**Maine Geological Survey**

**DEPARTMENT OF CONSERVATION**

Walter A. Anderson, State Geologist


# OPEN-FILE NO. 85-76

**Title:** St. Croix Region Crustal Strain Study


**Author:** David Tyler and Alfred Leick


**Date:** 1985


**Financial Support:** Preparation of this report was supported by funds furnished by the Nuclear Regulatory Commission, Grant No. NRC-G-04-82-009.




**Contents:** 22 page report

## INTRODUCTION

In the spring of 1982 engineers from a consulting geology and soils engineering firm brought to the attention of the Maine Geological Survey what they believed to be evidence of horizontal crustal motion in the vicinity of Grand Falls Dam on the St. Croix River. The evidence was based on foundation problems encountered at the dam site and a resurvey of International Boundary Commission (IBC) stations by a local survey firm (Anderson, 1982). The movement was described as being as much as 11 feet since about 1900.

The present study was undertaken to determine the strain regime in the area of the reported movement. Rather than focusing on local survey data, this study has concentrated on existing and new survey data for a network of geodetic stations located 10 or more miles away from the dam site. If there is crustal motion of the magnitude suggested, an indication of the regional strain rates should emerge from a study of the distant stations.

The original plan was to study the repeated triangulation data in the vicinity of the quadrilateral formed by stations Rye, Neal, Oak and Chamcook shown in Figure 1. These stations were first established by the U.S. Coast and Geodetic Survey (C&GS), now the National Geodetic Survey (NGS), between 1857 and 1890. Survey crews from the C&GS and NGS have worked in this region in 1859, 1887, 1890, 1917, 1928, 1946, 1963, and 1975. Unfortunately these repeat surveys were performed for the purpose of extending the control network and not to monitor suspected crustal motion. No attempt was made to remeasure directions or angles that had been measured previously. For this reason the record of triangulation data is not directly useful for detecting earth movement.

In August, 1983 a survey crew from Geo-Hydro Inc. and the University of Maine attempted a resurvey of the four station quadrilateral shown in Figure 1. The survey crew was equipped with three Macrometer satellite receivers and the associated equipment to perform precise satellite positioning survey work. In spite of repeated requests and an apparent agreement, the owner of the land on which station Chamcook is located denied the survey crew access to the station. The crew did succeed in occupying stations Rye, Neal and Oak on two nights. The geodetic analysis of crustal deformation must at this point rest on a comparison of these macrometer observations with the earlier triangulation surveys.

## MACROMETER SURVEY

The Macrometer is one of several surveying instruments that have been developed to make use of the Navstar Global Positioning System (GPS) for geodetic surveying. The GPS will eventually include a constellation of 18 satellites. In August of 1983, when the St. Croix survey was completed, there were six GPS satellites in orbit. Even with only six satellites, it is possible to achieve first order accuracy using a three hour period of observation with the Macrometer.

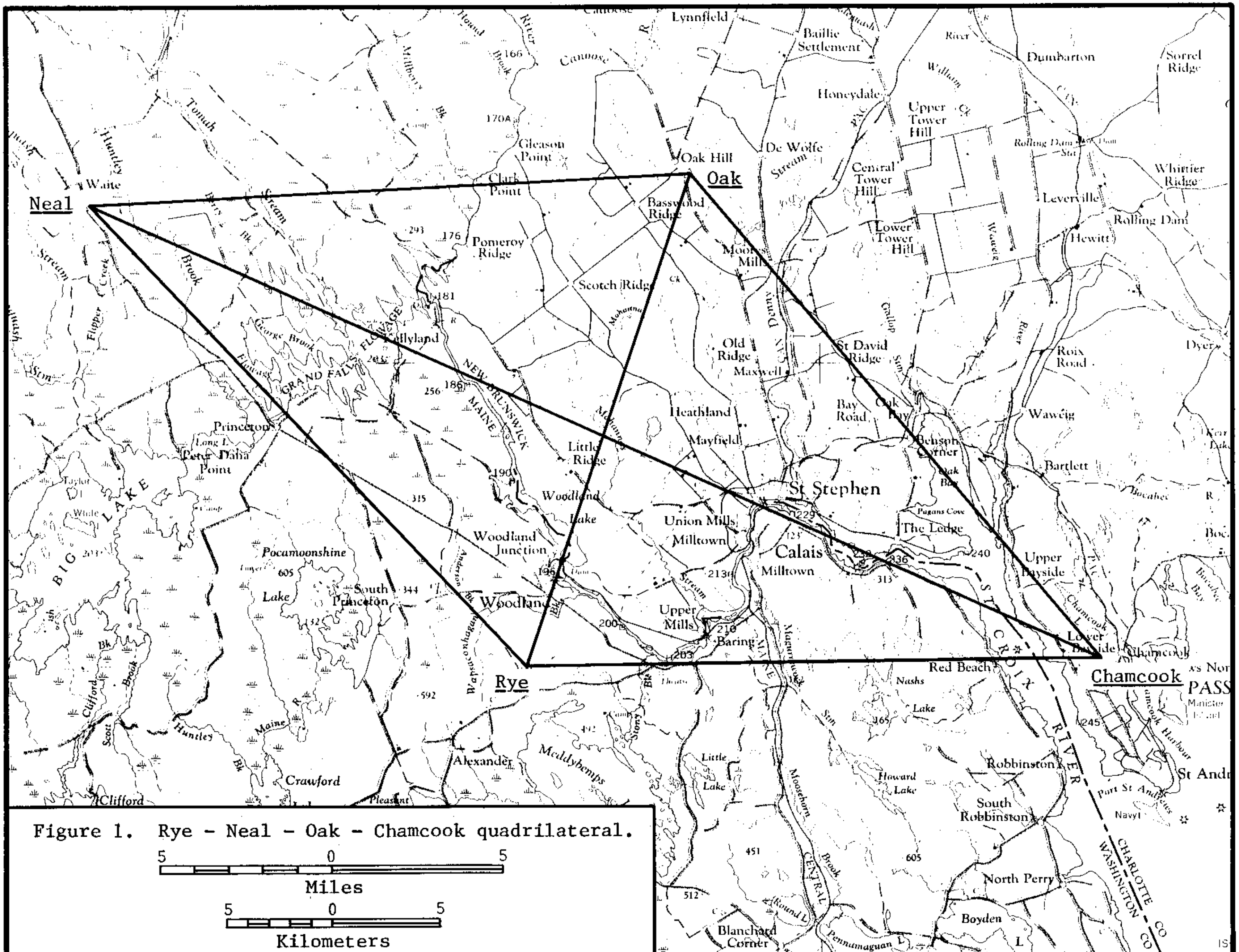


Figure 1. Rye - Neal - Oak - Chamcook quadrilateral.

The parameter that is measured with the Macrometer is a phase difference between a signal received from a GPS satellite and a reference signal generated within the receiver at a series of epochs (Leick, 1984). For relative positioning, the phases measured simultaneously at two or more stations for the same satellite are differenced, producing the so-called singly differenced observable. These single differences are differenced for the same epoch but for different satellites to form double differences. The double differences are further processed to produce least squares estimates of vectors between occupied stations. During the St. Croix survey, three stations, Rye, Neal and Oak, were occupied simultaneously. The resulting observations were reduced to vectors in cartesian coordinates between the three stations by Yehuda Bock at MIT.

It is, of course, difficult to obtain a clear and unambiguous picture of a possible regional pattern of deformation with only three stations. When all possible comparisons between the Macrometer survey and the earlier NGS survey data had been made, the results were sent to the NGS to obtain an independent opinion and interpretation. The computations made and the letter to the NGS is attached as Appendix A. The NGS response is attached as Appendix B. The salient points of the comparison are summarized below:

1) In 1975, the distance between stations Neal and Oak was measured with a Model 8 Geodimeter. The reduced mark-to-mark distance was 27,965.914 meters. The adjusted 1983 Macrometer distance between these two stations was 27,965.753 meters. The difference between the two measurements is 161 mm. The NGS estimates the standard error in their Geodimeter measurement to be 32 mm. The standard error of the Macrometer measurement developed from the adjustment of the triangle is 9 mm. Because only a single triangle was involved in the adjustment, this value may be somewhat optimistic. A recent survey of a 20 station network in Germany with the same instruments used on the St. Croix survey yielded standard errors of 1 to 2 parts per million (Bock et al., 1984). This would amount to from 30 to 60 mm for the line in question. The observing conditions experienced on the St. Croix survey were not as ideal as those on the German network. The errors may therefore be somewhat larger than 30 to 60 mm. Even with the uncertainty in the estimate of accuracy for the Macrometer measurement, the difference between the 1975 Geodimeter and the 1983 Macrometer measurements appears too large to be explained by error.

2) Geodetic latitudes and longitudes were computed with the NGS triangulation data and with the Macrometer data. The lengths of geodesic lines between the three stations and the angles between the geodesic lines were computed for each set of data. Figure 2 shows the differences with the signs in the sense of Macrometer minus NGS data. Edward McKay in his letter (see Appendix B), estimates that angle changes of 3.5 seconds are the maximum that should be expected. McKay mentions a scale problem with the network in the St. Croix area that could cause consistent length errors of up to one half meter. The differences in both angles and distances are significantly larger than can be easily explained with measurement errors.

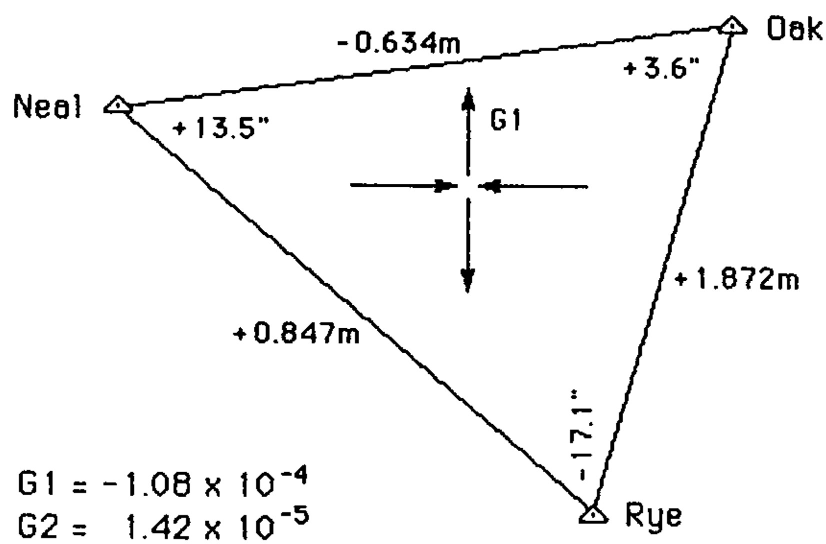


Figure 2. Difference in distances and angles in the sense of Marcometer (1983) minus triangulation (1890) survey data. Strain shown is based on angles only.

## STRAIN COMPUTATION

The Macrometer measurements can be compared to the earlier triangulation measurements to deduce crustal strains, but this must be done with caution. As described above, the Macrometer observations are used to compute vectors between two or more occupied stations. The vectors can be projected onto the ellipsoid and projected lengths (geodesics) can be computed. In the triangulation survey, directions or angles between stations are observed. Somewhere in the network of interconnected triangles, one or more distances are measured to provide scale for the network. It is possible to directly compare geodesic lengths computed by the two techniques to compute dilation but, as already noted, there may be a regional scale problem in the triangulation data.

The inter-station vectors based on the Macrometer observations can be used to compute relative geodetic positions and angles between geodesic lines. These computed angles can be compared to the observed angles from the triangulation survey to obtain an estimate of shear strain but not of dilation or rotation. This approach eliminates the influence of any scale errors in the triangulation data.

F. C. Frank has developed a method for computing the shear components of strain from repeated observations of the three angles of a single triangle (Frank, 1966). Frank's method has been applied to the Rye-Neal-Oak triangle with the following results:

$$G1 = -1.08 \times 10^{-4}$$
$$G2 = 1.42 \times 10^{-5}$$
$$Gm = 1.09 \times 10^{-4}$$

G1 measures a pure shear corresponding to east-west stretching and north-south compression, while G2 measures a pure shear corresponding to NE-SW stretching and NW-SE compression. Gm is the square root of the sum of the squares of G1 and G2 and is the total shear strain. In this triangle G1 dominates. The negative sign of G1 implies extension in the north-south direction and compression in the east-west direction. The maximum extension occurs along a line with an azimuth of 4 degrees from north. Because dilation cannot be deduced from angle changes alone, a value of the maximum extension cannot be computed.

In a triangle that is reasonably close to an equilateral triangle, as the Rye-Neal-Oak triangle is, an angular error of 1 second will produce an erroneous strain of as much as $9.0 \times 10^{-6}$. The NGS estimates that 3.5 seconds is the maximum error to be expected in the triangulation angles (see Appendix B). The anticipated errors of 30 mm to 60 mm in the Macrometer measurements would introduce angular errors considerably smaller than the 3.5 seconds expected in the triangulation data. For these reasons, the accumulation of error does not explain the computed crustal strain.

## SUMMARY

The data gathered and analyzed in this study do not provide unequivocal evidence of horizontal crustal deformation. A single triangle simply cannot yield enough information. However, the results do indicate a strong possibility of significant crustal motion. A more extensive study will be required to positively define what is happening.

If a further study of crustal deformation in this region is attempted, it is probably not wise to devote much time to the old NGS triangulation data. There do not appear to be any useful repeated direction or angle measurements. Any use of the old data would, therefore, require resurvey of the existing stations. These triangulation stations are often located in places difficult to reach because of the original survey requirements. Today's satellite receivers do not require intervisibility between stations, but only require a clear view of the sky.

A second generation "dual-frequency" Macrometer is presently in the testing stage. This instrument receives signals from the satellites on two frequencies and uses the dual frequency information to eliminate the influence of ionospheric refraction on the measurements. These instruments will be able to measure a vector between two stations to an accuracy of 10 mm or less independent of the distance. If the strain computed in the Rye-Neal-Oak triangle is a realistic value and if the strain has been accumulating at a fairly uniform rate over the approximately 100 years of record, survey networks repeatedly measured with the second-generation Macrometers at intervals of as little as one or two years will define the pattern of crustal deformation.

A network of perhaps a dozen stations set in bedrock at sites selected to ease access and to optimize the strain computation could be put in place and surveyed initially this year. A resurvey in 1986 would yield a great deal of information at a reasonable cost.

REFERENCES

Anderson, Walter A., 1982, Maine Geological Survey, personal communication.

Bock, Y., Abbot, R. I., Counselman, C. C., Gourevitch, R. W., King, R. W., and Leick, A., 1984, Three-Dimensional, 1-2ppm Survey of a Twenty Station Network via Interferometry with GPS: presented at the AGU Spring Meeting, Cincinnati, Ohio, May 14-17, 1984.

Frank, F. C., 1966, Deductions of Earth Strains from Survey Data: Bull. Seismol. Soc. Am., v. 56, p. 35-42.

Leick, Alfred, 1984, Macrometer Satellite Surveying: presented at the FIG Engineering Surveys Conference, Washington, D.C., March 10-11, 1984.

UNIVERSITY OF MAINE *at Orono*

**Department of Civil Engineering**

**103 Boardman Hall**
**Orono, Maine 04469**
**207/581-2561**

February 14, 1984

Mr. Jim Annis
National Geodetic Survey
Room 1026
6001 Executive Blvd.
Rockville, Maryland 20852

Dear Mr. Annis:

In the Spring of 1982 engineers from a consulting geology and soils engineering firm brought to the attention of the Maine Geological Survey what they believed to be evidence of horizontal crustal motion in the vicinity of Grand Falls Dam on the St. Croix River, north of Woodland, Maine. The evidence was based on foundation problems encountered at the dam site and a resurvey of International Boundary Commission (IBC) stations by a local survey firm. The resurvey indicated movement of as much as 11 feet since approximately 1900. I have not examined the IBC resurvey data.

We at the University of Maine were contacted by scientists from the Maine Geological Survey and asked to see if we thought recent crustal motion in the area was possible. The quadrilateral, NEAL, OAK, CHAMCOOK, RYE showed the area of suspected movement. We decided to look at these stations first rather than the IBC traverse station near the dam. We were skeptical that 11 feet of movement could have occurred but we thought if any significant movement had taken place, we should detect it in this quadrilateral.

For a variety of reasons we were unable to get into the field until the summer of 1983. For three days last August we were in the field with three Macrometer units operated by a field crew from GEO-HYDRO Inc. We were able to occupy stations Neal, Oak and Rye. A land owner would not allow access to station Chamcook. The tapes from the Macrometer observation were post processed at M.I.T.

Ms. Elizabeth Wade, of NGS, provided lists of observed directions from the four stations for all occupation dating back to 1859. We had originally hoped these would be enough triangulation data to allow at least a preliminary computation of strain rate but this was not the case. We are left with the Macrometer data and the observed directions to evaluate.

A comparison of the two data sets in every meaningful way we could think of is enclosed. We are at a loss as to how to interpret the results. You will find a number of questions as to the explanation of the enclosed computations. We would appreciate your thought on these questions.

Sincerely,

David A. Tyler
Associate Professor
Surveying Engineering

DAT:cs
Enclosures

## MINIMAL CONSTRAINT SOLUTION

Output DT4MAC shows the minimal constraint solution of the triangle Neal-Oak-Rye. The Macrometer observations are those as reduced at M.I.T. during post processing. The geodetic latitude, longitude, and height were converted to cartesian coordinates using the size of the M.I.T. adopted ellipsoid. The adjustment of the triangle was formulated in terms of cartesian coordinates. Minimal constraints were established by fixing all three station coordinates of Neal (1) using the published NGS values. The standard deviations of the observed coordinate differences were computed from the values listed in the M.I.T. output for the geodetic coordinates.

It has been assumed that all three vectors are stochastically independent. The reason for the slight misclosure of the triangle (sum of coordinate differences) is likely the fact that not every vector has been determined from the same pool of double difference observations.

## SPATIAL DISTANCE NEAL (1) - OAK (2)

Output DT5PROP shows among other things the adjusted spatial distances as computed from the minimal constraint adjustment. The adjusted distance NEAL (1) - OAK (2) is: 27965.753 m. NGS lists for the 1975 measurement of the same distance from mark to mark the following value: 27965.914 m.

Would it be possible for NGS to find out with which instrument this distance was measured and whether the resulting difference of 159 mm could be within the noise range of that instrument?

## ADJUSTING NGS ANGLES ON THE ELLIPSOID

Output DT7 shows the adjustment on the ellipsoid of the three NGS angles reduced to the geodesics. Only station OAK (2) has been adjusted. The observations are treated with equal weight due to lack of other information.

It is observed that the residuals are -0.04 seconds, which is very small considering the observation techniques of that time. Could it be possible that these (reduced) observations have been "corrected" by the field team in order to add up to 180 degrees plus the spherical excess? Is there any other reason to believe that these angles do not represent the original observations?

It is also observed that the adjusted position of OAK (2) agrees surprisingly well with the published NGS position for that point. The NGS positions were held fixed for stations NEAL (1) and RYE (3). It appears that the observations in the neighborhood of the triangle NEAL-OAK-RYE had no effect on the triangle during the adjustment. Is this possible?

## MACROMETER ELLIPSOIDAL POSITIONS

Output DT9DIR shows the lengths of the geodesics and the azimuths of the geodesics as computed from the Macrometer observations. For this purpose the adjusted ellipsoidal positions of DT4MAC were used.

The length of the geodesic NEAL (1) - OAK (2) is computed as 27965.0764 m. NGS lists this length for the 1975 measurement as 27965.210 m. The difference is 133 mm. Recall that there was a difference of 159 mm for the spatial distance from mark to mark. The difference in the differences is likely caused by slightly different heights used in the reduction of the spatial distance.

## LENGTH AND AZIMUTHS FOR NGS DATA

Output DT11DIR shows the lengths and azimuths of the geodesics based on the NGS angle observations, and based on the adjustment listed in DT7.

The data of DT11DIR and DT9DIR are used to compare the lengths and the angles between the geodesics. Figure 1 shows the difference in the sense of (MAC-NGS). As can be seen these differences are substantial. Considering the experience of NGS with old observations, are these differences within what can be typically expected? Could it be that these differences are due to a possible remonumentation?

## THE 1890 POSITION OF OAK

The published 1890 position of OAK differs significantly from the 1917 position. Is there any explanation for this difference?

## THE HEIGHT OF NEAL

The orthometric height of station NEAL differs significantly for the years 1890, 1928 and 1975. Is there any explanation for this?

A D J U S T M E N T
OF
MACROMETER NET

SEMI-MAJOR AXIS 6378206.400
INV. FLATTENING 294.980000

| STAT | LATITUDE | LONGITUDE | HEIGHT |
|---|---|---|---|
| 1 | 45 18 59.7190 | 292 18 57.2530 | 131.200 |
| 2 | 45 19 43.8763 | 292 40 19.7517 | 173.533 |
| 3 | 45 7 23.7817 | 292 34 28.3725 | 180.504 |

| STATION | | TARGET | INSTR | OBSERVATION | ST.DEV | CORRELATION MATRIX | | |
|---|---|---|---|---|---|---|---|---|
| 3 | 1 | 0.000 | 0.000 | 24612.885 | 0.011 | 1.00 | -0.65 | 0.45 |
| | | | | -6370.266 | 0.021 | | 1.00 | -0.59 |
| | | | | -15098.570 | 0.022 | | | 1.00 |
| 2 | 1 | 0.000 | 0.000 | 25447.879 | 0.018 | 1.00 | -0.65 | 0.57 |
| | | | | 11554.717 | 0.034 | | 1.00 | -0.75 |
| | | | | 988.609 | 0.036 | | | 1.00 |
| 2 | 3 | 0.000 | 0.000 | 835.013 | 0.101 | 1.00 | 0.22 | 0.09 |
| | | | | 17924.924 | 0.081 | | 1.00 | -0.26 |
| | | | | 16087.119 | 0.077 | | | 1.00 |

| ST | ST | OBSERVATION MARK TO MARK | RESIDUAL | ADJ. OBS |
|---|---|---|---|---|
| 3 | 1 | 24612.885 | -0.001 | 24612.884 |
| | | -6370.266 | 0.002 | -6370.264 |
| | | -15098.570 | 0.002 | -15098.568 |
| 2 | 1 | 25447.879 | 0.002 | 25447.881 |
| | | 11554.717 | -0.004 | 11554.713 |
| | | 988.609 | -0.004 | 988.605 |
| 2 | 3 | 835.013 | -0.016 | 834.997 |
| | | 17924.924 | 0.052 | 17924.976 |
| | | 16087.119 | 0.053 | 16087.172 |

NO. OF OBSERVATIONS 9
NO. OF PARAMETERS 6
DEGREE OF FREEDOM 3
A-POSTERIORI VARIANCE OF UNIT WEIGHT 0.53288164D+00
VPV 0.15986449D+01

ADJUSTED STATION POSITIONS

| STAT | LATITUDE | ST.DEV X (M) | LONGITUDE | ST.DEV Y (M) | HEIGHT | ST.DEV Z (M) |
|---|---|---|---|---|---|---|
| 1 | 45 18 59.7190 | | 292 18 57.2530 | | 131.200 | |
| 2 | 45 19 43.8761 | 0.013 | 292 40 19.7516 | 0.022 | 173.533 | 0.024 |
| 3 | 45 7 23.7819 | 0.008 | 292 34 28.3724 | 0.015 | 180.504 | 0.016 |

CORRELATION MATRIX

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 1, 1= | 1.00 | | | | | | | | |
| 2, 1= | -0.60 | 2, 2= | 1.00 | | | | | | |
| 3, 1= | 0.52 | 3, 2= | -0.71 | 3, 3= | 1.00 | | | | |
| 4, 1= | 0.08 | 4, 2= | -0.10 | 4, 3= | 0.08 | 4, 4= | 1.00 | | |
| 5, 1= | -0.09 | 5, 2= | 0.13 | 5, 3= | -0.11 | 5, 4= | -0.63 | 5, 5= | 1.00 |
| 6, 1= | 0.08 | 6, 2= | -0.11 | 6, 3= | 0.13 | 6, 4= | 0.44 | 6, 5= | -0.58 |
| 6, 6= | 1.00 | | | | | | | | |

SPATIAL DISTANCE ST.DEV
27965.753 0.009

adj. dist.
based on DT4 MAC

TIAL DISTANCE ST.DEV
29569.259 0.008

SPATIAL DISTANCE ST.DEV
24099.774 0.015

STANDARD DEVIATION STATION: 2

| NORTHING(M) | EASTING(M) | ELL.HEIGHT(M) |
|---|---|---|
| 0.127D-01 | 0.942D-02 | 0.311D-01 |

CORRELATION MATRIX

| | | |
|---|---|---|
| 1.00 | 0.00 | -0.00 |
| 0.00 | 1.00 | -0.00 |
| -0.00 | -0.00 | 1.00 |

STANDARD DEVIATION STATION: 3

| NORTHING(M) | EASTING(M) | ELL.HEIGHT(M) |
|---|---|---|
| 0.216D-01 | 0.154D-01 | 0.205D-01 |

CORRELATION MATRIX

| | | |
|---|---|---|
| 1.00 | -0.52 | -0.86 |
| -0.52 | 1.00 | 0.50 |
| -0.86 | 0.50 | 1.00 |

ADJUSTMENT ON THE E L L I P S O I D *NGS angles*

DUE TO CONTINUOUSLY CHANGING CURVATURE OF THE ELLIPSOIDAL SURFACE MINIMAL AND INNER CONSTRAINT SOLUTIONS (AS USED IN THE ADJUSTMENT OF PLANE CONFIGURATIONS) ARE, STRICTLY SPEAKING, NOT PERMISSIBLE

APPROXIMATE COORDINATES AND REFERENCE ELEMENTS

| STA. | STA. | LATITUDE | LONGITUDE | ORTHO. HEIGHT | GEOID UNDUL. | DEFLECT. VERT. XI | ETA |
|---|---|---|---|---|---|---|---|
| 1 | 1 | 45 18 59.7190 | 292 18 57.2530 | 0.0 | 0.0 | 0.000 | 0.000 |
| -2 | -2 | 45 19 43.8763 | 292 40 19.7517 | 0.0 | 0.0 | 0.000 | 0.000 |
| 3 | 3 | 45 7 23.8360 | 292 34 28.3970 | 0.0 | 0.0 | 0.000 | 0.000 |

SEMI-MAJOR AXIS = 6378206.400 METERS
FINV = 294.980000

O B S E R V A T I O N S

| STA. | STA. | STA. | OBSERVATION | SIGMA LB |
|---|---|---|---|---|
| 2 | 1 | 3 | 49 25 34.93 | 0 0 3.0 |
| 1 | 3 | 2 | 61 49 29.37 | 0 0 3.0 |
| 3 | 2 | 1 | 68 44 57.40 | 0 0 3.0 |

OBSERVATIONS REDUCED TO THE ELLIPSOID

| STATION | STATION | STATION | OBSERVATION | SIGMA LB |
|---|---|---|---|---|
| 2 | 1 | 3 | 49 25 34.93 | 0 0 3.0 |
| 1 | 3 | 2 | 61 49 29.37 | 0 0 3.0 |
| 3 | 2 | 1 | 68 44 57.40 | 0 0 3.0 |

O U T P U T

ITR 1 DVPV= 0.4D-03 SIG.DIGITS=16.0 AT 2
ITR 2 DVPV= 0.1D-06 SIG.DIGITS=16.0 AT 2

FL=1
STA STA STA OBSERVATION RESIDUAL ADJUSTED OBS (TAU 5)

| | | | | | | |
|---|---|---|---|---|---|---|
| 2 | 1 | 3 | 49 25 34.93 | 0 0 -0.04 | 49 25 34.90 | 1 |
| 1 | 3 | 2 | 61 49 29.37 | 0 0 -0.04 | 61 49 29.33 | 1 |
| 3 | 2 | 1 | 68 44 57.40 | 0 0 -0.04 | 68 44 57.36 | 1 |

| | | |
|---|---|---|
| NO. OF OBSERVATIONS | 3 | |
| NO. OF PARAMETERS | 2 | |
| NO. OF OBSERVED PARAMETERS | 0 | |
| NO. OF CONDITIONS | 0 | |
| DEGREE OF FREEDOM | 1 | |
| A-POSTERIORI VARIANCE OF UNIT WEIGHT | | 0.43465464D-03 |
| VPV | | 0.43465464D-03 |

CHISQ OF 1 DEGREES OF FREEDOM IS 0.0004

TABULATED VALUE 0.004 3.840

R E J E C T HO AT 10 SIGNIFICANCE LEVEL

ADJUSTED STATION POSITIONS

| STATION | LATITUDE | ST.DEV | LONGITUDE | ST.DEV |
|---|---|---|---|---|
| 1 | 45 18 59.7190 | | 292 18 57.2530 | |
| 2 | 45 19 43.8650 | 0 0 0.0002 | 292 40 19.7815 | 0 0 0.0003 |
| 3 | 45 7 23.8360 | | 292 34 28.3970 | |

ADJUSTED OBSERVATIONS REDUCED B A C K TO THE SURFACE

| STA. | STA. | STA. | OBSERVATION |
|---|---|---|---|
| 2 | 1 | 3 | 49 25 34.894 |
| 1 | 3 | 2 | 61 49 29.334 |
| 3 | 2 | 1 | 68 44 57.364 |

```
------------INPUT---------
PHI1 =      45   18   59.71900
LAMDA1 = 292   18   57.25300
PHI2 =      45   19   43.87610
LAMDA2 = 292   40   19.75160


-----------OUTPUT---------
GEODESIC DISTANCE =                        27965.0764 METERS
AZIMUTH FROM BEGINNING STATION =   87    4   45.42716
AZIMUTH FROM REMOTE STATION =        267   19   57.38562

------------INPUT---------
PHI1 =      45   18   59.71900
LAMDA1 = 292   18   57.25300
PHI2 =      45    7   23.78190
LAMDA2 = 292   34   28.37240


-----------OUTPUT---------
GEODESIC DISTANCE =                        29568.5208 METERS
AZIMUTH FROM BEGINNING STATION =  136   30   33.79775
AZIMUTH FROM REMOTE STATION =        316   41   34.72252

------------INPUT---------
PHI1 =      45    7   23.78190
LAMDA1 = 292   34   28.37240
PHI2 =      45   19   43.87610
LAMDA2 = 292   40   19.75160


-----------OUTPUT---------
GEODESIC DISTANCE =                        24099.1172 METERS
AZIMUTH FROM BEGINNING STATION =   18   30   46.94506
AZIMUTH FROM REMOTE STATION =        198   34   56.38650
```

length } of geodesics : Macrometer
azimuths }

```
------------INPUT---------
 PHI1 =      45  18  59.71900
 LAMDA1 = 292  18  57.25300
 PHI2 =      45  19  43.86500
 LAMDA2 = 292  40  19.78200


-----------OUTPUT---------
 GEODESIC DISTANCE =                      27965.7218 METERS
 AZIMUTH FROM BEGINNING STATION =    87    4   48.17910
 AZIMUTH FROM REMOTE STATION =       267   20    0.15916

------------INPUT---------
 PHI1 =      45  18  59.71900
 LAMDA1 = 292  18  57.25300
 PHI2 =      45   7  23.83600
 LAMDA2 = 292  34  28.39700


-----------OUTPUT---------
 GEODESIC DISTANCE =                      29567.6743 METERS
 AZIMUTH FROM BEGINNING STATION =   136   30   23.07721
 AZIMUTH FROM REMOTE STATION =       316   41   24.01953

------------INPUT---------
 PHI1 =      45   7  23.83600
 LAMDA1 = 292  34  28.39700
 PHI2 =      45  19  43.86500
 LAMDA2 = 292  40  19.78200


-----------OUTPUT---------
 GEODESIC DISTANCE =                      24097.2490 METERS
 AZIMUTH FROM BEGINNING STATION =    18   30   53.44362
 AZIMUTH FROM REMOTE STATION =       198   35    2.88919
```

length } geodesics for NGS adjustment
azimuths } see DT7

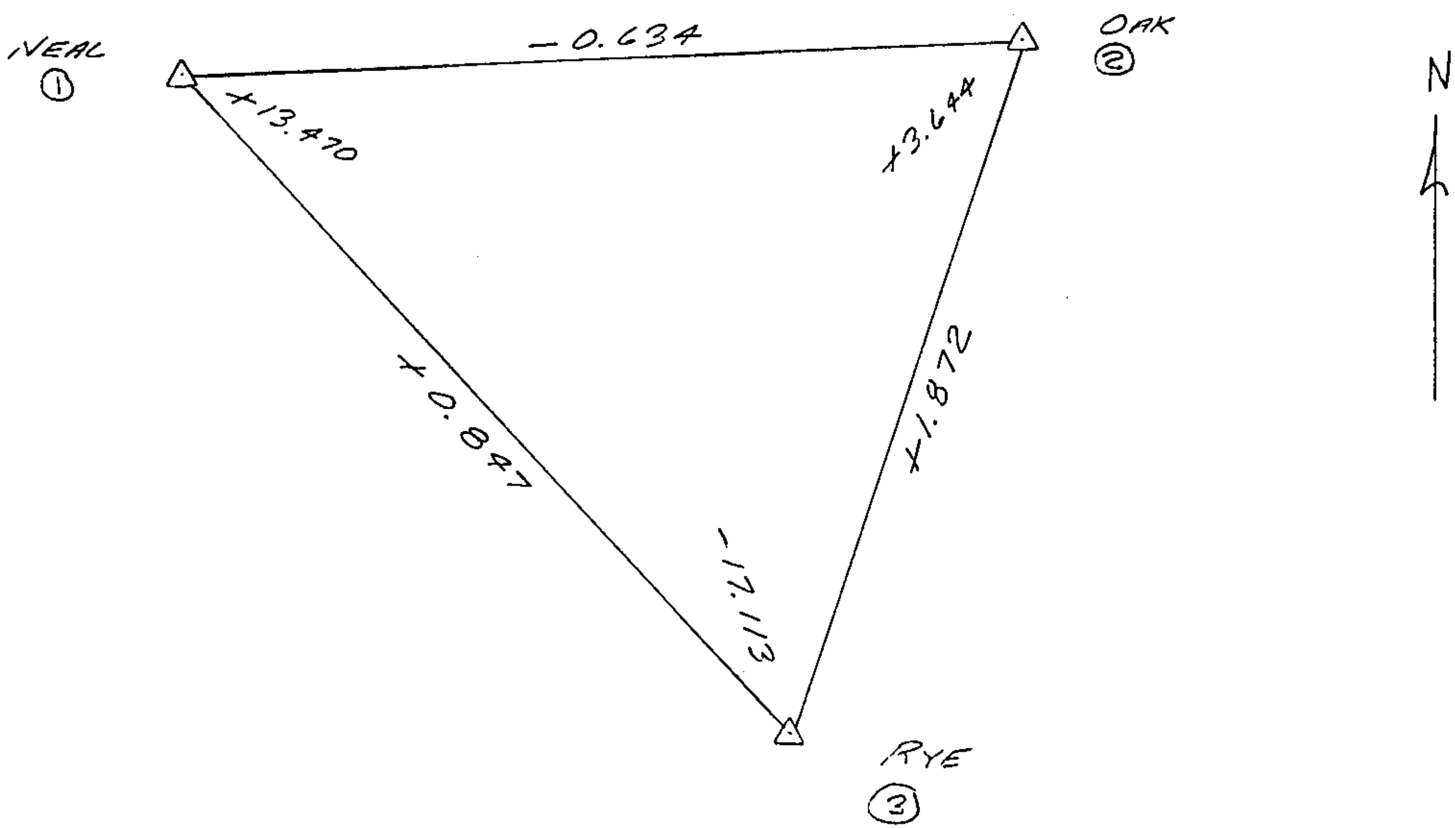


Figure 1 Differences in length (meters) and angle (seconds). (MAC − NGS)

UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL OCEAN SERVICE
OFFICE OF CHARTING AND GEODETIC SERVICES
ROCKVILLE, MARYLAND 20852

May 3, 1984

Professor David A. Tyler
Surveying Engineering
Department of Civil Engineering
103 Boardman Hall
University of Maine
Orono, Maine 04469

Dear Professor Tyler:

Your letter dated February 14, 1984, to Mr. James L. Annis has been forwarded to me for reply. We have reviewed your report and have the following comments.

1. MINIMAL CONSTRAINT SOLUTION

Why was this special M.I.T. ellipsoid chosen? The semi-major axis has the same value as for the Clarke Ellipsoid of 1866, but the inverse flattening is only a close approximation to the Clarke Ellipsoid of 1866. While this change does not affect the comparison between your results because all were referenced to the same ellipsoid, it is a curious value. It also distorts comparison of your results with those we compute or the published values.

2. SPATIAL DISTANCE NEAL(1)-OAK(2)

The 1975 measurement was made with a Model 8 Geodimeter number 80056. The reduced mark-to-mark distance is 27,965.914 meters. Your adjusted MACROMETER spatial distance (which is identical to a mark-to-mark distance) is 27,965.753 meters. The difference between these two is 0.161 meters or 161 millimeters (as opposed to 159 millimeters as mentioned in your report). Distance observations measured with this equipment and following the Federal Geodetic Control Committee specifications have an accuracy of 15 millimeters plus 1.0 part per million (one sigma value). Because the line is 27,966 meters long, the standard error assigned to this measurement is 0.032 meters or 32 millimeters. Therefore, the difference between the MACROMETER and Geodimeter distances is five times the expected accuracy of this measurement.

In addition to NEAL 1887 to OAK 1887, the line NEAL 1887 to VANCE MOUNTAIN 1888 was measured with the same Geodimeter on October 8, 1975, the same day as NEAL 1887 to OAK 1887 was measured, and on October 9, 1975. The two measurements of this distance differed by 61 millimeters. Using the mean distance, NEAL 1887 to OAK 1887 from the two days observations and direction observations computed from geodetic inversed azimuths in a triangle computation, the distance NEAL 1887 to OAK 1887 was computed. The computed value is 152 millimeters shorter than the observed value. This agrees very well with your spacial distance from the MACROMETER observations.

3. ADJUSTING NGS ANGLES ON THE ELLIPSOID

The adjustment of the triangle NEAL 1887 - OAK 1887 - RYE 1867 was really unnecessary. The least-squares adjustment of a single triangle is simply the triangle closure divided by three and this correction applied equally to each angle. To the best of our knowledge, the direction observations provided were NOT "corrected" in order to have the angles in the triangle add up to 180 degrees plus the spherical excess. However, during this period, 1867-1890, the observation technique was to observe single angles at each station and then perform a station adjustment to produce a single list of directions. The station adjustment would not force the triangle closure to be zero, however. The observations previously sent are the original observations.

Your comparison of the adjusted position for OAK 1887 with the NGS published position for that point is again not proper because you did not use the Clarke Ellipsoid of 1866 parameters. It is not surprising that the two positions agree very well because you used the published fixed base, NEAL 1887 to RYE 1867, plus the observations originally used to compute its position. In regards to your question concerning the observations in the neighborhood of the triangle NEAL 1887 - OAK 1887 - RYE 1867 having no effect on the triangle during the adjustment, I have enclosed the minimal constrained adjustment for these 1867-1890 data. As you can see, the overall adjustment did not differ significantly from the original observations.

4. MACROMETER ELLIPSOID POSITIONS

Again, the different ellipsoids may affect the results, both in the transformation of space coordinates to latitude, longitude, and height and in the computation of geodesics and geodetic azimuths. The length of the geodesic, NEAL 1887 to OAK 1887, as computed from the NGS published positions on the Clarke Ellipsoid of 1866 is 27,965.726 meters. The 1975 measured distance, reduced to the ellipsoid is 27,965.210 meters. The difference of 0.516 meters, or 1 part in 54,000, is the network distortion is the area due to a lack of length control when the network was originally readjusted in 1927. The NAD 1983 readjustemnt will remedy the situation because the 1975 measurements will be included in the adjustment

5. LENGTH AND AZIMUTHS FOR NGS DATA

We do not understand why you did the computations with the NGS angle observations. We recommend comparing the MACROMETER observations with the computed lengths and azimuths of the geodesics based on the published NGS values and using the Clarke Ellipsoid of 1866. If any other coordinates, other than NGS published values, are used, then a complete readjustment of ALL NGS observations in the area should have been completed. However, because your triangle adjustment agreed so closely with the published values, you in essence made that comparison. We would not expect differences of the magnitude shown in Figure 1. As mentioned, length changes of approximately one-half meter would seem reasonable, but near the maximum. Angle changes of 2-3 seconds would be acceptable with a value of 3.5 seconds as the maximum allowed. There has been no remonumentation of these three stations.

I recommend performing an investigative adjustment using all of the data in this area. If we do this and make the comparison with the MACROMETER data and still find large differences, we would have to assume that there might be crustal motion, but not on the order of 11 feet.

6. THE 1890 POSITION OF OAK

There are no 1890 and 1917 published positions for OAK 1887. The data sent to you is supposed to contain the current NAD 1927 published positions for all stations. In the 1890 data set, the old U.S. Standard Datum (renamed North American Datum in 1913) position was erroneously used as input. Therefore, you saw the shift from NAD to NAD 1927.

7. THE HEIGHT OF NEAL

There are no 1890, 1928, and 1975 elevations for NEAL 1887. The 1890 and 1928 data sets sent to you contained scaled elevations for station NEAL 1887. These values were scaled from topographic maps in the 1970's when these data were processed for the new adjustment. The large difference is due to the scaling process. We require approximate elevations for all occupied points to compute skew normal corrections to apply to direction observations. The correction is a function of the elevation of the observed point. The current published trigonometric elevation (from vertical angle or zenith distance observations) is 131.2 meters. Also, in 1978, precise leveling observations were performed at station NEAL 1887, and the unadjusted bench mark elevation is 131.28376 meters which checks the previously published trigonometric elevation.

I trust that this answers all of your computational questions. The potential for crustal motion is another matter, but it appears not to have occurred in this area if at all. It certainly would be desirable to have a more extensive set of measurements. I would be glad to discuss this problem further with you. I can be reached at (301) 443-8168.

Sincerely yours,

Edward J. McKay

Edward J. McKay
Assistant Chief
Horizontal Network Branch
National Geodetic Survey

Enclosure

Angle Comparisons

University of Maine MACROMETER vrs. Observed

At NEAL 1887:

| | Univ. of Maine Computed | NGS Computed |
|---|---|---|
| Azimuth to RYE 1867: | 136° 30' 33".80 | 316° 30' 33".80 |
| Azimuth to OAK 1887 | 87 04 45.43 | 267 04 45.42 |
| Computed Angle: | 49° 25' 48".37 | 49° 25' 48".38 |
| Observed Angle: | 49 25 34.93 | |
| Difference: | +13".44 | |

At OAK 1887:

| | Univ. of Maine Computed | NGS Computed |
|---|---|---|
| Azimuth to NEAL 1887: | 267° 19' 57".39 | 87° 19' 57".38 |
| Azimuth to RYE 1867: | 198 34 56.39 | 18 34 56.37 |
| Computed Angle: | 68° 45' 01".00 | 68° 45' 01".01 |
| Observed Angle: | 68 44 57.40 | |
| Difference: | +3".60 | |

At RYE 1867:

| | Univ. of Maine Computed | NGS Computed |
|---|---|---|
| Azimuth to OAK 1887: | 18° 30' 46".95 | 198° 30' 46".93 |
| Azimuth to NEAL 1887: | 316 41 34.72 | 136 41 34.72 |
| Computed Angle: | 61° 49' 12".23 | 61° 49' 12".21 |
| Observed Angle: | 61 49 29.37 | |
| Difference: | -17".14 | |

NOTE: NGS Computed values were computed using University of Maine MACROMETER GP's and NGS' HP41CV inverse program.
University of Maine azimuths are reference from north, NGS azimuths are reference from south.