14	35	53	6.52	4.62	-0.93	13.87
2	SCARP-3	SCARP-2	SLIDE-15	47	12	26.96	6.80	0.15	20.41
3	SCARP-3	SCARP-1	SLIDE-14	23	31	14.42	5.94	0.74	17.82
4	SCARP-3	SCARP-1	SLIDE-15	34	50	34.86	4.01	-0.38	12.04
5	SCARP-2	SLIDE-14	SCARP-4	87	17	22.08	7.06	2.22	21.19
6	SCARP-2	SLIDE-15	SCARP-4	51	18	37.80	8.53	2.70	25.59
7	SCARP-2	SLIDE-14	SCARP-3	79	22	15.72	8.07	-2.51	24.21
8	SCARP-2	SLIDE-15	SCARP-3	43	23	31.43	6.06	-2.88	18.18
9	SCARP-2	SLIDE-8	SCARP-4	64	56	36.84	6.92	0.36	20.76
10	SCARP-2	SLIDE-16	SCARP-4	30	12	50.19	8.31	-0.32	24.92
11	SCARP-2	SLIDE-8	SCARP-3	57	1	30.48	6.21	-0.42	18.62
12	SCARP-2	SLIDE-16	SCARP-3	22	17	43.82	4.00	0.20	12.01

BEAVER CREEK - AUGUST,1978 - MONUMENTATION OF LANDSLIDES -- SET-#2

HORIZONTAL ADJUSTMENT - JMODE=111

ANGLE NUMBER	AT STATION	FROM STATION	TO STATION	ADJUSTED ANGLE DEGREES	MINUTES	SECONDS	CORR.STD DEVIATION (SECONDS)	RESIDUAL (CALC-OBS) (SECONDS)	3-SIGMA TEST AT 99% PROB. (SECONDS)
13	SCARP-4	SCARP-3	SLIDE-16	27	9	42.19	4.18	1.18	12.53
14	SCARP-4	SCARP-3	SLIDE-8	38	37	0.41	3.56	0.63	10.68
15	SCARP-4	SCARP-2	SLIDE-16	34	10	44.72	2.84	-1.04	8.51
16	SCARP-4	SCARP-2	SLIDE-8	45	38	2.93	3.98	-0.36	11.93
17	SCARP-2	SLIDE-13	SCARP-3	84	48	41.33	4.04	0.00	12.11
18	SCARP-2	SLIDE-11	SCARP-3	75	16	7.42	3.50	-0.90	10.50
19	SCARP-2	SLIDE-12	SCARP-3	67	31	10.88	4.07	0.43	12.20
20	SCARP-2	SLIDE-9	SCARP-3	44	18	12.49	4.05	-1.31	12.14
21	SCARP-1	SLIDE-11	SCARP-2	45	33	57.49	2.87	0.30	8.61
22	SCARP-1	SLIDE-13	SCARP-2	33	59	3.71	3.92	-0.19	11.77
23	SCARP-1	SLIDE-12	SCARP-2	30	3	17.23	4.07	-0.40	12.20
24	SCARP-1	SLIDE-9	SCARP-2	29	42	26.07	4.60	0.38	13.79

HORIZONTAL ADJUSTMENT - JNODE=111

ANGLE NUMBER	AT STATION	FROM STATION	TO STATION	DEGREES	ADJUSTED ANGLE MINUTES	SECONDS	CORR.STD DEVIATION (SECONDS)	RESIDUAL (CALC-OBS) (SECONDS)	3-SIGMA TEST AT 99% PROB. (SECONDS)
25	SCARP-3	SCARP-1	SLIDE-13	33	21	17.75	4.90	0.93	14.70
26	SCARP-3	SCARP-1	SLIDE-12	41	27	29.60	4.93	2.22	14.79
27	SCARP-3	SCARP-1	SLIDE-11	54	17	43.12	5.05	0.22	15.16
28	SCARP-3	SCARP-2	SLIDE-13	45	43	9.84	3.83	-0.86	11.48
29	SCARP-3	SCARP-2	SLIDE-12	53	49	21.77	3.31	-1.77	9.93
30	SCARP-3	SCARP-2	SLIDE-11	66	39	35.21	3.21	-0.67	9.64
31	SCARP-3	SCARP-2	SLIDE-9	89	33	11.91	3.26	-1.76	9.77
32	SCARP-4	SCARP-2	SLIDE-11	37	24	37.09	2.78	-0.23	8.35
33	SCARP-4	SCARP-2	SLIDE-9	41	1	4.79	2.44	0.12	7.32
34	SCARP-1	SLIDE-1	SCARP-3	48	33	36.49	2.43	-0.48	7.28
35	SCARP-1	SLIDE-2	SCARP-3	46	28	46.00	3.55	-0.14	10.66
36	SCARP-1	SLIDE-3	SCARP-3	43	32	42.93	4.83	-0.89	14.48

BEAVER CREEK - AUGUST,1978 - MONUMENTATION OF LANDSLIDES -- SET-#2

HORIZONTAL ADJUSTMENT - MODE=111

ANGLE NUMBER	AT STATION	FROM STATION	TO STATION	ADJUSTED ANGLE DEGREES	MINUTES	SECONDS	CURR.STD DEVIATION (SECONDS)	RESIDUAL (CALC-OBS) (SECONDS)	3-SIGMA TEST AT 99% PROB. (SECONDS)
37	SCARP-1	SLIDE-4	SCARP-3	42	57	14.62	4.63	-1.11	13.88
38	SCARP-1	SLIDE-1	SCARP-2	56	17	14.17	3.83	1.18	11.49
39	SCARP-1	SLIDE-2	SCARP-2	54	12	23.68	3.99	0.78	11.97
40	SCARP-1	SLIDE-3	SCARP-2	51	16	20.61	4.71	1.91	14.12
41	SCARP-1	SLIDE-4	SCARP-2	50	40	52.30	4.57	1.74	13.71
42	SCARP-4	SCARP-2	SLIDE-4	43	51	47.03	4.98	-1.11	14.93
43	SCARP-4	SCARP-2	SLIDE-2	45	19	0.81	4.37	-1.73	13.12
44	SCARP-4	SCARP-2	SLIDE-1	46	50	15.97	2.25	-1.84	6.75
45	SCARP-4	SCARP-2	SLIDE-3	49	6	9.73	2.91	-2.62	8.72
46	SCARP-4	SCARP-3	SLIDE-4	36	50	44.50	3.83	4.59	11.49
47	SCARP-4	SCARP-3	SLIDE-2	38	17	58.29	3.54	5.92	10.61
48	SCARP-4	SCARP-3	SLIDE-1	39	49	13.44	2.73	5.84	8.19

HORIZONTAL ADJUSTMENT - JMODE=111

ANGLE NUMBER	AT STATION	FROM STATION	TO STATION	ADJUSTED ANGLE DEGREES	MINUTES	SECONDS	CORR.STD DEVIATION (SECONDS)	RESIDUAL (CALC-OBS) (SECONDS)	3-SIGMA TEST AT 99% PROB. (SECONDS)
49	SCARP-4	SCARP-3	SLIDE-3	42	5	7.21	2.83	7.69	8.49
50	SCARP-1	SLIDE-5	SCARP-2	44	57	18.44	2.35	0.88	7.06
51	SCARP-1	SLIDE-6	SCARP-2	41	12	46.59	2.70	0.93	8.11
52	SCARP-1	SLIDE-7	SCARP-2	38	56	53.36	3.20	0.61	9.60
53	SCARP-1	SLIDE-10	SCARP-2	32	5	48.58	3.30	-0.00	9.91
54	SCARP-1	SLIDE-5	SCARP-3	37	13	40.76	3.12	-0.61	9.35
55	SCARP-1	SLIDE-6	SCARP-3	33	29	8.91	2.83	-0.51	8.49
56	SCARP-1	SLIDE-7	SCARP-3	31	13	15.68	2.59	-0.40	7.76
57	SCARP-1	SLIDE-10	SCARP-3	24	22	10.89	2.17	0.41	6.51
58	SCARP-4	SCARP-3	SLIDE-5	47	24	23.36	2.31	0.13	6.94
59	SCARP-4	SCARP-3	SLIDE-6	54	15	30.93	2.44	-1.05	7.32
60	SCARP-4	SCARP-3	SLIDE-10	55	36	10.65	2.52	-0.90	7.57

HORIZONTAL ADJUSTMENT - JMODE=111

ANGLE NUMBER	AT STATION	FROM STATION	TO STATION	DEGREES	ADJUSTED ANGLE MINUTES	SECONDS	CORR.STD DEVIATION (SECONDS)	RESIDUAL (CALC-OBS) (SECONDS)	3-SIGMA TEST AT 99% PROB. (SECONDS)
61	SCARP-4	SCARP-3	SLIDE-7	62	22	46.13	3.37	-0.39	10.10
62	SCARP-4	SCARP-2	SLIDE-5	54	25	25.88	4.28	-0.29	12.84
63	SCARP-4	SCARP-2	SLIDE-6	61	16	33.46	3.70	0.81	11.10
64	SCARP-4	SCARP-2	SLIDE-10	62	37	13.17	2.56	0.74	7.69
65	SCARP-4	SCARP-2	SLIDE-7	69	23	48.65	2.91	0.29	8.73
66	INNER-1	INNER-2	SCARP-2	37	50	38.82	3.00	-0.34	9.01
67	INNER-1	SCARP-2	SCARP-3	38	51	27.84	2.74	1.07	8.23
68	INNER-1	SCARP-3	SCARP-4	60	56	12.89	3.53	0.46	10.59
69	INNER-2	INNER-3	SCARP-1	28	25	20.87	3.22	0.18	9.65
70	INNER-2	SCARP-1	SCARP-2	30	47	41.22	2.17	0.04	6.51
71	INNER-2	SCARP-2	SCARP-3	53	2	43.48	2.26	-0.19	6.77
72	INNER-2	SCARP-3	SCARP-4	34	46	47.31	2.01	1.06	6.04

HORIZONTAL ADJUSTMENT - JMODE=111

ANGLE NUMBER	AT STATION	FROM STATION	TO STATION	ADJUSTED ANGLE DEGREES	MINUTES	SECONDS	CORR.STD DEVIATION (SECONDS)	RESIDUAL (CALC-OBS) (SECONDS)	3-SIGMA TEST AT 99% PROB. (SECONDS)
73	INNER-2	SCARP-4	INNER-1	24	50	45.51	2.48	0.13	7.43
74	INNER-3	SCARP-1	SCARP-2	75	47	54.37	2.82	0.64	8.46
75	INNER-3	SCARP-2	SCARP-3	15	12	0.96	2.37	-1.27	7.10
76	INNER-3	SCARP-3	INNER-2	30	26	54.72	2.73	0.68	8.18
77	SCARP-1	SCARP-3	SCARP-2	7	43	37.68	3.01	-1.34	9.02
78	SCARP-1	SCARP-3	INNER-2	27	19	17.57	2.87	0.65	8.61
79	SCARP-1	INNER-2	INNER-3	30	7	49.08	3.48	-1.73	10.43
80	SCARP-2	SCARP-3	SCARP-4	7	55	6.37	3.50	-0.11	10.51
81	SCARP-2	SCARP-4	INNER-2	62	33	44.52	2.95	0.58	8.86
82	SCARP-2	INNER-2	INNER-3	75	8	2.23	2.84	0.68	8.51
83	SCARP-2	INNER-3	SCARP-1	54	28	36.65	2.78	0.25	8.34
84	SCARP-3	SCARP-4	INNER-1	64	55	4.96	3.20	0.64	9.60

HORIZONTAL ADJUSTMENT - JMODE=111

ANGLE NUMBER	AT STATION	FROM STATION	TO STATION	ADJUSTED ANGLE DEGREES	MINUTES	SECONDS	CORR.STD DEVIATION (SECONDS)	RESIDUAL (CALC-OBS) (SECONDS)	3-SIGMA TEST AT 99% PROB. (SECONDS)
85	SCARP-3	INNER-1	INNER-2	43	40	20.52	3.44	0.39	10.33
86	SCARP-3	INNER-2	INNER-3	37	17	19.71	3.87	-0.88	11.61
87	SCARP-3	INNER-3	SCARP-2	19	11	5.92	4.00	0.45	11.99
88	SCARP-3	INNER-3	SCARP-1	31	32	58.02	3.47	0.26	10.42
89	SCARP-4	INNER-1	INNER-2	17	30	54.94	3.24	0.21	9.73
90	SCARP-4	INNER-2	SCARP-2	29	36	44.69	2.94	1.28	8.82
91	SCARP-4	INNER-2	SCARP-1	34	50	44.71	2.37	0.37	7.11
92	SCARP-4	INNER-2	SCARP-3	36	37	47.21	3.13	2.41	9.40

MEAN RESIDUAL(ABSOLUTE,UNWEIGHTED)= 1.050

HORIZONTAL ADJUSTMENT - JMODE=111

ERROR ELLIPSES FOR 95 PERCENT PROBABILITY

STANDARD DEVIATION OF UNIT WEIGHT= 0.410

***** ERROR ELLIPSE AT *****			******* RELATIVE TO *******						
STATION NUMBER	STATION NAME	TYPE	STATION NUMBER	STATION NAME	TYPE	DEGREES OF FREEDOM	MAJOR AXIS	MINOR AXIS	ORIENTATION OF MAJOR AXIS CW FROM Y-AXIS
1	INNER-1	0	2	INNER-2	1	5	0.0022	0.0012	73 DEGREES
4	SCARP-1	0	2	INNER-2	1	32	0.0024	0.0015	135 DEGREES
5	SCARP-2	0	2	INNER-2	1	53	0.0014	0.0012	108 DEGREES
6	SCARP-3	0	2	INNER-2	1	50	0.0019	0.0014	27 DEGREES
7	SCARP-4	0	2	INNER-2	1	34	0.0035	0.0018	54 DEGREES
8	SLIDE-1	0	2	INNER-2	1	2	0.0046	0.0037	0 DEGREES
9	SLIDE-2	0	2	INNER-2	1	2	0.0043	0.0033	12 DEGREES
10	SLIDE-3	0	2	INNER-2	1	2	0.0044	0.0035	8 DEGREES
11	SLIDE-4	0	2	INNER-2	1	2	0.0041	0.0033	21 DEGREES

HORIZONTAL ADJUSTMENT - JMODE=111

ERROR ELLIPSES FOR 95 PERCENT PROBABILITY

STANDARD DEVIATION OF UNIT WEIGHT= 0.410

***** ERROR ELLIPSE AT ***** STATION NUMBER	STATION NAME	TYPE	******* RELATIVE TO ******* STATION NUMBER	STATION NAME	TYPE	DEGREES OF FREEDOM	MAJOR AXIS	MINOR AXIS	ORIENTATION OF MAJOR AXIS CW FROM Y-AXIS
12	SLIDE-5	0	2	INNER-2	1	2	0.0043	0.0034	18 DEGREES
13	SLIDE-6	0	2	INNER-2	1	2	0.0045	0.0033	15 DEGREES
14	SLIDE-7	0	2	INNER-2	1	2	0.0052	0.0037	2 DEGREES
15	SLIDE-8	0	2	INNER-2	1	2	0.0045	0.0028	175 DEGREES
16	SLIDE-9	0	2	INNER-2	1	2	0.0035	0.0026	0 DEGREES
17	SLIDE-10	0	2	INNER-2	1	2	0.0041	0.0034	16 DEGREES
18	SLIDE-11	0	2	INNER-2	1	3	0.0037	0.0026	160 DEGREES
19	SLIDE-12	0	2	INNER-2	1	2	0.0030	0.0024	153 DEGREES
20	SLIDE-13	0	2	INNER-2	1	2	0.0031	0.0024	142 DEGREES

HORIZONTAL ADJUSTMENT - JMODE=111

ERROR ELLIPSES FOR 95 PERCENT PROBABILITY

STANDARD DEVIATION OF UNIT WEIGHT= 0.410

***** ERROR ELLIPSE AT ***** STATION NUMBER	STATION NAME	TYPE	******* RELATIVE TO ******* STATION NUMBER	STATION NAME	TYPE	DEGREES OF FREEDOM	MAJOR AXIS	MINOR AXIS	ORIENTATION OF MAJOR AXIS CW FROM Y-AXIS
21	SLIDE-14	0	2	INNER-2	1	2	0.0032	0.0022	148 DEGREES
22	SLIDE-15	0	2	INNER-2	1	2	0.0027	0.0023	166 DEGREES
23	SLIDE-16	0	2	INNER-2	1	2	0.0033	0.0029	51 DEGREES

C.2.2 Vertical Adjustment

BEAVER CREEK - AUGUST,1978 - MONUMENTATION OF LANDSLIDES -- SET-#2 PAGE NO. 9

LEVEL ADJUSTMENT - JNODE=444

LINK NUMBER	FROM STATION	TO STATION	CALCULATED DIFF. IN ELEV	OBSERVED DIFF. IN ELEV	RESIDUAL (CALC-OBS)	LINK WEIGHT	LINK STANDARD DEVIATION	3-SIGMA TEST AT 99% PROB.
1	SLIDE-9	SLIDE-8	-1.1985	-1.1986	0.0001	0.50	0.0002	0.0006
2	SLIDE-8	SLIDE-11	-0.7122	-0.7122	-0.0000	1.00	0.0001	0.0004
3	SLIDE-11	SLIDE-12	4.1012	4.1012	0.0000	1.00	0.0002	0.0005
4	SLIDE-11	SLIDE-4	1.1510	1.1510	-0.0000	1.00	0.0002	0.0005
5	SLIDE-11	SLIDE-1	0.0874	0.0874	-0.0000	1.00	0.0002	0.0005
6	SLIDE-11	SLIDE-2	0.6172	0.6173	-0.0001	1.00	0.0002	0.0005
7	SLIDE-2	SLIDE-3	1.3631	1.3632	-0.0001	1.00	0.0002	0.0005
8	SLIDE-3	SLIDE-5	-0.1685	-0.1684	-0.0001	1.00	0.0002	0.0005
9	SLIDE-5	SLIDE-6	-1.6418	-1.6417	-0.0001	1.00	0.0002	0.0005
10	SLIDE-6	SLIDE-7	0.6227	0.6228	-0.0001	1.00	0.0002	0.0005
11	SLIDE-7	SLIDE-10	0.3510	0.3511	-0.0001	0.50	0.0002	0.0006
12	SLIDE-10	SLIDE-8	-0.4317	-0.4316	-0.0001	0.50	0.0002	0.0006

BEAVER CREEK - AUGUST,1978 - MONUMENTATION OF LANDSLIDES -- SET-#2

LEVEL ADJUSTMENT - JMODE=444

LINK NUMBER	FROM STATION	TO STATION	CALCULATED DIFF. IN ELEV	OBSERVED DIFF. IN ELEV	RESIDUAL (CALC-OBS)	LINK WEIGHT	LINK STANDARD DEVIATION	3-SIGMA TEST AT 99% PROB.
13	SCARP-4	SLIDE-16	-11.0294	-11.0293	-0.0001	0.25	0.0002	0.0007
14	SLIDE-16	SCARP-4	11.0294	11.0294	-0.0000	0.25	0.0002	0.0007
15	SCARP-4	SCARP-3	-0.3569	-0.3570	0.0001	1.00	0.0002	0.0005
16	SCARP-3	SCARP-2	-0.1763	-0.1764	0.0001	1.00	0.0002	0.0005
17	SCARP-2	SCARP-1	-0.9645	-0.9648	0.0003	0.50	0.0002	0.0006
18	SCARP-1	INNER-3	-0.4276	-0.4277	0.0001	1.00	0.0002	0.0005
19	INNER-3	INNER-2	1.9476	1.9475	0.0001	1.00	0.0002	0.0005
20	INNER-2	INNER-1	-1.2605	-1.2606	0.0001	1.00	0.0002	0.0005
21	INNER-1	SCARP-4	1.2381	1.2380	0.0001	1.00	0.0002	0.0005
22	EVCM-GEO	SCARP-4	1.9020	1.9022	-0.0001	0.25	0.0002	0.0007
23	SCARP-4	EVCM-GEO	-1.9020	-1.9019	-0.0001	0.25	0.0002	0.0007
24	SLIDE-16	SLIDE-15	1.0816	1.0816	-0.0000	1.00	0.0002	0.0005

BEAVER CREEK - AUGUST,1976 - MONUMENTATION OF LANDSLIDES -- SET-42

LEVEL ADJUSTMENT - JMODE=444

LINK NUMBER	FROM STATION	TO STATION	CALCULATED DIFF. IN ELEV	OBSERVED DIFF. IN ELEV	RESIDUAL (CALC-OBS)	LINK WEIGHT	LINK STANDARD DEVIATION	3-SIGMA TEST AT 99% PROB.
25	SLIDE-15	SLIDE-14	-1.5074	-1.5074	-0.0000	1.00	0.0002	0.0005
26	SLIDE-14	SLIDE-13	-1.5020	-1.5020	-0.0000	1.00	0.0002	0.0005
27	SLIDE-13	SLIDE-12	-0.4111	-0.4111	-0.0000	1.00	0.0002	0.0005
28	SLIDE-12	SLIDE-14	1.5390	1.5390	-0.0000	0.50	0.0002	0.0006
29	SLIDE-12	SLIDE-9	-2.1904	-2.1905	0.0001	0.50	0.0002	0.0006

MEAN RESIDUAL= -0.0000

STD. ERROR OF OBS. OF UNIT WEIGHT= 0.0002

C.3 May, 1979 Survey

C.3.1 Horizontal Adjustment

BEAVER CREEK - MAY,1979 - MONUMENTATION OF LANDSLIDES -- SET-#3 PAGE NO. 25

HORIZONTAL ADJUSTMENT - JMODE-III

ANGLE NUMBER	AT STATION	FROM STATION	TO STATION	ADJUSTED ANGLE DEGREES	MINUTES	SECONDS	CORR.STD DEVIATION (SECONDS)	RESIDUAL (CALC-OBS) (SECONDS)	3-SIGMA TEST AT 99% PROB. (SECONDS)
1	SCARP-1	SLIDE-5	SCARP-2	44	57	46.36	2.41	-0.09	7.24
2	SCARP-1	SLIDE-6	SCARP-2	41	13	12.32	2.60	-0.20	7.79
3	SCARP-1	SLIDE-7	SCARP-2	38	57	27.21	2.99	0.81	8.97
4	SCARP-1	SLIDE-10	SCARP-2	32	6	11.45	2.89	0.63	8.66
5	SCARP-1	SLIDE-5	SCARP-3	37	14	5.54	2.36	0.21	7.08
6	SCARP-1	SLIDE-6	SCARP-3	33	29	31.50	2.29	0.20	6.87
7	SCARP-1	SLIDE-7	SCARP-3	31	13	46.39	2.56	-0.85	7.69
8	SCARP-1	SLIDE-10	SCARP-3	24	22	30.63	2.68	-0.33	8.05
9	SCARP-4	SCARP-3	SLIDE-5	47	25	11.12	2.07	-0.16	6.22
10	SCARP-4	SCARP-3	SLIDE-6	54	16	30.00	2.63	0.14	7.89
11	SCARP-4	SCARP-3	SLIDE-10	55	36	50.78	2.99	0.85	8.96
12	SCARP-4	SCARP-3	SLIDE-7	62	23	49.47	2.95	-0.19	8.84

HORIZONTAL ADJUSTMENT - JMODE=111

ANGLE NUMBER	AT STATION	FROM STATION	TO STATION	ADJUSTED ANGLE DEGREES	MINUTES	SECONDS	CORR.STD DEVIATION (SECONDS)	RESIDUAL (CALC-OBS) (SECONDS)	3-SIGMA TEST AT 99% PROB. (SECONDS)
13	SCARP-4	SCARP-2	SLIDE-5	54	26	12.65	3.47	0.20	10.40
14	SCARP-4	SCARP-2	SLIDE-6	61	17	31.52	3.48	-0.09	10.45
15	SCARP-4	SCARP-2	SLIDE-10	62	37	52.30	2.94	-0.80	8.81
16	SCARP-4	SCARP-2	SLIDE-7	69	24	50.99	2.52	0.15	7.56
17	SCARP-4	SCARP-2	SLIDE-4	43	52	26.69	2.73	1.42	8.18
18	SCARP-4	SCARP-2	SLIDE-2	45	19	40.00	3.25	0.47	9.76
19	SCARP-4	SCARP-2	SLIDE-1	46	51	2.37	3.25	0.72	9.74
20	SCARP-4	SCARP-2	SLIDE-3	49	6	48.55	2.41	0.77	7.22
21	SCARP-1	SLIDE-1	SCARP-2	56	17	48.02	2.35	-2.23	7.04
22	SCARP-1	SLIDE-2	SCARP-2	54	12	48.78	2.49	-2.67	7.47
23	SCARP-1	SLIDE-3	SCARP-2	51	16	50.59	2.25	-0.62	6.76
24	SCARP-1	SLIDE-4	SCARP-2	50	41	23.01	2.34	-1.58	7.02

HORIZONTAL ADJUSTMENT - JMODE=111

ANGLE NUMBER	AT STATION	FROM STATION	TO STATION	ADJUSTED ANGLE DEGREES	MINUTES	SECONDS	CORR.STD DEVIATION (SECONDS)	RESIDUAL (CALC-OBS) (SECONDS)	3-SIGMA TEST AT 99% PROB. (SECONDS)
25	SCARP-1	SLIDE-1	SCARP-3	48	34	7.20	2.42	2.11	7.25
26	SCARP-1	SLIDE-2	SCARP-3	46	29	7.96	2.64	2.62	7.91
27	SCARP-1	SLIDE-3	SCARP-3	43	33	9.77	2.95	0.58	8.86
28	SCARP-1	SLIDE-4	SCARP-3	42	57	42.19	2.86	1.23	8.59
29	SCARP-4	SCARP-2	SLIDE-11	37	25	21.86	2.68	-0.88	8.04
30	SCARP-4	SCARP-2	SLIDE-9	41	1	48.81	2.78	0.07	8.34
31	SCARP-3	SCARP-2	SLIDE-13	45	43	57.60	2.98	1.27	8.95
32	SCARP-3	SCARP-2	SLIDE-12	53	50	13.91	2.83	1.43	8.49
33	SCARP-3	SCARP-2	SLIDE-11	66	40	28.26	2.53	1.14	7.58
34	SCARP-3	SCARP-2	SLIDE-9	89	33	41.85	2.49	1.08	7.47
35	SCARP-3	SCARP-1	SLIDE-13	33	22	2.77	2.62	0.90	7.86
36	SCARP-3	SCARP-1	SLIDE-12	41	28	19.08	2.62	0.91	7.85

HORIZONTAL ADJUSTMENT - JMODE=111

ANGLE NUMBER	AT STATION	FROM STATION	TO STATION	ADJUSTED ANGLE DEGREES	MINUTES	SECONDS	CORR.STD DEVIATION (SECONDS)	RESIDUAL (CALC-OBS) (SECONDS)	3-SIGMA TEST AT 99% PROB. (SECONDS)
37	SCARP-3	SCARP-1	SLIDE-11	54	18	33.43	2.94	0.43	8.81
38	SCARP-3	SCARP-1	SLIDE-9	77	11	47.02	3.54	-0.88	10.61
39	SCARP-1	SLIDE-11	SCARP-2	45	34	27.49	4.19	-0.61	12.56
40	SCARP-1	SLIDE-13	SCARP-2	33	59	37.67	4.90	-1.66	14.71
41	SCARP-1	SLIDE-12	SCARP-2	30	3	49.90	4.42	-1.83	13.26
42	SCARP-1	SLIDE-9	SCARP-2	29	42	53.58	4.76	-1.13	14.28
43	SCARP-2	SLIDE-13	SCARP-3	84	48	9.75	4.18	2.42	12.55
44	SCARP-2	SLIDE-11	SCARP-3	75	15	43.19	3.21	0.84	9.62
45	SCARP-2	SLIDE-12	SCARP-3	67	31	5.25	4.97	2.45	14.92
46	SCARP-2	SLIDE-9	SCARP-3	44	18	29.05	4.68	0.92	14.03
47	SCARP-4	SCARP-2	SLIDE-16	34	11	25.61	4.94	0.63	14.82
48	SCARP-4	SCARP-2	SLIDE-8	45	38	43.97	4.76	0.91	14.27

HORIZONTAL ADJUSTMENT - JNODE=111

ANGLE NUMBER	AT STATION	FROM STATION	TO STATION	ADJUSTED ANGLE DEGREES	MINUTES	SECONDS	CORR.STD DEVIATION (SECONDS)	RESIDUAL (CALC-OBS) (SECONDS)	3-SIGMA TEST AT 99% PROB. (SECONDS)
49	SCARP-4	SCARP-3	SLIDE-16	27	10	24.09	3.25	-0.82	9.76
50	SCARP-4	SCARP-3	SLIDE-8	38	37	42.44	3.41	-1.24	10.22
51	SCARP-2	SLIDE-8	SCARP-3	57	1	35.32	2.94	1.96	8.82
52	SCARP-2	SLIDE-16	SCARP-3	22	18	16.54	2.57	0.87	7.71
53	SCARP-2	SLIDE-8	SCARP-4	64	56	38.15	4.63	-1.10	13.90
54	SCARP-2	SLIDE-16	SCARP-4	30	13	19.37	5.08	-0.16	15.23
55	SCARP-2	SLIDE-14	SCARP-3	79	22	34.82	4.98	0.85	14.93
56	SCARP-2	SLIDE-15	SCARP-3	43	24	8.18	5.00	1.29	14.99
57	SCARP-2	SLIDE-14	SCARP-4	87	17	37.65	3.99	-0.77	11.96
58	SCARP-2	SLIDE-15	SCARP-4	51	19	11.01	3.50	-1.24	10.49
59	SCARP-3	SCARP-1	SLIDE-14	23	31	33.89	4.49	-0.79	13.46
60	SCARP-3	SCARP-1	SLIDE-15	34	51	0.81	4.49	-2.17	13.46

HORIZONTAL ADJUSTMENT - JMODE=111

ANGLE NUMBER	AT STATION	FROM STATION	TO STATION	ADJUSTED ANGLE DEGREES	MINUTES	SECONDS	CORR.STD DEVIATION (SECONDS)	RESIDUAL (CALC-OBS) (SECONDS)	3-SIGMA TEST AT 99% PROB. (SECONDS)
61	SCARP-3	SCARP-2	SLIDE-14	35	53	28.72	3.25	1.18	9.74
62	SCARP-3	SCARP-2	SLIDE-15	47	12	55.64	4.57	2.50	13.71
63	SCARP-4	SCARP-3	SLIDE-4	36	51	25.16	4.50	-2.82	13.51
64	SCARP-4	SCARP-3	SLIDE-2	38	18	38.47	3.71	-2.11	11.14
65	SCARP-4	SCARP-3	SLIDE-1	39	50	0.85	4.14	-2.49	12.43
66	SCARP-4	SCARP-3	SLIDE-3	42	5	47.02	4.09	-2.50	12.27
67	SCARP-2	SCARP-3	SCARP-4	7	55	2.83	3.84	2.63	11.52
68	SCARP-2	SCARP-4	INNER-1	33	5	2.10	4.19	-0.29	12.56
69	SCARP-2	INNER-1	INNER-2	29	29	13.11	3.53	0.37	10.58
70	SCARP-2	INNER-2	INNER-3	75	7	39.12	6.19	-0.11	18.56
71	SCARP-2	INNER-3	SCARP-1	54	28	38.49	8.05	0.00	24.15
72	SCARP-3	SCARP-4	INNER-1	64	55	35.78	5.90	1.01	17.71

HORIZONTAL ADJUSTMENT - JMODE=111

ANGLE NUMBER	AT STATION	FROM STATION	TO STATION	ADJUSTED ANGLE DEGREES	MINUTES	SECONDS	CORR.STD DEVIATION (SECONDS)	RESIDUAL (CALC-OBS) (SECONDS)	3-SIGMA TEST AT 99% PROB. (SECONDS)
73	SCARP-3	INNER-1	INNER-2	43	40	6.72	6.54	0.15	19.61
74	SCARP-3	INNER-2	INNER-3	37	17	8.69	8.09	-0.89	24.27
75	SCARP-3	INNER-3	SCARP-2	19	11	4.45	5.84	0.31	17.53
76	SCARP-3	SCARP-2	SCARP-1	12	21	54.83	2.80	-0.36	8.39
77	SCARP-4	INNER-1	INNER-2	17	31	0.14	4.05	-0.25	12.14
78	SCARP-4	INNER-1	SCARP-2	47	7	50.67	6.87	0.95	20.62
79	SCARP-4	INNER-1	SCARP-1	52	21	54.64	6.37	1.13	19.12
80	SCARP-4	INNER-1	SCARP-3	54	8	52.19	4.52	1.11	13.56
81	SCARP-1	SCARP-3	SCARP-4	0	47	11.97	6.81	-1.48	20.42
82	SCARP-1	SCARP-3	SCARP-2	7	43	40.82	6.29	0.11	18.87
83	SCARP-1	SCARP-3	INNER-2	27	19	31.64	3.08	-0.04	9.25
84	SCARP-1	SCARP-3	INNER-3	57	27	23.75	2.22	0.38	6.66

HORIZONTAL ADJUSTMENT - JMODE=111

ANGLE NUMBER	AT STATION	FROM STATION	TO STATION	ADJUSTED ANGLE DEGREES	MINUTES	SECONDS	CORR.STD DEVIATION (SECONDS)	RESIDUAL (CALC-OBS) (SECONDS)	3-SIGMA TEST AT 99% PROB. (SECONDS)
85	INNER-3	SCARP-1	SCARP-2	75	47	38.58	2.71	-0.80	8.14
86	INNER-3	SCARP-2	SCARP-3	15	11	58.39	3.06	2.67	9.19
87	INNER-3	SCARP-3	INNER-2	30	27	4.47	4.29	-0.84	12.86
88	INNER-2	INNER-3	SCARP-1	28	25	26.45	4.31	0.01	12.92
89	INNER-2	SCARP-1	SCARP-2	30	47	51.56	2.87	-0.47	8.61
90	INNER-2	SCARP-2	SCARP-3	53	2	28.82	3.21	0.25	9.63
91	INNER-2	SCARP-3	SCARP-4	34	46	25.44	3.62	-0.43	10.86
92	INNER-2	SCARP-4	INNER-1	24	51	1.58	3.70	2.59	11.11
93	INNER-1	INNER-2	SCARP-2	37	50	51.05	3.67	-1.33	11.02
94	INNER-1	SCARP-2	SCARP-3	38	51	35.21	3.50	-0.03	10.49
95	INNER-1	SCARP-3	SCARP-4	60	55	32.02	3.36	2.95	10.09

MEAN RESIDUAL(ABSOLUTE,UNWEIGHTED)= 1.012

HORIZONTAL ADJUSTMENT - JMODE=111

ERROR ELLIPSES FOR 95 PERCENT PROBABILITY

STANDARD DEVIATION OF UNIT WEIGHT= 0.383

***** ERROR ELLIPSE AT ***** STATION NUMBER	STATION NAME	TYPE	******* RELATIVE TO ******* STATION NUMBER	STATION NAME	TYPE	DEGREES OF FREEDOM	MAJOR AXIS	MINOR AXIS	ORIENTATION OF MAJOR AXIS CW FROM Y-AXIS
1	INNER-1	0	2	INNER-2	1	10	0.0021	0.0011	78 DEGREES
4	SCARP-1	0	2	INNER-2	1	34	0.0024	0.0016	136 DEGREES
5	SCARP-2	0	2	INNER-2	1	55	0.0014	0.0011	123 DEGREES
6	SCARP-3	0	2	INNER-2	1	53	0.0020	0.0013	24 DEGREES
7	SCARP-4	0	2	INNER-2	1	35	0.0036	0.0018	54 DEGREES
8	SLIDE-1	0	2	INNER-2	1	2	0.0044	0.0033	6 DEGREES
9	SLIDE-2	0	2	INNER-2	1	2	0.0042	0.0032	1 DEGREES
10	SLIDE-3	0	2	INNER-2	1	2	0.0043	0.0033	4 DEGREES
11	SLIDE-4	0	2	INNER-2	1	2	0.0040	0.0032	11 DEGREES

HORIZONTAL ADJUSTMENT - JMODE=111

ERROR ELLIPSES FOR 95 PERCENT PROBABILITY

STANDARD DEVIATION OF UNIT WEIGHT= 0.384

***** ERROR ELLIPSE AT *****			******* RELATIVE TO *******						
STATION NUMBER	STATION NAME	TYPE	STATION NUMBER	STATION NAME	TYPE	DEGREES OF FREEDOM	MAJOR AXIS	MINOR AXIS	ORIENTATION OF MAJOR AXIS CW FROM Y-AXIS
12	SLIDE-5	0	2	INNER-2	1	2	0.0042	0.0031	15 DEGREES
13	SLIDE-6	0	2	INNER-2	1	2	0.0044	0.0032	16 DEGREES
14	SLIDE-7	0	2	INNER-2	1	2	0.0049	0.0033	11 DEGREES
15	SLIDE-8	0	2	INNER-2	1	2	0.0047	0.0028	176 DEGREES
16	SLIDE-9	0	2	INNER-2	1	3	0.0035	0.0023	177 DEGREES
17	SLIDE-10	0	2	INNER-2	1	2	0.0042	0.0033	10 DEGREES
18	SLIDE-11	0	2	INNER-2	1	3	0.0038	0.0025	158 DEGREES
19	SLIDE-12	0	2	INNER-2	1	2	0.0031	0.0023	154 DEGREES
20	SLIDE-13	0	2	INNER-2	1	2	0.0031	0.0023	142 DEGREES

HORIZONTAL ADJUSTMENT - JMODE=111

ERROR ELLIPSES FOR 95 PERCENT PROBABILITY

STANDARD DEVIATION OF UNIT WEIGHT= 0.383

***** ERROR ELLIPSE AT ***** STATION NUMBER	STATION NAME	TYPE	******* RELATIVE TO ******* STATION NUMBER	STATION NAME	TYPE	DEGREES OF FREEDOM	MAJOR AXIS	MINOR AXIS	ORIENTATION OF MAJOR AXIS CW FROM Y-AXIS
21	SLIDE-14	0	2	INNER-2	1	2	0.0032	0.0020	150 DEGREES
22	SLIDE-15	0	2	INNER-2	1	2	0.0027	0.0021	168 DEGREES
23	SLIDE-16	0	2	INNER-2	1	2	0.0034	0.0028	43 DEGREES

C.3.2 Vertical Adjustment

BEAVER CREEK - MAY,1979 - MONUMENTATION OF LANDSLIDES -- SET-#3 PAGE NO. 9

LEVEL ADJUSTMENT - 3MODE-444

LINK NUMBER	FROM STATION	TO STATION	CALCULATED DIFF. IN ELEV	OBSERVED DIFF. IN ELEV	RESIDUAL (CALC-OBS)	LINK WEIGHT	LINK STANDARD DEVIATION	3-SIGMA TEST AT 99% PROB.
1	EVCM-GED	SCARP-4	1.8875	1.8876	-0.0001	0.25	0.0003	0.0008
2	SCARP-4	EVCM-GED	-1.8875	-1.8875	-0.0000	0.25	0.0003	0.0008
3	SCARP-4	SLIDE-16	-11.0231	-11.0230	-0.0001	0.13	0.0004	0.0011
4	SLIDE-16	SCARP-4	11.0231	11.0233	-0.0002	0.13	0.0004	0.0011
5	SCARP-4	SCARP-3	-0.3558	-0.3557	-0.0001	0.50	0.0002	0.0007
6	SCARP-3	SCARP-2	-0.1696	-0.1695	-0.0001	0.50	0.0002	0.0007
7	SCARP-2	SCARP-1	-0.9610	-0.9609	-0.0001	0.50	0.0002	0.0007
8	SCARP-1	INNER-3	-0.4265	-0.4262	-0.0003	0.17	0.0004	0.0011
9	INNER-3	INNER-2	1.9477	1.9479	-0.0002	0.25	0.0003	0.0010
10	INNER-2	INNER-1	-1.2586	-1.2584	-0.0002	0.25	0.0003	0.0010
11	INNER-1	SCARP-4	1.2239	1.2240	-0.0001	0.50	0.0002	0.0007
12	SLIDE-16	SLIDE-15	1.8800	1.8800	-0.0000	0.50	0.0002	0.0007

LEVEL ADJUSTMENT - [illegible]

LINK NUMBER	FROM STATION	TO STATION	CALCULATED DIFF. IN ELEV	OBSERVED DIFF. IN ELEV	RESIDUAL (CALC-OBS)	LINK WEIGHT	LINK STANDARD DEVIATION	3-SIGMA TEST AT 99% PROB.
13	SLIDE-15	SLIDE-14	-1.5108	-1.5108	0.0000	0.50	0.0002	0.0007
14	SLIDE-14	SLIDE-13	-1.4892	-1.4892	-0.0000	1.00	0.0002	0.0005
15	SLIDE-13	SLIDE-12	-0.4109	-0.4109	0.0000	1.00	0.0002	0.0005
16	SLIDE-12	SLIDE-10	1.5301	1.5301	0.0000	1.00	0.0002	0.0005
17	SLIDE-12	SLIDE-11	-4.1060	-4.1060	-0.0000	1.00	0.0002	0.0005
18	SLIDE-11	SLIDE-3	1.9797	1.9795	0.0002	0.50	0.0002	0.0007
19	SLIDE-11	SLIDE-2	0.6161	0.6161	-0.0000	0.50	0.0003	0.0008
20	SLIDE-11	SLIDE-4	1.1503	1.1503	0.0000	0.50	0.0003	0.0008
21	SLIDE-11	SLIDE-1	0.0828	0.0828	0.0000	0.50	0.0003	0.0008
22	SLIDE-3	SLIDE-5	-0.1662	-0.1664	0.0002	0.50	0.0002	0.0007
23	SLIDE-5	SLIDE-6	-1.6456	-1.6458	0.0002	0.50	0.0002	0.0007
24	SLIDE-6	SLIDE-7	0.6094	0.6093	0.0001	1.00	0.0002	0.0005

LEVEL ADJUSTMENT - [illegible]

LINK NUMBER	FROM STATION	TO STATION	CALCULATED DIFF. IN ELEV	OBSERVED DIFF. IN ELEV	RESIDUAL (CALC-OBS)	LINK WEIGHT	LINK STANDARD DEVIATION	3-SIGMA TEST AT 99% PROB.
25	SLIDE-7	SLIDE-10	0.3690	0.3688	0.0002	0.50	0.0002	0.0007
26	SLIDE-10	SLIDE-6	-0.4341	-0.4341	-0.0000	0.25	0.0004	0.0011
27	SLIDE-10	SLIDE-5	0.7061	0.7061	-0.0000	0.25	0.0004	0.0011
28	SLIDE-10	SLIDE-11	-1.1462	-1.1465	0.0003	0.25	0.0003	0.0009

MEAN RESIDUAL= -0.0000

STD. ERROR OF OBS. OF UNIT WEIGHT= 0.0002

C.4 August, 1979 Survey

C.4.1 Horizontal Adjustment

BEAVER CREEK - AUGUST,1979 - MONUMENTATION OF LANDSLIDES — SET-#4 PAGE NO. 24

HORIZONTAL ADJUSTMENT - JMODE=111

ANGLE NUMBER	AT STATION	FROM STATION	TO STATION	ADJUSTED ANGLE DEGREES	MINUTES	SECONDS	CORR.STD DEVIATION (SECONDS)	RESIDUAL (CALC-OBS) (SECONDS)	3-SIGMA TEST AT 99% PROB. (SECONDS)
1	SCARP-2	SCARP-3	SCARP-4	7	55	1.90	3.65	-1.02	10.95
2	SCARP-2	SCARP-4	INNER-1	33	5	21.08	3.35	-0.46	10.05
3	SCARP-2	INNER-1	INNER-2	29	29	12.28	3.36	1.21	10.07
4	SCARP-2	INNER-2	INNER-3	75	7	29.89	3.65	0.57	10.95
5	SCARP-2	INNER-3	SCARP-1	54	28	37.37	3.31	1.31	9.92
6	SCARP-3	SCARP-4	INNER-1	64	55	58.32	3.13	2.54	9.39
7	SCARP-3	INNER-1	INNER-2	43	39	48.39	3.81	-1.63	11.44
8	SCARP-3	INNER-2	SCARP-2	56	28	9.82	3.72	-0.95	11.16
9	SCARP-3	SCARP-2	SCARP-1	12	21	58.72	4.02	0.65	12.07
10	SCARP-4	INNER-1	INNER-2	17	31	2.28	3.94	3.83	11.82
11	SCARP-4	INNER-2	SCARP-2	29	36	56.78	3.12	0.21	9.35
12	SCARP-4	INNER-2	SCARP-3	36	37	58.34	2.71	-0.82	8.13

HORIZONTAL ADJUSTMENT - JMODE=111

ANGLE NUMBER	AT STATION	FROM STATION	TO STATION	ADJUSTED ANGLE DEGREES	MINUTES	SECONDS	CORR.STD DEVIATION (SECONDS)	RESIDUAL (CALC-OBS) (SECONDS)	3-SIGMA TEST AT 99% PROB. (SECONDS)
13	SCARP-1	SCARP-3	SCARP-2	7	43	43.79	2.39	0.72	7.17
14	SCARP-1	SCARP-2	INNER-2	19	35	57.48	3.16	0.64	9.49
15	SCARP-1	INNER-2	INNER-3	30	7	51.13	2.72	0.76	8.16
16	INNER-3	SCARP-1	SCARP-2	75	47	34.03	2.74	-0.88	8.21
17	INNER-3	SCARP-2	INNER-2	45	39	10.50	2.90	4.37	8.70
18	INNER-2	INNER-3	SCARP-1	28	25	24.35	2.96	0.14	8.87
19	INNER-2	SCARP-1	SCARP-2	30	47	55.27	3.55	0.17	10.65
20	INNER-2	SCARP-2	SCARP-3	53	2	14.92	3.58	-1.09	10.75
21	INNER-2	SCARP-3	SCARP-4	34	46	14.95	4.12	3.27	12.36
22	INNER-2	SCARP-4	INNER-1	24	51	17.02	3.97	0.17	11.92
23	INNER-1	INNER-2	SCARP-2	37	51	0.84	2.73	2.66	8.18
24	INNER-1	SCARP-2	SCARP-3	38	51	38.81	3.61	1.50	10.82

HORIZONTAL ADJUSTMENT - JMODE=111

ANGLE NUMBER	AT STATION	FROM STATION	TO STATION	ADJUSTED ANGLE DEGREES	MINUTES	SECONDS	CORR.STD DEVIATION (SECONDS)	RESIDUAL (CALC-OBS) (SECONDS)	3-SIGMA TEST AT 99% PROB. (SECONDS)
25	INNER-1	SCARP-3	SCARP-4	60	55	1.05	4.06	1.48	12.19
26	SCARP-1	SLIDE-11	SCARP-3	37	51	15.71	3.21	-0.71	9.63
27	SCARP-1	SLIDE-13	SCARP-3	26	16	30.82	3.74	-0.85	11.23
28	SCARP-1	SLIDE-12	SCARP-3	22	20	46.11	4.24	-2.00	12.72
29	SCARP-1	SLIDE-9	SCARP-3	21	59	45.20	4.00	-2.21	12.01
30	SCARP-3	SCARP-2	SLIDE-14	35	54	6.35	3.75	0.71	11.24
31	SCARP-3	SCARP-2	SLIDE-15	47	13	51.50	4.31	2.02	12.94
32	SCARP-3	SCARP-1	SLIDE-14	23	32	7.63	4.89	-0.50	14.67
33	SCARP-3	SCARP-1	SLIDE-15	34	51	52.78	4.46	-1.80	13.37
34	SCARP-2	SLIDE-14	SCARP-4	87	17	28.76	3.58	-1.18	10.74
35	SCARP-2	SLIDE-8	SCARP-4	64	56	40.36	3.09	-0.17	9.26
36	SCARP-2	SLIDE-15	SCARP-4	51	19	12.71	2.43	0.50	7.28

BEAVER CREEK - AUGUST,1979 - MONUMENTATION OF LANDSLIDES -- SET-#4

HORIZONTAL ADJUSTMENT - JMODE=111

ANGLE NUMBER	AT STATION	FROM STATION	TO STATION	ADJUSTED ANGLE DEGREES	MINUTES	SECONDS	CORR.STD DEVIATION (SECONDS)	RESIDUAL (CALC-OBS) (SECONDS)	3-SIGMA TEST AT 99% PROB. (SECONDS)
37	SCARP-2	SLIDE-16	SCARP-4	30	13	59.60	2.93	-1.09	8.79
38	SCARP-2	SLIDE-14	SCARP-3	79	22	26.86	4.57	1.43	13.70
39	SCARP-2	SLIDE-8	SCARP-3	57	4	38.46	6.98	0.43	20.95
40	SCARP-2	SLIDE-15	SCARP-3	43	24	10.81	6.21	-0.25	18.62
41	SCARP-2	SLIDE-16	SCARP-3	22	18	57.70	4.24	1.20	12.71
42	SCARP-4	SCARP-3	SLIDE-16	27	11	11.69	7.01	1.22	21.04
43	SCARP-4	SCARP-3	SLIDE-8	38	38	21.16	8.48	0.89	25.44
44	SCARP-4	SCARP-2	SLIDE-16	34	12	13.26	6.63	-0.95	19.89
45	SCARP-4	SCARP-2	SLIDE-8	45	39	22.72	5.94	-0.65	17.81
46	SCARP-2	SLIDE-13	SCARP-3	84	47	53.11	6.32	3.55	18.95
47	SCARP-2	SLIDE-11	SCARP-3	75	15	33.12	3.94	3.45	11.81
48	SCARP-2	SLIDE-12	SCARP-3	67	31	7.94	6.32	5.65	18.97

HORIZONTAL ADJUSTMENT - JMODE=111

ANGLE NUMBER	AT STATION	FROM STATION	TO STATION	ADJUSTED ANGLE DEGREES	MINUTES	SECONDS	CORR.STD DEVIATION (SECONDS)	RESIDUAL (CALC-OBS) (SECONDS)	3-SIGMA TEST AT 99% PROB. (SECONDS)
49	SCARP-2	SLIDE-9	SCARP-3	44	18	54.49	6.58	5.55	19.75
50	SCARP-3	SCARP-1	SLIDE-13	33	22	43.15	6.03	-0.38	18.10
51	SCARP-3	SCARP-1	SLIDE-12	41	29	16.86	6.21	0.32	18.62
52	SCARP-3	SCARP-1	SLIDE-11	54	19	10.41	4.21	-0.13	12.62
53	SCARP-3	SCARP-1	SLIDE-9	77	12	22.19	3.94	2.68	11.82
54	SCARP-3	SCARP-2	SLIDE-13	45	44	41.87	4.41	1.76	13.23
55	SCARP-3	SCARP-2	SLIDE-12	53	51	15.58	4.22	2.70	12.66
56	SCARP-3	SCARP-2	SLIDE-11	66	41	9.13	3.18	1.37	9.54
57	SCARP-3	SCARP-2	SLIDE-9	89	34	20.91	4.03	0.35	12.10
58	SCARP-4	SCARP-3	SLIDE-4	36	52	9.43	4.16	-1.19	12.49
59	SCARP-4	SCARP-3	SLIDE-2	38	19	20.52	4.90	-0.49	14.71
60	SCARP-4	SCARP-3	SLIDE-1	39	50	43.37	5.09	-0.88	15.28

HORIZONTAL ADJUSTMENT - JMODE=111

ANGLE NUMBER	AT STATION	FROM STATION	TO STATION	ADJUSTED ANGLE DEGREES	MINUTES	SECONDS	CORR.STD DEVIATION (SECONDS)	RESIDUAL (CALC-OBS) (SECONDS)	3-SIGMA TEST AT 99% PROB. (SECONDS)
61	SCARP-4	SCARP-3	SLIDE-3	42	6	31.31	5.06	-0.38	15.17
62	SCARP-1	SLIDE-1	SCARP-3	48	34	32.20	5.14	-0.31	15.42
63	SCARP-1	SLIDE-2	SCARP-3	46	29	38.47	4.31	0.18	12.94
64	SCARP-1	SLIDE-3	SCARP-3	43	33	38.51	3.47	0.32	10.40
65	SCARP-1	SLIDE-4	SCARP-3	42	58	13.84	3.50	1.31	10.50
66	SCARP-1	SLIDE-1	SCARP-2	56	18	15.99	5.12	0.12	15.35
67	SCARP-1	SLIDE-2	SCARP-2	54	13	22.26	4.73	-0.33	14.20
68	SCARP-1	SLIDE-3	SCARP-2	51	17	22.30	4.88	-0.43	14.65
69	SCARP-1	SLIDE-4	SCARP-2	50	41	57.64	5.06	-1.23	15.18
70	SCARP-4	SCARP-2	SLIDE-4	43	53	11.00	4.45	0.81	13.36
71	SCARP-4	SCARP-2	SLIDE-2	45	20	22.09	4.97	0.11	14.91
72	SCARP-4	SCARP-2	SLIDE-1	46	51	44.93	4.43	0.52	13.30

HORIZONTAL ADJUSTMENT - JMODE=111

ANGLE NUMBER	AT STATION	FROM STATION	TO STATION	ADJUSTED ANGLE DEGREES	MINUTES	SECONDS	CORR.STD DEVIATION (SECONDS)	RESIDUAL (CALC-OBS) (SECONDS)	3-SIGMA TEST AT 99% PROB. (SECONDS)
73	SCARP-4	SCARP-2	SLIDE-3	49	7	32.88	4.75	0.00	14.25
74	SCARP-4	SCARP-2	SLIDE-5	54	26	56.61	4.69	-0.66	14.07
75	SCARP-4	SCARP-2	SLIDE-6	61	18	13.37	2.95	-0.24	8.86
76	SCARP-4	SCARP-2	SLIDE-10	62	38	32.09	2.35	0.18	7.06
77	SCARP-4	SCARP-2	SLIDE-7	69	25	28.31	2.22	-0.16	6.67
78	SCARP-4	SCARP-3	SLIDE-5	47	25	55.04	2.35	0.73	7.04
79	SCARP-4	SCARP-3	SLIDE-6	54	17	11.80	2.69	0.40	8.08
80	SCARP-4	SCARP-3	SLIDE-10	55	37	30.52	3.13	0.05	9.40
81	SCARP-4	SCARP-3	SLIDE-7	62	24	26.74	2.92	0.32	8.75
82	SCARP-1	SLIDE-5	SCARP-3	37	14	33.12	2.54	0.99	7.61
83	SCARP-1	SLIDE-6	SCARP-3	33	29	57.86	2.35	0.56	7.05
84	SCARP-1	SLIDE-7	SCARP-3	31	14	12.87	2.35	0.97	7.04

****

HORIZONTAL ADJUSTMENT - JMODE=111

****

ANGLE NUMBER	AT STATION	FROM STATION	TO STATION	ADJUSTED ANGLE DEGREES	MINUTES	SECONDS	CORR.STD DEVIATION (SECONDS)	RESIDUAL (CALC-OBS) (SECONDS)	3-SIGMA TEST AT 99% PROB. (SECONDS)
85	SCARP-1	SLIDE-10	SCARP-1	24	22	51.38	2.63	0.47	7.88
86	SCARP-1	SLIDE-5	SCARP-2	44	58	16.92	2.51	-1.57	7.52
87	SCARP-1	SLIDE-6	SCARP-2	41	13	41.66	2.43	-1.16	7.30
88	SCARP-1	SLIDE-7	SCARP-2	38	57	56.67	2.37	-1.53	7.12
89	SCARP-1	SLIDE-10	SCARP-2	32	6	35.18	2.32	-1.02	6.96

****

MEAN RESIDUAL(ABSOLUTE,UNWEIGHTED)= 1.138

****

****

HORIZONTAL ADJUSTMENT - JMODE=111

ERROR ELLIPSES FOR 95 PERCENT PROBABILITY

STANDARD DEVIATION OF UNIT WEIGHT= 0.480

***** ERROR ELLIPSE AT ***** STATION NUMBER	STATION NAME	TYPE	******* RELATIVE TO ******* STATION NUMBER	STATION NAME	TYPE	DEGREES OF FREEDOM	MAJOR AXIS	MINOR AXIS	ORIENTATION OF MAJOR AXIS CW FROM Y-AXIS
1	INNER-1	0	2	INNER-2	1	7	0.0027	0.0015	77 DEGREES
4	SCARP-1	0	2	INNER-2	1	32	0.0037	0.0025	141 DEGREES
5	SCARP-2	0	2	INNER-2	1	50	0.0020	0.0017	107 DEGREES
6	SCARP-3	0	2	INNER-2	1	51	0.0026	0.0020	23 DEGREES
7	SCARP-4	0	2	INNER-2	1	31	0.0049	0.0028	57 DEGREES
8	SLIDE-1	0	2	INNER-2	1	2	0.0061	0.0044	10 DEGREES
9	SLIDE-2	0	2	INNER-2	1	2	0.0059	0.0044	13 DEGREES
10	SLIDE-3	0	2	INNER-2	1	2	0.0060	0.0043	16 DEGREES
11	SLIDE-4	0	2	INNER-2	1	2	0.0056	0.0042	18 DEGREES

HORIZONTAL ADJUSTMENT - JMODE=111

ERROR ELLIPSES FOR 95 PERCENT PROBABILITY

STANDARD DEVIATION OF UNIT WEIGHT= 0.480

***** ERROR ELLIPSE AT ***** STATION NUMBER	STATION NAME	TYPE	******* RELATIVE TO ******* STATION NUMBER	STATION NAME	TYPE	DEGREES OF FREEDOM	MAJOR AXIS	MINOR AXIS	ORIENTATION OF MAJOR AXIS CW FROM Y-AXIS
12	SLIDE-5	0	2	INNER-2	1	2	0.0059	0.0043	18 DEGREES
13	SLIDE-6	0	2	INNER-2	1	2	0.0062	0.0045	18 DEGREES
14	SLIDE-7	0	2	INNER-2	1	2	0.0065	0.0045	21 DEGREES
15	SLIDE-8	0	2	INNER-2	1	2	0.0064	0.0041	176 DEGREES
16	SLIDE-9	0	2	INNER-2	1	2	0.0050	0.0034	4 DEGREES
17	SLIDE-10	0	2	INNER-2	1	2	0.0057	0.0043	28 DEGREES
18	SLIDE-11	0	2	INNER-2	1	2	0.0058	0.0038	162 DEGREES
19	SLIDE-12	0	2	INNER-2	1	2	0.0040	0.0033	157 DEGREES
20	SLIDE-13	0	2	INNER-2	1	2	0.0042	0.0033	146 DEGREES

HORIZONTAL ADJUSTMENT - JMODE=111

ERROR ELLIPSES FOR 95 PERCENT PROBABILITY

STANDARD DEVIATION OF UNIT WEIGHT= 0.480

***** ERROR ELLIPSE AT ***** STATION NUMBER	STATION NAME	TYPE	******* RELATIVE TO ******* STATION NUMBER	STATION NAME	TYPE	DEGREES OF FREEDOM	MAJOR AXIS	MINOR AXIS	ORIENTATION OF MAJOR AXIS CW FROM Y-AXIS
21	SLIDE-14	0	2	INNER-2	1	2	0.0042	0.0029	148 DEGREES
22	SLIDE-15	0	2	INNER-2	1	2	0.0036	0.0030	165 DEGREES
23	SLIDE-16	0	2	INNER-2	1	2	0.0045	0.0039	43 DEGREES

C.4.2 Vertical Adjustment

BEAVER CREEK - AUGUST,1978 - MONUMENTATION OF LANDSLIDES -- SET-#4 PAGE NO. 9

LEVEL ADJUSTMENT - JMODE=444

LINK NUMBER	FROM STATION	TO STATION	CALCULATED DIFF. IN ELEV	OBSERVED DIFF. IN ELEV	RESIDUAL (CALC-OBS)	LINK WEIGHT	LINK STANDARD DEVIATION	3-SIGMA TEST AT 99% PROB.
1	EVCH-GEO	SCARP-4	1.8729	1.8727	0.0002	0.25	0.0005	0.0015
2	SCARP-4	EVCH-GEO	-1.8729	-1.8731	0.0002	0.25	0.0005	0.0015
3	SCARP-4	SLIDE-16	-11.0160	-11.0167	0.0007	0.25	0.0005	0.0015
4	SLIDE-16	SCARP-4	11.0160	11.0152	0.0008	0.25	0.0005	0.0015
5	SCARP-4	SCARP-3	-0.3524	-0.3525	0.0001	0.50	0.0005	0.0014
6	SCARP-3	SCARP-2	-0.1614	-0.1614	0.0000	0.50	0.0005	0.0014
7	SCARP-2	SCARP-1	-0.9594	-0.9595	0.0001	0.25	0.0006	0.0018
8	SCARP-1	INNER-3	-0.4245	-0.4246	0.0001	0.50	0.0005	0.0014
9	INNER-3	INNER-2	1.9480	1.9480	0.0000	0.50	0.0005	0.0014
10	INNER-2	INNER-1	-1.2604	-1.2605	0.0001	0.50	0.0005	0.0014
11	INNER-1	SCARP-4	1.2101	1.2101	0.0000	0.50	0.0005	0.0014
12	SLIDE-16	SLIDE-15	1.8799	1.8799	-0.0000	0.50	0.0004	0.0013

LEVEL ADJUSTMENT - JMODE=444

LINK NUMBER	FROM STATION	TO STATION	CALCULATED DIFF. IN ELEV	OBSERVED DIFF. IN ELEV	RESIDUAL (CALC-OBS)	LINK WEIGHT	LINK STANDARD DEVIATION	3-SIGMA TEST AT 99% PROB.
13	SLIDE-15	SLIDE-14	-1.5159	-1.5159	0.0000	1.00	0.0003	0.0010
14	SLIDE-14	SLIDE-13	-1.4785	-1.4785	-0.0000	1.00	0.0003	0.0010
15	SLIDE-13	SLIDE-12	-0.4097	-0.4097	-0.0000	1.00	0.0003	0.0010
16	SLIDE-12	SLIDE-16	1.5242	1.5242	0.0000	0.50	0.0004	0.0013
17	SLIDE-12	SLIDE-11	-4.1072	-4.1072	0.0000	0.50	0.0005	0.0015
18	SLIDE-11	SLIDE-1	0.0781	0.0781	-0.0000	0.50	0.0005	0.0015
19	SLIDE-11	SLIDE-2	0.6137	0.6137	0.0000	0.50	0.0005	0.0015
20	SLIDE-11	SLIDE-4	1.1482	1.1482	-0.0000	0.50	0.0005	0.0015
21	SLIDE-11	SLIDE-3	1.9738	1.9734	0.0004	0.50	0.0004	0.0013
22	SLIDE-3	SLIDE-5	-0.1679	-0.1681	0.0002	1.00	0.0003	0.0010
23	SLIDE-5	SLIDE-6	-1.6423	-1.6425	0.0002	1.00	0.0003	0.0010
24	SLIDE-6	SLIDE-7	0.6096	0.6094	0.0002	1.00	0.0003	0.0010

LEVEL ADJUSTMENT - JMODE=444

LINK NUMBER	FROM STATION	TO STATION	CALCULATED DIFF. IN ELEV	OBSERVED DIFF. IN ELEV	RESIDUAL (CALC-OBS)	LINK WEIGHT	LINK STANDARD DEVIATION	3-SIGMA TEST AT 99% PROB.
25	SLIDE-7	SLIDE-10	0.3744	0.3742	0.0002	1.00	0.0003	0.0010
26	SLIDE-10	SLIDE-8	-0.4360	-0.4364	0.0004	0.50	0.0004	0.0013
27	SLIDE-8	SLIDE-9	1.2017	1.2017	-0.0000	1.00	0.0004	0.0011
28	SLIDE-8	SLIDE-11	-0.7115	-0.7117	0.0002	1.00	0.0003	0.0010

MEAN RESIDUAL= -0.0001

STD. ERROR OF OBS. OF UNIT WEIGHT= 0.0064

APPENDIX D

Final Adjusted Coordinates

Page No.

D.1.1 Horizontal: X,Y

BEAVER CREEK - MAY,1978 - MONUMENTATION OF LANDSLIDES -- SET-#1 PAGE NO. 15

HORIZONTAL ADJUSTMENT - JNODE=111

SOLUTION TERMINATED AFTER 2 ITERATIONS

DEGREES OF FREEDOM IN NETWORK= 16

STATION NUMBER	STATION NAME	PRELIMINARY X-COORDINATE	PRELIMINARY Y-COORDINATE	FINAL ADJUSTED X-COORDINATE	FINAL ADJUSTED Y-COORDINATE	X DIFF.	Y DIFF.	RESULT	THETA CW FROM Y-AXIS
1	INNER-1	232.9106	107.0104	232.9106	107.0104	0.0000	-0.0000	0.0000	101.044
4	SCARP-1	58.5863	167.7215	58.5863	167.7215	0.0000	-0.0000	0.0000	155.506
5	SCARP-2	152.0199	153.2088	152.0199	153.2088	-0.0000	0.0000	0.0000	277.120
6	SCARP-3	210.2494	164.8048	210.2494	164.8048	-0.0000	0.0000	0.0000	299.466
7	SCARP-4	277.0616	160.5146	277.0616	160.5146	-0.0000	0.0000	0.0000	320.742
8	SLIDE-1	156.7343	274.6724	156.7343	274.6724	-0.0000	-0.0000	0.0001	194.519
9	SLIDE-2	157.5601	268.0054	157.5601	268.0054	0.0000	0.0000	0.0000	14.599
10	SLIDE-3	170.4231	270.0040	170.4231	270.0040	-0.0000	0.0000	0.0000	354.132

HORIZONTAL ADJUSTMENT - JMODE=111

STATION NUMBER	STATION NAME	PRELIMINARY X-COORDINATE	PRELIMINARY Y-COORDINATE	FINAL ADJUSTED X-COORDINATE	FINAL ADJUSTED Y-COORDINATE	X DIFF.	Y DIFF.	RESULT	THETA CW FROM Y-AXIS
11	SLIDE-4	161.1390	259.5858	161.1390	259.5858	-0.0000	-0.0000	0.0000	243.627
12	SLIDE-5	192.3850	265.3753	192.3850	265.3753	-0.0000	0.0000	0.0000	331.684
13	SLIDE-6	211.7071	264.8253	211.7071	264.8253	-0.0000	-0.0000	0.0000	212.478
14	SLIDE-7	229.7600	267.0170	229.7600	267.0170	-0.0000	-0.0000	0.0000	223.151
15	SLIDE-8	187.4055	242.0612	187.4055	242.0612	0.0000	0.0000	0.0000	57.421
16	SLIDE-9	198.5795	221.1124	198.5795	221.1124	-0.0000	-0.0000	0.0000	238.707
17	SLIDE-10	229.1826	241.0701	229.1826	241.0701	0.0000	-0.0000	0.0000	148.758
18	SLIDE-11	157.3737	241.4471	157.3737	241.4471	0.0000	-0.0000	0.0000	134.319
19	SLIDE-12	162.9380	208.2445	162.9380	208.2445	0.0000	0.0000	0.0000	30.456
20	SLIDE-13	146.1042	208.8130	146.1042	208.8130	0.0000	-0.0000	0.0001	128.335
21	SLIDE-14	151.5985	191.6860	151.5985	191.6860	0.0000	-0.0000	0.0000	141.638
22	SLIDE-15	177.2279	188.7450	177.2279	188.7450	-0.0000	0.0000	0.0000	335.743

HORIZONTAL ADJUSTMENT - JMODE=111

STATION NUMBER	STATION NAME	PRELIMINARY X-COORDINATE	PRELIMINARY Y-COORDINATE	FINAL ADJUSTED X-COORDINATE	FINAL ADJUSTED Y-COORDINATE	X DIFF.	Y DIFF.	RESULT	THETA CW FROM Y-AXIS
23	SLIDE-16	217.0463	196.3338	217.0463	196.3338	-0.0000	-0.0000	0.0000	230.203

D.1.2 Vertical: Z

BEAVER CREEK - MAY,1978 - MONUMENTATION OF LANDSLIDES -- SET-#1 PAGE NO. 7

LEVEL ADJUSTMENT - JNODE=444

STATION NUMBER	STATION NAME	PRELIMINARY ELEVATION	ADJUSTED ELEVATION	STANDARD DEVIATION	DIFFERENCE (PRLM-ADJ)
1	SCARP-4	101.9052	101.9052	0.0007	-0.0000
2	SLIDE-1	85.3215	85.3215	0.0015	-0.0000
3	SLIDE-2	85.8514	85.8514	0.0014	-0.0000
4	SLIDE-3	87.2168	87.2168	0.0014	0.0000
5	SLIDE-4	86.3852	86.3852	0.0014	0.0000
6	SLIDE-5	87.0505	87.0505	0.0014	0.0000
7	SLIDE-6	85.4071	85.4071	0.0015	0.0000
8	SLIDE-7	86.0278	86.0278	0.0015	-0.0000
9	SLIDE-8	85.9466	85.9466	0.0014	0.0000
10	SLIDE-9	87.1444	87.1444	0.0013	-0.0000
11	SLIDE-10	86.3786	86.3786	0.0015	0.0000
12	SLIDE-11	85.2342	85.2342	0.0013	0.0000

LEVEL ADJUSTMENT - JNODE=444

STATION NUMBER	STATION NAME	PRELIMINARY ELEVATION	ADJUSTED ELEVATION	STANDARD DEVIATION	DIFFERENCE (PRLM-ADJ)
13	SLIDE-12	89.3357	89.3357	0.0012	0.0000
14	SLIDE-13	89.7466	89.7466	0.0012	-0.0000
15	SLIDE-14	91.2505	91.2505	0.0012	-0.0000
16	SLIDE-15	92.7563	92.7563	0.0011	0.0000
17	SLIDE-16	90.8732	90.8732	0.0010	-0.0000

LARGEST CORRECTION= -0.0000

D.2.1 Horizontal: X,Y

BEAVER CREEK - AUGUST,1978 - MONUMENTATION OF LANDSLIDES -- SET-#2 PAGE NO. 21

HORIZONTAL ADJUSTMENT - JMODE=111

SOLUTION TERMINATED AFTER 2 ITERATIONS

DEGREES OF FREEDOM IN NETWORK= 78

STATION NUMBER	STATION NAME	PRELIMINARY X-COORDINATE	PRELIMINARY Y-COORDINATE	FINAL ADJUSTED X-COORDINATE	FINAL ADJUSTED Y-COORDINATE	X DIFF.	Y DIFF.	RESULT	THETA CW FROM Y-AXIS
1	INNER-1	232.9106	107.0104	232.9099	107.0111	-0.0007	0.0007	0.0010	316.794
4	SCARP-1	58.5863	167.7215	58.5855	167.7223	-0.0008	0.0008	0.0011	312.647
5	SCARP-2	152.0199	153.2088	152.0195	153.2111	-0.0004	0.0023	0.0024	350.224
6	SCARP-3	210.2494	164.8048	210.2483	164.8078	-0.0011	0.0030	0.0032	340.426
7	SCARP-4	277.0616	160.5146	277.0617	160.5197	0.0001	0.0051	0.0051	1.087
8	SLIDE-1	156.7343	274.6724	156.7328	274.6783	-0.0015	0.0059	0.0061	345.192
9	SLIDE-2	157.5601	268.0054	157.5598	268.0131	-0.0003	0.0077	0.0077	358.108
10	SLIDE-3	170.4231	270.0040	170.4300	270.0092	0.0069	0.0052	0.0086	53.216

HORIZONTAL ADJUSTMENT - JMODE=111

STATION NUMBER	STATION NAME	PRELIMINARY X-COORDINATE	PRELIMINARY Y-COORDINATE	FINAL ADJUSTED X-COORDINATE	FINAL ADJUSTED Y-COORDINATE	X DIFF.	Y DIFF.	RESULT	THETA CW FROM Y-AXIS
11	SLIDE-4	161.1390	259.5858	161.1406	259.5884	0.0016	0.0026	0.0031	31.643
12	SLIDE-5	192.3850	265.3753	192.3818	265.3850	-0.0032	0.0097	0.0103	341.629
13	SLIDE-6	211.7071	264.8253	211.7022	264.8364	-0.0049	0.0111	0.0121	336.094
14	SLIDE-7	229.7600	267.0170	229.7568	267.0270	-0.0032	0.0100	0.0105	342.095
15	SLIDE-8	187.4055	242.0612	187.4020	242.0724	-0.0035	0.0112	0.0117	342.671
16	SLIDE-9	198.5795	221.1124	198.5759	221.1211	-0.0036	0.0087	0.0094	337.508
17	SLIDE-10	229.1826	241.0701	229.1803	241.0818	-0.0023	0.0117	0.0119	348.806
18	SLIDE-11	157.3737	241.4471	157.3667	241.4533	-0.0070	0.0062	0.0093	311.407
19	SLIDE-12	162.9380	208.2445	162.9348	208.2527	-0.0032	0.0082	0.0088	338.345
20	SLIDE-13	146.1042	208.8130	146.1009	208.8224	-0.0033	0.0094	0.0100	340.498
21	SLIDE-14	151.5985	191.6860	151.5933	191.6889	-0.0052	0.0029	0.0059	299.362
22	SLIDE-15	177.2279	188.7450	177.2248	188.7515	-0.0031	0.0065	0.0072	334.577

HORIZONTAL ADJUSTMENT - JMODE=111

STATION NUMBER	STATION NAME	PRELIMINARY X-COORDINATE	PRELIMINARY Y-COORDINATE	FINAL ADJUSTED X-COORDINATE	FINAL ADJUSTED Y-COORDINATE	X DIFF.	Y DIFF.	RESULT	THETA CW FROM Y-AXIS
23	SLIDE-16	217.0463	196.3338	217.0435	196.3460	-0.0028	0.0122	0.0125	347.062

D.2.2 Vertical: Z

BEAVER CREEK - AUGUST,1978 - MONUMENTATION OF LANDSLIDES -- SET-#2 PAGE NO. 7

LEVEL ADJUSTMENT - JMODE=444

STATION NUMBER	STATION NAME	PRELIMINARY ELEVATION	ADJUSTED ELEVATION	STANDARD DEVIATION	DIFFERENCE (PRLM-ADJ)
1	INNER-1	100.6639	100.6639	0.0003	-0.0000
2	INNER-2	101.9244	101.9244	0.0003	0.0000
3	INNER-3	99.9768	99.9768	0.0003	0.0000
4	SCARP-1	100.4044	100.4044	0.0003	0.0000
5	SCARP-2	101.3689	101.3689	0.0003	-0.0000
6	SCARP-3	101.5452	101.5452	0.0003	0.0000
7	SCARP-4	101.9052	101.9020	0.0002	0.0032
8	SLIDE-1	85.3215	85.3199	0.0005	0.0016
9	SLIDE-2	85.8514	85.8498	0.0005	0.0016
10	SLIDE-3	87.2168	87.2129	0.0005	0.0039
11	SLIDE-4	86.3852	86.3835	0.0005	0.0017
12	SLIDE-5	87.0505	87.0444	0.0005	0.0061

LEVEL ADJUSTMENT - JMODE=444

STATION NUMBER	STATION NAME	PRELIMINARY ELEVATION	ADJUSTED ELEVATION	STANDARD DEVIATION	DIFFERENCE (PRLM-ADJ)
13	SLIDE-6	85.4071	85.4027	0.0005	0.0044
14	SLIDE-7	86.0278	86.0254	0.0005	0.0024
15	SLIDE-8	85.9466	85.9447	0.0004	0.0019
16	SLIDE-9	87.1444	87.1433	0.0004	0.0011
17	SLIDE-10	86.3786	86.3764	0.0005	0.0022
18	SLIDE-11	85.2342	85.2325	0.0004	0.0017
19	SLIDE-12	89.3357	89.3337	0.0004	0.0020
20	SLIDE-13	89.7486	89.7448	0.0004	0.0038
21	SLIDE-14	91.2505	91.2469	0.0004	0.0036
22	SLIDE-15	92.7563	92.7543	0.0004	0.0020
23	SLIDE-16	90.8732	90.8727	0.0003	0.0005

LARGEST CORRECTION= 0.0061

D.3 May, 1979 Survey

D.3.1 Horizontal: X,Y

BEAVER CREEK - MAY,1979 - MONUMENTATION OF LANDSLIDES -- SET-#3 PAGE NO. 22

HORIZONTAL ADJUSTMENT - JMODE=111

SOLUTION TERMINATED AFTER 2 ITERATIONS

DEGREES OF FREEDOM IN NETWORK= 81

STATION NUMBER	STATION NAME	PRELIMINARY X-COORDINATE	PRELIMINARY Y-COORDINATE	FINAL ADJUSTED X-COORDINATE	FINAL ADJUSTED Y-COORDINATE	X DIFF.	Y DIFF.	RESULT	THETA CW FROM Y-AXIS
1	INNER-1	232.9106	107.0104	232.9126	107.0126	0.0020	0.0022	0.0030	41.923
4	SCARP-1	58.5863	167.7215	58.5873	167.7257	0.0010	0.0042	0.0043	12.941
5	SCARP-2	152.0199	153.2088	152.0216	153.2170	0.0017	0.0082	0.0083	11.661
6	SCARP-3	210.2494	164.8048	210.2527	164.8174	0.0033	0.0126	0.0131	14.671
7	SCARP-4	277.0616	160.5146	277.0642	160.5346	0.0026	0.0200	0.0202	7.338
8	SLIDE-1	156.7343	274.6724	156.7377	274.7259	0.0034	0.0535	0.0536	3.600
9	SLIDE-2	157.5601	268.0054	157.5658	268.0504	0.0057	0.0450	0.0453	7.280
10	SLIDE-3	170.4231	270.0040	170.4331	270.0489	0.0100	0.0449	0.0460	12.544

HORIZONTAL ADJUSTMENT - JMODE=111

STATION NUMBER	STATION NAME	PRELIMINARY X-COORDINATE	PRELIMINARY Y-COORDINATE	FINAL ADJUSTED X-COORDINATE	FINAL ADJUSTED Y-COORDINATE	X DIFF.	Y DIFF.	RESULT	THETA CW FROM Y-AXIS
11	SLIDE-4	161.1390	259.5858	161.1447	259.6262	0.0057	0.0404	0.0408	7.993
12	SLIDE-5	192.3850	265.3753	192.3899	265.4262	0.0049	0.0509	0.0511	5.519
13	SLIDE-6	211.7071	264.8253	211.7169	264.8804	0.0098	0.0551	0.0559	10.103
14	SLIDE-7	229.7600	267.0170	229.7712	267.0812	0.0112	0.0642	0.0652	9.881
15	SLIDE-8	187.4055	242.0612	187.4071	242.1058	0.0016	0.0446	0.0446	1.994
16	SLIDE-9	198.5795	221.1124	198.5813	221.1515	0.0018	0.0391	0.0391	2.668
17	SLIDE-10	229.1826	241.0701	229.1852	241.1142	0.0026	0.0441	0.0441	3.396
18	SLIDE-11	157.3737	241.4471	157.3762	241.4888	0.0025	0.0417	0.0417	3.417
19	SLIDE-12	162.9380	208.2445	162.9394	208.2793	0.0014	0.0348	0.0349	2.323
20	SLIDE-13	146.1042	208.8130	146.1064	208.8479	0.0022	0.0349	0.0350	3.634
21	SLIDE-14	151.5985	191.6860	151.5896	191.7060	-0.0089	0.0200	0.0219	336.053
22	SLIDE-15	177.2279	188.7450	177.2232	188.7697	-0.0047	0.0247	0.0251	349.316

BEAVER CREEK - MAY,1979 - MONUMENTATION OF LANDSLIDES -- SET-#3

HORIZONTAL ADJUSTMENT - JMODE=111

STATION NUMBER	STATION NAME	PRELIMINARY X-COORDINATE	PRELIMINARY Y-COORDINATE	FINAL ADJUSTED X-COORDINATE	FINAL ADJUSTED Y-COORDINATE	X DIFF.	Y DIFF.	RESULT	THETA CW FROM Y-AXIS
23	SLIDE-16	217.0463	196.3338	217.0453	196.3716	-0.0010	0.0378	0.0378	358.430

D.3.2 Vertical: Z

BEAVER CREEK - MAY,1979 - MONUMENTATION OF LANDSLIDES -- SET-#3 PAGE NO. 7

LEVEL ADJUSTMENT - JMODE=444

STATION NUMBER	STATION NAME	PRELIMINARY ELEVATION	ADJUSTED ELEVATION	STANDARD DEVIATION	DIFFERENCE (PRLM-ADJ)
1	INNER-1	100.6639	100.6637	0.0004	0.0002
2	INNER-2	101.9244	101.9223	0.0005	0.0021
3	INNER-3	99.9768	99.9746	0.0005	0.0022
4	SCARP-1	100.4044	100.4011	0.0005	0.0033
5	SCARP-2	101.3689	101.3621	0.0004	0.0068
6	SCARP-3	101.5452	101.5317	0.0004	0.0135
7	SCARP-4	101.9052	101.8875	0.0003	0.0177
8	SLIDE-1	85.3215	85.3111	0.0006	0.0104
9	SLIDE-2	85.8514	85.8444	0.0006	0.0070
10	SLIDE-3	87.2168	87.2080	0.0006	0.0088
11	SLIDE-4	86.3852	86.3786	0.0006	0.0066
12	SLIDE-5	87.0505	87.0417	0.0006	0.0088

LEVEL ADJUSTMENT - JMODE=444

STATION NUMBER	STATION NAME	PRELIMINARY ELEVATION	ADJUSTED ELEVATION	STANDARD DEVIATION	DIFFERENCE (PRLM-ADJ)
13	SLIDE-6	85.4071	85.3961	0.0006	0.0110
14	SLIDE-7	86.0278	86.0055	0.0006	0.0223
15	SLIDE-8	85.9466	85.9404	0.0007	0.0062
16	SLIDE-9	87.1444	87.1406	0.0007	0.0038
17	SLIDE-10	86.3786	86.3745	0.0004	0.0041
18	SLIDE-11	85.2342	85.2283	0.0005	0.0059
19	SLIDE-12	89.3357	89.3343	0.0005	0.0014
20	SLIDE-13	89.7486	89.7452	0.0005	0.0034
21	SLIDE-14	91.2505	91.2344	0.0005	0.0161
22	SLIDE-15	92.7563	92.7452	0.0005	0.0111
23	SLIDE-16	90.8732	90.8644	0.0004	0.0088

LARGEST CORRECTION= 0.0223

D.4.1 Horizontal: X,Y

BEAVER CREEK - AUGUST,1979 - MONUMENTATION OF LANDSLIDES -- SET-#4 PAGE NO. 21

HORIZONTAL ADJUSTMENT - JMODE=111

SOLUTION TERMINATED AFTER 2 ITERATIONS

DEGREES OF FREEDOM IN NETWORK= 72

STATION NUMBER	STATION NAME	PRELIMINARY X-COORDINATE	PRELIMINARY Y-COORDINATE	FINAL ADJUSTED X-COORDINATE	FINAL ADJUSTED Y-COORDINATE	X DIFF.	Y DIFF.	RESULT	THETA CW FROM Y-AXIS
1	INNER-1	232.9106	107.0104	232.9114	107.0142	0.0008	0.0038	0.0039	11.209
4	SCARP-1	58.5863	167.7215	58.5867	167.7243	0.0004	0.0028	0.0029	7.849
5	SCARP-2	152.0199	153.2088	152.0205	153.2198	0.0006	0.0110	0.0110	2.998
6	SCARP-3	210.2494	164.8048	210.2512	164.8248	0.0018	0.0200	0.0200	5.117
7	SCARP-4	277.0616	160.5146	277.0613	160.5474	-0.0003	0.0328	0.0328	359.393
8	SLIDE-1	156.7343	274.6724	156.7383	274.7641	0.0040	0.0917	0.0918	2.499
9	SLIDE-2	157.5601	268.0054	157.5641	268.0889	0.0040	0.0835	0.0836	2.711
10	SLIDE-3	170.4231	270.0040	170.4330	270.0883	0.0099	0.0843	0.0849	6.687

HORIZONTAL ADJUSTMENT - JMODE=111

STATION NUMBER	STATION NAME	PRELIMINARY X-COORDINATE	PRELIMINARY Y-COORDINATE	FINAL ADJUSTED X-COORDINATE	FINAL ADJUSTED Y-COORDINATE	X DIFF.	Y DIFF.	RESULT	THETA CW FROM Y-AXIS
11	SLIDE-4	161.1390	259.5858	161.1442	259.6638	0.0052	0.0780	0.0782	3.822
12	SLIDE-5	192.3850	265.3753	192.3897	265.4641	0.0047	0.0888	0.0890	3.001
13	SLIDE-6	211.7071	264.8253	211.7160	264.9184	0.0089	0.0931	0.0936	5.429
14	SLIDE-7	229.7600	267.0170	229.7690	267.1213	0.0090	0.1043	0.1047	4.914
15	SLIDE-8	187.4055	242.0612	187.4066	242.1339	0.0011	0.0727	0.0727	0.904
16	SLIDE-9	198.5795	221.1124	198.5811	221.1846	0.0016	0.0722	0.0722	1.285
17	SLIDE-10	229.1826	241.0701	229.1842	241.1445	0.0016	0.0744	0.0744	1.204
18	SLIDE-11	157.3737	241.4471	157.3742	241.5168	0.0005	0.0697	0.0697	0.430
19	SLIDE-12	162.9380	208.2445	162.9380	208.3060	-0.0000	0.0615	0.0615	359.966
20	SLIDE-13	146.1042	208.8130	146.1036	208.8692	-0.0006	0.0562	0.0562	359.408
21	SLIDE-14	151.5985	191.6860	151.5869	191.7214	-0.0116	0.0354	0.0373	341.914
22	SLIDE-15	177.2279	188.7450	177.2256	188.7840	-0.0023	0.0390	0.0391	356.603

HORIZONTAL ADJUSTMENT - JMODE=111

STATION NUMBER	STATION NAME	PRELIMINARY X-COORDINATE	PRELIMINARY Y-COORDINATE	FINAL ADJUSTED X-COORDINATE	FINAL ADJUSTED Y-COORDINATE	X DIFF.	Y DIFF.	RESULT	THETA CW FROM Y-AXIS
23	SLIDE-16	217.0463	196.3338	217.0405	196.3977	-0.0058	0.0639	0.0642	354.798

D.4.2 Vertical: Z

BEAVER CREEK - AUGUST,1976 - MONUMENTATION OF LANDSLIDES -- SET-#4 PAGE NO. 7

LEVEL ADJUSTMENT - JMODE=444

STATION NUMBER	STATION NAME	PRELIMINARY ELEVATION	ADJUSTED ELEVATION	STANDARD DEVIATION	DIFFERENCE (PRLM-ADJ)
1	INNER-1	100.6639	100.6627	0.0007	0.0012
2	INNER-2	101.9244	101.9232	0.0008	0.0012
3	INNER-3	99.9768	99.9751	0.0009	0.0017
4	SCARP-1	100.4044	100.3997	0.0009	0.0047
5	SCARP-2	101.3689	101.3591	0.0008	0.0098
6	SCARP-3	101.5452	101.5205	0.0007	0.0248
7	SCARP-4	101.9052	101.8729	0.0005	0.0323
8	SLIDE-1	85.3215	85.3036	0.0011	0.0179
9	SLIDE-2	85.8514	85.8392	0.0011	0.0122
10	SLIDE-3	87.2168	87.1993	0.0011	0.0175
11	SLIDE-4	86.3852	86.3737	0.0011	0.0115
12	SLIDE-5	87.0505	87.0314	0.0011	0.0191

LEVEL ADJUSTMENT - JMODE=444

STATION NUMBER	STATION NAME	PRELIMINARY ELEVATION	ADJUSTED ELEVATION	STANDARD DEVIATION	DIFFERENCE (PRLM-ADJ)
13	SLIDE-6	85.4071	85.3891	0.0011	0.0180
14	SLIDE-7	86.0278	85.9987	0.0011	0.0291
15	SLIDE-8	85.9466	85.9371	0.0010	0.0095
16	SLIDE-9	87.1444	87.1388	0.0011	0.0056
17	SLIDE-10	86.3786	86.3731	0.0011	0.0055
18	SLIDE-11	85.2342	85.2255	0.0010	0.0087
19	SLIDE-12	89.3357	89.3327	0.0008	0.0029
20	SLIDE-13	89.7486	89.7424	0.0009	0.0061
21	SLIDE-14	91.2505	91.2209	0.0009	0.0295
22	SLIDE-15	92.7563	92.7368	0.0008	0.0194
23	SLIDE-16	90.8732	90.8569	0.0007	0.0163

LARGEST CORRECTION= 0.0323

APPENDIX E

Rate of Movement Calculations

E.1 Horizontal Movement Calculations

The coordinates from the May, 1978 survey were used as the starting coordinates for all monuments. The movements in each subsequent time period were then calculated by subtracting the May, 1978 coordinates from the respective final adjusted coordinates. The resultant horizontal movement is the resultant of the movements in the X and Y direction. The rates of movement for each time period were found by dividing the resultant movement by the time period in months. The time periods are as follows:

May 15, 1978 to August 28, 1978 = 3.4 months

May 15, 1978 to May 15, 1979 = 12.0 months

May 15, 1978 to August 21, 1979 = 15.2 months

The results of the horizontal movement calculations are presented in Table E.1.

E.2 Vertical Movement Calculations

The calculation of the vertical movements and the rates of vertical movement also followed the procedure outlined above. There was no movement of the geodetic vertical control monuments during the study period. The results of the vertical movement calculations are presented in Table E.2.

Table E.1: Rates of Resultant Horizontal Movement

STATION NAME	May/78 to Aug/78 (mm)	RATE mm/month	May/78 to May/79 (mm)	RATE mm/month	May/78 to Aug/79 (mm)	RATE mm/month
INNER-1	1.0	0.3	3.0	0.3	3.9	0.3
INNER-2	0.0	0.0	0.0	0.0	0.0	0.0
INNER-3	0.0	0.0	0.0	0.0	0.0	0.0
SCARP-1	1.1	0.3	4.3	0.4	2.9	0.2
SCARP-2	2.4	0.7	8.3	0.7	11.0	0.7
SCARP-3	3.2	0.9	13.1	1.1	20.0	1.3
SCARP-4	5.1	1.5	20.2	1.7	32.8	2.2
SLIDE-1	6.1	1.8	53.6	4.5	91.8	6.0
SLIDE-2	7.7	2.3	45.3	3.8	83.6	5.5
SLIDE-3	8.6	2.5	46.0	3.8	84.9	5.6
SLIDE-4	3.1	0.9	40.8	3.4	78.2	5.1
SLIDE-5	10.3	3.0	51.1	4.3	89.0	5.9
SLIDE-6	12.1	3.6	55.9	4.7	93.6	6.2
SLIDE-7	10.5	3.1	65.2	5.4	104.7	6.9
SLIDE-8	11.7	3.4	44.6	3.7	72.7	4.8
SLIDE-9	9.4	2.8	39.1	3.3	72.2	4.8
SLIDE-10	11.9	3.5	44.1	3.7	74.4	4.9
SLIDE-11	9.3	2.7	41.7	3.5	69.7	4.6
SLIDE-12	8.8	2.6	34.9	2.9	61.5	4.0
SLIDE-13	10.0	2.9	35.0	2.9	56.2	3.7
SLIDE-14	5.9	1.7	21.9	1.8	37.3	2.5
SLIDE-15	7.2	2.1	25.1	2.1	39.1	2.6
SLIDE-16	12.5	3.7	37.8	3.2	64.2	4.2

...s of Vertical Movement

STATION NAME	May/78 to Aug/78 (mm)	RATE mm/month	May/78 to May/79 (mm)	RATE mm/month	May/78 to Aug/79 (mm)	RATE mm/month
INNER-1	0.0	0.0	0.2	0.0	1.2	0.1
INNER-2	0.0	0.0	2.1	0.0	1.2	0.1
INNER-3	0.0	0.0	2.2	0.0	1.7	0.1
SCARP-1	0.0	0.0	3.3	0.3	4.7	0.3
SCARP-2	0.0	0.0	6.8	0.6	9.8	0.6
SCARP-3	0.0	0.0	13.5	1.1	24.8	1.6
SCARP-4	3.2	0.9	17.7	1.5	32.3	2.1
SLIDE-1	1.6	0.5	10.4	0.9	17.9	1.2
SLIDE-2	1.6	0.5	7.0	0.8	12.2	0.8
SLIDE-3	3.9	1.2	8.8	0.7	17.5	1.2
SLIDE-4	1.7	0.5	6.6	0.6	11.5	0.8
SLIDE-5	6.1	1.8	8.8	0.7	19.1	1.3
SLIDE-6	4.4	1.3	11.0	0.9	18.0	1.2
SLIDE-7	2.4	0.7	22.3	1.9	29.1	1.9
SLIDE-8	1.9	0.3	6.2	0.5	9.5	0.6
SLIDE-9	1.1	0.3	3.8	0.3	5.6	0.4
SLIDE-10	2.2	0.7	4.1	0.3	5.5	0.4
SLIDE-11	1.7	0.5	5.9	0.5	8.7	0.6
SLIDE-12	2.0	0.6	1.4	0.1	2.9	0.2
SLIDE-13	3.8	1.1	3.4	0.3	6.1	0.4
SLIDE-14	3.6	1.1	16.1	1.3	29.5	1.9
SLIDE-15	2.0	0.6	11.1	0.9	19.4	1.3
SLIDE-16	0.5	0.2	8.8	0.7	16.3	1.1

APPENDIX F

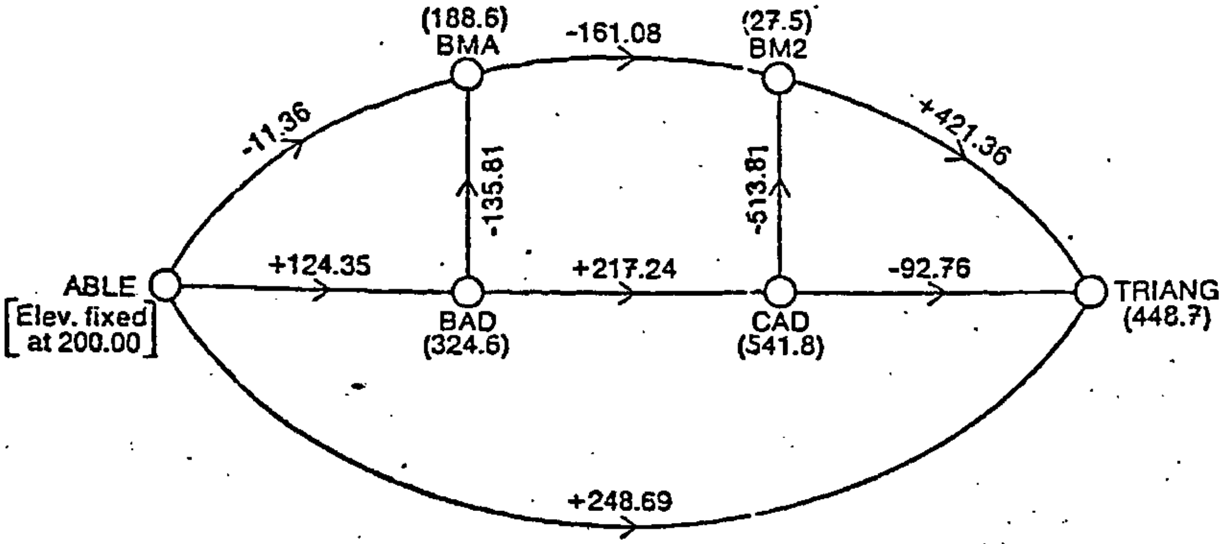
Verification of the Computer Program LSQADJ

F.1 Example #1 - Level Adjustment

A comparison was made between LSQADJ and the Geodetic Survey of Canada program LEVELOB. The program LEVELOB was written and documented by Peterson, 1966. The example chosen was Example (b), pp 17, (loc cit). The results of the adjustments from LSQADJ and LEVELOB are presented in Figures F.1, F.2 and F.3.

Figure F.1 illustrates the level net to be adjusted and partial results of the adjustments. The adjusted elevations and the respective standard deviations calculated by both programs agree exactly. Figure F.2 illustrates that the mean residual and standard error of unit weight also agree exactly. Figure F.3 shows that the standard deviations calculated for each link after the adjustment agree exactly.

The comparison reveals that the level adjustment portion of the program LSQADJ yields the exact same results as the Geodetic Survey of Canada program LEVELOB. The exact agreement between the two programs indicates that the level adjustment portion of the program LSQADJ works correctly and can be used with confidence.



LEVEL NET - EXAMPLE-#1

LSQADJ

STATION NUMBER	STATION NAME	PRELIMINARY ELEVATION	ADJUSTED ELEVATION	STANDARD DEVIATION
1	BMA	188.6000	188.5898	0.0915
2	BM2	27.5000	27.5772	0.1178
3	TRIANG	448.7000	448.8149	0.1153
4	CAD	541.8000	541.5303	0.1068
5	BAD	324.6000	324.3452	0.0882

LEVELOB (from Peterson, 1966)

	ADJUSTED ELEVATION MATRIX		S.D.
1	BAD	324.3452	.0882
2	CAD	541.5303	.1067
3	TRIANG	448.8149	.1153
4	BM2	27.5772	.1177
5	BMA	188.5898	.0914
6	ABLE	200.0000	0

FIGURE F.1: EXAMPLE #1

LSQADJ

LINK NUMBER	FROM STATION	TO STATION	CALCULATED DIFF. IN ELEV	OBSERVED DIFF. IN ELEV
1	ABLE	BAD	124.3452	124.3500
2	BAD	CAD	217.1851	217.2400
3	CAD	TRIANG	-92.7154	-92.7600
4	ABLE	BMA	-11.4102	-11.3600
5	BMA	BM2	-161.0127	-161.0800
6	BM2	TRIANG	421.2378	421.3600
7	BAD	BMA	-135.7554	-135.8100
8	CAD	BM2	-513.9532	-513.8100
9	ABLE	TRIANG	248.8149	248.6900

MEAN RESIDUAL= 0.0170

STD. ERROR OF OBS. OF UNIT WEIGHT= 0.1456

LEVELOB (from Peterson, 1966)

LINE NO.	FROM STA.	TO STA.	ADJ.ELEV. DIFF.	OBS.ELEV. DIFF.
1	ABLE	BAD	124.3452	124.3500
2	BAD	CAD	217.1851	217.2400
3	CAD	TRIANG	-92.7154	-92.7600
4	ABLE	BMA	-11.4102	-11.3600
5	BMA	BM2	-161.0127	-161.0800
6	BM2	TRIANG	421.2378	421.3600
7	BAD	BMA	-135.7554	-135.8100
8	CAD	BM2	-513.9531	-513.8100
9	ABLE	TRIANG	248.8149	248.6900

MEAN RESIDUAL .0169

STD.ERROR OF OBS.OF UNIT WT. .1455

FIGURE F.2: EXAMPLE #1

LSQADJ

LINK NUMBER	FROM STATION	TO STATION	RESIDUAL (CALC-OBS)	LINK WEIGHT	LINK STANDARD DEVIATION
1	ABLE	BAD	-0.0048	1.47	0.0882
2	BAD	CAD	-0.0549	2.50	0.0799
3	CAD	TRIANG	0.0446	1.79	0.0856
4	ABLE	BMA	-0.0502	1.32	0.0915
5	BMA	BM2	0.0673	0.95	0.1038
6	BM2	TRIANG	-0.1222	1.25	0.0940
7	BAD	BMA	0.0546	2.38	0.0766
8	CAD	BM2	-0.1432	1.52	0.0867
9	ABLE	TRIANG	0.1249	0.58	0.1153

LEVELOB (from Peterson,1966)

LINE NO.	FROM STA.	TO STA.	RESIDUAL (OBS-ADJ)	WEIGHT	LINK S.D.
1	ABLE	BAD	.0048	1.4706	.0882
2	BAD	CAD	.0549	2.5000	.0799
3	CAD	TRIANG	-0.0446	1.7857	.0856
4	ABLE	BMA	.0502	1.3158	.0914
5	BMA	BM2	-0.0673	.9524	.1038
6	BM2	TRIANG	.1222	1.2500	.0940
7	BAD	BMA	-0.0546	2.3810	.0766
8	CAD	BM2	.1431	1.5152	.0867
9	ABLE	TRIANG	-0.1249	.5848	.1153

FIGURE F.9. EXAMPLE #1
7

F.2 Example #2 - Level Adjustment

A comparison was made between program LSQADJ and the results of a level adjustment published by Moffitt and Bouchard, 1975. The example chosen was Example A-1, pp 773, loc cit. The results of the adjustment from LSQADJ and Moffitt and Bouchard are presented in Figure F.4 and F.5.

Figure F.4 illustrates that the adjusted elevations from LSQADJ and Moffitt and Bouchard agree exactly. Figure F.5 shows that the calculated residuals and standard deviation of unit weight also agree exactly. The link standard deviations do not agree since Moffitt and Bouchard calculate them by a method different than the one used by MSQADJ and LEVELOB:

Moffitt and Bouchard (1975)

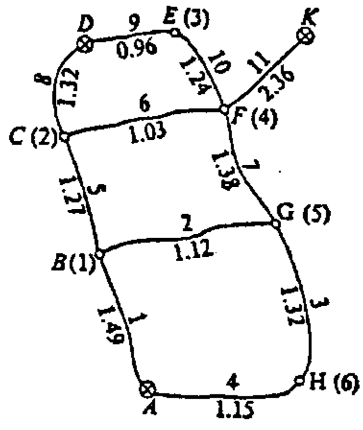
$$\sigma_{LINK} = \sigma o \frac{1}{P_{LINK}}$$

LSQADJ and LEVELOB

$$\sigma^2_{LINK} = \sigma^2_{Z_T} + \sigma^2_{Z_F} - Z\sigma_{Z_T Z_F}$$

The method used by LSQADJ and LEVELOB is more strictly correct since it uses the values from the variance-covariance matrix.

In summary, the level adjustment portion of the program LSQADJ program appears to work correctly when compared with Moffitt and Bouchard (1975).



Level net.

LINE	LENGTH (miles)	FROM TO	OBSERVED DE
1	1.49	A–B	− 3.278
2	1.12	B–G	− 1.467
3	1.32	G–H	+ 9.756
4	1.15	H–A	− 4.975
5	1.27	B–C	+ 8.429
6	1.03	C–F	− 6.528
7	1.38	F–G	− 3.352
8	1.32	C–D	+16.724
9	0.96	D–E	−12.563
10	1.29	E–F	−10.721
11	2.36	F–K	+12.249

LSQADJ

STATION NUMBER	STATION NAME	PRELIMINARY ELEVATION	ADJUSTED ELEVATION	STANDARD DEVIATION
1	B	853.1470	853.1497	0.0148
2	C	861.5760	861.5862	0.0141
3	E	865.7690	865.7699	0.0148
4	F	855.0480	855.0433	0.0140
5	G	851.6800	851.6780	0.0159
6	H	861.4360	861.4158	0.0161

MOFFITT AND BOUCHARD (1975)

SOLUTION (ft)	ADJUSTED ELEVATION (ft)
$\mathbf{X} = \begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \\ x_5 \\ x_6 \end{bmatrix} = \begin{bmatrix} +0.003 \\ +0.010 \\ +0.001 \\ -0.005 \\ -0.002 \\ -0.020 \end{bmatrix}$	$B = 853.147 + 0.003 = 853.150$ $C = 861.576 + 0.010 = 861.586$ $E = 865.769 + 0.001 = 865.770$ $F = 855.048 - 0.005 = 855.043$ $G = 851.680 - 0.002 = 851.678$ $H = 861.436 - 0.020 = 861.416$

FIGURE F.4: EXAMPLE #2

LINK NUMBER	FROM STATION	TO STATION	RESIDUAL (CALC-OBS)	LINK WEIGHT	LINK STANDARD DEVIATION
1	A	B	0.0027	0.67	0.0148
2	B	G	-0.0046	0.89	0.0151
3	G	H	-0.0182	0.76	0.0166
4	H	A	-0.0158	0.87	0.0161
5	B	C	0.0075	0.79	0.0151
6	C	F	-0.0148	0.97	0.0141
7	F	G	-0.0133	0.73	0.0157
8	C	D	0.0268	0.76	0.0141
9	D	E	-0.0041	1.04	0.0148
10	E	F	-0.0055	0.77	0.0157
11	F	K	-0.0213	0.42	0.0140

STD. ERROR OF OBS. OF UNIT WEIGHT= 0.0182 ✓

MOFFITT AND BOUCHARD (1975)

$v_1 = +0.003$ ft $v_5 = +0.008$ ft $v_9 = -0.004$ ft
$v_2 = -0.005$ ft $v_6 = -0.015$ ft $v_{10} = -0.006$ ft
$v_3 = -0.018$ ft $v_7 = -0.013$ ft $v_{11} = -0.021$ ft
$v_4 = -0.016$ ft $v_8 = +0.027$ ft

For this level network, the standard error of unit weight is ± 0.018 ft. The standard error of the measured DE's can then be found

$\sigma_1 = \pm 0.022$ ft $\sigma_5 = \pm 0.020$ ft $\sigma_9 = \pm 0.018$ ft
$\sigma_2 = \pm 0.019$ ft $\sigma_6 = \pm 0.018$ ft $\sigma_{10} = \pm 0.020$ ft
$\sigma_3 = \pm 0.021$ ft $\sigma_7 = \pm 0.021$ ft $\sigma_{11} = \pm 0.028$ ft
$\sigma_4 = \pm 0.019$ ft $\sigma_8 = \pm 0.021$ ft

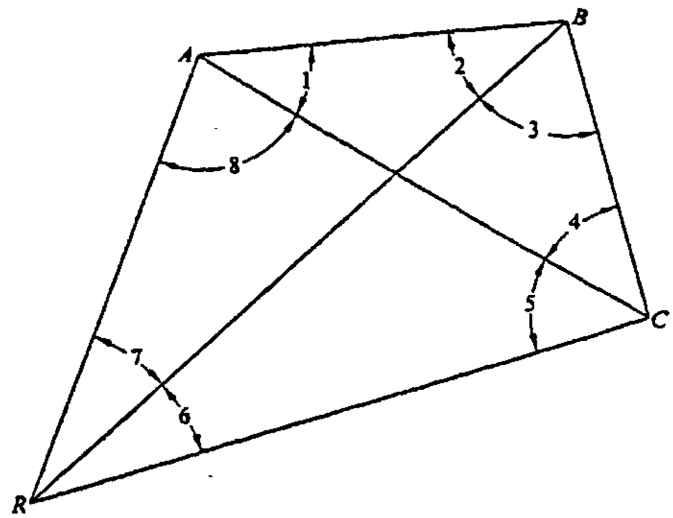
FIGURE F.5: EXAMPLE #2

F.3 Example #3 - Horizontal Adjustment

A comparison was made between the program LSQADJ and the published results of a horizontal adjustment by Moffitt and Bouchard, 1975. The example chosen was Example A.5, pp 797, loc cit. The results of the adjustments from LSQADJ and Moffitt and Bouchard are given in Figures F.6 and F.7.

Figure F.6 illustrates the quadrilateral to be adjusted and partial results of the adjustments. The results agree very closely, but not exactly, i.e., the Y-coordinate of C disagrees by 0.03 ft. This disagreement is due to the round-off error in the results of Moffitt and Bouchard. The primary source is the conversion between radians and seconds. Moffitt and Bouchard use 4.85×10^{-6} radians per second. LSQADJ use a more accurate value of $\frac{1}{206264.81} = 4.8481368 \times 10^{-6}$ radians per second. The point is that Moffitt and Bouchard work with 8 significant figures and LSQADJ use 16 significant figures. However, Moffitt and Bouchard are not consistent during formation of the observation equations since the values of cosine are expressed to 5 significant figures and the final observation equations to 3 significant figures. A large amount of accuracy was also undoubtedly lost in the inversion of the A^TPA matrix. This round-off error could easily account for a slight disagreement in the eighth significant figure. Figure F.7 shows that the agreement between the residuals is almost exact, i.e., to within 0.16 seconds.

This comparison indicates that the horizontal portion of the LSQADJ program works correctly. Any disagreement can only be due to round off error in the adjustment by Moffitt and Bouchard.



Quadrilateral to be adjusted by variation of coordinates.

1. 40° 08′ 17.9″
2. 44° 49′ 14.7″
3. 53° 11′ 23.7″
4. 41° 51′ 09.9″
5. 61° 29′ 34.3″
6. 23° 27′ 51.2″
7. 23° 06′ 37.3″
8. 71° 55′ 49.0″

LSQADJ

STATION NAME	PRELIMINARY X-COORDINATE	Y-COORDINATE	FINAL ADJUSTED X-COORDINATE	Y-COORDINATE
C	530279.2400	478351.1200	530279.1409	478350.8570
R	486460.0000	457042.9400	486461.0077	457045.9230

MOFFITT AND BOUCHARD (1975)

Approx X_C = 530,279.24
−0.10
Adjusted X_C = 530,279.14

Approx Y_C = 478,351.12
−0.30
Adjusted Y_C = 478,350.82

Approx X_R = 486,460.00
+1.00
Adjusted X_R = 486,461.00

Approx Y_R = 457,042.94
+3.00
Adjusted Y_R = 457,045.94

FIGURE F.6: EXAMPLE #3

LSQADJ

ANGLE NUMBER	AT STATION	FROM STATION	TO STATION	RESIDUAL (CALC-OBS) (SECONDS)
1	A	B	C	-0.45
2	B	R	A	-3.85
3	B	C	R	0.49
4	C	A	B	-2.39
5	C	R	A	3.60
6	R	B	C	-0.81
7	R	A	B	4.77
8	A	C	R	0.63

MOFFITT AND BOUCHARD (1975)

$v_1 = -0.51''$ $v_5 = +3.44''$

$v_2 = -3.75''$ $v_6 = -0.64''$

$v_3 = +0.37''$ $v_7 = +4.67''$

$v_4 = -2.31''$ $v_8 = +0.69''$

FIGURE F.7: EXAMPLE #3

F.4 Example #4 - Error Ellipses

A comparison was made between the program LSQADJ and an adjustment by the Horizontal Control Section, (1974). The example chosen is Example #1, pp 5A, Standards for Cadastral Surveys, (loc cit). The results of the Horizontal Control Section and LSQADJ are presented in Figures F.8 and F.9, respectively.

Figure F.8 shows the 95% error ellipse calculated by the Horizontal Control Section using an approximation technique. The 95% error ellipse calculated by LSQADJ is shown on Figure F.9. The magnitude and orientation of the two error ellipses agree almost exactly. Any disagreement is due to the fact that the Horizontal Control Section used an approximation technique.

The close agreement indicates that the program LSQADJ calculates the error ellipses correctly with respect to both magnitude and direction.

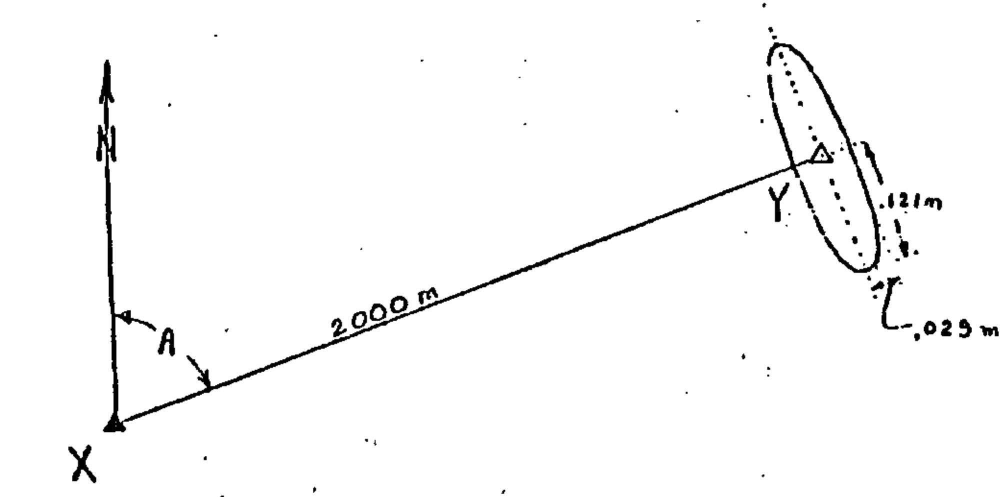


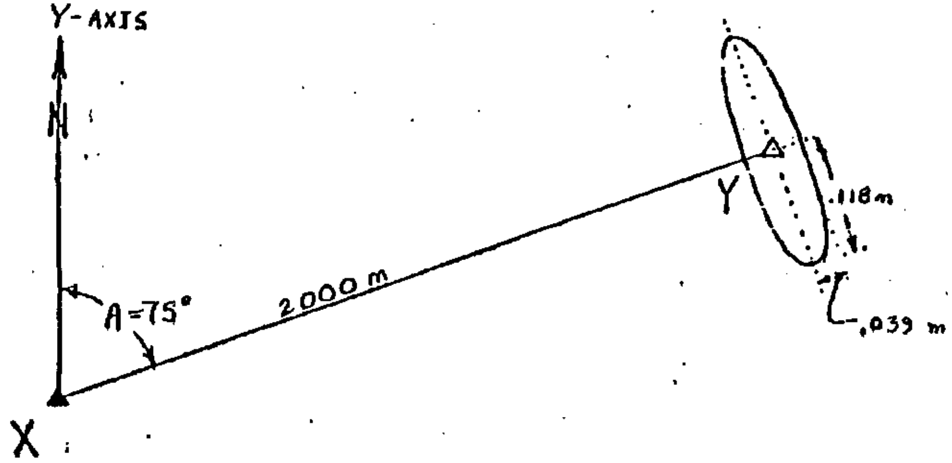
FIGURE F.8: EXAMPLE #4

In the above simple example, if the azimuth A were to be measured with a technique having a standard deviation of 5", the 95% confidence region of the position of Y relative to the position of X would have a semi axis perpendicular to XY of:

$$2\ 1/2 \times 5'' \times \sin 1'' \times 2000\ m = 0.121 \text{ metres}$$

If the distance XY were to be measured with a technique having a standard deviation of (±1 cm ± 3 ppm), the 95% confidence region of the position of Y relative to the position of X would have a semi axis in the direction of XY of:

$$2\ 1/2 \times \sqrt{.01^2 + (3 \times 2000 \times 10^{-6})^2} = 0.029 \text{ metres}$$



***** ERROR ELLIPSE AI ***** STATION NUMBER	STATION NAME	TYPE	******* RELATIVE TO ******* STATION NUMBER	STATION NAME	TYPE	DEGREES OF FREEDOM
3	Y	0	1	A	1	0

MAJOR AXIS	MINOR AXIS	ORIENTATION OF MAJOR AXIS CW FROM Y-AXIS
0.2373	0.0783	164.9999 DEGREES

FIGURE F.9: EXAMPLE #4