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Maximized Utility of the Global Positioning System

Sponsored by the Iowa Department of Transportation,
Highway Division, and the Highway Research Advisory Board

Iowa DOT Project HR-316
ERI Project 3131
ISU-ERI-Ames-91208

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Iowa Department of Transportation

Final

report

College of Engineering
Iowa State University

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engineering research institute
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TABLE OF CONTENTS

List of Figures

List of Tables

EXECUTIVE SUMMARY

The Ashtech XII GPS receivers in this project were studied in static, pseudo-static, kinematic, and pseudo-kinematic modes. In order to maximize the utility of GPS, four projects were undertaken: Campus, Des Moines, Iowa, and Mustang. The Campus project shows that, for points within a radius of one mile, the GPS and the method of collocation can determine the elevation of points with an accuracy of ±2 mm. The Des Moines project shows that in an area approximately five miles long, GPS and the method of collocation yields elevation of points with an accuracy of about 3 mm, provided that control points are established along the direction of the project. Accuracy of elevation within ±0.6 m can be obtained for points within a 100-mile radius by using the gravimetric method of determining local undulation. This is demonstrated by the Iowa project.

According to the findings of the Mustang project, for improved accuracy in planimetry and azimuth, a separate adjustment by constraining the known azimuth yields an azimuth accuracy of about 2" and two-dimensional position accuracy of 5 cm. The Mustang project also shows that for points within 30 miles, vertical accuracy of less than 10 cm can be achieved by using GPS data, the Geolab adjustment program, and the method of collocation.

This research also shows that the gravimetric method of computing local undulation is both time-consuming and tedious. The method of collocation for determining local undulation is less time consuming and is also suitable for highway applications. Both Geolab and the collocation method are project oriented. The Iowa DOT personnel were trained to use the GPS and worked along with the ISU research team in all four projects. The use of GPS in phototgrammetry is promising and requires further investigation.

MAXIMIZED UTILITY OF GPS

1.0 INTRODUCTION

This project, begun in Jan. 1989 and completed in Dec. 1990, had the primary objective of obtaining sufficiently accurate horizontal and vertical control by of using Global Positioning System (GPS) for highway applications. The secondary objective was to train the Iowa Department of Transportation (Ia DOT) personnel in GPS operation and computation.

After the research requirements of this project were studied, appropriate specifications for a GPS receiver were established. Because state law requires open bidding, bids for the GPS receiver were requested from vendors such as Trimble, Ashtech, Wild, and Micrometer. Only Trimble and Ashtech submitted bids; Trimble's was $77,000, including two training sessions at Iowa State University (ISU) and Ashtech's was 66,000, including one training session at ISU. Because the equipment allocation was only $70,000, it was decided to purchase Ashtech's receiver and use the remaining funds for training in pseudo-kinematics and for preparation of this final report.

The ISU research group studied the operation of the Ashtech GPS receiver in static, pseudo-static, kinematic, and pseudo-kinematic modes. The group also studied related software, namely Linecomp, Sat- Visibility, Previewben, and Navproc, all by Ashtech; Global Undulation and State Plane Coordinate transformation, by NGS; and Local Undulation, traverse and height by collocation, by past ISU students. All computation except gravimetric local undulation was done on microcomputers and Lotus 123 was used extensively as the spreadsheet software.

In order to collect data from satellites continuously, it was decided to have two permanent stations: one on top of the Ia DOT Building at Ames, and the other on top of Town Engineering Building at ISU. Accordingly, two permanent brackets to hold the antenna on top of the buildings were established. This setup, by utilizing AC power, has the capability to record data automatically continuously.

By using the Electronic Distance Measuring Instrument (EDMI) Calibration Baseline at ISU, the GPS receiver was tested for distance measurement accuracy. It was found that GPS measurements differed from the baseline distance by about 5.3 mm, the difference between 1369.2500 m, the calibrated baseline distance, and the GPS-recorded distance that used static mode of 1369.2553 m. This precision of about 1/27,000 is considered satisfactory for most highway applications which require an accuracy from 1/10,000 to 1/100,000.

Four projects were then undertaken to further evaluate and improve the horizontal as well as the vertical accuracies of the GPS receiver.

(1) The Campus project - with all points concentrated within a one-mile radius.
(2) The Des Moines project - a typical DOT project with all the points within a five-mile radius.
(3) The Iowa project - with all the points within a 100-mile

radius in the state of Iowa.

(4) The Mustang project - an extension of the Iowa project. The Mustang Project includes a typical DOT project of about 10 miles within the inner 30 mile radius of the Iowa project.

The Campus project (see fig. 5.1) indicated that by using GPS with the collocation method and sufficient ground control or Bench Marks (BMS), an accuracy of ±2 mm in elevation can be obtained within a one-mile radius. In this project local gravity anomalies were measured and found to be correlated with the local geoid undulation. It is recommended that further studies be done to determine local geoid undulation using local gravity anomalies without any external control.

The Des Moines project (see fig. 5.4) indicated that if four or more BMS along the highway are available, then by GPS and the collocation method an accuracy of ±3 mm in elevation can be obtained within a 5-mile radius. It was also observed that after global and local undulation correction using surface gravity, the average error in elevation is less than 0.2 ft, which is further reduced to .009 ft by the collocation method. This project also showed that differences in horizontal distance accuracy between the GPS and the DOT are less than 0.2 ft, and that a direction or azimuth accuracy between GPS and DOT methods, if fewer than 30 seconds, can be obtained by pseudo-static methods. In this project the DOT used an EDM with ± 0.01 ft accuracy and a theodolite with angular accuracy of ±10".

The Iowa project (see fig. 5.6) showed that by using GPS differential static measurement and at least two horizontal and three vertical controls with a three-dimensional least-squares adjustment program such as Geolab, it is possible to determine the three-dimensional coordinates or positions of central stations with an accuracy better than 1/100,000, which is the standard for first-order trilateration network. The estimated accuracy of the unknown central stations such as at Town and Ia DOT is about ±10 cm in x & y and about ±80 cm in elevation. By using elevation control well distributed both in azimuth and distance from the central station and the method of collocation, the accuracy in absolute elevation is improved to ±10 cm or better.

The Mustang project (see fig. 5.7) showed that for a typical large DOT project, which is within 30 miles of a central station and controlled by three or more previously established stations, the elevation difference between the DOT method and the GPS collocation method is -4 cms (304.15 to 304.19) at the northwest point, 0 cm (307.12 to 307.12) at south and about +4 cm (320.92 to 320.88) at the northeast point. The relative accuracy of DOT leveling is about 3 mm/100 m. In this project the angular misclosure using DOT traverse data and GPS control is less than 2". The linear misclosure is less than 10 cm on the ground state-plane coordinate which gives a precision of 0.10m/12000 m = 1/120000 that is of the first order traverse standard. In this project, the DOT traverse data were collected by a total station with 1" angular accuracy and 1 cm linear accuracy (1369.257 DOT vs 1369.247).

It can be concluded that the GPS can be used to control both horizontal and vertical surveying in a typical DOT project. Since GPS gives both horizontal and vertical positions to an accuracy of about 10 cm, it is recommended that in horizontal work both angular and linear measurements be controlled by GPS. In leveling, it is recommended that the absolute value of mean sea level (M.S.L.) of a central point be obtained by GPS and the others by differential leveling controlled by loop misclosure. The DOT personnel can perform one mile/hr leveling that requires no computation; besides, it is on a national reference system. This method will be both cost effective and accurate and will compare favorably with current methods. In the Mustang project, six GPS points were selected for use in controlling photogrammetric aerial triangulation. Aerial photos were taken by Ia DOT after targeting the GPS points; the photos confirmed that the GPS points can be used in an aerial triangulation. At this time no aerial triangulation has been done. It is recommended that the cost effectiveness and accuracy of GPS in aerial triangulation be studied further and implemented by Ia DOT.

Static, pseudo-static, kinematic and Pseudo-kinematic processing of GPS data were studied. Table 5.15 shows both pseudo-kinematic and kinematic methods are accurate for short distances; however, for long distances they are not reliable. The pseudo-kinematic method is found to be more suitable for field survey. Static method is reliable and accurate but time consuming. Pseudo-static is reliable for local direction measurement of lines of about 1/2 to 1 km long. Total stations are very accurate and reliable and faster to use for short distances. It is therefore recommended that the GPS-static method be used for DOT application, and, in some rare cases where time is a factor, that pseudo-static be used.

The ISU research group trained DOT personnel in both field operation of the GPS and in office computation. Since the office computations are highly technical and project-oriented, it is recommended that in order for the Ia DOT to become self-sufficient the this technology the Ia DOT work closely with the ISU research group for about two more years and consider hiring some of the graduate students who worked on this project.

The work done by the ISU research team and its conclusions and recommendations are reported in the following chapters:

Chapter 2 describes the GPS SYSTEM & RECEIVERS;
Chapter 3 describes the coordinate systems;
Chapter 4 describes the various adjustments of GPS OBSERVATIONS;
Chapter 5 describes various evaluation projects; and
Chapter 6 gives the recommendations and conclusions.

2.0 THE GLOBAL POSITIONING SATELLITE (GPS) SYSTEM

For the past decade, the U. S. Department of Defense has been developing the GPS system. When this system is fully operational, perhaps by 1993, approximately 18 to 24 satellites will orbit at about 20000 km above the earth in three to six orbit planes. The objective is to provide visibility to four to six satellites about 5° above the horizon at any time anywhere in the world so as to provide sufficient geometry (see fig. 2.1). These satellites will emit two coded signals that can be used by a receiver to determine the receiver's position, velocity and time. Presently there are about 15 operational satellites. Of the nine original Block I satellites, only six are operational; the Block II satellites are being continuously deployed, the latest one in Nov. 1990. The present configuration gives a window of about 12 hours for three-dimensional observations and about 20 hours for two-dimensional observations. The window of observation advances four to five min/day, which results in some periods of observation during midnight or early morning hours.

2.1 Satellite Orbit and Signal Characteristics

The satellite, m, of the GPS, orbits the earth along an elliptical (nearly circular) path (see fig. 2.2). The satellite operates in a 12-hr orbit at an altitude of 20,183 km with an inclination of 55° to the equator. A constellation of 18 to 24 satellites in three to six orbital planes, 30° to 60° apart, is proposed. At the time of this writing, it appears there will be 24 satellites in six orbital planes. Two systems of nomenclature exist. One system is the NAVSTAR (Navigation Satellite Timing and Ranging), which is launch dependent. The other is the SV (space vehicle) system, which is related to its designated p-code.

The satellite coordinates [x,y,z] on an earth centered WGS-72/84 geocentric coordinate system (see Figs. 2.2 & 2.3) are determined by using these orbital parameters:

$(A)^{1/2}$ = square root of semi-major axis of the satellite orbit.

e = eccentricity of the elliptical orbit

Ω_o = longitude (right ascension) of the ascending node or reference time

i_o = inclination angle at reference time

ω = argument of perigee

M_o = mean anomaly at reference time, corresponding to time anomaly V and eccentric anomaly E

t_{oe} = ephemeris reference time or epoch of perigee

Their corrections are

i = rate of inclination

Δn = mean motion difference from computed value

Ω = rate of right ascension

C_{us} = amplitude of the sine harmonic connection to the argument of latitude

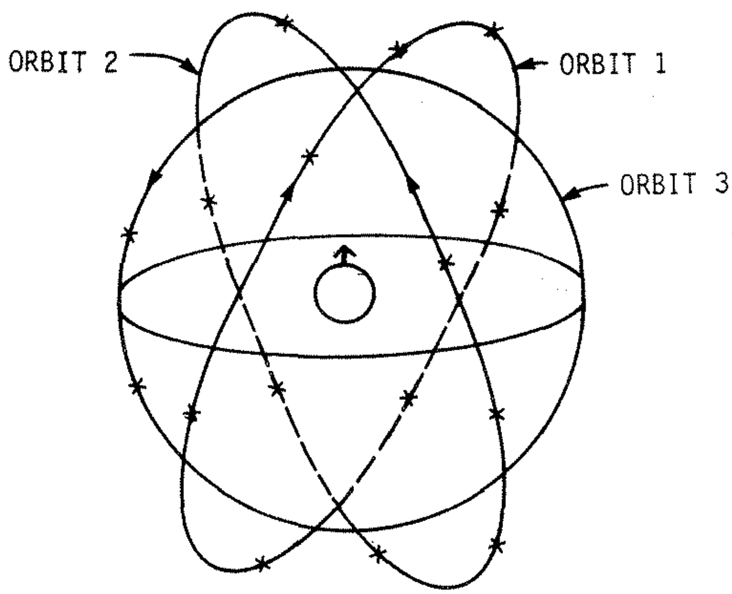


Figure 2.1 GPS System

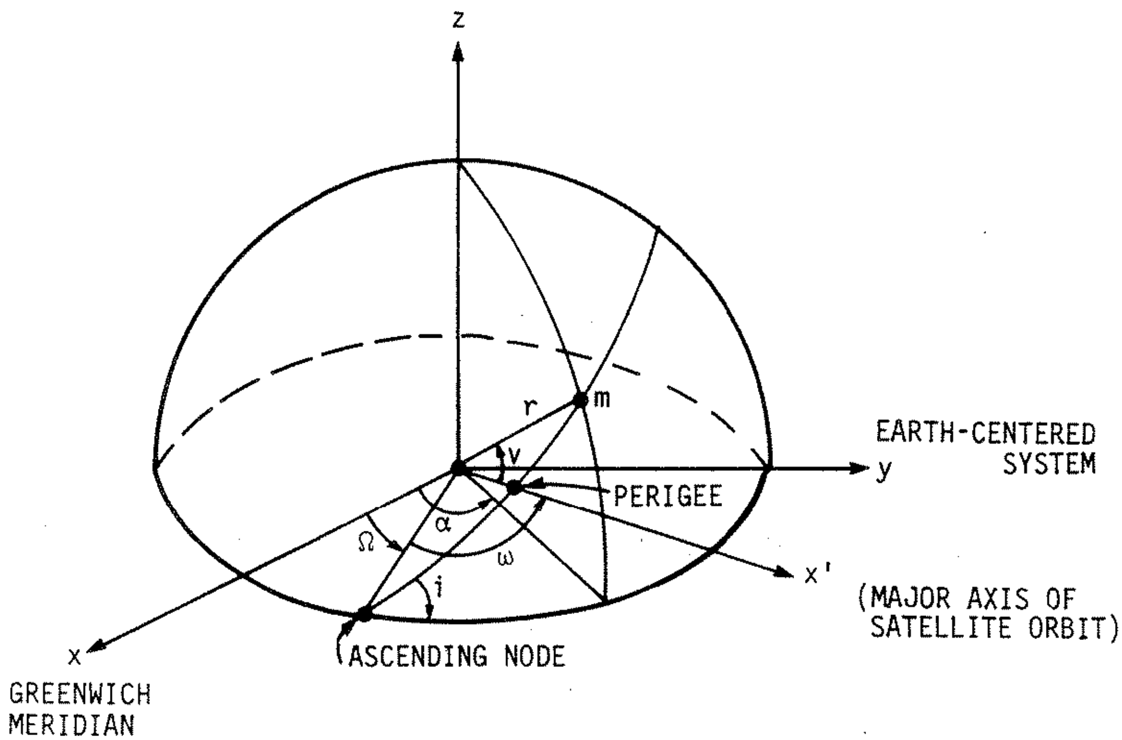


Figure 2.2 Satellite Orbit

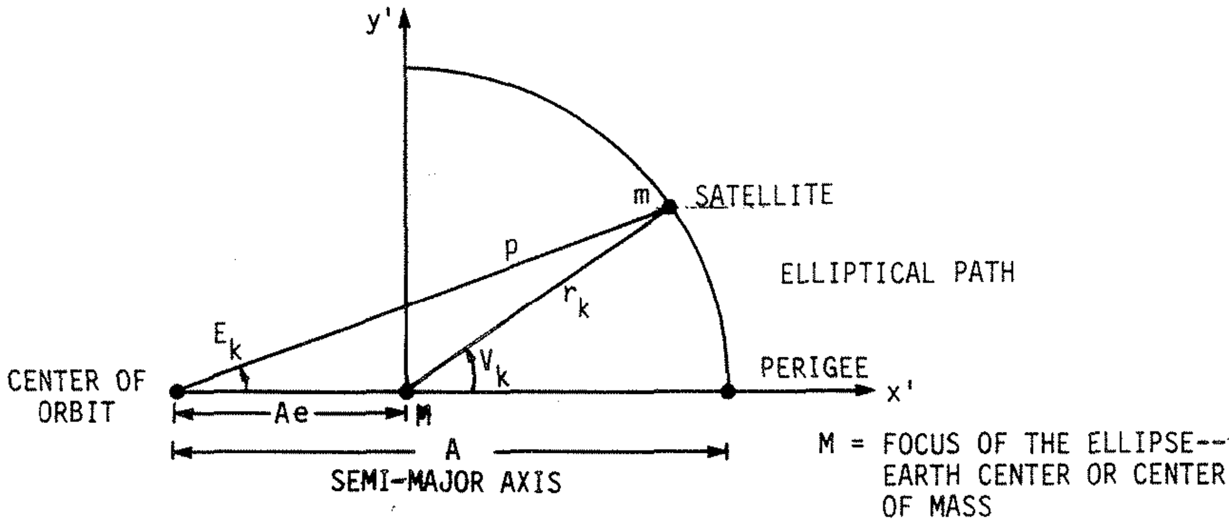


Figure 2.3 Satellite in the Elliptical Plane

C_{uc} = amplitude of the cosine harmonic correction
C_{rs} = amplitude of the sine harmonic correction term to the orbit radius
C_{rc} = amplitude of the cosine harmonic correction to the orbit radius
C_{ic} = amplitude of the cosine harmonic correction term to the angle of inclination
C_{is} = amplitude of the sine harmonic correction term to the angle of inclination.

These parameters and corrections are provided by a control segment that consists of four monitor stations (MS): an upload station (ULS), and a master control station (MCS). The monitor stations are located at Hawaii; Elmendorf AFB, Alaska; Guam; and Vandenberg AFB, California. Using the data collected at the Mss, the MCS, located at Vandenberg AFB, computes the satellite's orbital parameters and their correction terms. The ULS, also located at Vandenberg AFB, updates the navigation message (containing the orbital parameters) of each satellite at 6-hour and 24-hour intervals. The message also includes AODE (age of data):

$$AODE = t_{oe} - t_1$$

where t_1 = the time of last data

The satellite transmits signals L_1 at center frequency of 1575.42 MHz and L_2 at center frequency of 1227.6 MHz. Each of the two signals is modulated by a 10.23 MHz clock-rate precision, P signal, and/or a 1.023 MHz clear/acquisition (C/A) signal. The C/A code is short, repeating every millisecond. Each satellite broadcasts a different C/A code from the family of 1023 specified codes. The selection of codes minimizes interference between C/A signals and permits positive satellite identification. The p-code is a long sequence, repeating every 280 days, and each satellite is assigned a week - long portion of this sequence. The high-rate, long-duration p-code appears as random noise to an observer and hence is described as pseudo-random noise.

Each of these two modulation binary signals has been formed by a p-code or C/A code, which is module 2 added to 50 bps (bits per second) data to form P + D and C/A + D, respectively. The modulation D contains information regarding the satellite ephemeris, satellite clock correction terms (af_o, af_1,af_2), ionospheric delay term (TGD), and the like.

The L_1 in the phase component of the carrier is modulated by the P signal; P + D and the quadrature carrier are modulated by C/A + D. Thus, the L_1 signal transmitted by the satellite is given by

$$S_{L_1}(t) - A_p P_i(t) + D_i(t)\cos(\omega_1+\phi) + A_c C_i(t) D_i(t)\sin(\omega_1 t+\phi)$$

The L_2 is biphase modulated by the p-code; thus the L_2 signal transmitted is given by

$$S_{L_2}(t) = B_p P_i(t) D_i(t) \cos(\omega_2 + \alpha)$$

2.2 Ashtech XII GPS Receiver

The Ashtech XII, L_1, GPS receiver used in the project is a self-contained modular unit that uses C/A code radiated by the GPS to derive three dimensional position, velocity, and time information (see Figs. 2.4, 2.5, and 2.6). The receiver employs 12 channels to receive data from up to 12 satellites simultaneously and provides multiplexed output that is completely updated every second up to 999 seconds depending on the set "second update rate." The receiver measures the phase of the C/A code and that of the carrier wave L_1. The phase values of C/A codes from 4 or more satellites' coordinates are used to compute and display instantaneously the position of the receiver antenna with a positional accuracy of about ±15 m. The carrier phase measurements are used in differential mode. By post-processing of the data from two stations the spatial distance between the stations can be determined with an accuracy level of ±1 cm.

The receiver can operate in four survey modes; static, pseudo-static, kinematic, and pseudo-kinematic. In the static mode, data are collected simultaneously at two stations for about 45 minutes to 2 hours and post-processed to give the precise distance between them by eliminating errors associated with satellite information and receiver biases. The pseudo-static mode is the same as static except that the data are collected for about 15 to 30 minutes. The pseudo-static mode can give the geodetic azimuth of a line greater than 1/2 mile to an accuracy of ±2", but the accuracy of the distance measured is about ± 5 cm depending on the geometry of the satellite locations.

In the kinematic mode, one receiver (base) is placed at one known point while the second (rover) is placed at the second known point established by antenna swap or a previous survey. After collecting the data at the second point for about 5 minutes, the rover can be moved to additional points where similar brief observations are made. This method requires continuous tracking of four or more satellites by both the base and rover receiver. In the antenna swap method of establishing the second common point, after a few minutes of initial data collection the antennae of base and receiver are switched and additional readings are recorded for another few minutes; on completion the receivers/antennae are returned to the original locations. This method gives distances to ±2 cm and azimuths to the ±1" and is suitable for small open areas.

The pseudo-kinematic survey is similar to the kinematic mode except that a second known point is required and continuous tracking of four or more satellites is not required. The receiver occupies the points for at least two short periods of 5 min separated by a larger period of an hour. This method gives an accuracy of ±5 cm in distance depending on the geometry of the satellite locations. It is suitable for small areas with overhead

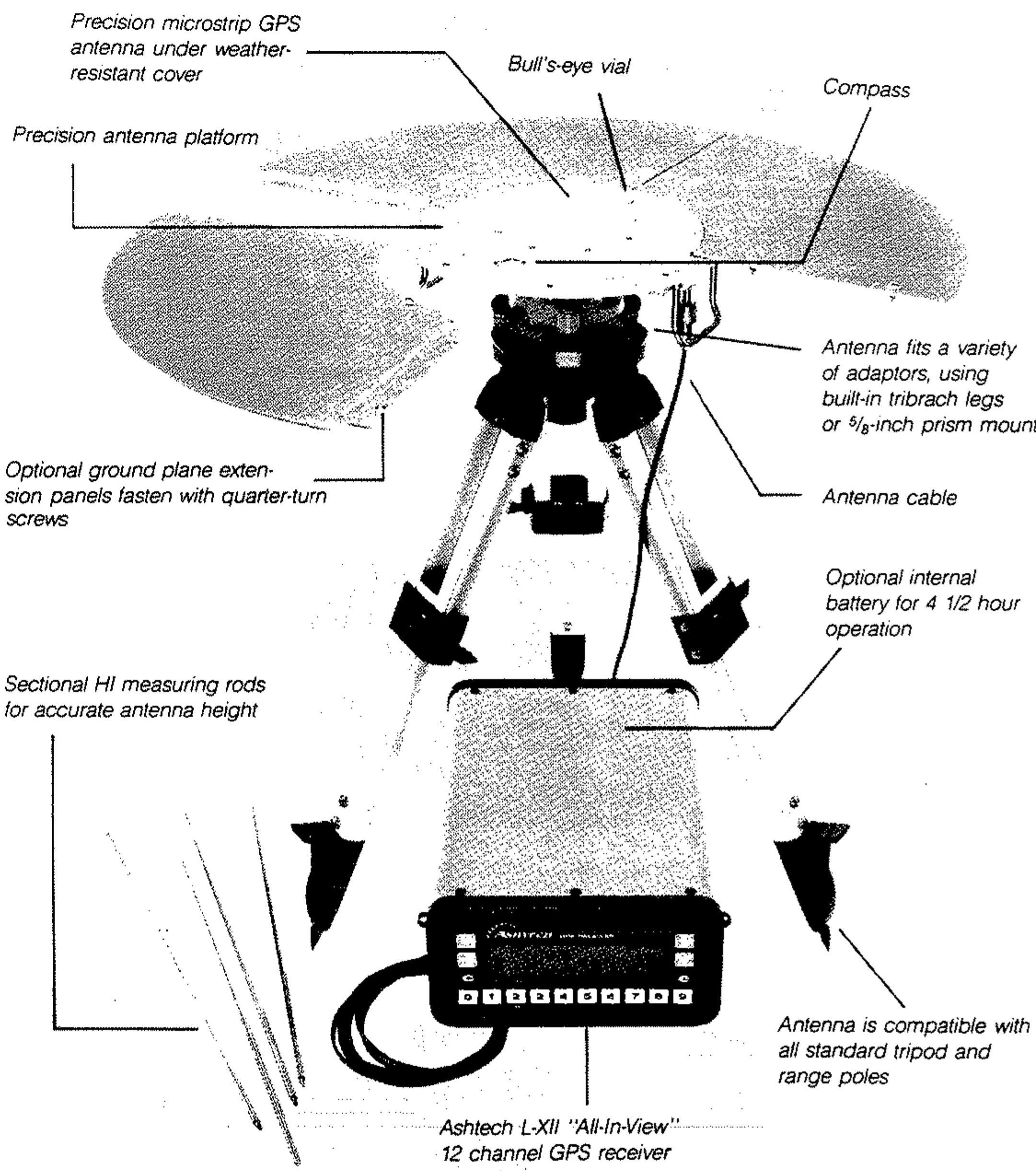


Figure 2.4 Ashtech XII GPS Receiver

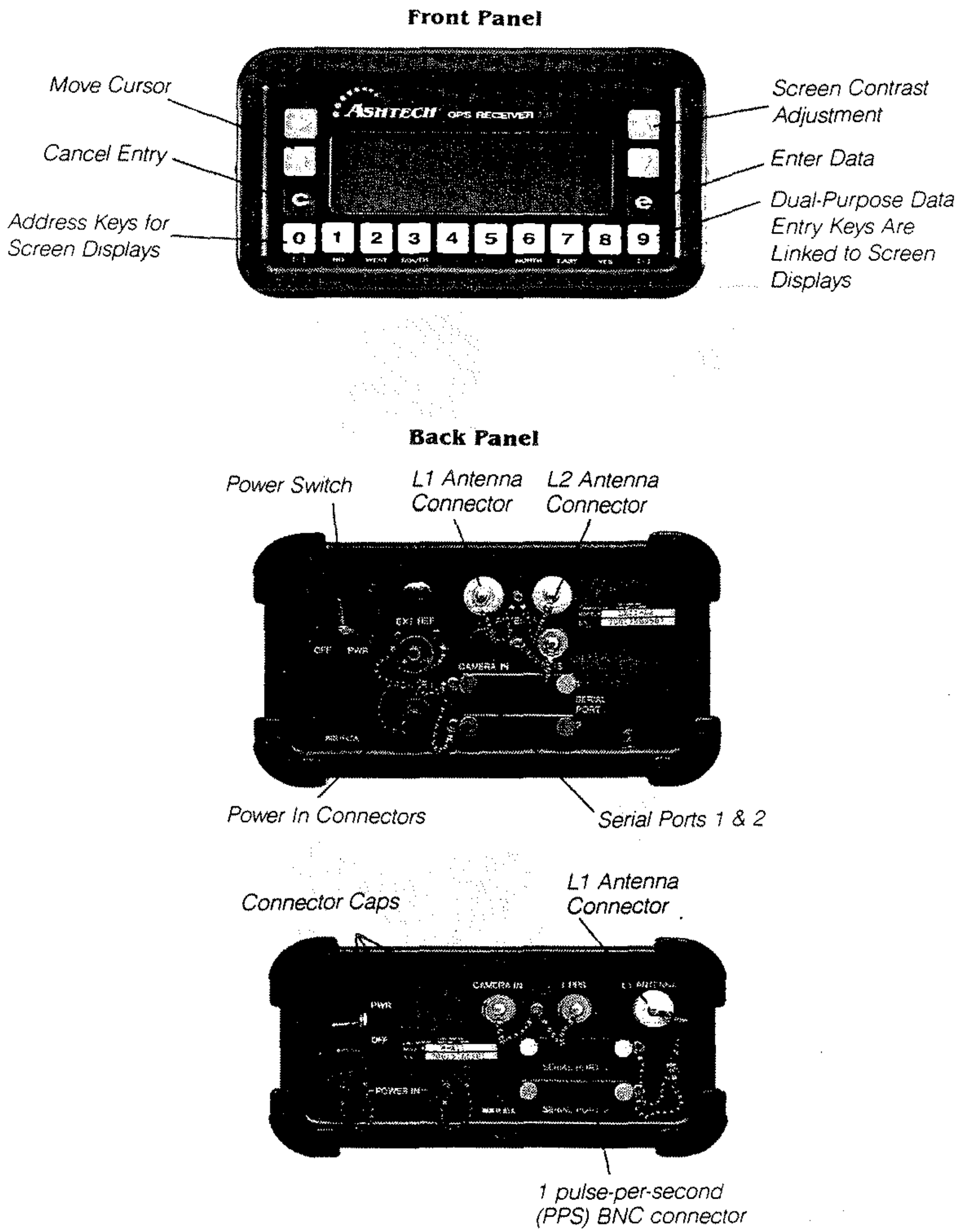


Figure 2.5 GPS Receiver Front and Back Panel

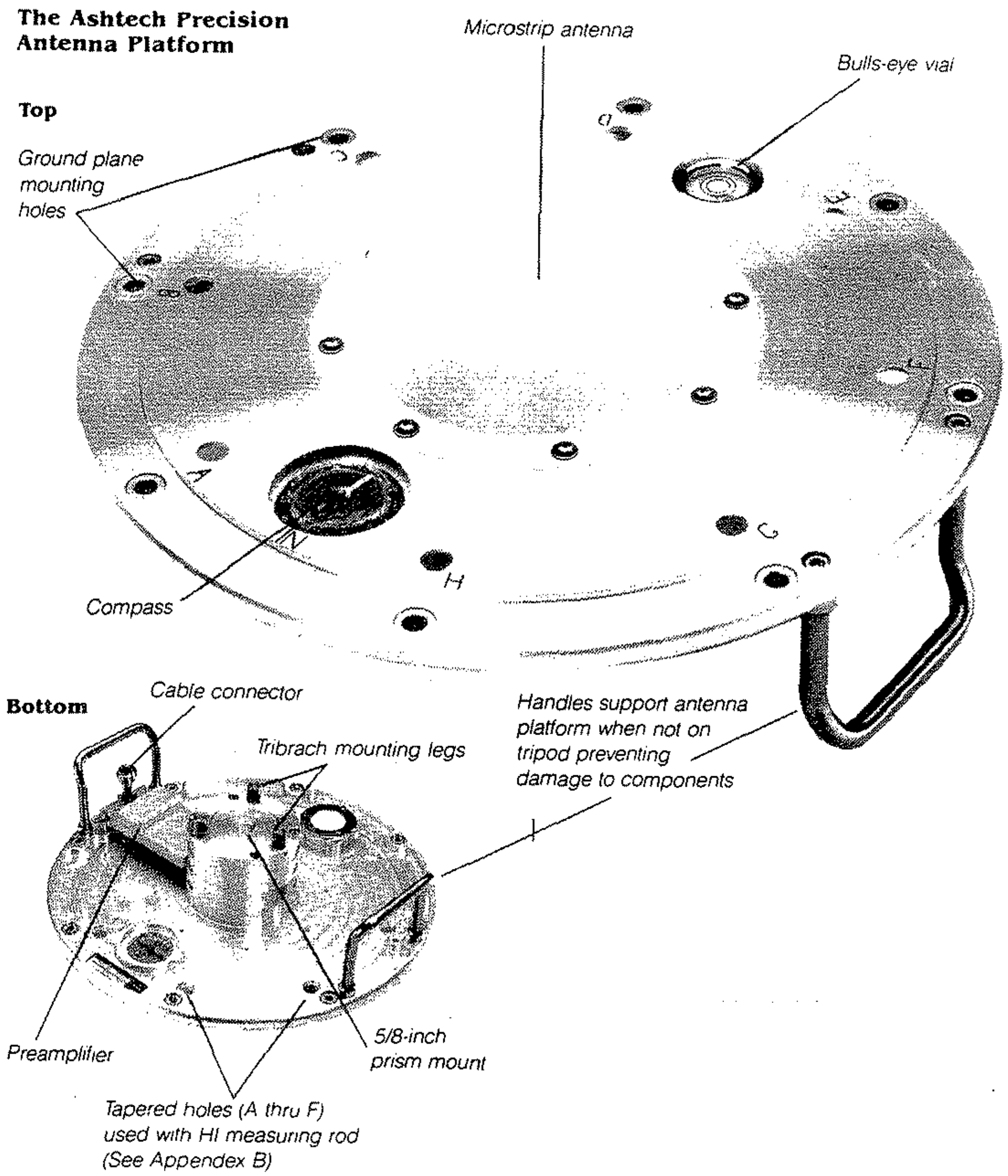


Figure 2.6 Microstrip Antenna

obstructions.

Figure 2.4 shows a typical GPS receiver component. The receiver is powered by either an internal battery or by external DC (12 V) or AC (110 V) power source. The internal battery maintains the non-volatile memory. The input and output of the receiver are controlled by the front panel and back panel (see fig. 2.5). The power in the sockets in the back panel enables connections to external batteries. The antenna connection in the back panel is used to connect the microstrip antenna (see Fig. 2.6) mounted on a precision-machined platform for accurate positioning above the survey mark. The serial ports in the back panel of the receiver are used for transferring recorded data from the receiver's solid-state memory to an external computer for post-processing or for other communications to or from the receiver.

2.2.1 Receiver system operation

Prior to observation, it is important to ensure the location is clear of objects obstructing the line of sight to the satellites. The next step is to select the time window for observation by using the satellite program called GPSMAP (see appendix). This program is a part of the software GPSS (Geodetic Post Processing Software) provided by Ashtech. The GPSMAP program, using the satellites orbital parameters, gives the table of azimuth and elevation of the satellites for different times at a given location. Thus an approximate location ϕ,λ should be known within $\pm 1^0$. By using the table, the time of observation is selected such that at least four satellites are available for a continuous period of an hour to two hours. The best determination of position, (x,y,z), is obtained with (GDOP $(\sigma_x^2+\sigma_y^2+\sigma_z^2)$) Global dilution of position, less than 10. The standard error σ_x, σ_y, σ_z in x,y,z can be estimated by using the approximate satellite and position coordinates. However, it is important that rays from two satellites intersect at 45 degrees to 90 degrees with respect to the location in the x-y plane and that rays from two other satellites intersect at 45 to 90 degrees in either the x-z or y-z planes.

After the antenna is positioned over the survey marker, the antenna cable and external battery pack (if used) are connected with receiver see Fig. 2.7 for typical setup. Turning the power switch to the "ON" position begins the survey data collections. When the receiver is switched on, the system initiates a self test procedure to verify system integrity. If a problem is located, an error message will remain on the display and operation will stop. After the self-test, the receiver begins an automatic search for all satellites. The status of each satellite being searched is displayed on the "Skysearch" information displayed (see Fig. 2.8) on the front panel of the receiver by pressing the [o] key. Channel numbers and their associated satellites, SV, are listed across the display. As the receiver scans the frequencies, the status (STAT) number of the search changes from frequency number, to SN ("sniffed") and finally to "LK" as the system "locks" on the frequency of the particular satellite. As the satellites are

Figure 2.7 GPS Receiver Setup at Station of 105, Campus

Figure 2.8 Skysearch Information Display

located, the total number found is displayed as SV. Before a satellite is located, the display shows the time elapsed since the receiver was turned on. After the first satellite is found, the receiver time is set and GPS time is displayed. After the "GPS-UTC" parameters are collected from any satellite, which takes about 12 minutes, the Greenwich mean time (GMT) is displayed.

The receiver collects and displays orbit parameters from each satellite found and computes elevation, azimuth and other information. [1] Tracking information, displayed on the front panel by pressing the [1] key, shows the satellites (SV) being tracked, the number of continuous (CNT) data collected from the satellites since last lock or cycle slip, the elevation (Elev) to each satellite, the azimuth (AZM) to each satellite, the range accuracy (URA) to each satellite, the health (HEL) of each satellite, and the age of satellite, also indicating the time elapsed since the lock with the satellite was lost (see Fig. 2.9).

From the information received from the constellation of satellites, the receiver computes and displays the latitude (Lat), longitude (Long), altitude (ALT), the course over ground and speed over the ground of the receiver. In addition it computes and displays information on destination points (known as "way points") the distance to destination (DTD), the course to destination (CTD), and time to destination (TTD). The [2] position and navigation, displayed, seen on the front panel by pressing [2], shows LAT, LON, ALT, COG, SOG, DTD, CTD, TTD, and also the quality of geometry (see Fig. 2.10). The quality of the geometry is measured by GDOP, which has several components: PDOP ($\sigma_x^2+\sigma_y^2+\sigma_z^2$), HDOP ($\sigma_y^2+\sigma_y^2$), VDOP ($\sigma_v^2$), and TDOT ($\sigma_t^2$).

The satellites tracked and data collected can be controlled by the control parameters menu. Pressing the [4] key of the front panel displays the several parameters that can be changed by the operator (see Fig. 2.11). Initially, before tracking of satellites, the operator can enter the estimated ϕ,λ parameter of the position (POS) by pressing the [e] key to place display in the "data" entry mode, moving the cursor with the arrow keys. The operator can control the data recording interval, the minimum number of satellites to be used, the minimum elevation of satellites to be used, the use of elevation control in static mode, and the use of unhealthy satellites. The satellite selection menu [7] enables the specific satellite data to be collected. The site information menu [9] is used to enter site name, session ID, receiver number, antenna number, month/day operations interval, the instrument height, wet and dry bulb temperatures, and barometric pressure. It can also be used to control the recording of data as well as the number of epochs to be recorded in the kinematic survey.

The [3] history of recorded display show the amount of data collected from each satellite. The record & delete file directory menu [8] shows the names of files in the internal memory and can also delete any files or close any file during observation. The differential GPS display [5] are used in special real time differential GPS applications. The way points [6] for navigation are used in the application of GPS in navigation.

Figure 2.9 Tracking Information Display

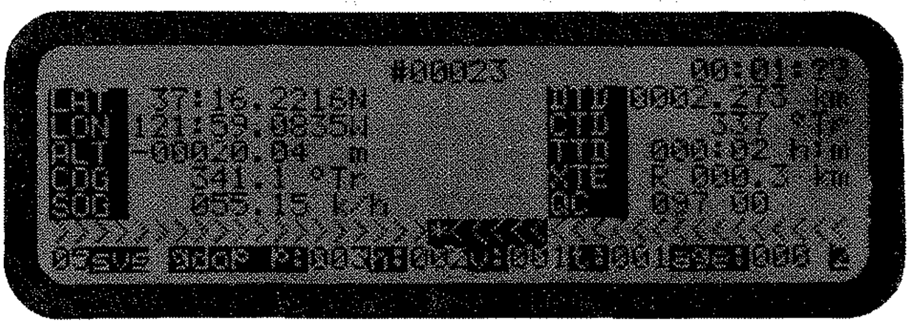


Figure 2.10 Position and Navigation Display

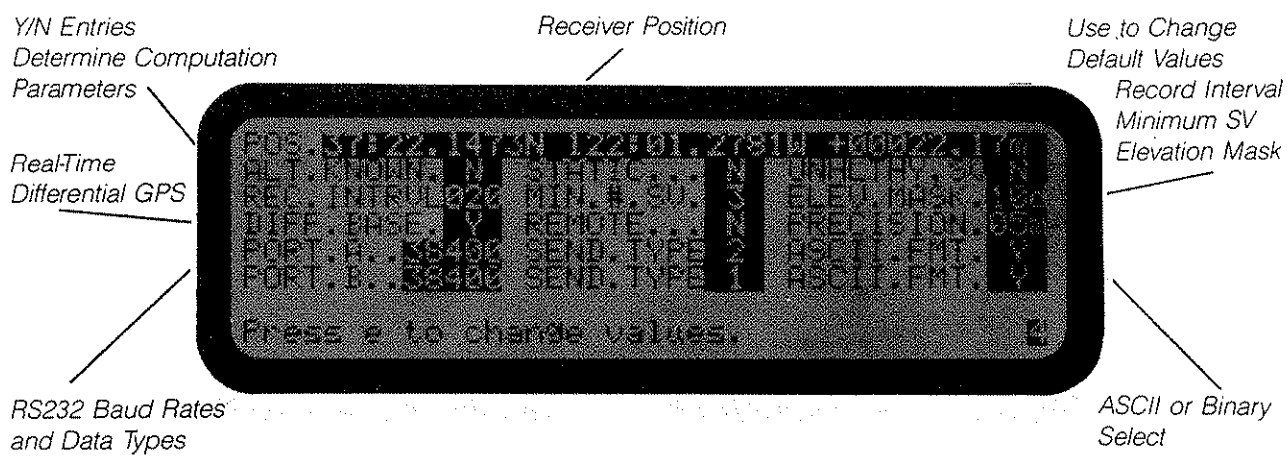


Figure 2.11 Control Parameters Menu

2.2.2 General Operating Theory

2.2.2.1 Stand-Alone Mode

The receiver performs a cross-correlation operation to extract the signal and recover the data from the satellite. The receiver initially generates an appropriate C/A code, compensating for both Doppler shift and the estimated time difference, and performs a cross-correlation with the received signal. The correlation function between the received signal and the generated C/A code is given by

$$C_i'(t-t')S_{L_1}(t) = A_p C_i'(t-t')P_i(t)D_i(t)\cos(\omega_i t+\phi)$$

$$+A_c C'_i(t-t')C_i(t)D_i(t)(\sin\omega_1 t+\phi)$$

where C'(t-t') is the C/A code generated by the receiver shifted in time t' with respect to C/A code generated by the satellite. The correlation in maximum C'(t-t'). C(t) is one. Thus, a value of t' can be determined when the maximum correlation occurs. Because the period (T_o) of C/A code is set at 1 m sec, the transit time is $\tau' = t'+n$ where n is an integer. The pseudo range, R', between the satellite and the receiver is given by $R' = C\tau'$ where C is the velocity of the electromagnetic wave.

The cross-correlation of the C/A code also enables access to the data code D(t), which contains satellite orbital parameters, satellite clock error, ionospheric delay, and so on. Using these data, the receiver computes the satellite coordinates (U_s,V_s,W_s) and the error in transit time. The corrected pseudo range, R, is given by

$$R = C(\tau'+\Delta\tau_s) = C\tau = [(U_s-U)^2+(V_s-V)^2+(W_s-W)^2]^{1/2}-C\Delta\tau$$

where U,V,W are the receivers coordinates and
$\Delta\tau_s$ = satellite clock, ionospheric and atmospheric error
$\Delta\tau$ = the synchronization error between satellite and receiver clock
τ = corrected transit time.

Thus, by using pseudo-range measurements to four or more satellites, the four unknowns, U,V,W, and $\Delta\tau$ are computed (see Fig. 2.12). The computations are performed every epoch. Since there are 12 channels, data from 12 satellites are collected every epoch. The (U,V,W) coordinates are converted to latitude ϕ, longitude λ, and elevation H and displayed on the display screen of the receiver. If only those satellites are visible, then the receiver can compute the three unknowns. In practice, if the elevation is constrained, the receiver can use three satellites and compute the

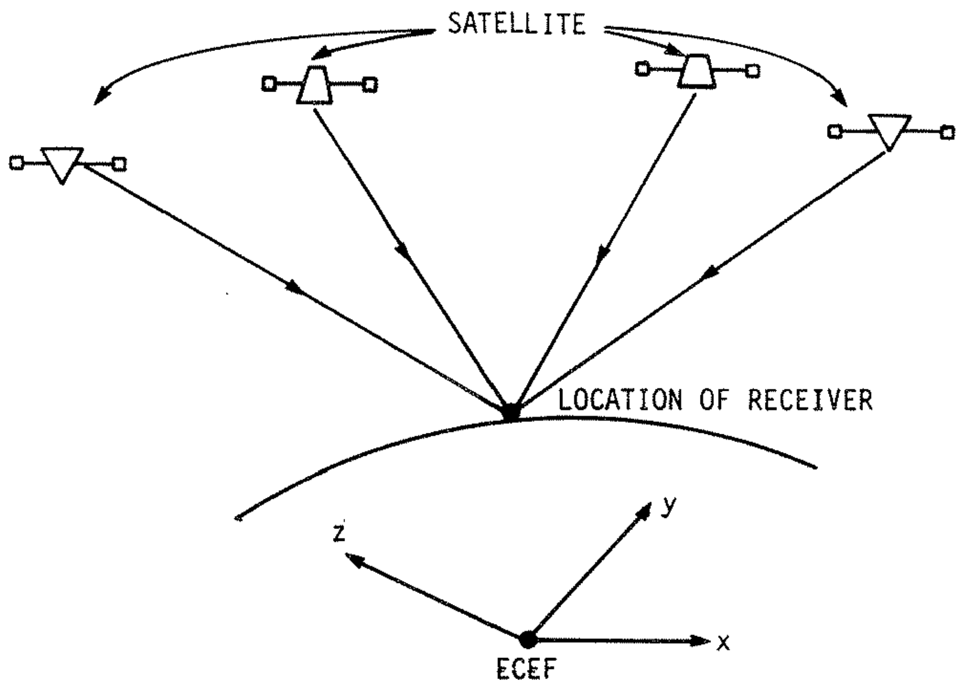


Figure 2.12 Satellite Receiver Operation

ϕ, λ, and $\Delta\tau$.

Because of the relative motion of the satellite with respect to the receiver, the signal is subject to varying Doppler shift. The electronic correlation process must time-shift the receiver codes at rates proportional to the Doppler shift. Since

$$t = \frac{l}{\lambda} T_o$$

where

λ = wave of signal
l = portion of the distance < λ and
t = portion of the time < T_o

we have

$$t = \frac{l}{c} T_o f$$

(where f=frequency)

therefore

$$dt = \frac{l}{c} T_o df = T_o \frac{f}{C} dl$$

However, the phase angle ϕ is given by

$$\phi = \omega t$$

where

$$\omega = \frac{2\pi}{T_o}$$

that is,

$$d\phi = \omega dt$$

therefore

$$dl = \frac{C}{2\pi f} d\Phi$$

also

$$R_2 - R_1 = (c/2\pi f)(\Phi_2 - \Phi_1) = dl \text{ (delta range)}$$

and because

$$(U_s - U)^2 + (V_s - V)^2 + (W_s - W)^2 = R^2$$

we have

$$(U_s - U)(dU_s - dU) + (V_s - V)(dV_s - dV) + (W_s - W)(dW_s - dW) = RdR = Rdl = \frac{RC}{2\pi f} d\Phi$$

where (dU_s, dV_s, dW_s) and (dU, dV, dW) are the velocity components of the satellite and receiver, respectively. Using the delta range and velocity of the satellite, the velocity of the receiver, $(dU^2+dV^2+dW^2)^{1/2}$, was computed by the receiver every epoch. The delta range is derived by tracking the carrier phase and computing the change in the carrier phase to the satellite over every subsequent epoch. By knowing the velocity of the satellite from the satellite orbital parameters, the velocity of the receiver is computed and displayed using the delta range or Doppler shift of three or more satellites. The computed positions ϕ, λ, h, and the receiver's velocity, dU, dV, dW, as well as pseudo range, doppler shift and the like are stored in the central memory's every epoch for future references.

2.2.2.2 Differential GPS

If receiver 1 and 2 (see Fig. 2.13) are located at two stations, then the phase difference, $\Delta\phi$, between the signals received by the two receivers corresponds to the difference in distance traveled by the signal to the two receivers. Thus, $\Delta\phi = \Delta D\cos\theta$ (see Fig. 2.13) where θ is the direction of the signal with respect to base line and ΔD is the component of the difference in distances to the satellite in the direction of the baseline. Since the wavelength of the carrier wave is 19 cm, only portions of phase difference less than 19 cm can be measured initially. In practice, the distance between the receiver can be estimated by using the stand alone mode to with in ± 5 m. Thus we have

$$\Delta\Phi = U_o + U + \Delta D\cos\theta + \nu + t$$

where

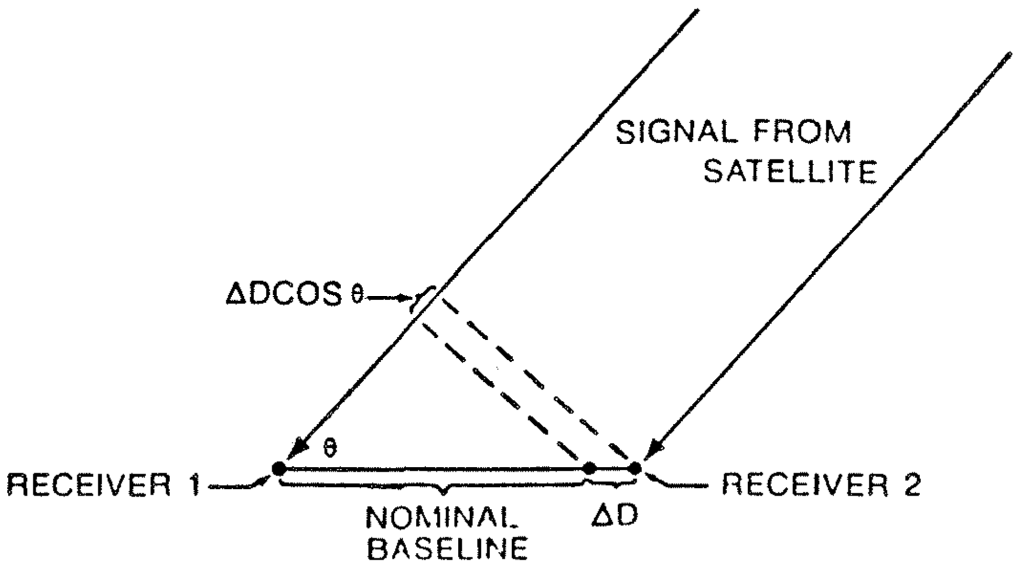


Figure 2.13 Interferometric Method

U_o = predicted phase difference between stations
U = unknown integer
$\Delta\phi$ = measured phase difference
ν = measured noise
t = clock synchronization error

Now, if we observe the phase difference to four or more satellites then the clock synchronization error will be the same. Since

$$\Delta D = \frac{\Delta X}{D}\delta x + \frac{\Delta Y}{D}\delta y + \frac{\Delta Z}{D}\delta z$$

where D = estimated distance between two stations,

$\Delta X, \Delta Y, \Delta Z$ = estimated difference in X,Y,Z coordinates between two stations, and
$\delta x, \delta y, \delta z$ = corrections for estimate of difference, so
we have

$$\Delta\phi = U_o + \left[\frac{\Delta X}{D}\cos\theta, \frac{\Delta Y}{D}\cos\theta, \frac{\Delta Z}{D}\cos\theta\right]\begin{bmatrix}\delta x\\ \delta y\\ \delta z\end{bmatrix} + U + t + V$$

If $\Delta\phi_1$, $\Delta\phi_2$, $\Delta\phi_3$, and $\Delta\phi_4$ are observations to four satellites, then

$$\begin{bmatrix}Z_1\\ Z_2\\ Z_3\\ Z_4\end{bmatrix} = \begin{bmatrix}\Delta\phi_1 - U_{o_1} - U_1\\ \Delta\phi_2 - U_{o_2} - U_2\\ \Delta\phi_3 - U_{o_3} - U_3\\ \Delta\phi_4 - U_{o_4} - U_4\end{bmatrix} + \begin{bmatrix}-V_1\\ -V_2\\ -V_3\\ -V_4\end{bmatrix} = \begin{bmatrix}\frac{\Delta X}{D}\cos\theta_1 & \frac{\Delta Y}{D}\cos\theta_1 & \frac{\Delta Z}{D}\cos\theta_1 & 1\\ \frac{\Delta X}{D}\cos\theta_2 & \frac{\Delta Y}{D}\cos\theta_2 & \frac{\Delta Z}{D}\cos\theta_2 & 1\\ \frac{\Delta Z}{D}\cos\theta_3 & \frac{\Delta Y}{D}\cos\theta_3 & \frac{\Delta Z}{D}\cos\theta_3 & 1\end{bmatrix}\begin{bmatrix}\delta z\\ \delta y\\ \delta z\\ t\end{bmatrix}$$

If the measured noise, ν, is random and the integer U is determined, $\delta x, \delta y, \delta z$, and t can be determined by the principle of least squares using a number of observations of four or more satellites. In practice this is done by post-processing the data collected. The unknown integers, U, are determined by single, double, float double, and triple-differences method.

Suppose $S(k_1,j,i)$ is the signal carrier phase received by receiver K^1 from satellite j at epoch i and $S(k_2,j,i)$ is the carrier phase at receiver K_2 from satellite j at epoch i; then

$$S(K_1, j, i) = C_j + n_1\pi - \phi_{K_1}$$

where C_j is the initial phase of the signal from satellite j, n_1

$$S(K_2,j,i) = C_j+n_2\pi-\phi_{K_2}$$

& n_2 are integers, and ϕ_{K1} and ϕ_{K2} are phases measured by receivers K_1 and K_2.
A single difference, SD(j,i) is formed by differencing the carrier phase observable from two receivers k_1 and k_2 at the same epoch i from the satellite j. Thus

$$SD(j,i) = S(K_2,j,i)-S(K_1,j,i)$$

$$=(n_2-n_1)\pi-\phi_{K_2}+\phi_{K_1}$$

$$= U_j+\Delta\phi_j+t$$

where U_j is the integer for satellite j, t is the receiver clock error, and $\Delta\phi_j$, is the true phase difference. SD(j,i) is independent of the satellite clock error.

A double difference DD (j_1,j_2,i) is formed by differencing a single difference between a reference satellite j and another satellite j_2 at the same epoch i. This results in

$$DO(j_1,j_2,i) = SD(j_2,i)-SD(j_1,i)$$

$$= U_{j_2}+\Delta\phi_{j_1}-\Delta\phi_{j_1}$$

$$=(U_{j_2}-U_{j_1})\left[\frac{\Delta X}{D}(\cos\theta_1-\cos\theta_2)\quad \frac{\Delta Y}{D}(\cos\theta_1-\cos\theta_2)\quad \frac{\Delta Z}{D}(\cos\theta_1-\cos\theta_2)\right]\begin{bmatrix}\delta x\\ \delta y\\ \delta z\end{bmatrix}$$

The double difference DD(j_1,j_2,i) is independent of (δx,δy,δz), the receiver clock error. By keeping track of the complete cycles in the phase measurement, the integer ambiguities can be determined. If the ambiguity (U_{j2}-U_{j1}) is solved as a variable, then the solution is known as float double difference.

A triple difference TD (j_1,j_2,i) is formed by differencing the double difference for the same satellite pair at some integer of succeeding epochs i and i + 1. Thus

$$TD(J_1, J_2, i) = DD(J_1, J_2, i+1) - DD(J_1, J_2, i)$$

$$= \frac{\Delta X}{D}(\cos\theta_{i1} - \cos\theta_{(i+1)} - \cos\theta_{(i+1)2})\,\delta X + \frac{\Delta Y}{D}(\cos\theta_{i1} - \cos\theta_{(i+1)} - \cos\theta_{(1+1)2})$$

$$+ \frac{\Delta Y}{D}(\cos\theta_{i1} - \cos\theta_{(i+1)} - \cos\theta_{i2} + \cos\theta_{(i+1)2})\,\delta Z$$

The triple difference is independent of the integer ambiguities and clock error. The triple difference solution needs a number of observations and since the coefficients of $\delta x, \delta y$, and δz are small compared to double difference, it may not be reliable.

2.3 Post Processing Software

Ashtech provides Geodetic Post-Processing Software, GPPS, which includes post-processing of data in static, kinematic, and pseudo-kinematic modes as well as a variety of coordinate conversions. GPPS is compatible with Geolab, a network adjustment network.

The latest release of GPPS software in July 1990 is completely automatic. Before running the latest release of the software, the accompanying EPROMS for the navigation and channel boards must be changed. Any data collected with earlier ROM versions must be converted by running a program called "Convert.Exe."

The Ashtech receiver is connected with the post processing computer with the appropriate cable with RS 232 connector on the back panel. GPPS presents the following main menu:

a) auto processing
b) down load receiver
c) editing Planning
d) manual processing
e) post mission
f) select directory

The "auto processing" option will allow the user to automatically process the data in static or pseudo-kinematic modes. The "download receiver" option enables the user to download the data from the receiver to the PC using a program "HOSE," which also allows the direct download of an almanac file for use in a satellite visibility program. HOSE program bendata, navigation, and site files in the PC. The "editing/planning" option enables the user to convert files to print and edit various data files by using the program called "file t001" in order to produce a satellite visibility chart using the "GPSMAP" program and the almanac-data file. "Manual Processing" allows the user to run the "ANTSWAP" used in kinematic surveys and create both common navigation files using

"COMNAV" program and create log files used in the kinematic survey by using "Gem log" program, run "KINSRVY," the program for computing the rover position using data collected for kinematic survey, run the "Line Comp" program for computing the baseline vector from static or pseudo-kinematic data, run the "Make U file," which creates the U file consisting of difference phase data files from the bendata and navigation files from each of the base stations, and run the "Make Inp" program to create and edit Baseline.Inp files required in "line comp." The "post mission" menu enables the user to create data for adjusting networks, and "select directory" permits the user to choose different directories in the PC.

The common procedure used in this project (see Fig. 2.14), is to download the data from the receiver and create the Bendata, navigation, and site data files. Then, by using the manual processing, the U files and Baseline.Inp files are created and the Linecomp is executed. The linecomp programs will compute and print the baseline vector, baseline distance, base line azimuth, latitude, longitude, and elevation as well as the X,Y,Z coordinates of the base stations using double difference, float double difference, and triple difference. They also provide statistical data for analyzing the results.

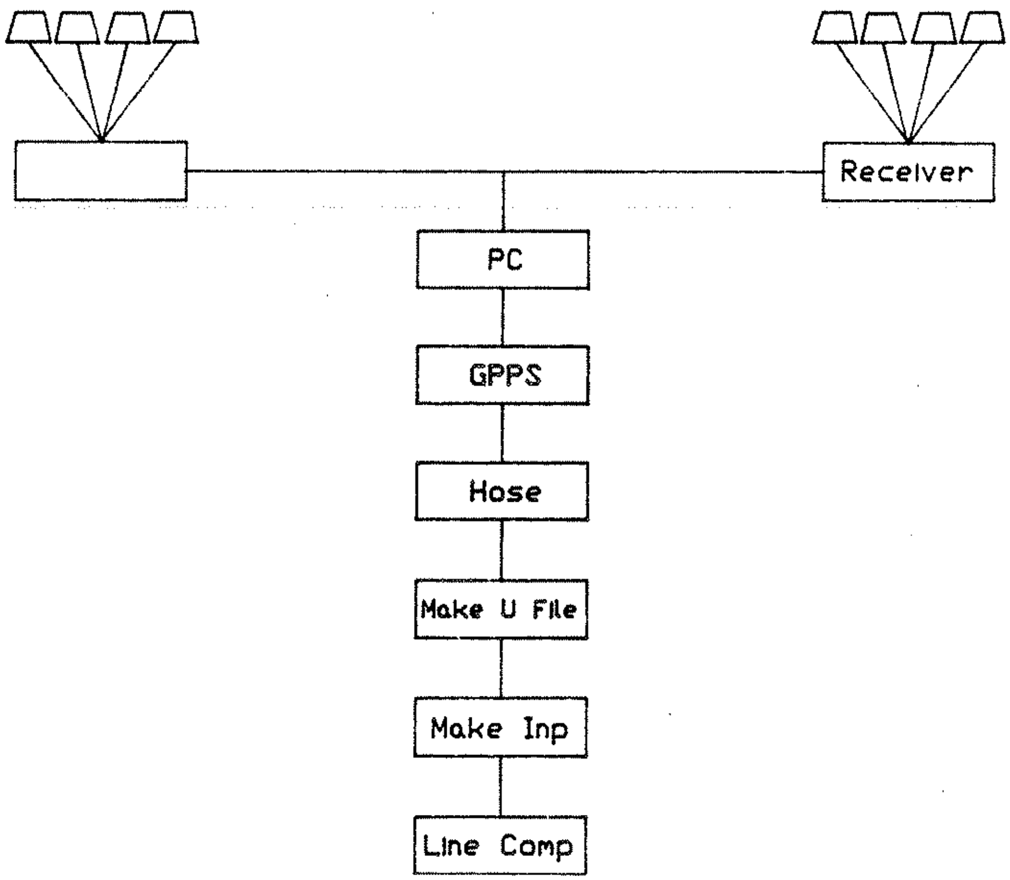


Figure 2.14 Post Processing of GPS Data

3.0 COORDINATE SYSTEMS

The surveying measurements are made at and between position marks on the earth's physical surface defined by a set of points in three dimensions such as P_1, P_2, P_3 and the like. In the GPS and Iowa DOT environment the positions are defined by three systems: Local, World Geodetic System (WGS) 80, which is also referred to as NAD83 datum, and WGS 84 (see Fig. 3.1). In addition, three systems, spherical, rectangular, and projections, are used in this project.

3.1 WGS 84

At present GPS uses the WGS 84 coordinates system. In this system, the origin is at the center of mass of the earth, the Z-axis is parallel to the mean axis of rotation of the earth and the X-axis is perpendicular to the Z-axis and is in the meridian plane containing Greenwich, England. The reference ellipsoid adopted has a major axis a = 6,378,137 meters and flattening f = 1/298.257223563. On this system, if P is a point on the surface of the earth, PP'O' is the prime vertical of the ellipsoid at P' and P'O is the radius vector from center O. Then the angle between P'O' and the equatorial plane, ϕ, is defined as the latitude, and the angle between P'O and the equatorial plane, ψ, is defined as the geocentric latitude (see Fig. 3.2).
From the geometry of the ellipsoid:

$$N = P'O' = \frac{a}{(1-e^2\sin^2\phi)^{1/2}}$$

$$e^2 = 2f-f^2$$

$$OO' = Ne^2\sin\phi$$

$$\psi = (1-e^2)\tan\phi$$

$$X = (H+h)\cos\phi\cos\lambda$$

$$Y = (N+h)\sin\phi\sin\lambda$$

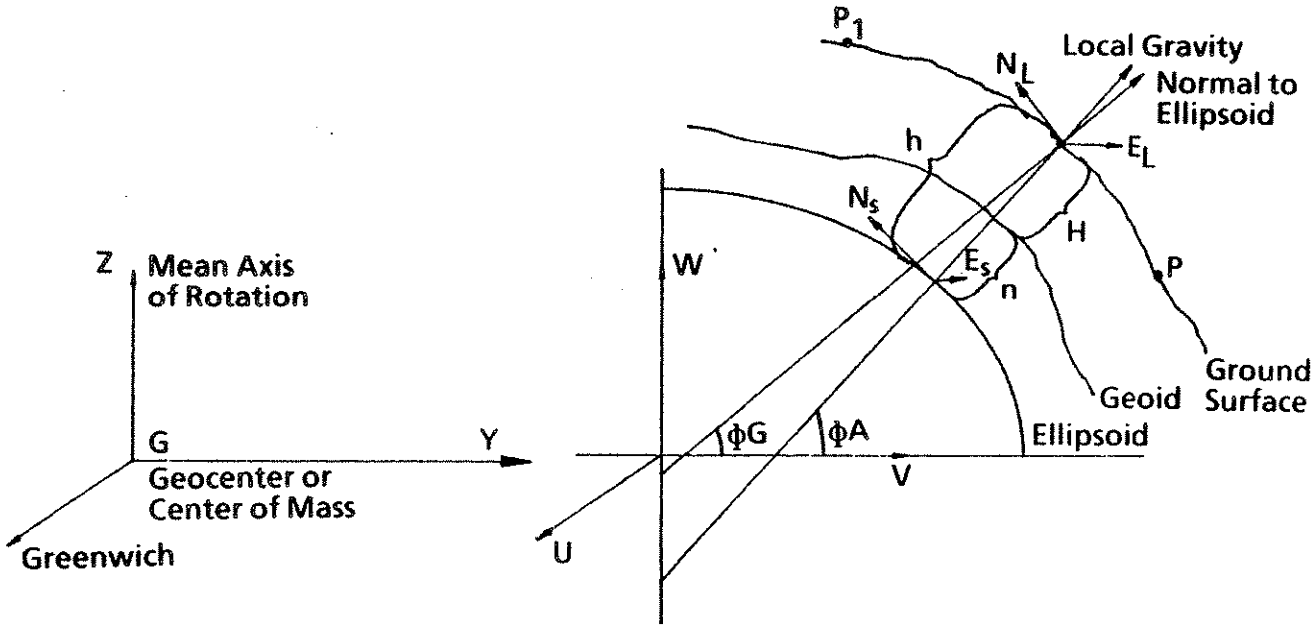


Figure 3.1 Cartesian Systems

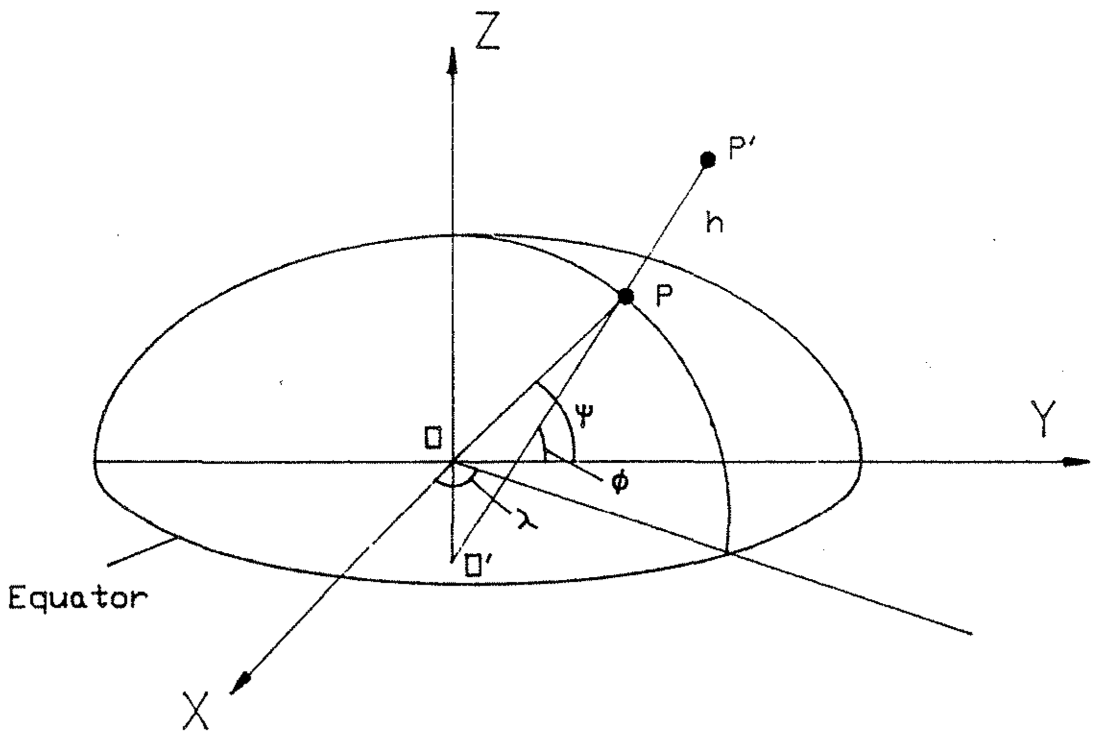


Figure 3.2 Spherical Coordinate System

$$Z = [N(1-e^2)+h]\sin\phi$$

h = P'P = ellipsoidal height of point P above the reference ellipsoid.

(X,Y,Z) = Cartesian coordinates of P

(ϕ,λ,h) = Spherical coordinates of point P

3.2 NAD83

At present, the coordinates of points in the U.S. National Triangulation Network are on the North American Datum (NAD)83. This uses a reference ellipsoid where rectangular coordinate axes are parallel to WGS 84, an ellipsoid fairly similar to WGS 84 with a = 6378137 m, which is the same as WGS 84, and f = 1/298.257222101, which is fairly close to that of WGS. The origin of NAD 83 is shifted in 1 m in the y-direction and -1 m in the z-direction. Thus, if (U,V,W) are the Cartesian coordinates of point P in the NAD83, then (X,Y,Z) in the WGS 84 is given by

$$X = U \text{ m}$$

$$Y = V + 1 \text{ m}$$

$$Z = W - 1 \text{ m}$$

3.3 Local System

At present, the Iowa DOT uses a local system for each project. The Z-axis, H, is along the direction of the gravity at that point; the Y-axis, N_L, is parallel with the local north (determined by sun or star or measured); and the X-axis, E_L, is perpendicular to both Y and Z. The angle between the direction of the gravity and the equatorial plane, ϕ_A, is defined as the astronomic latitude. The origin in X,Y is assumed and for the origin in Z, the geoid or the mean sea level of the North American Datum 1927 is used. Thus, if (E_L,N_L,H) are the local coordinates of the point P, then (X,Y,Z) in WGS 84 is given by

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} -\sin\lambda & -\sin\phi\cos\lambda & \cos\phi\cos\lambda \\ \cos\lambda & -\sin\phi\sin\lambda & \cos\phi\cos\lambda \\ 0 & \cos\phi & \sin\phi \end{bmatrix} \begin{bmatrix} E_L \\ N_L \\ H_L \end{bmatrix} + \begin{bmatrix} X_o \\ Y_o \\ Z_o \end{bmatrix}$$

Where ϕ, λ are the spherical coordinates of the point P and (X_o, Y_o, Z_o) is the coordinate of the origin in the WGS 84 system. Commonly used spherical coordinates in the local system are the zenith angle, ξ, and the azimuth, AZ (see Fig. 3.3). If the slope distance, OP, is S then we have

$$E_L = S \sin \xi \sin AZ$$

$$N_L = S \sin \xi \, cosAZ$$

$$H_L = H_o + Scos\xi$$

3.4 State-Plane System

For regional or state mapping, the coordinate system (X,Y), known as the state -plane coordinate system, is used in the United States. At present, the Iowa DOT does not use this system. With the use of GPS, the state plane coordinates can be easily computed, and it is therefore recommended that the state plane coordinate system be adopted by the Iowa DOT. The projection adopted for the state of Iowa is the Lambert conformal projection. If ϕ, λ are NAD83 spherical coordinates of point P, then the projection coordinates E_s and N_s are given by

$$E_s = C + Rsin\theta$$

$$N_s = R_b - Rcos\Theta$$

where C and R_b are constants, R is a function of the latitude, and

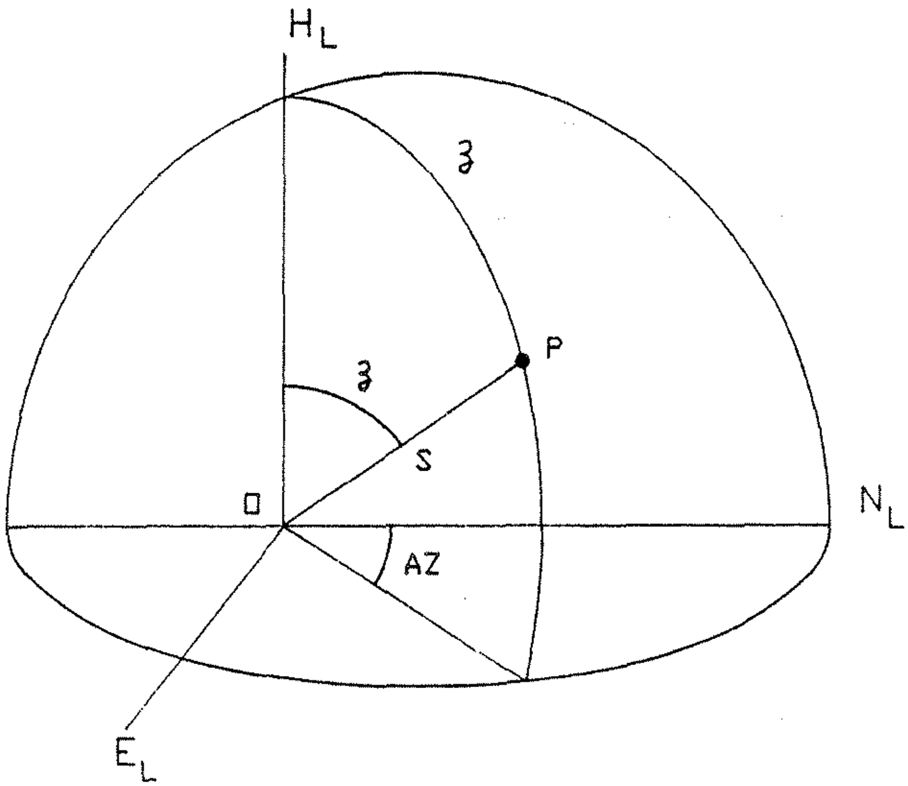


Figure 3.3 Local System

θ= convergence = $\sin \phi_o(\lambda - \lambda_{cm})$ where

ϕ_o = standard parallel of this projection

λ_{cm} = central median

If S is the slope distance between two points on the local system, then the projected coordinate, GD, is given by

$$GD = K\frac{R}{(R+h_m)}S\sin\xi$$

where, $S \sin\xi$ = MD = the horizontal distance

$$\frac{R}{(R + H_m)} = \textit{sea level factor}$$

and where

R = the radius of curvature along the line OP

H_m = the mean sea level elevation

K = scale factor, which is a function of ϕ'

AZ = grid azimuth = AZ - θ

Software for transforming ϕ,λ to state-plane coordinates and vice versa are <u>published</u> and available to the public through National Geodetic Surveys (NGS). The program also gives the scale factor and the convergence for a given ϕ,λ or (E_s, N_s).

3.5 Surface State-Plane System

Because of the scale factor and convergence, the state plane coordinates are unsuitable for setting out work. Thus, it is not currently used by Iowa DOT. The advantages of the state-plane system is its ability to tie different projects in the state to the state system and eventually to the national system. However, the advantage of a local system is in setting out work. In this project, a coordinate system called the surface state-plane system is developed that has the advantage of both state-plane and local systems and is suitable for working with GPS. If (E_s, N_s) are the state-plane coordinates of point P_1, and (E_{so}, N_{so}) are the state plane coordinates of a point P which is approximately the center of a project, then the surface state plane coordinates (E_{ss}, N_{ss}), are given by

$$E_{gs} = E_{go} + (E_g - E_{go})/GF$$

$$N_{gs} = N_{go} + (N_g - N_{go})/GF$$

where

GF = grid factor

$$= K*R/(R + h_m)$$

If the slope distance S and zenith angle ξ are measured by total station then

$$E_{gs} = E_{go} + S\sin\xi \sin AZ$$

$$N_{gs} = E_{go} + S\sin\xi \cos AZ$$

If the station coordinates (ϕ,λ,h) are measured by GPS, then the observed slope distance, S, geodetic distance, S_G, and direction, α, between two stations (ϕ_1,λ_1, h_1) or (X_1,Y_1,Z_1) and (ϕ_2,λ_2xh_2) or (X_2,Y_2,Z_2) are given by

$$s^2 = (x_2 - x_1)^2 + (y_2 - y_1)^2 + (z_2 - z_1)^2$$

$$s_e = s\left[\frac{1 - (\Delta\, h/s)^2}{(1 + h_1/R_\alpha)(1 + h_2/R_\alpha)}\right] + (1/24)\,\frac{L^3}{R_\alpha^2}$$

$$\acute{e}^2 = \frac{e^2}{(1 - e^2)}$$

$$\Delta h = h_2 - h_1$$

$$\tan \alpha = \frac{\cos U_2 \ \sin\Delta\lambda}{\cos U_1 \ \sin U_2 - \sin U_1 \ \cos U_2 \ \cos\lambda}$$

$$\Delta\lambda = \lambda_2 - \lambda_1$$

$$U_i = \tan^{-1}((1 - f)\tan\phi_i)$$

$$AZ = \alpha + \eta\tan\phi_1$$

η = deviation of the local Z axis in the prime vertical from the normal to the ellipsoid.

The map distance, MD = S sinξ, is the horizontal distance on the obtained local horizontal plane. MD is used in setting out work and is the distance obtained by scaling the highway plan. Also, distances between stations used commonly in the Iowa DOT practice are horizontal distances.

3.6 Orthometric Height

The Iowa DOT uses the height, H, above mean sea level (see Fig. 3.4), defined as the vertical datum by the NGS. The vertical datum is the geoid that utilizes the closest-fit gravity equipotential surface, the mean sea level. The distance along the vertical between the geoid and point P is the orthometric height, H, commonly known as mean sea level elevation. The ellipsoidal height, h, is measured along a line normal to the ellipsoid tangent that intersects the equatorial plane at latitude angle ϕ. The vertical differs from the ellipsoidal normal by the deflection of the vertical. Its meridianal component is ξ (shown in Fig. 3.5) and the prime vertical component is η. The difference between ellipsoidal height and orthometric height is defined as the geoid undulation, n. Thus

$$n = h - H$$

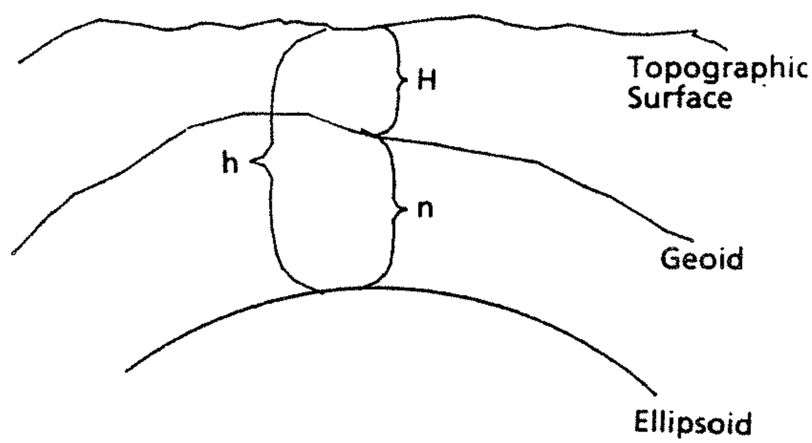


Figure 3.4 Geoid Undulation

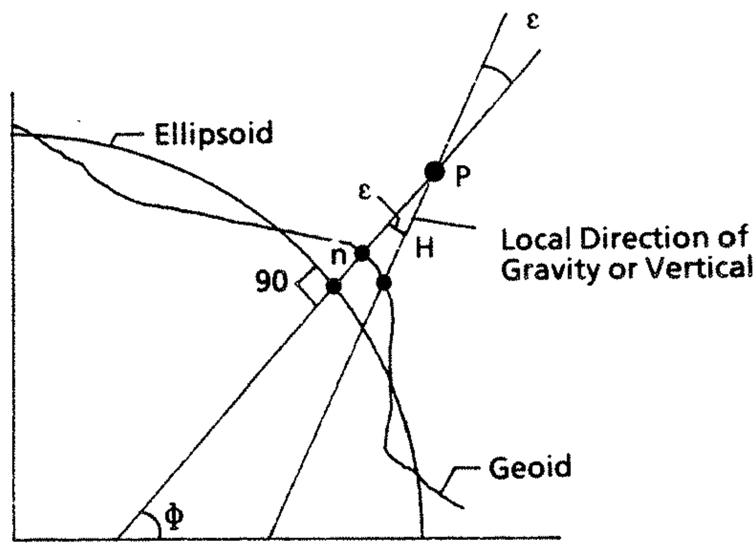


Figure 3.5 Deflection of the Vertical

$$\text{or} \quad H = h - n$$

With GPS, ellipsoidal height, h, can be determined accurately. An equally accurate solution for the geoid undulation, n, is desired. Gravimetric methods for the geoid modeling or n determination are preferred over the less direct and more field-time-intensive astronomic methods. The gravimetric geoid modelling is accomplished by the residualization and superposition of global (n_g) and local geopotential components (n_l) (Ref. 21). Thus we have

$$n = n_g + n_l$$

n_g can be determined by global gravity anomalies: n_l can be determined by local gravity anomalies or by interpolation using local vertical control points. The deviation of the geoid from an ellipsoid may be assumed to be due to disturbing potential T caused by mass and density anomalies in the geophysical structure of the earth. The spherical harmonic expansion of the disturbing potential, T, is

$$T(\theta,\ \lambda) = \frac{GH}{R}\sum_{n=2}^{n_{max}}\sum_{m=0}^{n} (C_{nm}\cos m\lambda + S_{nm}\cos M\lambda)\,P_{nm}(\cos\theta)$$

from (Ref. 21). G is the universal gravitational constant, M is the mass of the earth, and R its mean radius. C_{nm} and $S_{nm}$are fully normalized potential coefficients, corrected for the ellipsoid, and P_{nm} is the fully normalized Legendre function. These quantities are of degree n and order m. The infinite series is truncated to degree and order n_{max} (Ref. 21). From the well- known Brun's formula, we have

$$T = n_g\gamma\ ,$$

where $\gamma = GM/R^2$ is the normal (theoretical) gravity at a spherical surface. Thus, the global geoidal undulation

$$n_g(\theta,\lambda) = R\sum_{n=2}^{n_{max}}\sum_{m=0}^{n} (C_{nm}\cos m\lambda + S_{nm}\sin m\lambda)\,P_{nm}(\cos\theta)$$

Also, a close deriviation of the fundamental equation of physical geodesy is

$$\Delta g = -\frac{\partial T}{\partial r} - \frac{2T}{r}$$

where Δg_g is the global gravity anomaly and r is the radial earth direction. Thus, we have

$$\Delta g_g(\theta,\lambda) = \frac{GH}{R^2}\sum_{n=2}^{n_{max}}\sum_{m=o}^{n}(n-1)(C_{nm}\cos m\lambda + S_{nm}\sin m\lambda)P_{nm}(\cos\theta)$$

$$= g_o - g_c$$

where g_o is the observed surface gravity at location (θ,λ) and g_c is the computed gravity on the reference ellipsoid. The lower degree and order harmonic coefficients are obtained by least squares fitting of (non-GPS) satellite altimetry data. The higher ones are similarly obtained by surface gravimetry all across the globe. Using the harmonic coefficients the program "Geoid" computes the global undulation n_g at a given (ϕ,λ).

The local undulation, n_c, can be determined by analyzing local geopotential (high frequency) gravity anomalies. These free air gravity anomalies (Ref. 5) are observations derived from "open" or "closed" form equations. Stokes' theorem states that the gravity potential in the exterior space of an enclosing level surface of a rotating mass is uniquely determined. On the basis of this theorem, the geoidal undulation is given by Stokes' integral (Ref.6)

$$\eta = \frac{R}{4\pi\gamma}\iint \Delta g S(\psi)\,d\sigma$$

where γ is the average normal gravity over the ellipsoid, Δg the gravity anomaly, and ψ is the spherical distance between the point of interest and a surrounding residual gravity data point. The Stokes' function, $S(\psi)$, is

$$S(\psi) = csc\frac{\psi}{2} - 6\sin(\frac{\psi}{2}) + 1 - 5c\cos\psi - 3\cos\psi\ln(\sin\frac{\psi}{2} + \sin^2\frac{\psi}{2})$$

and $d\sigma$ is a surface element. Thus we have

$$n = n_g + n_l = \frac{R}{4\pi\lambda}\iint (\Delta g_g + \Delta g_l)\, S(\psi)\, d\sigma$$

The global gravity anomalies, Δg_g, are computed from the spherical harmonic series. The computed global gravity anomalies are then subtracted from the local observed free-air anomalies to produce residual or local gravity anomaly, Δg_L. When the enclosing surface is a spherical cap (around a point of interest) having concentric radial components k, then the local geoidal undulation n_l is given by (Ref. 21)

$$n_l = \sum_k C_k \Delta g_l$$

where

$$C_k = R(\alpha_{2k} - \alpha_{1k})\int_{\psi_{1k}}^{\psi_{2k}} \sin(\psi)\, S(\psi)\, d(\psi)$$

The concentric radial limits are bounded by radial limits ψ_{1k} and ψ_{2k} and azimuth limits α_{1k} and α_{2k}. To obtain the local undulation by the gravity method, a series of programs written by Steve Erck (Ref. 1) and the program written by Ohio State University (OSU) research team, which uses the spherical harmonic expansion to generate global gravity anomalies and geoidal undulation, were used.

An alternate method of determining the local undulation is to use existing vertical control, BMS, the differential GPS measurements, and the interpolation technique - the method of collocation. The ellipsoidal height, h, determined by GPS measurements between a known point and any other point is given by

$$h = h_o + \Delta h$$

where

h_o = ellipsoidal height of the reference point

Δh = differential GPS measurement

Thus, the orthometric height H at a point is given by

$$H = \Delta h + H_o' - \Delta n_g - \Delta n_l - S - n_n$$

$$= \Delta h - \Delta n_g - \Delta N - S - n_n + H_o$$

where

Δn_g = change in global undulation from reference point

Δn_l = change in local undulation form reference point

s = signal due to unmodeled geoid undulation etc.

n_n = noise due to Δh measurements etc.

$\Delta N = \Delta n_l - \Delta H_o$

$H_o = H'_o + \Delta H_o$

H_o = orthometric height of reference point

ΔH_o = correction

In practice ΔN, S, and n_n are unknown. However, Δh can be obtained by GPS differential measurement; n_g can be computed from global gravity observations; H_o and h_o can be estimated; and H is known at the controls and unknown at other points. Thus, the general form of the observation equation in the method of collocation (Ref. 34) is

$$l = AX + S_q + n_q + Os_p$$

where

l = the vector of observation = $H - (H_o + \Delta h - \Delta n_g)$

AX = mathematical model for ΔN

A = coefficient matrix

X = vector of parameters (e.g., h_o,a,b,c,d)

S_q = a signal vector at q control points

n_q = a noise vector due to measuring etc. at q control points

S_p = a signal vector at p unknown point

O = null matrix

The least-squares collocation solution is then given by

$$X = (A^T C_q^{-1} A)^{-1} A^T C_q^{-1} l$$

$$S_p = C_{pq}C_q^{-1}(l-AX)$$

where C_q is the covariance matrix of the observations at control point q

C_{pq} is the covariance matrix between unknown points p and control points q

Here, C_q and C_{pq} can be determined with the covariance function and iterative processes

(1) In the first iteration we can use $C_q = I$ and $C_{pq} = 0$, select various models of AX, and then solve for X and S_p

(2) If the residuals at the control points and check points indicate that correlations are larger than expected, then one can use the residuals and a covariance function to solve for X and S_p

(3) If the residuals are still large, then step (2) with a new set of residuals can be repeated until satisfactory residuals are obtained.

4.0 ADJUSTMENT OF GPS OBSERVATIONS

GPS observation gives

- precise slope distances (if the ambiguity is resolved between points)
- fairly accurate, three-dimensional coordinate differences
- accurate azimuth between points depending on the distance
- approximate location of points depending on the geometry of the satellites used and the accuracy of the satellites' coordinates.

In order to use these observations for Iowa DOT statewide applications, they have to be controlled by existing control points (see Fig. 4.1) and adjusted to give precise locations of points after eliminating random and systematic errors. On the basis of our research, the recommended procedures are to adjust the raw data by using a three-dimensional adjustment program, Geolab, then adjust horizontal position with azimuth control and vertical control by collocation.

4.1 Geolab

Geolab is a general-purpose, least-squares three-dimensional geodetic adjustment program. This program is used in this project to simultaneously adjust baseline distances, directions, and coordinate differences, all of which are obtained by GPS, and the known coordinates of some points from North American triangulation network. The general observation equation between stations 1 and 2 (see Fig. 4.2) can be written using Taylor's series (Ref. 29).

$$a_1\delta\phi_1+a_2\delta\lambda_1+a_3\delta\phi_2+a_4\delta\lambda_2+a_5\delta z+a_6\delta h_1+a_7\delta h_2 = l+v$$

where

$$\delta\phi_1 = \phi_1-\phi_{10}$$

$$\delta\phi_2 = \phi_2-\phi_{20}$$

$$\delta\lambda_1 = \lambda_1-\lambda_{10}$$

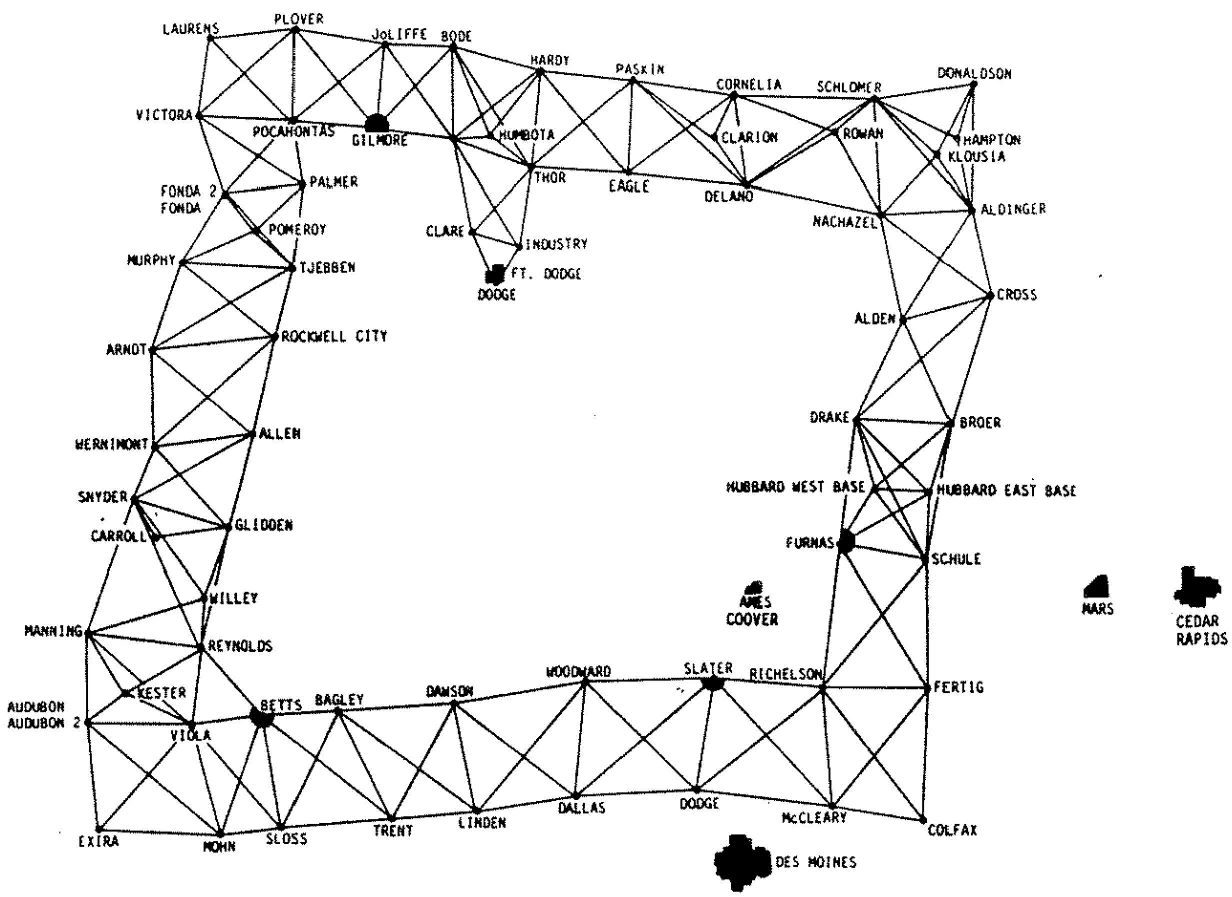


Figure 4.1 Central Iowa Triangulation Network

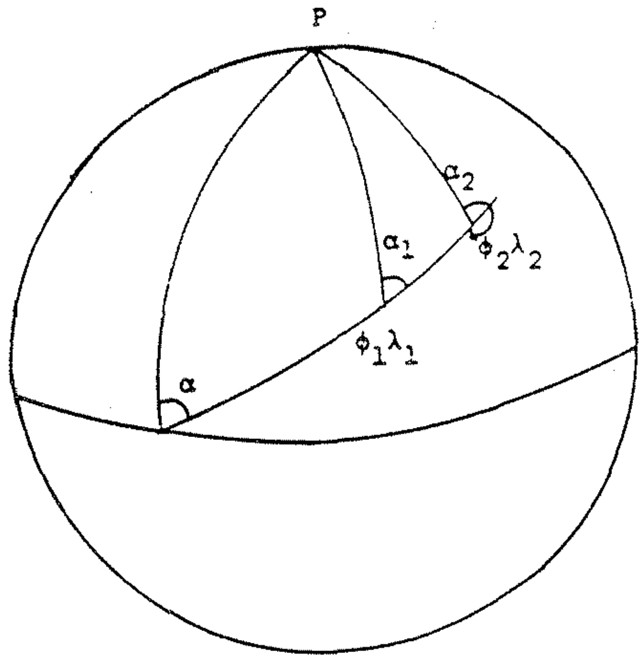


Figure 4.2 Geodetic Directions from Stations 1 & 2

$$\delta\lambda_2 = \lambda_2 - \lambda_{20}$$

$$\delta z = \alpha_1 - \alpha_{10}$$

$$\delta h_1 = h_1 - h_{10}$$

$$\delta h_2 = h_2 - h_{20}$$

where ϕ_{10}, ϕ_{20}, λ_{10}, λ_{20}, h_{10}, and h_{20} are the estimated coordinates and $\delta\phi_1$, $\delta\phi_2$, $\delta\lambda_1$, $\delta\lambda_2$, δh_1, and δh_2 are the locations to be determined by least squares. α_{10} is the estimated azimuth at station 1 and a_1, a_2, a_3, a_4, a_5, a_6, and a_7 are the coefficients. l is the observed value minus the computed value, and v is the residual.

For geodetic azimuth observations, the coefficients are

$$a_1 = -\frac{M_1}{S}\sin\alpha_{12}$$

$$a_2 = \frac{N_2}{S}\cos\phi_2\cos\alpha_{21} + \sin\phi_1$$

$$a_3 = -\frac{M_2}{S}\sin\alpha_{21}$$

$$a_4 = \frac{N_2}{S}\cos\phi_2\cos\alpha_{21}$$

$$a_5 = a_6 = a_7 = 0$$

where

α_{ij} = computed azimuth from i to j

$$M_i = \frac{C}{(1+e'^2\cos^2\phi_i)^{3/2}}$$

$$N_i = \frac{C}{(1+e'^2\cos^2\phi_i)^{1/2}}$$

$$c = \frac{a}{(1-f)}$$

$$e'^2 = \frac{f(2-f)}{(1-f)^2}$$

a = major axis of the ellipsoid

f = flattening

For geodetic distance observations the coefficients are

$$a_1 = \frac{M_1}{\rho}\cos\alpha_{12}$$

$$a_2 = \frac{N_2}{\rho}\cos\phi_2\sin\alpha_{21}$$

$$a_3 = \frac{M_2}{\rho}\cos\alpha_{21}$$

$$a_4 = -a_2$$

$$a_5 = a_6 = a_7 = 0$$

For direct observations of latitude, $a_1=1$ and $a_2=a_3=a_4=a_5=a_6=a_7=0$; for longitude, $a_2=1$ and $a_1=a_3=a_4=a_5=a_6=a_7=0$; and for elevation, $a_6=1$ and $a_1=a_2=a_3=a_4=a_5=a_7=0$.

For observations of geodetic differences in x coordinates,

$$a_1 = +[(v_1+N_1+h_1)\sin\phi_1\cos\lambda_1+\frac{ae^2\cos^2\phi_1\sin\phi_1\cos\lambda_1}{(1-e^2\sin^2\phi_1)^{3/2}}]$$

$$a_2 = (v_1+N_1+h_1)\cos\phi_1\sin\lambda_1$$

$$a_3 = -\left[(v_2+N_2+h_2)\sin\phi_2\sin\lambda_2+\frac{\mathrm{ae}\cos^2\phi_2\sin\phi_2\cos\lambda_2}{(1-e^2\sin^2\phi_2)^3/2}\right]$$

$$a_4 = -[(v_2+N_2+h_2)\cos\phi_2\sin\lambda_2]$$

$$a_5 = 0$$

$$a_6 = -\cos\phi_1\cos\lambda_1$$

$$a_7 = \cos\phi_2\cos\lambda_2$$

For observations of geocentric y coordinate differences,

$$a_1 = -[-(v_1+N_1+h_1)\sin\phi_1\sin\lambda_1+\frac{ae^2\cos^2\phi_1\sin\phi_1\sin\lambda_1}{(1-e^2\sin^2\phi_1)^{3/2}}]$$

$$a_2 = +(v_1+N_1+h_1)\cos\phi_1\cos\lambda_1$$

$$a_3 = \left[-(v_2+N_2+h_2)\sin\phi_2\sin\lambda_2+\frac{ae^2\cos^2\phi_2\sin\phi_2\sin\lambda_2}{(1-e^2\sin^2\phi_2)^{3/2}}\right]$$

$$a_4=-(v_2+N_2+h_1)\cos\phi_2\sin\lambda_2$$

$$a_5 = 0$$

$$a_6 = -\cos\phi_1\sin\lambda_1$$

$$a_7 = \cos\phi_2\sin\lambda_2$$

For observations in z coordinate differences,

$$a_1 = -[((1-e^2)v_1+N_1+h_1)\cos\phi_1+\frac{(1-e^2)ae^2\sin^2\phi_1\cos\phi_1}{(1-e^2\sin^2\phi_2)^{3/2}}]$$

$$a_2 = 0$$

$$a_3 = [((1-e^2)v_2+N_2+h_2)\cos\phi_2+\frac{(1-e^2)ae^2\sin^2\phi_2\cos\phi_2}{(1-e^2\sin^2\phi_2)^{3/2}}]$$

$$a_4 = 0$$

$$a_5 = 0$$

$$a_6 = -\cos\phi_1$$

$$a_7 = \cos\phi_2$$

where ν_i is the radius of curvature of the prime at point i and (N_i + h_i) is the height above mean sea level at point i.

Each azimuth, distance, position and coordinate difference observations generate observation equations of the form

$$A_k x = L_k + V_k$$

where x is a vector containing the corrections, A_k is a row matrix of coefficients, L_k is the difference between the computed and observed values, and V_k is the residual. If P_k is the weight matrix of observation, the corresponding partial normal equation is

$$N_k x = V_k$$

$$P_k = \frac{1}{\sigma_k^2}$$

$$N_k = A_k^T P_k A_k$$

$$U_k = A^T P_k L_k$$

where σ_k is the standard error of an observation. The final normal equation takes the form

$$Nx = U$$

where

$$N = \Sigma N_k$$

$$U = \Sigma U_k$$

In the computer programs, the normal equations are divided into partitions or blocks. The size of an individual partition depends on the size of real memory work space available to the program. The normal equations are decomposed into a product consisting of an upper triangular matrix and its transpose in the form

$$N = C^T C$$

The forward solution transforms the normal equation into the system

$$CX = (C^T)^{-1}U$$

The reverse solution solves the triangular system for the x vector

$$X = C^{-1}(C^T)^{-1}U$$

The variance - covariance, Σ_x, of the adjusted parameters are given by

$$\sum_x = \sigma_o^2 C^{-1}(C^T)^{-1}$$

where σ_o^2 is the variance of unit weight. The Geolab program computes and prints the final coordinates and related statistical information, which can be used to analyze any errors before accepting the final computation.

4.2 Vertical Adjustment

Geolab, when used with GPS data, gives ellipsoidal height, h. The ellipsoidal height, when used, must be transformed to orthometric height, H, using the equation

$$H = h - n_g - n_l \quad \text{(see Fig. 4.3)}$$

The global undulation, n_g, can be obtained by using the standard programs published by NGS (which uses the spherical harmonic expansion of the global gravity anomalies). The local undulation, n_l, was accomplished by two methods.

The first method is the gravimetric geoid modeling. In this method a high degree and order global geopotential model, the OSU86F, is improved by the superposition of a local geoidal undulation from a small spherical cap. Because the degree and order of the global model is 360, the spherical cap radius is 180/360 of 0.5 degrees (8). This was done on the ISU VAX 11/780 and NAS AS/9160 mainframe computers (See Fig. 4.4). The first step in this gravity data processing was the selection of the free air gravity data from the Iowa Geological Survey Bureau (IGSB) gravity data base (Ref. 21) for the vicinities of the stations. Because the free air gravity data were reduced to the GRS67 ellipsoid, a correction had to be applied to both latitude and gravity anomaly (Ref. 14). The latitude correction first required a transformation of the latitude from the GRS67 ellipsoid to geodetic coordinates (Ref. 21). This is given by

$$\phi = \tan^{-1}[(1-e_{167}^2)\tan\phi_{67}]$$

This equation was used in the reverse with the GRS80 first eccentricity to obtain GRS80 latitude

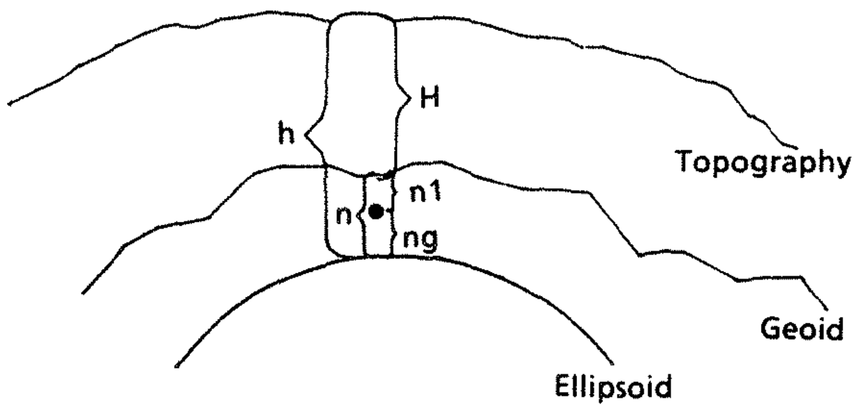


Figure 4.3 Local Undulation

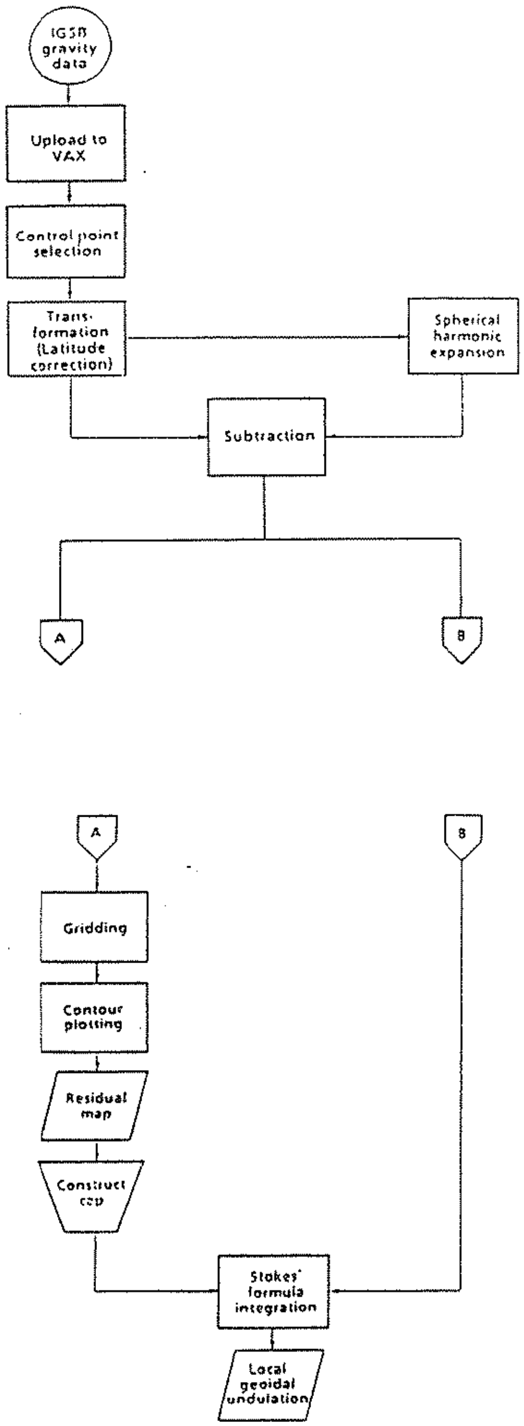


Figure 4.4 Computation of Gravimetric Local Undulation

$$\phi_{80} = \tan^{-1}\left[\frac{\tan\phi}{(1-e_{180}^{2})}\right]$$

The gravity latitude correction was achieved by adding the following (in mGal) to the GRS67 gravity anomalies (Ref. 10).

$$\Delta g = -0.8316-0.0782\sin^2\phi_{67}+0.0007\sin^4\phi_{67}$$

Therefore,

$$\Delta g_{80} = \Delta g_{67}+\Delta g_{6780}$$

where Δg_{67} and Δg_{80} are the GRS67 and GRS80 gravity anomalies respectively. The results obtained are the GRS80 locations and values of the free air gravity data . These locations are the input to the spherical harmonic expansion computer program (12) that generates global geopotential gravity anomalies and geoidal undulations at the locations. The global geopotential model is the OSU86F to a degree and order expansion of 360. It utilizes a 30 square-minute grid of mean gravity anomalies from satellite altimetry and some gravity data from land, including the United States (Ref. 21). The computer program was adapted to run on the NAS AS/9160 computer. Its output was subtracted from the free air gravity data to yield the residual gravity data. Figure 4.4 indicates a bifurcation at this point in the processing flow. The left branch details the interpretive intervention required in the analyses of the residual gravity data. The data are gridded on the NAS AS/9160, using local quintic polynomials, prior to contour plotting. The spherical caps are constructed on these residual (gravity) maps for each station (see Fig. 4.5 for a typical map). The method of sphericap construction compartmentalizes the residual gravity data points into high and low anomalies and areas of evenly spaced data. The concentrically bound compartments of the spherical cap are also bound by lines of equal azimuth. It is necessary that at least one data point be contained in each compartment and that all compartments fill the circle of the spherical cap. When the geometry of the spherical is known, it is entered along with the residual gravity data into the Stokes' formula integration program. This VAX computer program computes the local undulation or improvement to the global geoidal undulation.

The second method of vertical adjustment is the method of collocation or interpolation. In this method, at a number of control points in an area, both ellipsoidal height by GPS and orthometric height by leveling were determined, which in turn enables the local undulation, n_1, to be determined at the control

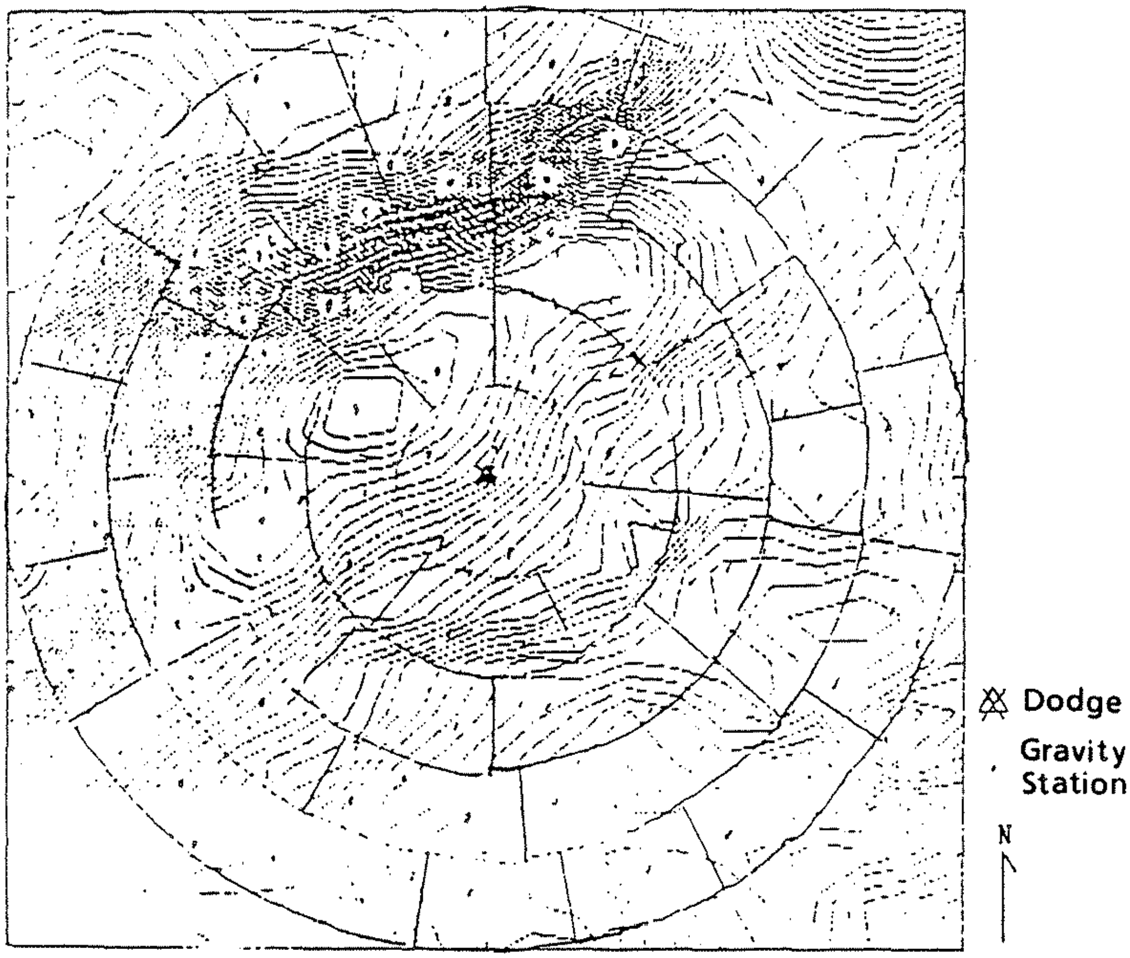


Figure 4.5 Dodge Small Spherical Cap of 0.5 Deg Radius

points. Knowing the n_l at a number of control points, n_l at any point in the area can be interpolated by using the method of collocation. H_1 is the orthometric height at a reference point; then

$$H_1 = (h_1 - n_{g_1}) - n_{l_1}$$

and H_2 is the orthometric height at another point. Then,

$$H_2 = h_2 - n_{g_2} - n_{l_2}$$

From these equations we have

$$H_2 - H_1 = (h_2 - n_{g_2}) - (h_1 - n_{g_1}) - (n_{l_2} - n_{l_1})$$

that is,

$$H_2 = H_1 + [(h_2 - n_{g_2}) - (h_1 - n_{g_2})] - (n_{l_2} - n_{l_1})$$

and

$$(n_{l_2} - n_{l_1}) = H_1 - H_2 + [(h_2 - n_{g_2}) - (h_1 - n_{g_1})]$$

For the method of interpolation a function can be assumed to represent $(n_{12} - n_{11})$. Let

$$(n_{l_2} - n_{l_1}) = a_0 + a_1 x + a_2 y + a_3 x^2 + a_4 y^2 + a_5 xy + a_6 z$$

or

$$= a_0 + (K_0 + K_1 D + K_2 D^2 + K_3 D^3)(b_1 \sin\alpha + b_2 \cos\alpha)$$

$$= a_0 + K_1 X + K_2 Y + K_3 DX + K_4 DY + K_5 D^2 X + K_6 D^2 Y$$

where (X,Y,Z) is the differential, three-dimensional coordinate of station 2 from station 1 and D, α are the distance and direction for 1 to 2. a_0, a_1, a_2 and so forth are the parameters. A suitable model can be selected depending on the number of control points and their distribution. Thus, we have the general observation equation

$$(h_2 - h_1) - (n_{g_2} - n_{g_1}) - (H_2 - H_1) = a_0 + a_1 x + a_2 y + a_3 x^2 + a_4 y^2 + a_5 xy + a_6 z$$

in which $(h_2 - h_1)$ is observed by differential GPS from station 1, $(n_{g2} - n_{g1})$ is obtained from the global geoid, H_2 is the known mean sea level elevation of station 2, and H_1 is either estimated or known. Using least squares, the parameters a_0, a_1, ...,a_6 are determined. Now, if H_i is the orthometric height of unknown point i, then it is given by

$$H_i = H_1+[(h_i-n_{g_i})-(h_1-n_{g_1})]-(n_{l_i}-n_{l_1})$$

$$= H_1+[(h_i-h_1)-(n_{g_i}-n_{g_1})]-(a_0+a_1x_i+a_2y_i+ \cdots)$$

in which $(h_i - h_1)$ is obtained precisely by using the three-dimensional Geolab adjustment program to constrain the elevations, latitude, and longitude of known points together with the spatial distances and the three-dimensional differential coordinate obtained by differential GPS observations. The observation equations, generated by using the Lotus spreadsheet are then fed into a least-squares collocation program to determine the selected parameters for local undulation and the local undulation at any station other than the control stations.

4.3 Horizontal Adjustment

The post-processing software of the differential GPS usually gives spatial distance, ellipsoidal azimuth, ellipsoidal height difference, and ellipsoidal, spherical, and cartesian coordinate differences. Accuracy of all except spatial distance depends on the accuracy of the satellite coordinates. The ellipsoidal azimuth differs from the true azimuth because of deviation of the vertical (ξ,η). The deviation of the vertical (see Fig. 4.6) varies from point to point, which causes the difference between the ellipsoidal azimuth and true azimuth. Thus, in an initial adjustment of the GPS observation only the spatial distances and three-dimensional coordinate differences together with known control points are used. For horizontal adjustment in a small area about 10 x 10 miles, assuming deviation of the vertical is constant and distances between points are more than 1000 meters, the adjustment of the GPS observation can include the constraining of the GPS azimuth observations. The latitude, ϕ, longitude λ output of the Geolab program can then be used to give the state-plane coordinates, convergence, and scale factor for horizontal adjustment. In typical Iowa DOT applications, a traverse with total stations is performed to obtain horizontal distances and directions between stations along the center line of a highway. Figure 4.7 shows a typical traverse from A to B. Thus, using either state-plane coordinates or surface state-plane coordinates of points A, A_1, B, and B_1 can be computed and adjusted to give its horizontal distances and directions. For Iowa DOT applications, horizontal distances and true azimuth are generally used. The surface state-plane uses the true azimuth and surface distances. The Geolab gives the spherical coordinates, which are then converted to state-plane coordinates. From the state-plane coordinates both grid distances and grid azimuth can be computed. The grid azimuth is

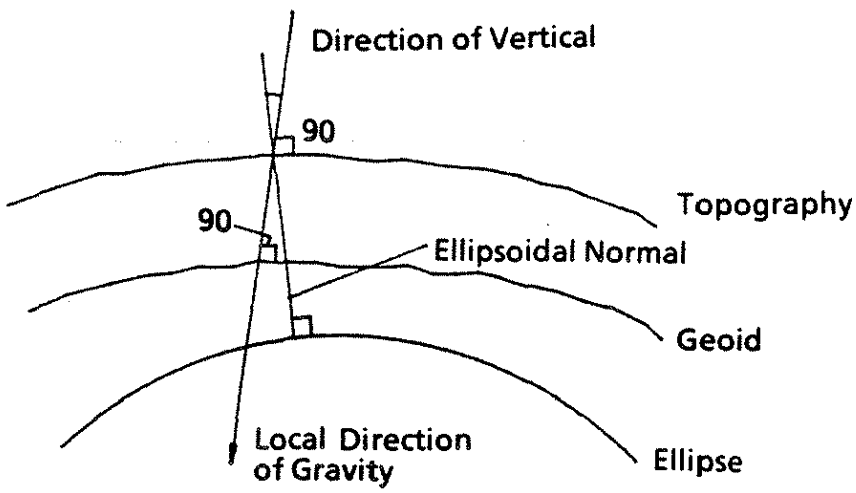


Figure 4.6 Ellipsoidal Normal

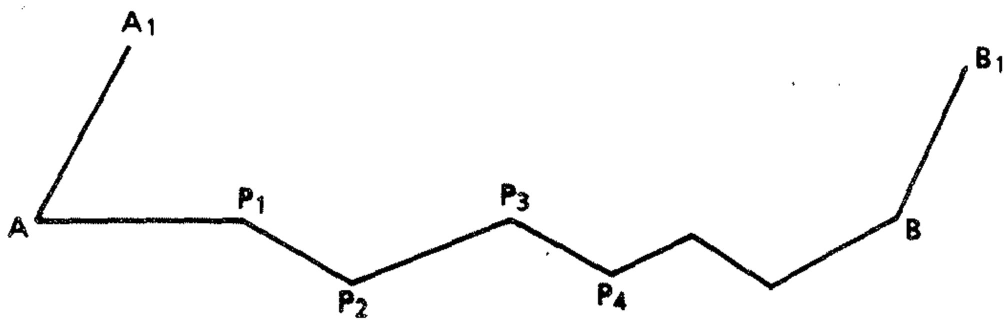


Figure 4.7 Traverse

converted to true azimuth by adding the convergence of meridian. The grid distance is converted to surface distance by dividing it by the grid factor. The grid factor is the product of scale factor and sea level factor. In a typical traverse program the horizontal distances and angles between points obtained by total stations are used with starting azimuth, starting coordinates, and closing azimuth and coordinates. The program gives the misclosure in azimuth x and y coordinates. If the misclosure is within allowable error, then the programs adjust the misclosure by either a compass rule or a least-squares conditions method to give the adjusted coordinates of the traverse points. For most Iowa DOT applications, allowable closure in azimuth is 2" per station and in distance is 1 m per 10,000 m or better.

5.0 EVALUATION PROJECTS

In order to evaluate the capability of GPS and develop methods suitable for Iowa DOT applications, a number of projects were undertaken during this research period.

The first project consisted of evaluating the accuracy of GPS distance measurement. In 1984 a EDMI calibration baseline consisting of five monuments on an east-west line was established by ISU research team in cooperation with the National Geodetic Surveys (REF). The baseline is located about 3 miles southwest of the ISU campus. The distances between monuments are determined using precise EDM and Invar tape to a mm accuracy. The distance between the farthest two points was measured by GPS static differential mode. The data were collected for about two hours and post-processed. Table 5.1 below shows the comparison. The agreement between the two measurements is about 5 mm, indicating that GPS static differentical mode will yield distances of more than sufficent accuracy for Iowa DOT applications.

Table 5.1

Calibrated Baseline Spatial Distance	GPS Spatial Distance	Difference	Precision
1369.2500 (m)	1369.2553 (m)	5.3 mm	1/270000

Four projects, namely Campus, Des Moines, Iowa, and Mustang, were then carried out to further evaluate and develop methods to use GPS for establishing horizontal and vertical control points in Iowa DOT applications.

5.1 Campus Project

The purpose of this project is to compare elevations of several points on the ISU campus within a one-mile radius obtained by four different methods:

1. GPS
2. Three Wire Leveling
3. Geolab
4. Gravity anomalies

Figure 5.1 shows the location of nine points used for this project. The points 105 and 103 are NGS benchmarks with known mean sea level elevations. The Old Town is a temporary point established on top of Town Engineering Building at ISU. The other points are survey benchmarks used in various class projects at ISU. In this project, station 105 is used as a reference point.

The static GPS observations were made from May 10, 1989 through May 16, 1989. Prior to each observation, the program GPSMap was run to select the window of observation of about two hours. The appendix "GPSMap" describes the procedure of running the program. Once the data are collected at the two stations they

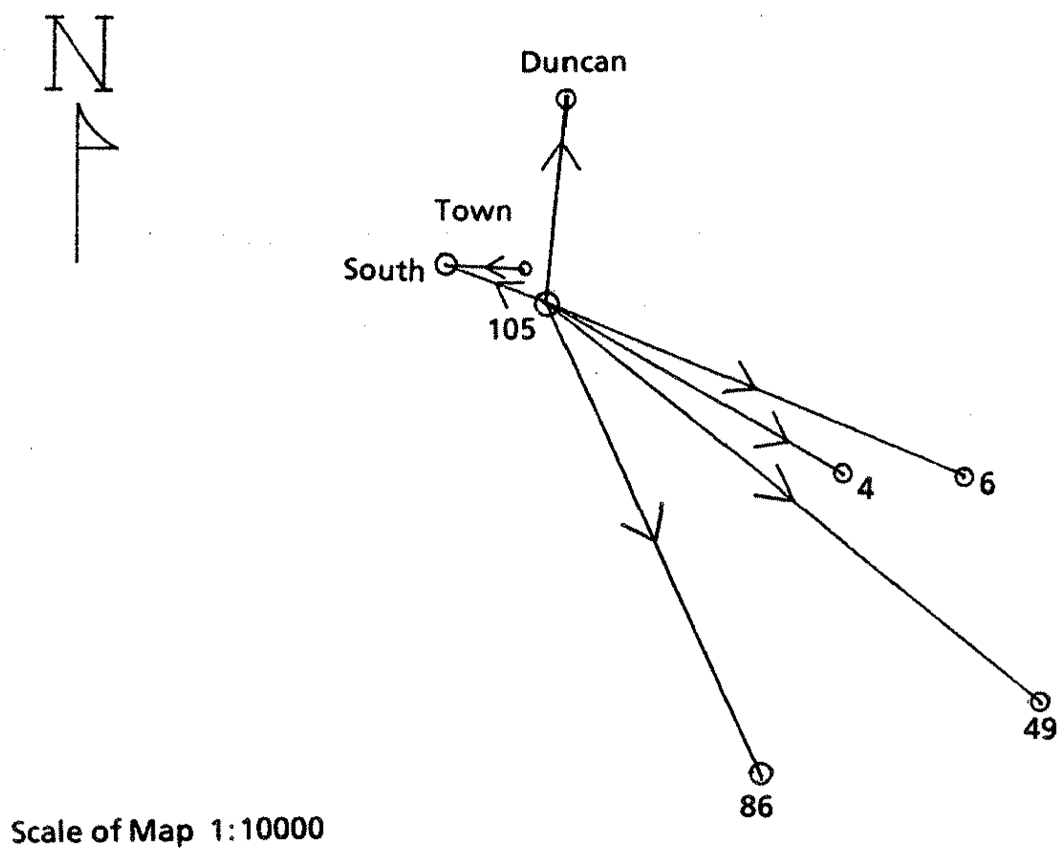


Figure 5.1 Campus Project

are processed by the GPPS software to give the spatial distance, azimuth, Cartesian coordinate differences, and the height difference between two stations. The appendix "GPPS" describes the procedure of running this program. After all the GPS data are collected in the network, the global undulations are computed by the Geoid software. Appendix "Geoid" describes the procedure of running this software which was used in all projects except Campus, this is followed by the computation of local undulation by the gravimetric method. The appendix "Local Undulation" describes the procedure of using this software. From this information the GPS and Geolab coordinate values of the points are computed and tabulated (see Table 5.2). The appendix "Calculations" describes the procedure used in developing the table. The appendix "Geolab" describes the procedure for running the program to give the Geolab coordinates. The appendix "SP83" describes the procedure for running the program to obtain the state-plane coordinates from spherical coordinates and vice versa.

The three-wire leveling is a precise method of obtaining orthometric height difference between stations. The line of leveling closely approximates equipotential surface and is thus independent of the geoid undulation. The three-wire leveling using in invar rods was done in the summer of 1989 to determine the three-wire leveling elevations of the points in the Campus project.

The GPS, Geolab, and TWL elevations as well as state plane coordinates and the like are tabulated by using the spreadsheet program "Lotus 123" (see Table 5.2). The appendix "Lotus" describes the columns in the table. These values are then used in the computation of the local undulation by the method of collocation. The Figure 5.2 shows the variation of the difference between GPS and TWL with distance. The data from this table are used in computing the coefficients of the model selected for the method of collocation. The program (see appendix Lobs) was used in computing the coefficients. After trial and error, the best two models that fit the data in the campus project are

$$\Delta h = a_0+a_1x+a_2y+a_3D(x+y)+a_4xy$$

and

$$\Delta h = a_0+a_1x+a_2x^2+a_3y^2+a_4xy$$

Table 5.3 gives the coefficients in the two models with the standard error of unit weight and the residual at a checkpoint, 6. Table 5.3 suggests that model 1 is significantly better than 2 and that the method of collocation can predict the elevation to an accuracy of ±2 mm for the Campus project.

Table 5.2

STATION	STATE PLANE COORDINATES X	Y	SCALE FACTOR	ANGLE OF CONVERGENCE (seconds)	GEOLAB OUTPUT (meters)	GPS WITHOUT LOCAL UNDULATION (meters)	THREE WIRE LEVELING (meters)
SOUTH	1487262.290	1058832.456	1.00000694	-375.29	294.06421	294.06300	294.05770
105	1487397.400	1058782.827	1.00000703	-371.30	292.69080	292.69080	292.69080
DUNCAN	1487424.243	1059061.932	1.00000655	-370.53	291.45421	291.45421	291.42694
86	1486314.637	1058142.267	1.00000815	-403.17	282.87099	282.85250	282.91754
49	1488070.188	1058245.891	1.00000796	-351.41	277.74585	277.72700	277.86134
4	1487801.469	1058549.679	1.00000743	-359.39	289.14594	289.13630	289.13882
6	1487963.300	1058549.443	1.00000743	-354.62	287.04948	287.03050	287.07772
TOWN					313.43400	313.28960	
103							293.56050

GLOBAL UNDULATION (meters)	GPS-TML	ISU CAMPUS BENCHMARKS (meters)	ISU CB-TML	X-X0 X0=STATION 105	Y-Y0 Y0=STATION 105	(X-X0)^2	(Y-Y0)^2
-28.76769	0.0053		0	-135.11	49.629	18254.7121	2463.037641
-28.77110	0	292.687	-0.0038	0	0	0	0
-28.76768	0.02727		0	26.843	279.105	720.54664901	77899.601025
-28.78611	-0.06504	282.903	-0.01454	-1082.763	-640.56	1172375.7142	410317.1136
-28.79216	-0.13434	277.91	0.04866	672.788	-536.936	452643.69294	288300.2681
-28.78251	-0.00252	289.127	-0.01182	404.069	-233.148	163271.75676	54357.989904
-28.78577	-0.04722	287.067	-0.01072	565.9	-233.384	320242.81	54468.091456

MEAN	-0.030935714
VARIANCE	0.0026551614
STAND. ERROR	0.0515282585

XY	DISTANCE (meters)	DISTANCE FROM 105 OLD COORDINATES (meters)	NEW DISTANCE - OLD DISTANCE (meters)
1574761583237	143.9366171		
1574830824044	0	0	0
1575274392495	280.39284526		
1572732339470	1258.0512024		
1574744161971	860.78101805	861.08224	-0.3012219471
1574911767426	466.50803494	466.54548	-0.0374450583
1575082722419	612.13634221	612.27295	-0.1366077884

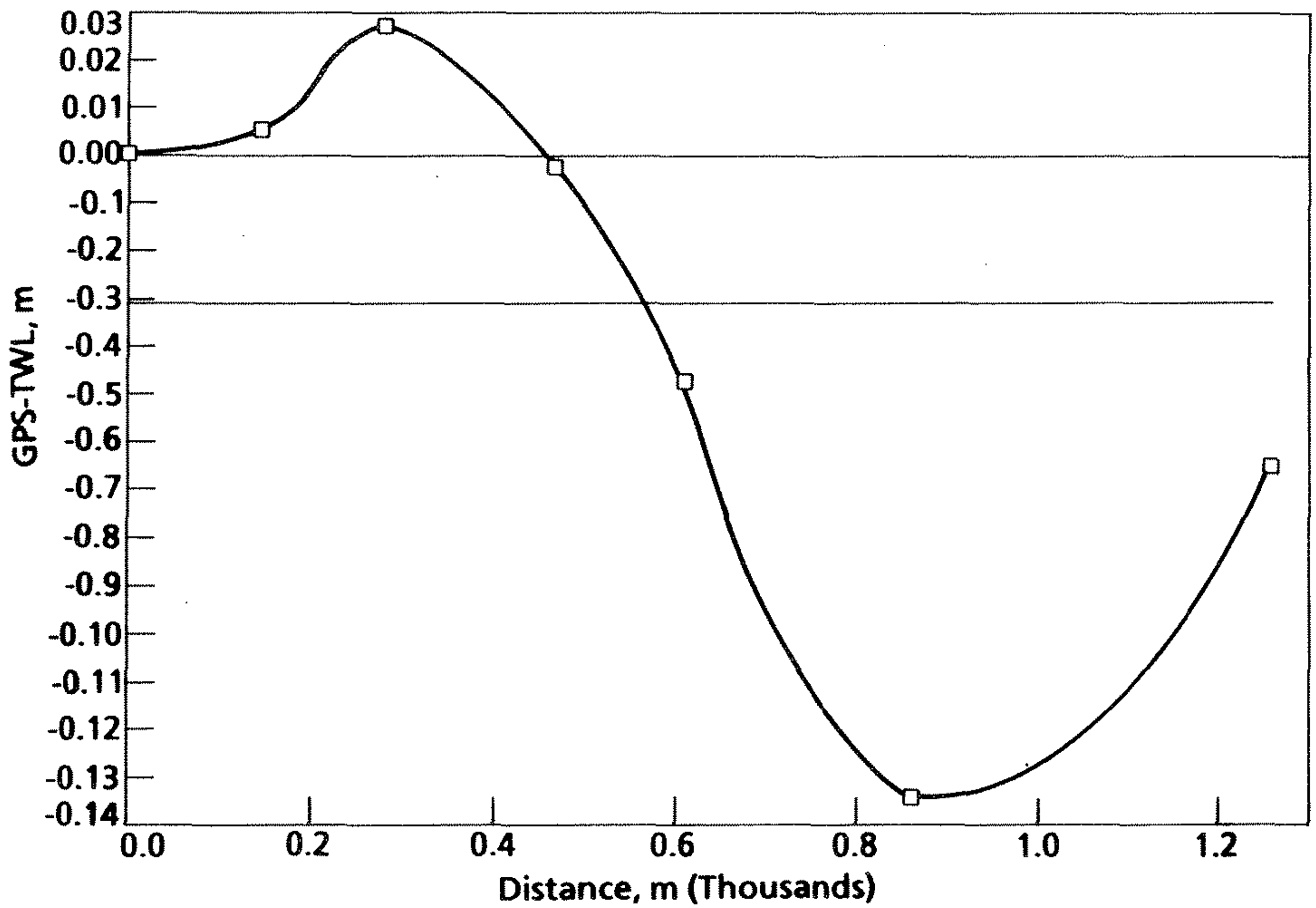


Figure 5.2 Local Undulation in Campus Project

Table 5.3

	Model 1	Model 2
a_0	-1.422189×10^{-3}	1.637893×10^{-2}
a_1	-8.763373×10^{-5}	1.049360×10^{-4}
a_2	-6.634330×10^{-6}	-2.005078×10^{-7}
a_3	3.508212×10^{-7}	2.111838×10^{-8}
a_4	-5.7073205×10^{-6}	3.731166×10^{-7}
σ_0	0.0019 m	0.02 m
Residual at check pt 6	0.003 m	0.01 m

Even though gravity observations are not part of this project, gravity anomalies were observed using gravitimeter, obtained on loan from the Iowa Geological Survey. Table 5.4 shows the gravity anomalies for the campus project using station 105 as the reference station and the differences between GPS and leveling and the distances of stations from 105. Figure 5.3 shows the correlation between gravity anomalies and GPS - Levelling. The study of this relationship is beyond the scope of this project, but it is recommended that this be studied further.

Table 5.4

Gravity Anomalies (G) vs GPS - Levelling (H)

Station	H (m)	G (mgals)	Diff G (mgals)	Dist. (m)
105	0	-0.29270	0	0
South	0.0053	-0.29276	-0.00006	143.9
Duncan	0.02727	-0.29063	0.002073	280.3
86	-0.06504	-0.29709	-0.00439	1258
49	-0.13434	-0.29821	-0.00550	860
4	-0.00252	-0.29614	-0.00344	466
6	-0.04722	-0.29670	-0.00400	612

5.2 Des Moines Project

The Des Moines project was conducted in cooperation with Iowa DOT personnel. This is a small Iowa DOT project, approximately three miles long (see Fig. 5.4). This project was done from the month of May through June 1989. The project was divided into three subprojects:

1. Des Moines I.
   Six stations were observed from old Town roof point. The name of the stations are: First PI, Second PI, OS, BM #9, BM #10, and BM #11.

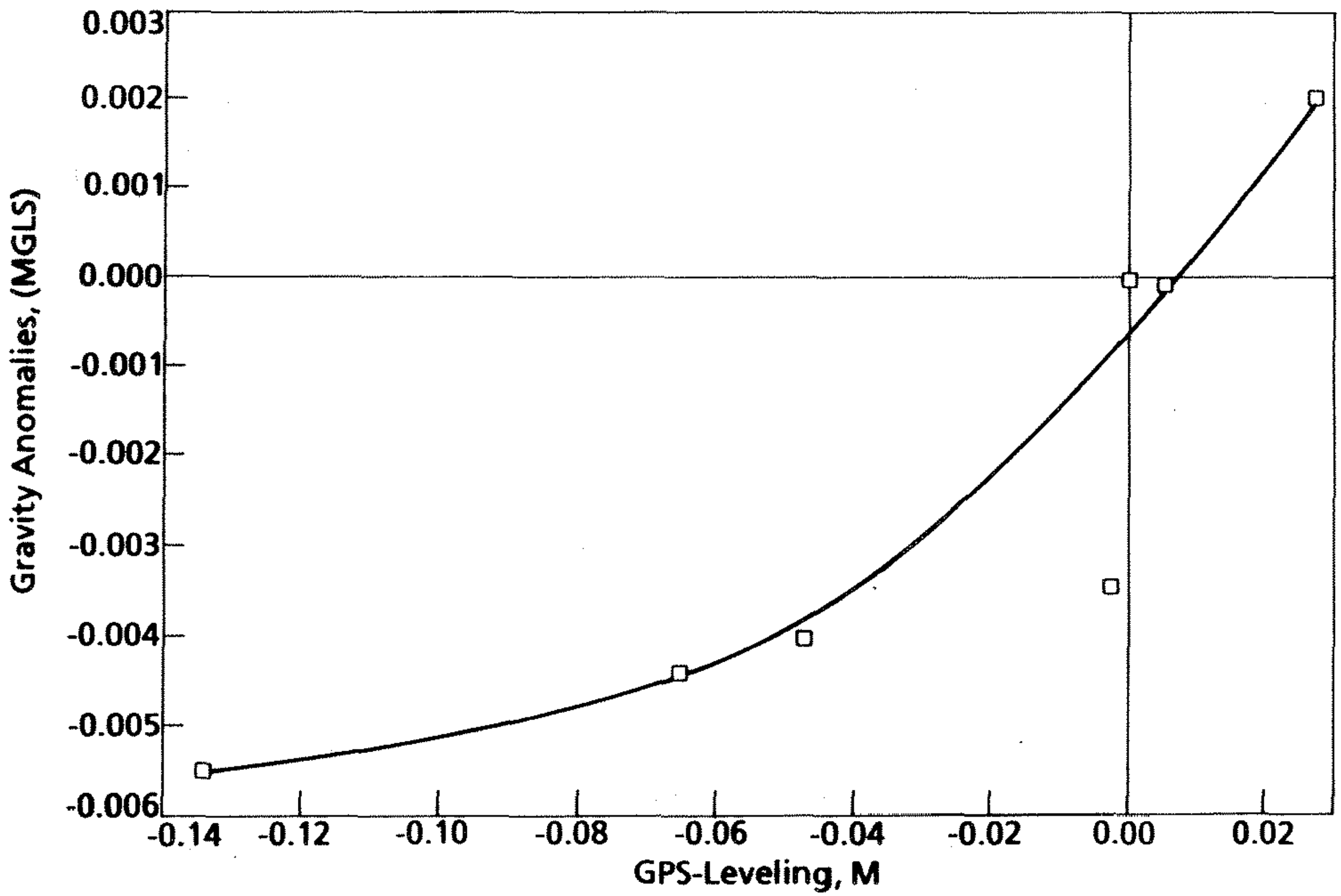


Figure 5.3 Gravity Anomalies vs (GPS - Levelling)

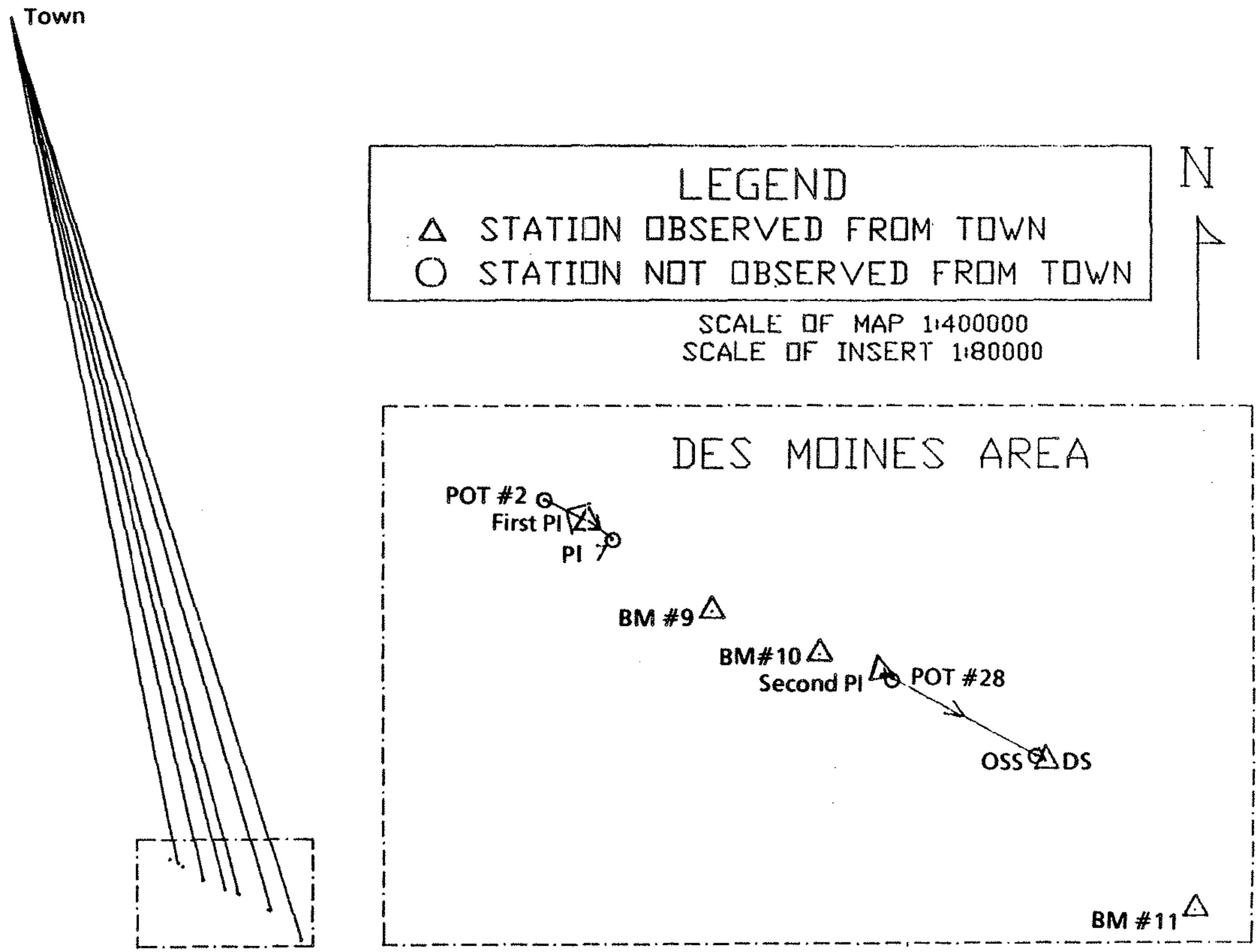


Figure 5.4 Des Moines Project

2. Des Moines II.
   The baseline between Second PI and OS was observed in static mode.

3. Des Moines III.
   Four baselines
   a. First PI - POT #2
   b. First PI - PI 7
   c. OS - OSS
   d. Second PI - POT #28
   were observed in pseudo-static mode.

The purpose of this project is to determine the elevation of six stations observed from a reference station located about 30 miles from the project area and to compare them with the elevations determined by Iowa DOT. The Table (5.5) shows the Lotus 123 spread sheet for this project. The worst error of about 1.0549 ft is found in the elevation calculation without the local undulation (gravitimetric method). The maximum error for the ones without global or local undulation is 0.67 ft and for the ones with local and global is 0.65 ft. Figure 5.5 shows that after global and local undulation correction the average errors in elevation are less than 0.2 ft and the error varies sinusoidally with distance. After trial and error, the best model for the method of collocation was

$$\Delta h = a_0+a_1D+a_2D^2+a_3D^3$$

Table 5.6 gives the coefficients of the model and the standard error which indicates that elevation with an accuracy of ±3 mm can be determined by using GPS and method of collocation for a small Iowa DOT project less than five miles long, provided there are four or more control points and they lie along the direction of the project.

Table 5.6

$a_0 = 0.00064$
$a_1 = 7.759\text{x}10^{-4}$
$a_2 = -1.959\text{x}10^{-7}$
$a_3 = 1.289\text{x}10^{-11}$
$\sigma_0 = .009 \text{ ft} \approx 0.003 \text{ m}$

The purpose of the Des Moines II project was to compare the distance and height difference of a baseline obtained by static GPS method with that obtained by Iowa DOT. In this project the Iowa DOT used EDM to measure distances to an accuracy of ±0.01 ft and ±10" theoditite to measure direction. The Table 5.5 shows that the distances calculated by using GPS coordinates agree with the DOT with a precision of 0.85/15086 ≈ 1:15 to 0.31/8403 ≈ 1:20,000, indicating the distances obtained by GPS coordinates are satisfactory for Iowa DOT applications. Table 5.5 also shows that the direct horizontal GPS distance agrees with DOT with a precision

Table 5.5

DES MOINES PROJECT

STATION	STATE PLANE COORDINATES X	Y	SCALE FACTOR	ANGLE OF CONVERGENCE (seconds)	DISTANCE (FT)	GLOBAL UNDULATION (meters)	LOCAL UNDULATION (meters)	GEOLAB OUTPUT ELEVATION (meters)
TOWN						-28.77007	0.0705884111	314.18409
FIRST PI	1499004.72	1000797.014	1.00014849	-29.08	9998.566	-30.00666	-0.33254605	239.31922
SECOND PI	1503092.66	998689.652	1.00015516	90.34	5431.003	-30.13535	-0.1680291718	251.23752
OS	1505367.034	997510.778	1.00015895	156.75	2928.368	-30.20749	-0.186983121	262.92487
BM#9	1500719.897	999569.946	1.00015236	21.03	7894.258	-30.06697	-0.2707377048	249.44088
BM#10	1502224.91	998955.446	1.00015432	65	6294.377	-30.11142	-0.1862612578	240.76436
BM#11	1507464.024	995466.769	1.00016559	217.94	0	-30.29185	-0.0960290048	248.29546
POT #2	1498402.22	1001100.635	1.00014753	-46.69	10670.36	-29.98798	-0.6076256994	
PI 7	1499342.905	1000548.832	1.00014927	-19.2	9580.184	-30.01866	-0.2121120211	
OSS	1505219.555	997592.662	1.00015869	152.45	3091.449	-30.20273	-0.1386038386	
POT #28	1503230.128	998619.051	1.00015539	94.36	5278.518	-30.13976	-0.5468533539	

GPS WITHOUT LOCAL UNDULATION (meters)	DOT (meters)	STATION REF GPS WITHOUT GLOBAL&LOCAL (feet)	BM #11 GPS WITHOUT LOCAL (feet)	ELEVATION DOT (feet)	DIFFERENCES GPS with local and global - DOT (feet)	GPS without local and global - DOT (feet)	GPS without local - DOT (feet)
313.28960							
238.00469	239.4751000	29.10332	30.038972	28.984	0.278974	0.1192062	1.054972
250.07538	251.3838100	-10.075993	-9.5625477	-10.086	0.28716842	0.010007	0.5234523
261.63040	263.0684590	-47.74909	-47.472441	-48.421	0.65027469	0.6719087	0.948559
248.16150	249.4169100	-4.0212766	-3.283491	-3.633	-0.22367458	-0.3882766	0.349509
239.55125	240.7742014	24.37306	24.965018	24.722	-0.05301608	-0.3489368	0.243018
247.16068	248.3095600				0	0	0

	DISTANCES (feet) Calculation	GPS/Linecomp	DOT	CALC - DOT	GPS - DOT	GPS(HOR. DIST.)	GPS(HOR. DIST.) - DOT
FIRST PI to SECOND PI	15087.21351		15086.3561	0.85741			
SECOND PI to OS	8403.563002	8403.4421	8403.25	0.313002	0.1921	8403.3511289	0.1011289345

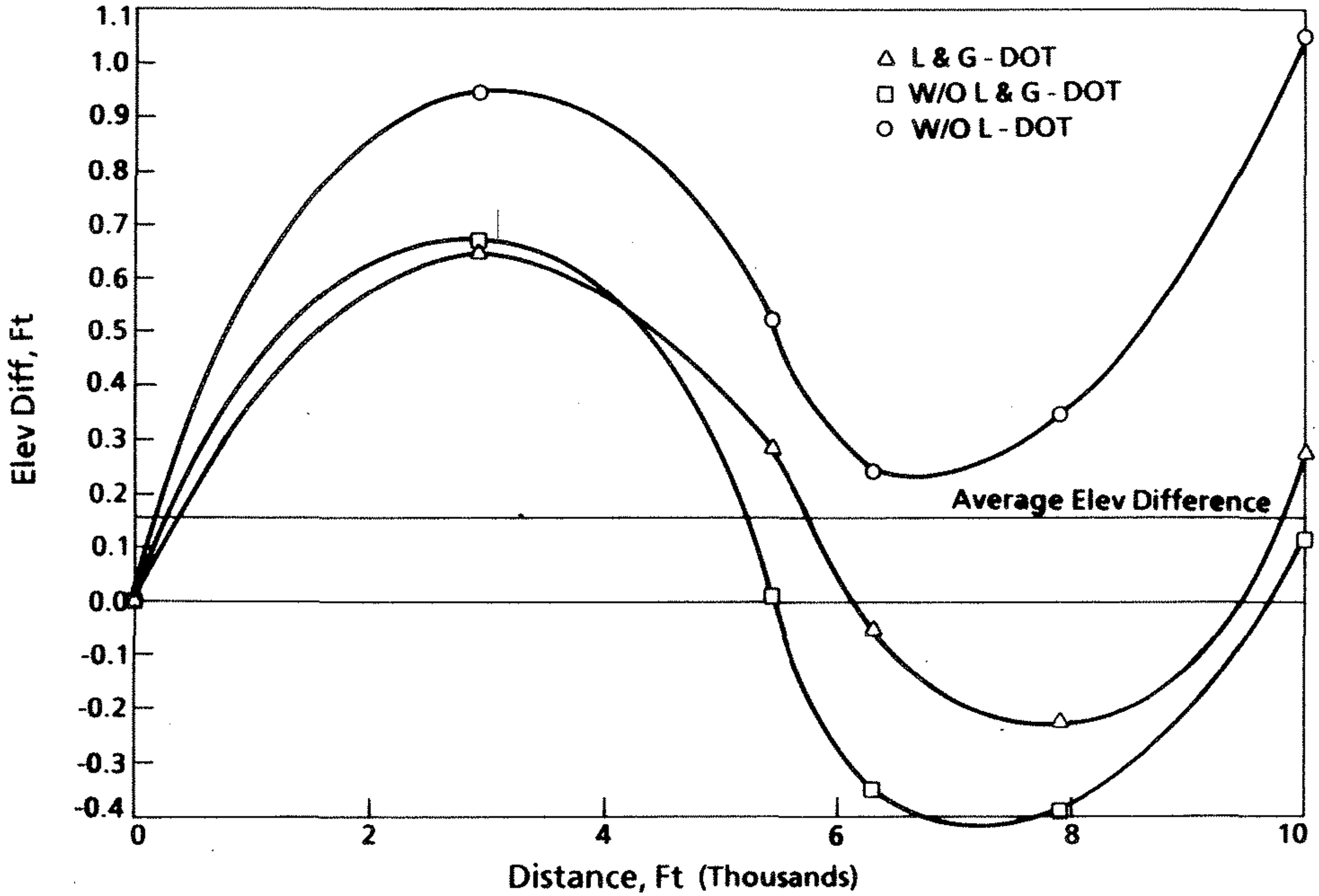


Figure 5.5 Local Undulation in Des Moines Project

of 0.1/8403 ≈ 1:80,000, which is better than the accuracy required for normal Iowa DOT applications. Table 5.7 indicates that elevation difference between GPS and Iowa DOT in a baseline using global undulation is 0.10 ft over a distance of 8400 ft, or about 0.02 ft per 200 ft, which is just about satisfactory for Iowa DOT applications.

The purpose of Des Moines III project is to compare the azimuth of four baselines obtained by the GPS pseudo-static method of 15, 30, and 60 min. observations in the Iowa DOT value. Table 5.7 shows that for short azimuth lines (PI to POT #2) the relative accuracy of GPS pseudo-static observation is about 10" to 20" for long azimuth lines (OS to OSS) the relative accuracy is about 1" irrespective of the length of observation. Table 5.7 also shows that differences between GPS azimuth and DOT azimuth increased from about 10" at first PI to about 15" at second PI over a distance of 15,000 ft and increased to 40" at OS over a distance of 23,000 ft ≈ 5 miles. Typically, for Iowa DOT projects, the expected angular accuracy with a 10" theodotite is about 15" per station. Thus it can be concluded that the GPS pseudo-static observation can be used as azimuth control for Iowa DOT applications.

5.3 Iowa Project

The purpose of this project is to use GPS and Geolab to determine three-dimensional coordinates in a large network of about 30-100 miles radius. In addition the project was used to evaluate the accuracy of the gravimetric local undulation method. The project uses points that are widespread over central Iowa (see Fig. 5.6). The points used are

1. New Town roof (Ames)
2. 105 (ISU Campus)
3. DOT (Ames)
4. Slater
5. Nevada
6. Hampton
7. Belts (Guthrie County)
8. HI 65 (on highway 65 about 10 miles form Nevada)
9. Boone
10. Dodge
11. Hardy
12. Humbota

The observations were made from August 16, 1989 through January 18, 1990. This project took a long time to finish because of the distance of the points and the number of observations. In order to collect data continuously from satellites it was decided to have two permanent base stations: one on top of Iowa DOT building, the point DOT, and the other on top of Town Engineering Building, ISU, the point New Town. Accordingly, two permanent brackets to hold the antenna on top of the buildings were established. This setup, by utilizing AC power, has the capability to automatically record data throughout the night and day.

Table 5.7

DES MOINES II

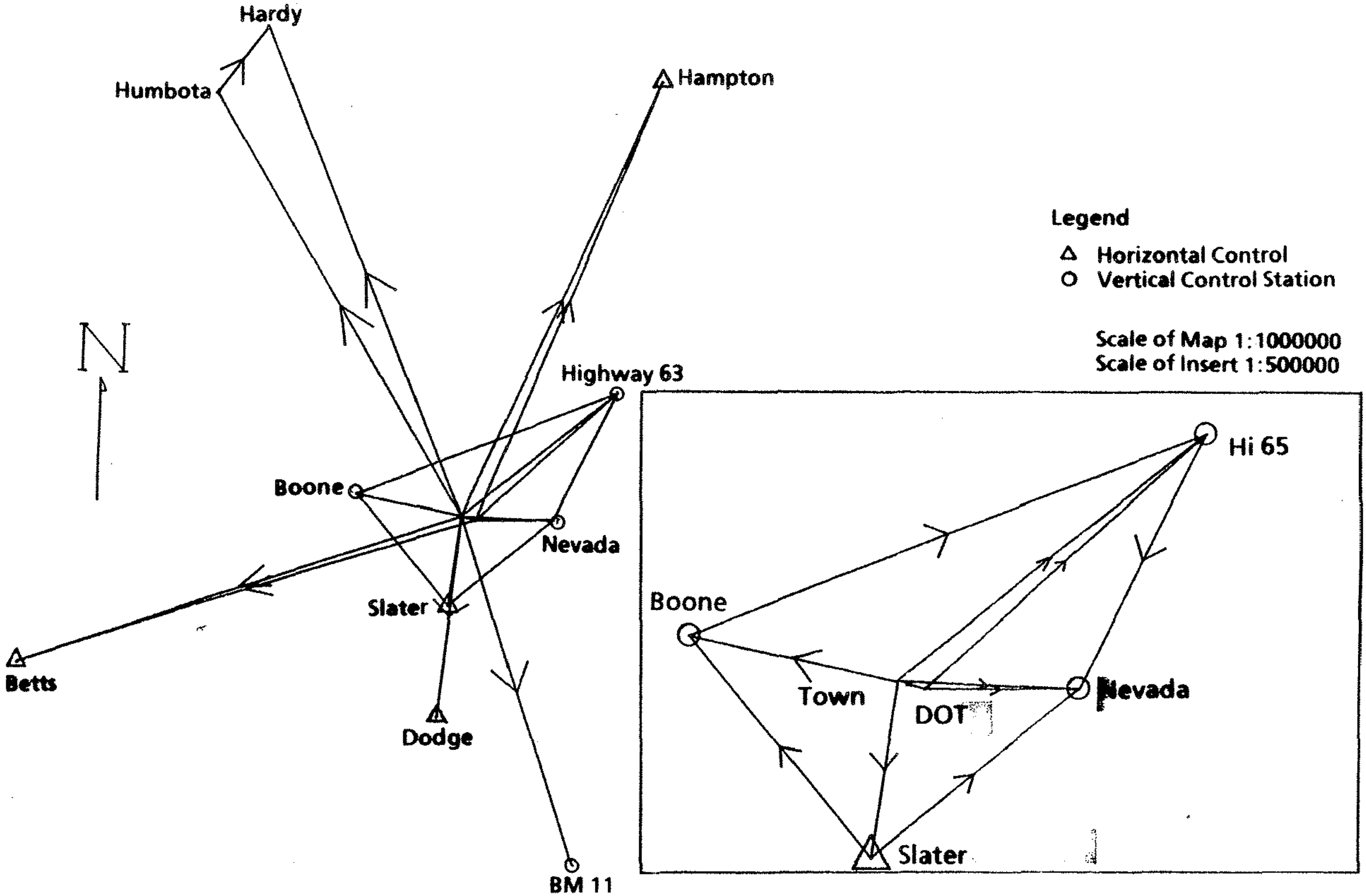
STATION	ELEVATION (feet)		ELEVATION DIFFERENCES		(REF. POINT OS)		
	GPS W/O L UNDUL.	DOT	GPS W/OUT LOCAL	DOT	GPS W/OUT LOCAL -DOT	GPS WITH LOCAL - DOT	GPS W/OUT LOCAL AND GLOBAL-DOT
OS	858.8834	863.075					
SECOND PI			38.43609	38.335	0.10109	0.1632	-0.13566

DES MOINES III

STATION	STATE PLANE X	COORDINATES Y	SCALE FACTOR	CONVERGENCE ANGLE (seconds)	GEOLAB (feet)	ELEVATION GPS (feet)
POT #2	1498402.22	1001100.635	1.00014753	-46.69	787.4738232	782.24777
PI #7	1499342.905	1000548.832	1.00014927	-19.2	795.188165	791.27535
OSS	1505219.555	997592.662	1.00015869	152.45	874.6106657	870.54499
POT #28	1503230.128	998619.051	1.00015539	94.36	827.9263496	822.948031

		AZIMUTH Degrees	Minutes	Seconds	DIFFERENCE IN CONVERGENCE (seconds)
FIRST PI to POT #2	CALC. 15 MIN	0	0	0	
	CALC. 30 MIN	0	0	0	
	CALC. 60 MIN	0	0	0	
	DOT	0	0	0	0
FIRST PI to PI 7	CALC. 15 MIN	9	31	57.7	
	CALC. 30 MIN	9	31	44.7	
	CALC. 60 MIN	9	31	52.86	
	DOT	9	31	37	27.49
SECOND PI to POT #28	CALC. 15 MIN	0	28	25.1	
	CALC. 30 MIN	0	28	24.8	
	CALC. 60 MIN	0	28	28.13	
	DOT	0	25	51	141.05
OS to OSS	CALC. 15 MIN	2	20	47.15	
	CALC. 30 MIN	2	20	48.39	
	CALC. 60 MIN	2	20	47.9	
	DOT	2	16	50	199.14

Figure 5.6 Iowa Project



The points Dodge, Town, Hardy, and Humbota were used in evaluating the local undulation by gravimetric method. Table 5.8 below gives the orthometric heights published by National Geodetic Survey (NGS) and the values obtained by GPS with global and local conclations. This table indicates that local undulation improves the elevation determination of Hardy and Humbota by about 0.5 meters.

Table 5.8

Station	NGS (Levelling)	GPS with Global	GPS with Global and Local
Dodge	307.23 m	307.23 (fixed)	308.75
Hardy	357.47 m	356.45	357.58
Humbota	348.29 m	343.92	345.13

Orthometric Heights

Table 5.9, gives the orthometric height differences and GPS misclosures. The loop misclosures indicate that the NGS elevation of Humbota may be in error by about three meters. The orthometric height difference shows a difference of 0.6 m between NGS leveling and GPS leveling using global and local correction over a distance of 130 km.

Table 5.9

Line	NGS	GPS(G+L)	Distance
Dodge-Hardy	50.24 m	50.83 m	129 km
Dodge-Humbota	41.06 m	36.38 m	120 km
Hardy-Humbota	9.18 m	12.45 m	15 km

Orthometric Height Differences

GPS Loop Misclosure

Town-Hardy	43.9575
Hardy-Humbota	-12.4719
Humbota-Town	-31.6131
	-0.1275

Thus, it can be concluded that local undulation improves height determination over long distance and that GPS differential leveling with global and local undulation correction can yield an accuracy of 0.6 m per 130 km or 1 mm per 200 m. The process of determining local undulation by the gravimetric method was found to be time consuming; this problem could be improved by better programming techniques.

In order to determine the three-dimensional coordinates using GPS and Geolab for the point in the Iowa Project, more than 25 GPS measurements were used. Of the 12 points in the network, 3 points are NGS fully controlled points, 4 points are NGS vertical controlled points, and 3 points are NGS horizontal controlled points. After many combinations of observation in different adjustment, it was found that for satisfactory results all spatial distances and three-dimensional coordinate differences observed by GPS must be used as observations with reliable weights. In addition, at least 3 vertical control points and 2 horizontal points need to be fixed. Also, for each unknown point, at least three GPS observations from other stations are required. The appendix A1FIX.IOB shows the final input file used in the Geolab adjustment. In this adjustment a station was fixed in all three coordinates, GPS spatial distances were constrained to ±0.01 m, and GPS coordinate differences were constrained to ±0.01 m. Included in the network are points BM9, BM10, BM11, and Old Town from the Des Moines project. The appendix, A1FIX.OUT, shows the final Geolab adjusted geographic coordinates of the points in the network. The appendix also gives the dimensions and orientation of the 95% confidence level error ellipse for each point in the network. The error ellipse indicates that the standard error of the coordinates of the unknown central points in the network with GPS measurement to three or more points, N Town and DOT, is about ±10 cm in horizontal and about ±80 cm in vertical. The Geolab does not include geoid undulation, and the adjusted elevations are ellipsoid elevations.

5.4 Mustang Project

The purpose of the Mustang project is to apply the GPS technology to establish vertical and horizontal control for a large Iowa DOT project. The project is along Highway 30, south of Nevada, and is within 30 miles of the central stations Town and DOT of the Iowa Project (see Fig. 5.7). The project is controlled by four stations: Slater, Town, DOT, and Nevada established in the Iowa Project. The six GPS points (NE, SE, N, S, NW, and SW) are selected to control both the survey and photogrammetric work of Iowa DOT. BM1 and BM2 are local NGS benchmarks. Table 5.10 shows the "Lotus 123" spreadsheet developed from GPS observations. The observations were done from Spring 1990 to Fall 1990.

In order to provide vertical control, the elevation of at least one of the six points is needed to an absolute accuracy of ±10 cm. The method of collocation of determining the local undulation was found to provide this required accuracy. From Table 5.10 it can be seen that eight height control points were available to be used in the method of collocation to determine the local undulation. After trial and error, the best model for the local undulation, Δn, was found to be

$$\Delta n = a_0\_a_1x+a_2y+a_3x^2+a_4y^2+a_5xy+a_6z$$

and Table 5.11 gives the parameters and the standard error of the unit weight. The standard error indicates that the elevation in

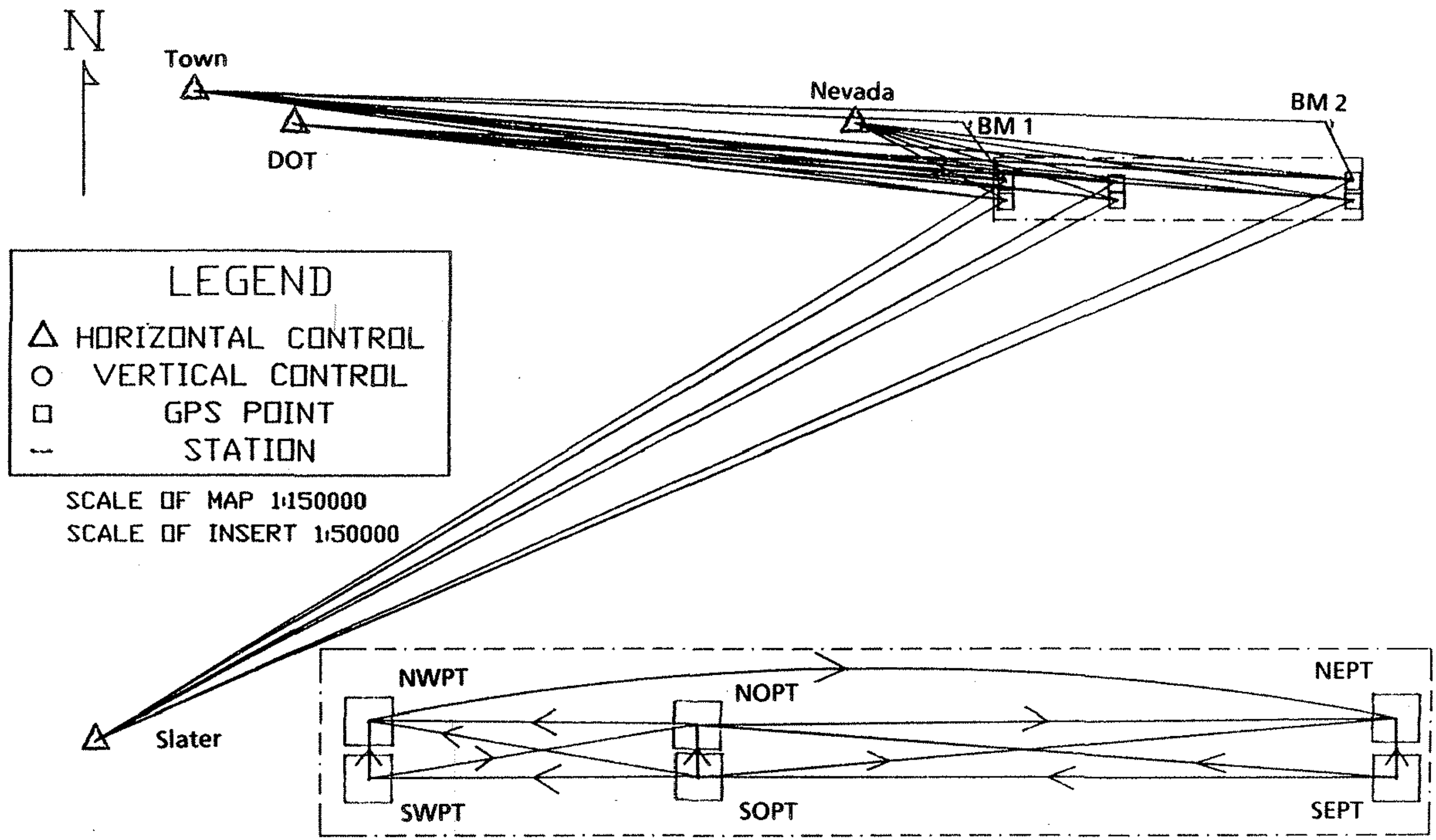


Figure 5.7 Mustang Project

Table 5.10

MUSTANG PROJECT
(INCLUDING FURNAS)

STATION	LATITUDE DEGREES	LATITUDE MINUTES	LATITUDE SECONDS	LONGITUDE DEGREES	LONGITUDE MINUTES	LONGITUDE SECONDS	GLOBAL UNDULATION (M)	LOCAL UNDULATION (M)
	CALCULATED LOCATION (WRT TOWN)							
NTOWN	42	1	45.39475	93	39	9.278874	-28.77	0.098136
DOT	42	1	20.066469	93	37	30.051986	-28.83	0.017515
FURNAS	42	[illegible]	0.0698148	93	26	39.839856	-29.04	
SLATER	41	51	1.302612	93	40	52.215606	-28.97	-0.414034
NWPT	42	0	35.208396	93	24	20.5686	-29.26	-0.257210
SWPT	42	0	19.4933412	93	24	20.563578	-29.26	-0.309159
NOPT	42	0	34.0667	93	22	18.79671002	-29.32	-0.231304
SOPT	42	0	20.004768	93	22	18.08421602	-29.33	-0.298039
NEPT	42	0	35.309592	93	17	59.25282001	-29.47	-0.326061
SEPT	42	0	18.99838	93	17	58.81896601	-29.48	-0.323490
NEVADA	42	1	21.475827	93	27	5.413905	-29.14	-0.104390
BM1(NEVADA)	42	1	21.4047012	93	25	7.101642	-29.21	-0.210328
BM2(COLO)	42	1	21.2191932	93	18	29.862	-29.43	-0.304356
HI 65	42	13	51.383229	93	18	35.80978	-29.10	-0.159063
BOONE	42	3	58.330784	93	53	0.085556	-28.37	0.417844
105	42	1	44.511772	93	39	7.866454	-28.77	0.087326
BM11	41	17	32.95541	93	24	38.43817	-30.29	-0.096029
DODGE	41	42	10.84563	93	42	24.6648	-29.42	

STATION	GPS ELEVATION (WRT TOWN) (WOL) (M)	ELEVATION DIFFERENCES GPS (WRT TOWN) (WOL) (M)	ELEVATION NGS (M)	ELEVATION DIFFERENCES NGS (WRT TOWN) (M)	DIFFERENCE GPS-NGS (M)
NTOWN	314.130	0	313.2348	0	0
DOT	291.812	-22.318			
FURNAS	327.910	13.7801			
SLATER	318.722	4.592			
NWPT	303.536	-10.594			
SWPT	302.177	-11.953			
NOPT	307.024	-7.106			
SOPT	306.494	-7.636			
NEPT	320.065	5.935			
SEPT	315.697	1.567			
NEVADA	[illegible]	[illegible]	305.5115	-8.2233	-0.6787
BM1(NEVADA)	306.912	[illegible]	307.4872	-6.3476	-0.8644
BM2(COLO)	323.474	9.344	324.2374	10.4026	-1.0596
HI 65	339.526	[illegible]	340.0155	26.7807	-0.7727
BOONE	348.171	34.041	346.7798	32.944	1.098
105	292.964	[illegible]	292.6909	-21.144	-0.022
BM11	247.761	-66.369	248.3096	-65.5252	-0.8438
DODGE	307.146	[illegible]	307.2300	-6.6049	-0.3852

STATION	NORTH (Y)	STATE PLANE COORDINATES EAST (X)	CONVERGENCE DEGREES	MINUTES	SECONDS	SCALE FACTOR
NTOWN	1058817.104	1487364.583	0	-6	12.27	1.00000697
DOT	1058016.113	1489876.045	0	-4	58.24	1.00000836
FURNAS	1066649.545	1504599.257	0	2	15.66	0.99999411
SLATER	1042605.124	1484961.913	0	-7	22.04	1.00003831
NWPT	1056629.096	1507810.595	0	3	50.05	1.00001081
SWPT	1056144.222	1507811.251	0	3	50.05	1.00001168
NOPT	1056597.555	1510612.717	0	5	12.58	1.00001093
SOPT	1056163.713	1510629.771	0	5	13.06	1.00001165
NEPT	1056647.501	1516584.964	0	8	8.49	1.00001091
SEPT	1056143.950	1516596.141	0	8	8.79	1.00001171
NEVADA	1058053.431	1504016.551	0	1	58.32	1.00000828
BM1(NEVADA)	1058053.327	1506738.460	0	3	18.51	1.00000829
BM2(COLO)	1058062.363	1515877.412	0	7	47.74	1.00000830
HI 65	1081207.610	1515688.543	0	7	42.71	0.99997424
BOONE	1062963.829	1468271.621	0	-15	35.35	1.00000008
105	1058774.375	1487396.997	0	-6	11.31	1.00000704
BM11	995466.769	1507464.024	0	3	27.94	1.00016559
DODGE	1022571.427	1482781.292	0	-8	26.69	1.00008586

STATION	(X - XO) XO = TOWN	(Y - YO) YO = TOWN	(X - XO)^2	(Y - YO)^2	(X-XO)(Y-YO)	DISTANCE (meters)	DISTANCE^2 (meters)	DISTANCE^3 (meters)
NTOWN	0.000	0.000	0.000	0.000	0.000	0.000	0	0
DOT	2511.462	-800.991	6307441.377	641586.582	-2011658.459	2636.101	6949027.9595	18318338864
FURNAS	17234.674	7832.441	297033987.996	61347132.018	134989567.259	18930.957	358381119.9	6784497447183
SLATER	-2402.670	-16211.980	5772823.129	262828295.520	38952037.987	16389.055	268601118.65	4402118464455
NWPT	20446.012	-2188.008	418039406.704	4787379.008	-44736037.824	20562.752	422826785.71	8694482497018
SWPT	20446.668	-2672.982	418066232.302	7144298.186	-54651530.857	20620.634	425210530.49	8768110556416
NOPT	23248.134	-2219.549	540475734.482	4926397.763	-51600372.572	23353.846	545402132.25	12737237512584
SOPT	23265.188	-2653.391	541269972.675	7040483.799	-61731640.453	23416.009	548309456.47	12839218921555
NEPT	29220.381	-2169.603	853830665.785	4707177.178	-63396626.279	29300.816	858537842.96	25155859727509
SEPT	29231.558	-2673.154	854483983.107	7145752.208	-78140456.194	29353.530	861629735.31	25291874462947
NEVADA	16651.968	-763.673	277288038.273	583196.451	-12716658.358	16669.470	277871234.72	4631966249792
BM1(NEVADA)	19373.877	-763.777	375347110.011	583355.306	-14797321.653	19388.926	375930465.32	7288888107766
BM2(COLO)	28512.829	-754.741	812981417.583	569633.977	-21519801.073	28522.816	813551051.56	23204767220351
HI 65	28323.960	22390.506	802246710.082	501334758.936	634197796.324	36105.145	1303581469	47065997480647
BOONE	-19092.962	4146.725	364541197.933	17195328.226	-79173262.949	19538.079	381736526.16	7458399025799
105	32.414	-42.729	1050.667	1825.767	-1385.018	53.632	2876.434837	154270.11735
BM11	20099.441	-63350.335	403987528.512	4013264944.612	-1273306320.667	66462.414	4417252473.1	293581262558744
DODGE	-4583.291	-36245.677	21006556.391	1313749101.188	166124485.183	36534.308	1334755657.6	48764374035582

the Iowa Project area can be determined to an accuracy of about ±10 cms. At this stage it was found to be necessary to do separate Geolab adjustment for vertical and horizontal control. For vertical coordinate determination, the Geolab adjustment was done by using all the GPS distances including those between the six GPS Mustang points and coordinate differences as observations by fixing four control stations and by constraining the elevation of BM1 and BM2. The height differences obtained after Geolab adjustment were then used to predict the elevation of the points NW, S, and NE. The Table (5.12) shows height differences by Geolab and GPS method from the reference station Town.

Table 5.11

Collocation Parameters for Mustang

$$a_0 = -0.189277$$
$$a_1 = 5.246769\text{x}10^{-5}$$
$$a_2 = 9.342854\text{x}10^{-6}$$
$$a_3 = 1.391356\text{x}10^{-9}$$
$$a_4 = -1.084435\text{x}10^{-10}$$
$$a_5 = -2.503207\text{x}10^{-10}$$
$$a_6 = -8.240223\text{x}10^{-3}$$
$$\sigma_0 = 0.118 \text{ m}$$

Table 5.12

Point	GPS Height Diff.	Geolab Height Diff.
NW	-10.62	-10.55 m
NE	5.94	6.12 m
S	-7.64	7.65 m

Using the Geolab height differences, which are free of observation errors, the elevation of the points is determined by applying the local undulation correction. Table 5.13 gives the elevation determined by GPS collocation and by Iowa DOT leveling. The table shows a maximum error of 4 cm, which is satisfactory as local control points for Iowa DOT applications. The relative accuracy of ±10 cm over a distance of 6000 m is about 2 mm/100m.

Table 5.13

Point	GPS (Collocation)	Ia DOT Levelling	Error
NW	304.19 m	304.15	.04 m
NE	320.88 m	320.92	-.04 m
S	307.12 m	307.12	.00

The normal relative accuracy of Iowa DOT leveling is about 3 mm/ 100 m. Thus the relative accuracy of GPS with collocation is comparable to the Iowa DOT leveling procedure. In a project such as Mustang, the elevation of the central point in the project, South in this case, can be established by GPS collocation. The elevation of other points are established by differential leveling adjusted by loop misclosure. This method will determine elevation of points with absolute accuracy of ±10 cm and relative accuracy of ±3 mm, satisfactory for normal Iowa DOT applications. It can be argued that the reliablity of NGS elevations of BM has an absolute accuracy of ±10 cm because of vertical movement and global adjustment of the leveling network.

For horizontal coordinate determination it was found necessary to do a separate Geolab adjustment while constraining the azimuth from GPS baseline observations. Appendix "Traverse" summarizes the results of Traverse between GPS points. The angles and distances between traverse points were done by Iowa DOT personnel using Total station. The Total station has 1" angular accuracy and 1 cm linear accuracy. The Total station, calibrated with EDM baseline at ISU, gave a horizontal distance of 1369.257 instead of the calibrated distance of 1369.247, indicating an error of 1 cm. The maximum angular misclosure was about 7" with six setups which is about 1" per setup. This is less than Iowa DOT specification of 2" per set-up. The maximum linear misclosure is about 0.4 m over 8000 m. This gives a precision of 1/20,000 which is less than the Iowa DOT specification of 1/10,000. The Table (5.14) gives the summary of Traverse misclosures. The table shows a large angular misclosure from station South, probably due to centering error in one of the short distance setups. The misclosure from NW to NE of 1" in angular and 0.1 m in distance over 12,000 m indicates the possibility of obtaining a precision of 1/120,000 with GPS control points and Total station.

Table 5.14

From	To	Angular Misclosure	Misclosure in N	Misclosure in E
NW	NE	-1.15"	0.0786 m	-0.0273 m
S	NW	-6.48"	0.0029 m	-0.105 m
S	NE	-7.74"	0.3599 m	-0.05664 m

In order to evaluate the use of kinematic and pseudo-kinematic procedures in GPS observations, a series of special observations was done as part of the Mustang Project. Table 5.15 summarizes the results and comparisons of static, kinematic, pseudo-kinematic and DOT. Appendix Kinematic and Pseudo-Kinematic gives the procedure adopted. The comparisions indicate that the static method consistently gives good results. The error in Pseudo-kinematic varies from 0.006 to 0.585 indicating the inconsistency in linear measurement; however, this is satisfactory for azimuth determination. The error in kinematic varies from 0.0046 for short distance to 0.708 for long distance, suggesting again that it is reliable for azimuth determination and not for spatial distance measurement. The kinematic method is very sensitive to signal Lock the pseudo kinematic. Thus for Iowa DOT applications pseudo-kinematic methods may be preferred.

Table 5.15

METHOD OF MEASUREMENT

Line	Static (M)	Pseudo-Kinematic (M)	Kinematic (M)	DOT (M)
S-NW	2857.308	2856.723	XXX	2857.31
S-SW	2818.77	2818.691	XXX	2818.791
S-N	434.245	434.251	XXX	434.243
TOWN-SE	29354.614	XXX	29353.906	XXX
NE-POT2492+85.35	XXX	XXX	290.116	290.158
NE-SE	503.383	XXX	503.339	503.339

COMPARISONS

Line	PSEUDO-KIN - STATIC	PSEUDO-KIN -DOT	KINEMATIC -STATIC	KINEMATIC -DOT	STATIC -DOT
S-NW	-0.585	-0.587	XXX	XXX	-0.002
S-SW	-0.079	-0.1	XXX	XXX	-0.021
S-N	0.006	0.008	XXX	XXX	0.002
TOWN-SE	XXX	XXX	-0.708	XXX	---
NE-POT2492+85.35	XXX	XXX	XXX	-0.042	---
NE-SE	XXX	XXX	-0.044	0	0.034

Aerial photographs at a scale of 1:3000 were taken over the Mustang Project after targeting the GPS points. On studying the photographs and their overlap, it appears that the six GPS points can be used in block adjustment to obtain the coordinates of pass points necessary to setup a stereo model, which can be used for determining crosssection elevation and contours for the highway project. The study of this application is beyond the scope of this present study. It is recommended that a separate study be done to determine the cost effectiveness and accuracy of GPS technology in photogrammetry.

6.0 CONCLUSIONS AND RECOMMENDATIONS

With the deployment of all 18 satellites GPS technology will be invaluable for Iowa DOT applications. The static method of GPS measurement can give spatial distances to a precision of 1/200,000 or better. Kinematic and Pseudo-kinematic methods will be satisfactory for azimuth observation but are not recommended for Iowa DOT applications.

GPS observations adjusted by Geolab while constraining the GPS azimuth with at least 2 horizontal and 3 vertical control points can give surface state-plane coordinates of points which can be used to control traverse lines using precise Total stations. It is recommended that Iowa DOT adopt this method.

With sufficient vertical control points in large areas, the local undulation by the method of collocation can be used with GPS and Geolab to determine elevations of points with absolute accuracy of ±10 cm. These points can be used as reference elevation data in Iowa DOT applications. It is recommended that this method be used in a project where no NGS vertical control benchmarks are available in an area.

With four or more vertical control points available along the direction of a project, the local undulation by method of collocation can be used to determine the elevation of points within ±2 cm. It is recommended that this method be used whenever applicable.

Local undulation by gravimetric method are suitable for long baselines. Where the baselines are typically short, however it is time consuming and is not recommended for Iowa DOT applications.

Local gravity anomalies obtained using gravitimeters appear to be correlated with local undulation. It is recommended that this approach be studied as a separate project because while promising, it may never yield a solution.

GPS can be used in various photogrammetric applications. It is recommended that the cost effectiveness and accuracy of GPS in photogrammetry be studied separately.

The Iowa DOT personnel from field and office staff worked closely with the ISU research team in all these projects. The Iowa DOT personnel are comfortable in collecting GPS data in the field and performing the initial GPS data processing. They also are familiar with the Traverse adjustments. Both vertical and Geolab adjustments are project oriented. It is recommended that Iowa DOT uses GPS in most of their future work and employ the assistance of the ISU research team for vertical and Geolab adjustment. It is felt that within a year or two Iowa DOT personnel should be able to use the GPS independent of external assistance, especially if they hire the graduate students who worked with GPS and therefore have the theoretical knowledge required for this work.

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BIBLIOGRAPHY

1. ACSM-NGS. Coordinate Transformation Workshop (Unpublished Xeroxed paper), ACSM, Falls Church, Virginia, 1987.
2. Ashjaee, J. New Results on the Accuracy of the C/A Code GPS Receiver: Proceedings of the First International Symposium on Precise Positioning with the Global Positioning System, U.S. Department of Commerce, Rockville, Maryland, Vol. 1, pp. 207-214, 1985.
3. Ashtech Inc. Ashtech XII Receiver Operations Manual, Sunnyvale, California, 1990.
4. Ashtech Inc. Ashtech XII Model L Operating and Processing Manual, Sunnyvale, California, 1989.
5. Ashtech Inc. Documentation for Ashtech GPPS Software, Sunnyvale, California, 1989.
6. Baker, P. J. Global Positioning System (GPS) policy: Proceedings of the Fourth International Geodetic Symposium on Satellite Positioning, Sponsored by the Defense Mapping Agency and the the National Geodetic Survey at Austin, Texas, Vol. 1, pp.51-64, 1986.
7. Bitwise Ideas Inc. Geolab Documentation, Ottawa, Ontario, Canada, 1988.
8. Bitwise Ideas Inc. The GPS Environment for Geolab Manual, Ottawa, Ontario, Canada, 1987.
9. Bodnar, A. N. Jr. User's Guide for the Establishment of Tidal Bench Marks and Leveling Requirements for Tide Stations, National Geodetic Survey Charting and Geodetic Services National Ocean Service, NOAA, Rockville, Maryland, p. 11, 1975.
10. Bomford, G. Geodesy, 4th ed., Claredon Press, Oxford, pp. 736-739, 1980.
11. Bouchard, R. H. Optimized Observation Periods Required to Achieve Geodetic Accuracies Using the Global Positioning System, M. S. Thesis, Naval Postgraduate School, Monterey, California, 1988.
12. Brown, R. G. and Hwang, P. Y. C. "GPS Geodesy: A Kalman Filter Solution to the Wavelength Ambiguity Problem," Proc. of the 39th Annual Meeting of the Institute of Navigation, pp. 87-92, June 20-23, 1983.
13. Brown, R. G. and Hwang, P. Y. C. "A Kalman Filter Approach to GPS Geodesy," Global Positioning System, Vol. II, Institute of Navigation, Washington, D.C., pp. 155-166, 1984.
14. Brown, R. G. and Hwang, P. Y. C. "GPS Geodesy: Real-Time Processing Possibilities with Karman Filter Approach," Institute of Navigation, January, 1987.
15. Brown, R. G., Jeyapalan, K., et al, "Use of Global Positioning System for Precise Relative Positioning and Land Surveying," Final Report, Iowa High Technology Council, July, 1985.
16. Counselman, C. C. and Shapiro, I. I. "Miniature Interferometric Terminals for Earth Surveying," Bulletin Geodesic, 53(2), 1979.
17. Davis, R. E., Foote, F. S., Anderson, J. M. and Mikhail, E. M. Surveying: Theory and Practice, 6th ed., McGraw-Hill, New York, pp. 160-168, 1986.

18. Defense Mapping Agency Department of Defense World Geodetic System, DMA Technical Report 8350.2, Washington, D.C., pp. 3-10, 3-11, 1987.
19. Defense Mapping Agency Geodesy for the Layman, DMA Technical Report, 80-003, pp. 24, 39, 64, 1983.
20. Denker, H. and Wenzel, G. "Local Geoid Determination and Comparison with GPS Result," Bulletin Geodesique, 61(4), pp. 349-366, 1987.
21. Erck, E.S. "Orthometric Height Difference Recovery Tests from GPS Observations and Gravimetry," M.S. Thesis, Iowa State University, 1989.
22. Ewing C. E. and Mitchell, M. M. Introduction to Geodesy, New York: Elsevier, 1979.
23. Fell, P. J. "The Use of Standard Values and Refraction Bias Parameters in Orbit Determination," The Canadian Surveyor, 29(3), pp. 301-305, 1975.
24. Fell, P. J. "Geodetic Positioning Using a Global Positioning System of Satellites," Report No. 289, Dept. of Geodetic Science, Ohio State University, 1980.
25. Fury, R. J. "Prediction of the Deflections of the Vertical by Gravimetric Methods," NOAA Technical Report NOS NGS 28, 1984.
26. Fury, R. J. National Geodetic Survey, U. S. Dept. of Commerce, Rockville, Maryland, Personal communication, 1988.
27. Gigierano, J. D. Geological Survey Bureau, Iowa City, Iowa, Personal communication, 1988.
28. Heiskanan, W. A. and Moritz, H. Physical Geodesy, Graaz, Austria: Institute of Physical Geodesy, Technical University, Reprint, 1984.
29. Jeyapalan, K. "Feasibility Study of the Triangulation of Tanzania," California State University, Fresno, California, 1979.
30. Jeyapalan, K. et al. "Use of GPS for Precise Prediction of Local Geoid Undulation," ASCM-ASPRS Annual Convention (pp. 78-83), Denver, Colorado, 1990.
31. Jeyapalan, K. "Data Snooping Using Observations and Parameters With Constraints," International Archives of Photogrammetry, Vol. XXXV, 1984
32. Jeyapalan, K. "Evaluation of a Prototype Global Positioning System (GPS) Satellite Receiver," ACSM-ASPRS Annual Convention, Vol. 2, 1986.
33. Jeyapalan, K. and Mohamed, M. "The Accuracy Obtainable Using Global Positioning Satellite System," ACSM-ASP Annual Convention, Washington, D.C., 1984.
34. Jeyapalan, K. "Calibration of Comparators by the Method of Collocation," Unpublished Report, Topographic Division, U.S. Geological Survey, Reston, Virgina, pp. 2-7, 1977.
35. Kaula, W. M. "The Need for Vertical Control," Surveying and Mapping, 47(1), pp. 57-64, 1987.
36. Kearsley, A. H. W. "Tests on the Recovery of Precise Geoid Height Differences from Gravimetry," Journal of Geophysical Research, 93, no. B6, pp. 6559-6570, June, 1988.
37. King, R. W., Masters, E. G., Rizos, C. and Collins, J. Surveying with GPS, School of Surveying. The University of New South Wales, Kensington N.S.W., Australia, p. 128, 1985.

38. Ma, Wei-ming. Local Geoid Determination Using the Global Positioning System, M. S. Thesis, Naval Postgraduate School, Monterey, California, 1988.
39. Mikhail, E. M. Observations and Least Squares, IEP-Dun-Donnelley, New York, pp. 418-426, 1976.
40. Milliken, R. J. and Zoller, C. J. "Principle of Operation of NAVSTAR and System Characteristics," Global Positioning System, Institute of Navigation, Washington, D.C., Vol. 1, pp. 3-14, 1980.
41. Moritz, H. "Geodetic Reference System 1980," Bulletin Geodesique, 54(3), pp. 395-405, 1980.
42. NASA. Directory of Station Locations, 4th ed., Godard Space Flight Center, Greenbelt, Maryland, pp. 1-11, 1978.
43. National Geodetic Survey. Geodetic Glossary, Rockville, Maryland: U.S. Government Printing Office, 1986.
44. Rapp, R. H. and Cruz J. Y. "Spherical Harmonic Expansions of the Earth's Gravitational Potential to Degree 360 Using 30' Mean Anomalies," Report no. 376. Department of Geodetic Science and Surveying. The Ohio State University, Columbus, Ohio, December, 1986.
45. Rapp, R. H. Department of Geodetic Science and Surveying, The Ohio State University, Columbus, Ohio, Personal communication, 1988.
46. Reilly, J. Surveying with GPS (Unpublished Xeroxed paper), Presented at ASCE/ICEA Surveying Conference, Ames, Iowa, ASCE/ICEA, 1988.
47. Remondi, B. W. "Global Positioning System Carrier Phase: Description and Use," Bulletin Geodesique, 59(4), pp. 361-377, 1985.
48. Remondi, B. W. Using the Global Positioning System (GPS) Phase Observable for Relative Geodesy: Modeling, Processing and Results, Ph.D. Dissertation, The University of Texas at Austin, 1984.
49. Rockwell International. Instruction Manual Collins Navcore I GPS C/A Receiver, Cedar Rapids, Iowa, August 1986.
50. Strange, W. E., Vincent, S.F,, Berry, R. H., and Marsh, J.G. "Detailed Gravimetric Geoid for the United States," The Use of Artificial Satellites for Geodesy, Geophysical monograph 15. Eds. S. W. Henriksen, A. Mancicni, B. H. Chovitz. Washington: American Geophysical Union, pp. 169-176, 1972.
51. Torge, W. Geodesy, Berlin: DeGruyter, 1980.
52. Trimble Navigation. Trimble Model 4000SX GPS Surveyor-Preliminary-Installation and Operation Manual, Sunnyvale, California, p. 96, 1987.
53. Van Dierendonck, A. J., Russell, S. S., Kopitzke, E. R., and Birnbaum, M. "The GPS Navigation Message," Global Positioning System, Institute of Navigation, Washington, D.C., 1980.
54. Wells, David G. et al. Guide to GPS Positioning, Fredericton, New Brunswick, Canada: University of New Brunswick Graphic Services, 1987.

Appendix GPS Map

GPSMAP

The program will compute the satellite visibility of a certain location at a certain time interval. The program is stored in the SATMAP directory. Type GPSMAP and press return to call the program. Enter the name of the latest almanac file, for example ALM89.404 and press return. It will ask the location which you want to check. Select one of the location or insert 0 if the location is not in the list. Insert the latitude, longitude and altitude if you choose item 0 and press return.

On the next screen, you have to insert the date and other information such as the offset time etc. Press return and choose one of the output options and press return. For example we choose option 1 (Azimuth and elevation visibility table). Choose item 5 to quit.

The almanac file is created by running ashtoalm.exe program which is stored in the same directory. The input of this program is the navigation file of the latest GPS observation.

Appendix GPPS

GPPS

Below are the steps to process the GPS data after an observation. There are several programs to run to get the final result, but the programs are combine into one program called GPPS. To call the big program, just type GPPS and return. Usually a new directory is created so that the files which are created will be in the directory separated from the other observations.

The steps that have to done are:

1. Connect the receiver to the to computer by using a RS232 cable. The connection will go from the serial port 1 of the receiver to the serial port of the personal computer.
2. Transfer the data from both receivers to the personal computer.
3. Create a COMMON.NAV file with the ephemeris files from the receivers obtained from step 1 as the input files.
4. Create U-files for each of the points. The input files for this program are the COMMON.NAV and the bendata file for that particular point. If a problem occurs and a COMMON.NAV file can not be created, use a navigation file for the input. Note use the same navigation file for for all U-files creation.
5. Create the input file for the final computation. In this process, the monitor has to insert the observation data, such as the weather, the height, the name of the station, the name of the U-file created and so on so forth.
6. Run the linecomp program which will compute the final

result.

To do the real process, do step 1 first, and then run GPPS program. A screen like below will be displayed on the PC monitor.

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¤                          B) Download Receiver                                          ¤
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¤                          C) Editing/Planning                                           ¤
¤                                                                                        ¤
¤                                                                                        ¤
¤                          D) Manual Processing                                          ¤
¤                                                                                        ¤
¤                                                                                        ¤
¤                          E) Post Mission                                               ¤
¤                                                                                        ¤
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¤                          F) Select Directory                                           ¤
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   <F1> - DOS SHELL                                                     <ESC> - QUIT
```

Select option B to do step 2. In this option do:

1. If there is no communication error than continue, else check the cable and start over.
2. Select option A to see the files in the receiver memory.
3. Select option B. In this option, the operator can select which file/s in the receiver he/she wants to transfer to the PC. To select a file put Y for yes under the DOWNLOAD column and N for no. When it transfer the file to the PC, the PC will create bendata file, navigation file, and

sitedata file, and maybe some other files. To select the the name of the file, use column TEMPLATE. Usually, use the first three character to represent the name of the point and the next for to represent the day and month of the observation following with a dot and DAT for data. For example, if it is a point called North and the date is March 25, then type NPT0325.DAT under the TEMPLATE column for the file. The program will automatically create a bendata file called BNPT0325.DAT, a navigation file called NNPT0325.DAT etc. After it is done with transferring the data press the esc key in the keyboard. It is now back in the main menu.

To do step 3, select option D (Manual processing). In this option select the COMNAV menu. This program will use all files in the current directory which start with E as the input files. E stands for Ephemerish file. The program will create COMMON.NAV file.

To do step 4, select option MAKEUFIL of the menu. The operator has to run this program once for every point in the observation. The program will ask for the bendata file of the point, and the navigation file or the COMMON.NAV file. If the operator choose to use the navigation file, he/she can only use the same file for all points. The operator will also be asked to enter the name of the output file. It has to start with the letter U. Usually the first three letters represent the name of the point and the next four represents the date following with a dot and DAT.

To do step 5, select option MAKEINP. In this option, select option A (Edit BASELINE.INP Data). Next, do the following:

1. Select option A to edit the header information. In this option, type the name of the observations and the time they were taken in UTC time. Press F10 key to get back to the previous menu.
2. Select option B to edit the fixed station parameters. In this option, the operator has to insert the name of the station chosen to be the base or fixed station, the weather, the name of the U-file of that point and also change the Position Extraction to 1 if the U-file is used. If a slant height is measured, then insert 0.105m for the radius, if a straight height is measured, then insert 0.000 for the radius. Press F10 if done.
3. Select option C to edit the unknown station. Do the same thing as in step 2 and press return.
4. Select option D and/or E to edit any other parameter. Press F10 to get back to the menu.
5. Select F for done to get back to the previous menu.
6. Select option C (Write a BASELINE.INP File). This is the option to save the data edited to a file. It will ask the operator to insert a name. Usually, the first three letters represent the name of the fixed station and the next three represent the name of the unknown station following with a dot and a INP for input.
7. Press Esc to go to the previou menu.

The last step is to select LINECOMP option. This program will calculate the distance of the two stations, the locations for each of them and some other necessary parameters. The program will ask the printer for the name of the input file which was created at step 5 before. It will also ask for the name of the name of the output file. Usually the name for the output is the same as the input except for the last three characters, instead of INP it is OUT.

The output will be saved in the output file. To get out of the program press Esc key twice. To make a printout, type PRINT the name of the output file.

Appendix Geoid

GEOID

The name of the program is geoid.exe. The program was developed and written by TRIMBLE NAVIGATION, LTD. The purpose of running this program is to find the global undulation of a particular point. The program runs interactively. It will ask the operator to insert the data needed. The data needed are, the latitude and longitude and ellipsoidal elevation of a particular point. The elevation does not have to be very accurate, but the other two are crucial. Closeby points will have about the same global undulations. *The elevation and undulation are in meters.* The latitude and longitude are in degrees, minutes and seconds. To call the program, type GEOID. Next is an example of running the program. The data are:

Lat: N 42^{o} 01′ 42.5"

Lon: W 93^{o} 39′ 02.05"

Elev: 300.5m

```
      TRIMBLE NAVIGATION, LTD.
GEOPOTENTIAL SERIES EVALUATION PROGRAM

COPYRIGHT (C) 1986 TRIMBLE NAVIGATION, LTD.
              VERSION 86.060


*** BINARY FILE CONTAINING HARMONIC COEFFICIENTS packcs.dat
LOADING GEOPOTENTIAL COEFFICIENTS - PLEASE BE PATIENT
HARMONIC COEFFICIENTS LOADED
entering latitude:

enter N or S
N
enter integer degrees
42
enter integer minutes
1
enter seconds (real value)
42.5
entering longitude:

enter E or W
W
enter integer degrees
93
enter integer minutes
39
enter seconds (real value)
2.05
ENTER ELLIPSOID HT(M) 300.5
LAT LON HT  42.028472  266.349431  300.5000
GEOID HT(M)  -28.77484

ANOTHER CALCULATION ? (Y/N) N
Stop - Program terminated.
```

Appendix Local Undulation

Local Undulation Program

To calculate the local undulation of a point, several programs are run using both wylbur and vax machines at the I.S.U. campus. The programs are mostly run in vax, only two of them are run using wylbur to conserve time. Below is an example of how to run the programs. For the example, the data are:

Lat: N 42° 0′ 34.07"

Lon: W 93° 22′ 18.8"

The name of the point is North. For most of the programs, an input file has to be prepared. Since the programs were written in Fortran, the columns of data in the files are very important. Follow the example of the input files at the end of this documentation.

Step 1.

The first program to run is SELCPSQ. The program runs in Vax machine. The first thing to do is to prepare an input file for the program. See SELCNOPT.DAT.

NCP = 2259 is obtained from the GRAVIA.NOA file, the number represents the number of gravitation stations in Iowa.

XC = the latitude of the point in decimal

YC = the longitude of the point in decimal, it is negative because it is with respect to West.

SO2 = 0.5/cos(latitude)

Name the file SELCNOPT.DAT. Before running the program, several files have to be assigned for the inputs and outputs:

ASSIGN SELCNOPT.DAT FOR010

ASSIGN GRAVIA.NOA FOR011

ASSIGN SELCNOPT.PAR FOR020

ASSIGN SELCNOPT.PLG FOR021

The 'ASSIGN' command is a special command for the program. It will assign a file as an input or output of the program. For example, for the first ASSIGN command, the file SELCNOPT.DAT is assigned port number 010 (FOR010) of the program. In the program port 010 is assign as an input port, so that SELCNOPT.DAT will be an input file for the program. For this particular program the ports 010 and 011 are the inputs and the ports 020 and 021 are the outputs. The file SELCNOPT.PAR will store the input file. This is for checking purposes only. The SELCNOPT.PLG stores the result of the computation. To execute the program, type RUN SELCPSQ.

Step2.

The next program to run is G6780PP program. See the G67NOPT.dat file for the input file.

PHI80I = the latitude of the point.

LAMI = the longitude of the point (do not forget the minus sign if it is West).

NGP = this is the number of line in the SELCNOPT.PLG file

SELCNOPT.PLG is one of the output of SELCPSQ program. One way to count the line is to edit the file and type RES for resequence. This will print the number of lines in the file. Note that blank lines have to be omitted.

The next step is to assign the input and output files for the program:

ASSIGN G67NOPT.DAT FOR010

ASSIGN SELCNOPT.PLG FOR011

ASSIGN G67NOPT.PAR FOR020

ASSIGN G67NOPT.PLH FOR021

ASSIGN G67NOPT.XYG FOR022

The input ports are 010, and 011, the output ports are 020, 021, 022. Then execute the program, RUN G6780PP.

Step 3.

The next program is the DG36080 program. This program is executed in the wylbur machine. Two files are needed for running this program: DG36080.COM and DG36080.NAS. These two files have to be in the current directory and the DG36080.NAS file has to have one and only one version in the current directory, otherwise it will not work. The input file of this program is G67NOPT.PLH file obtained from the previous program. The output is called DGNOPT.PLG. To run the program type:

SUBMIT DG36080/PARAMETERS=(G67NOPT.PLH, DGNOPT.PLG)

This command will submit the program and the files to the wylbur environment. To check the status of the program type:

RUN PUBLIC:RJECHK

>DG36080

When done checking, type ctrl C to quit.

When it submits the program to Wylbur, it will create a log file called DG36080.LOG. This file can be read to debug also.

Step 4.

The next program to run is SUBTOCP. See the file SUBNOPT.DAT for the input file.

NCP = this is the same as NGP in G67NOPT.DAT file.

Port assignments:

```
ASSIGN SUBNOPT.DAT FOR010
ASSIGN G67NOPT.XYG FOR011
ASSIGN DGNOPT.PLG FOR012
ASSIGN SUBNOPT.PAR FOR020
ASSIGN SUBNOPT.XYG FOR021
```

Output ports: 020 and 021

Input ports: 010, 011, 012

Type RUN SUBTOCP

Step 5.

The next program to run is the SURFGRD. This program also runs in the Wylbur environment, so that the two files needed are SURFGRD.COM and SURFGRD.NAS. SURFGRD.NAS has to have only one version in the current directory. The input file for this is called SURFNOPT.DAT. See the file.

NCP = NGP

XMIN = the minimum x in the diagram (usually -0.5)

XMAX = the maximum x in the diagram (usually 0.5)

YMIN = the minimum y in the diagram (usually -0.5)

YMAX = the maximum y in the diagram (usually 0.5)

DX = the x margin (usually 0.05)

DY = the y margin (usually 0.05)

Type:

```
SUBMIT SURFGRD/PARAMETERS=(file1, file2, file3)
```

file1 = SURFNOPT.DAT

file2 = SUBNOPT.XYG

file3 = SURFNOPT.AGR

File1 and file2 are inputs and file3 is output. To check the program do as explained in the DG36080 program. After the program is completed, edit file3 and delete the first two lines(header and a blank line) and also the last blank line.

Step 6.

This step is creating a diagram using a program called AGRAPH. This program is stored in a special library. To run this program, first type:

@Classlib:[EE]LLOGIN.COM

Then type:

RUN AGRAPH

The input file is the SURFNOPT.AGR file. The program will ask the terminal the operator is using (TEXTRONIC, GRAPHON, etc). The diagram wanted is the contour line diagram of the area of the point. Make a hardcopy of the diagram.

Step 7.

Next program to execute is the GPS_PLOT program. The program will take the SUBNOPT.XYG file as an input. The file has to be edited and eliminate the header material and extraneous material at the end of the file. Then type RUN GPS_PLOT.EXE

The program will ask for the name of the input file and will then create another diagram. Make a hardcopy of the diagram.

Step 8.

The next step is the longest one. Lay the contour line diagram on top of glass table and put the a light underneath the table so that two overlapping diagrams can be seen. Put the other diagram on top of the first one so that they overlapped perfectly. Divide the top diagram into compartments with these rules:

1. The contour lines inside the compartment have to have almost similar arc shape.
2. There has to be at least one point in the compartment otherwise the program will not run.

Step 9.

The last step is to run the STOKCAP program. One of the input file is the STOKNOPT.DAT

NCP = NGP

NC = the number of compartments created in step 8.

PSI1K = the inner limit of the compartment.

PSI2K = the outer limit of the compartment.

ALF1K = the angle of the right limit of the compartment.

ALF2K = the angle of the left limit of the compartment.

Do this for all compartments

Port assignments:

ASSIGN STOKNOPT.DAT FOR010

ASSIGN SUBNOPT.XYG FOR011

ASSIGN STOKNOPT.UND FOR020

Output is 020, inputs are 010 and 011.

Edit the STOKNOPT.UND file and read the local undulation of the point.

COMPUTATION CENTER
IOWA STATE UNIVERSITY
Student Coding Form

Programmer:	File No:	"E" No:	Prob. No:	Data Deck No:	DO NOT RUN	COURSE:	Instructor:	S.____ P.____ V.____	Page ____ of ____

FORTRAN STATEMENT

```
         INPUT FILE FOR SELCPSQ
LINE 1  SELCPSQ OF PROJECT NAME
LINE 2     NCP=2259,XC=nnn.nnnnnnnnn,YC=nnnn.nnnnnnnnn,SOZ=nnn.nnnnnnnnn

         INPUT FILE FOR G6780PP
LINE 1  G6780PP OF PROJECT NAME
LINE 2     PHI8OT=nnn.nnnnnnnnn,LAMI=nnnn.nnnnnnnnn,NGP=nnn

         INPUT FILE FOR SUBTOCP
LINE 1  SUBTOCP OF PROJECT NAME
LINE 2     NCP=nnn

         INPUT FILE FOR SURFGRD
LINE 1  SURFGRD OF PROJECT NAME
LINE 2     NCP=nnnn,
LINE 3     XMIN=nn.nnnnnnnnn,XMAX=nn.nnnnnnnnn,DX=n.nnnnnnnnn
LINE 4     YMIN=nn.nnnnnnnnn,YMAX=nn.nnnnnnnnn,DY=n.nnnnnnnnn

         INPUT FILE FOR STOKCAP
LINE 1  STOKCAP OF PROJECT NAME
           NCP=nnn,nczmn
               PSI1K=nnn.nnnnnnnnn,PSI2K=nnn.nnnnnnnnn
               ALF1K=nnn.nnnnnnnnn,ALF2K=nnn.nnnnnnnnn
```

IDENTIFICATION SEQUENCE

Appendix Calculation

Calculations

After doing the observation and running the programs to process the data, some calculations have to be done to get better accuracy solutions. A table will then be created to enable an observer to compare the differences between the known quantities and the calculation ones.

The first step to do is to get the observation data from the linecomp output. The output has three solutions, the tripple difference, the float double difference, and the fixed double difference solutions. To get the best solution, check the ratio which is listed near the Top twenty cases based on (O-C)-squared area of the printout. If the ratio is bigger than two, always select the fixed double difference solutions. If it is less than two then compare the rms residual between the fixed double difference solution and the float double difference solution. Use the solution with the smallest number. Tripple difference solution is never used.

Since the ashtech receivers run in differential mode (they are not stand alone receivers), the latitude, longitude, and elevation of one of the points have to be known and fixed. From the linecomp, the difference of the latitude, the longitude and the elevation of the two points can be calculated. For example, if point A and point B are observed, and point A is the known station, than the calculation will look like below:

From linecomp compute:

$B_{latitude} - A_{latitude} = D_{lat}$

$B_{longitude} - A_{longitude} = D_{lon}$

$B_{elev} - A_{elev} = D_{elev}$

The known location of A is

Latitude = A_{lat}

Longitude = A_{lon}

Elevation = A_{elev}

To get the location of B use the formulas below:

$B_{lat} = A_{lat} + D_{lat}$

$B_{lon} = B_{lon} + D_{lon}$

$B_{elev} = A_{elev} + D_{elev} - (N_B - N_A) - (n_B - n_A)$

N_B = Global undulation of B

N_A = Global undulation of A

n_B = Local undulation of B

n_A = Local undulation of A

Global undulation for all points can be computed by running the GEOID program. Local undulation can be computed by running several programs explained in the other part of the report. Depending on the need, the local undulations may or may not be included in the calculations.

The step is to run the SP83 program to find the state plane coordinate of all the points. From this program, the operator can also get the scale factor and angle of convergence of every point.

To get a better result, the operator can run the GEOLAB program.

After all of the above have been done, the results are inserted in a table, so that it is easier to see and compare.

Appendix Geolab

Geolab is a series of programs which are used to provide solutions to surveying and adjustment of survey network problems. We have been using the Geolab program this summer to adjust coordinates in the Iowa Project, the Midwest Project (Neb-Wisc-Town-DOT), and the Mustang Project on data collected near Nevada. The manual lists the specific programs involved, their purposes, and the sequence in which they are executed. In this report, I'll give details about how the input file is made, how to run the programs and how to get the output (to the screen and a hard copy of the adjustment).

The text input file that Geolab reads, interprets and processes is very versatile and can be tailored to the user's needs. Usually when making a new file an old one is edited and saved under a new name. Usually the PE2 editor is used to do this editing, however, Wordstar or other text editors may be used. Any line that is preceded by an * will not be read or processed as part of the input file. The first non * line is the title line where you can explain your project. The second input (non *) line is where you determine the options for this Geolab file. These options are detailed in the Geolab manual and include ellipsoidal parameters, number of iterations and confidence intervals for statistical analysis along with others.

Station definition and approximate coordinates are the first data values entered. If you want these values fixed a fourteen is entered before the station name. A four will mean these values will be adjusted. The geoid undulation of the stations is entered next with the code number nine preceding the station name. On the adjustments we have made the next sections are following a leading * until the section on distance observations. The number two comes before the from station and to station. Following the station names is the distance which we get from the Linecomp output of the GPS data for the specified points. The standard deviation we have been using for this section is 0.01 but is adjustable. So far for adjustments we have wanted we have ignored (*) the angle observations, azimuths, vertical angles, and zenith angle sections. We have fixed the heights of some stations like Nevada, Boone, HI65, and BM11 when these benchmark elevations are known. This is done in the section where the number forty five precedes the station name. Height difference between two stations follows and was used when we leveled between two points old and new town. This was entered as a fixed value. When latitude and longitude of particular stations are known (like Slater, Betts, Hampton) these values can be set in the 2D coordinate observation section which begins with the leading number ninety six. You must be careful here and have the right number of rows beginning with the number ninety eight for the position observation variance diagonal matrix. These numbers control how far the fixed coordinates are allowed to vary. Everything else is usually disregarded (*) except the 3-D XYZ

Coordinate Difference section. The code number forty one begins each row in this part. The numbers entered here also come from the Linecomp output, but you must be careful to make sure that you get the stations in the right spot (to or from station) and the signs of the numbers entered correctly. The number of rows of the position difference variance diagonal matrix must match the number of rows of stations that are input in this section.

After editing a file to make a new input file the file is saved as (name).IOB. Note also that the columns of most of the entries have certain limits which the values have to be in in order for the data to process. These limits are listed in the manual for each section in the input file.

To run the series of Geolab programs and have the output returned to the screen type: ADJUST (name).IOB CON . To run the programs and have the output create another file type the following: ADJUST (name).IOB (name).OUT . In all these cases (name) represents the name the user gave to the file. Later it may be necessary to get a hard copy of the output file for study and analysis. To do this get into DOS and type A: (if the output file was saved on a diskette and is in drive A), PRINT (name).OUT and be prepared to wait for a period of time. The output file, especially if you have very many stations, tends to be quite a few pages long. By going back and changing certain fixed parameters in the input file you can end up with different adjustments and compare and contrast the results.

Appendix SP83

A Description of SP83 Program

SP83 is a PC program that converts an input latitude and longitude value to State Plane Coordinates based on the NAD 83 values or vica versa. The program first askes whether the user would like to convert from geodetic positions to state plane coordinates or from state plane coordinates to geodetic positions. The next question the user must respond to concerns whether the user would like to run the program interactively (input from the keyboard) or not (reading input data from a file). If an output file is desired, the user can input a response to arrange this.

If option one was chosen earlier (convert from geodetic positions to state plane coordinates) the program prompts the user for the latitude and longitude of a particular point followed by a request for up to three NAD 83 State Plane Coordinate Zone Codes (1401 Iowa N, 1402 Iowa S). If option two (convert from state plane coordinates to geodetic positions) was selected, the program asks the user to input the northing "Y" value in meters followed by the easting "X" value in meters. Again, a request is for up to three zone codes is made.

The program for option one provides output including the northing(Y) and easting(X) in meters, the zone(s), the convergence and the scale factor. Output for option two includes the latitude and longitude for the state plane coordinate in question and the zone(s).

Appendix Transform Program

A Description of the TRNSFORM Program

The transformation program by Tremble called TRNSFORM is a conversion program between NAD27, WGS72, and WGS84 coordinates. It is run on a personal computer. The first question the user must respond to is whether or not you want to create a resluts file. If so, you must input the name of this file. Otherwise, when you exit the program, the information will be lost.

A series of constants for each system appears on the screen along with systematic transformation parameter values relating one system to another. A station name is requested along with whether the input coordinates are NAD27, WGS72, or WGS84. Whether or not to model regional irregularities is then asked. Usually, the answer is yes for absolute position transformations and no for relative transformations. The next option querries the user concerning the input coordinates. You can either choose to enter them as geodetic coordinates (O, ,h) (option one) or cartesian coordinates (x,y,z) (option two). After choosing option one or option two and entering the values, the program will output the NAD27, WGS72, and WGS84 coordinates of the point in question. This output will include both geodetic and cartesian coordinates and will be sent to the monitor and/or file specified earlier. It will also tell you which values were input and which ones were transformed. The user can then request another transformation or exit the program.

Appendix *LOTUS*

Summary of Lotus Table

The first six columns in the table contain the latitude and longitude of the individual stations with respect to the station on the roof of Town Engineering. These are recorded in degrees, minutes, and seconds. The next column lists the global undulation of each station in meters which was obtained from running the program Geoid on the Compaq computer. A column of values representing the local undulation in meters of the various sites follows. These were computed using Steve Erk's series of programs utilizing the VAX and WYLBER computer systems. The GPS elevations in meters for each of the stations comes next. The elevation of Town was set from the Geolab adjustment and the other stations were calculated from the output of the Linecomp program which was run when we were processing the collected GPS data. The differences in global undulation are also included, but the calculations were done without the local undulation differences. The GPS elevation differences between each station and Town follow in the next column. When known, the NGS elevations of the various points were included in the following column. Again, elevation differences between the stations where the NGS elevations are known and Town are computed and recorded in the next column of the table. The final column on the first page displays the difference between the GPS elevation differences and the NGS elvation differences in meters. The top half of the second page includes information from the SP83 program which converts geodetic positions to state plane coordinates or vica versa. The geodetic positions from the first page were input into the program which was run on the Compaq. Also, the state plane coordinate zone was entered (Ia-N 1401). The output from the program includes the northing and easting of each station along with the convergence and the scale factor for that particular station. The bottom half of the second page uses the x and y state plane coordinates for the various columns. The first column represents each stations difference in easting with respect to Town. The second shows each stations diiference in northing with respect to Town. The third and fourth columns are simply the first and second columns respectively squared. The fifth column is the first column on the bottom half of the page times the second column. The last three columns deal with distances between the stations. The first represents the distance between stations in meters. The next column displays the distance squared, while the last gives the cube of the distances between stations in meters.

Appendix Lobs

BASIC PROGRAM LOBS.BASIC

```
5      REM LEAST SQUARES BY OBSERVATION
10     DIM L(N%,1)
20     DIM A(N%,X%),  P(X%,X%),  EX(X%,1)
30     DIM CX(X%,1)
40     DIM AT(X%,N%), R(50), ATP(X%,X%)
50     DIM ATPA(X%,X%), ATPL(X%,1), AI(X%,X%)
69     PRINT  " INPUT # OF OBSERVATIONS"
70     NPUT NO
200    PRINT  " INPUT # OF PARAMETERS"
270    INPUT N1
350    ERASE L
351    ERASE A
352    ERASE AT
353    ERASE P
354    ERASE ATP
355    ERASE ATPL
356    ERASE AI
357    ERASE  CX
358    ERASE EX
359    ERASE ATPA
380    DIM L(NO,1), A(NO,N1), AT(N1,NO), P(NO,NO), ATP(N1,NO),
ATPL(N1,1),AI(N1,N1)
390    DIM CX(N1,1), EX(NO,1), ATPA(N1,N1)
400    ITERO = 0
1180   PRINT  " INPUT COEFFICIENTS OF OBSERVATION EQUATIONS AND
WEIGHTS"
1190   FOR K = 1 TO NO
1200   FOR J = 1 TO N1
1220   PRINT "COEFFICIENT  ", K, J
1230   INPUT  A(K,J)
1240   PRINT  A(K,J)
1250   NEXT  J
1260   PRINT " INPUT OBSERVED VALUE ", K
1270   INPUT  L(K,1)
1280   PRINT  " INPUT WEIGHT OF OBSERVED VALUE ", K
1300   INPUT  P(K,K)
1390   NEXT  K
1410   DOF = 0
1420   REM  LEAST SQUARES
1430   M = NO
1450   L = N1
1460   PRINT  " M =", M, "N1 = ", N1, "L = "L
1470   FOR I = 1 TO M
1480   FOR J = 1 TO L
1490   AT(J,I) = A(I,J)
```

```
1500  NEXT J
1510  NEXT I
1520  REM  ATP = AT * P
1530  N = NO
1540  FOR I = 1  TO L
1550  FOR J =1  TO N
1560  ATP(I,J) = 0
1570    FOR K = 1  TO M
1580    ATP(I,J) = ATP(I,J) + AT(I,J) * P(K,J)
1590  NEXT K
1600  NEXT J
1610  NEXT I
1620  REM  ATPA = ATP * A
1630  N = N1
1640  FOR I = 1 TO L
1650  FOR J = 1 TO N
1660  ATPA(I,J) = 0
1680  ATPA(I.J) = 0
1690  FOR K = 1 TO  M
1710  ATPA(I,J) = ATPA(I,J) + ATP(I,K) * A(K,J)
1720  NEXT K
1730  NEXT J
1740  NEXT I
1750  REM  ATPL = ATP * L
1760  N = 1
1770  FOR I = 1 TO L
1780  FOR J = 1 TO N
1790    ATPL(I,J) = 0
1800    FOR K = 1  TO M
1810    ATPL(I,J) = ATPL(I,J) + ATP(I,K) * L(K,J)
1820  NEXT K
1830  NEXT J
1840  NEXT I
1970  REM  AI = INV(ATPA)
1980  I = N1
1990  M = N1
2000  N = I - 1
2020  MI = M - 1
2030  FOR J = 1 TO I
2040  FOR K = 1 TO I
2050  AI(J,K) = ATPA(J,K)
2055  NEXT K
2060  NEXT J
2070  FOR K =1 TO I
2080  FOR J = 1 TO MI
2090      R(J) = AI(1,J+1) / AI(1,1)
2100  NEXT J
2110      R(M) = 1! / AI(1,1)
```

```
2120  FOR L = 1 TO N
2130  FOR J  = 1 TO MI
2140      AI(I,J) = AI(L+1,J+1) - AI(L+1,1) * R(J)
2150  NEXT J
2160      AI(L,M) = -AI(L+1,1) * R(M)
2170  NEXT L
2180  FOR J = 1 TO M
2190      AI(I,J) = R(J)
2200  NEXT I
2210  NEXT K
2220  REM CX = AI * ATPL
2230  L = N1
2240  N = 1
2250  M = N1
2260  FOR I = 1 TO L
2270  FOR J = 1 TO N
2280  CX(I,J) = O
2300  FOR K = 1 TO M
2310  CX(I,J) = CX(I,J) + AI(I,K) * ATPL (K,J)
2320  NEXT K
2325  PRINT  " PARAMETER  #  ", I, CX(I,J)
2330  NEXT J
2340  NEXT I
2480  PRINT  " RESIDUAL"
2490  L = NO
2500  N = 1
2510  M = N1
2520  REM EX = A * CX
2530  FOR I = 1 TO L
2540  FOR J = 1 TO N
2560  EX(I,J) = 0
2570  FOR K = 1 TO M
2580  EX(I,J) = EX(I,J) + A(I,K) * CX(K,J)
2590  NEXT K
2600  NEXT J
2610  NEXT I
2620  SD = 0
2630  FOR K = 1 TO NO
2640  V = EX(K,1) - L(K,1)
2650  PRINT K, V
2660  SD = SD + V * V
2670  NEXT K
2680  SD = SQR(SD / (NO - N1 + DOF))
2690  PRINT SD
2695  PRINT " STD.DEV", SD
2700  ITER = ITER + 1
2710  IF ITER < 3 GOTO 350
2720  END
```

Appendix A1FIX.IOB

A1FIX.10B

```
*     Welcome to GeoLab, the survey laboratory of software tools you've
*     been waiting for.  This file is an example of the text input file
*     which GeoLab reads, interprets, and processes.
*
*     GeoLab input files may have initial comments like this - the
*     records beginning with '*' are completely ignored.
*
*     The following title record must be the first (non *) record:
Trilateration for the Big Iowa Project using fixed dd
*
*     The second record must be the options record:
0  0 9         01131 112                         00 0 5 50   0.001      95.0    00

*     This demonstration input file includes most observations handled
*     by GeoLab.  You may alter this data file and try different
*     adjustments.  The GeoLab program laboratory will accept any number
*     of stations, with any number and combination of observations and
*     auxiliary parameters.  Approximately four thousand (4000) stations
*     may be adjusted simultaneously using a 10 mega-byte hard disk,
*     depending on the amount of correlation among observations and
*     stations.

*     Station Definition and Approximate Coordinates follow.  Note that
*     either 3-D Cartesian coordinates or ellipsoidal coordinates (as
*     below) can be given here.  Also note that this input file is only
*     an example of some of the general capabilities of GeoLab.  Many
*     other options exist in the package.
*
*     Station                              Latitude       Longitude         Elevation
  4   nevada                               42  1 21.73930w 93 27  5.40472  305.946
  4   hi65                                 42 13 51.59435w 93 18 35.73896  340.091
  4   boone                                42  3 58.60393w 93 53  0.06752  346.775
 14   dodge                                41 42 10.84562w 93 42 24.66480  307.23
  4   bm09                                 41 29 46.06120w 93 29 28.96768  248.310
  4   bm10                                 41 29 26.13574w 93 28 24.10000  239.551
  4   bm11                                 41 27 32.95541w 93 24 38.43817  248.310
  4   105                                  42  1 44.78573w 93 39  7.84961  292.691
  4   ntown                                42  1 45.89465w 93 39  9.27878  313.856
  4   dot                                  42  1 20.33369w 93 37 19.75853  291.534
  4   slater                               41 53  0.30116w 93 40 52.21372  318.403
  4   hampt                                42 44 33.25579w 93 12 27.55318  348.872
  4   betts                                41 47 27.08097w 94 37 47.90140  399.326
  4   oldtown                              42  1 46.22651w 93 39  9.19842  313.290
  4   hardy                                42 49 48.54614w 94  5 23.94494  357.47
  4   humbota                              42 43 14.14510w 94 12  4.77805  348.29
*
*     Geoidal Data Specification: (Optional)
*     Station                                  N\S Deflection  E\W Deflection Geoid H
eight
  9   ntown                                       0.00000         0.00000   -28.77
  9   slater                                      0.00000         0.00000   -28.97
  9   nevada                                      0.00000                   -29.14
  9   hampt                                       0.00000                   -28.63
  9   betts                                       0.00000         0.00000   -28.20
  9   hi65                                                        0.00000   -29.10
  9   boone                                                       0         -28.37
  9   bm11                                        0.00000         0.00000   -30.29
  9   dodge                                       0.00000         0.00000   -29.42
  9   105                                                                   -28.77
  9   dot                                                                   -28.83
  9   oldtown                                                               -28.77
  9   bm09                                                                  -30.07
```

```
  9   bm10                                                                  -30.11
  9   hardy                                                                 -27.56
  9   humbota                                                               -27.56
*
*     Astronomic Coordinate Specification: (Optional)
*     Station                           Astro Latitude  Astro Longitude
* 7   1001                                30 00  1.08   w 90 00  1.94000
* 7   site A                              30 10 56.48   w 89 59 01.10000
* 7   site B-2                            30 25 37.30   w 90 00 54.33000
* 7   1004                                30 01 45.69   w 90 14 15.54000
* 7   1005                                30 11 49.69   w 90 15 01.50000
* 7   1006                                30 23 38.59   w 90 16 02.12000
* 7   1007                                30 00  3.51   w 90 30 49.12000
* 7   1008                                30 11 36.81   w 90 30 36.41000
* 7   1009                                30 24 16.69   w 90 30 59.39000

*
*     Auxiliary Parameter (any number of them) Declaration:
*943dcWGSXX                       SCAL ROTZ TRAX TRAY TRAZ

*
*     Auxiliary Parameter Observations (Weighted Auxiliary Parameters):
*
*703dcWGSXX                       SCAL                .05          0.10
*703dcWGSXX                       TRAX                .0           0.2
*703dcWGSXX                       TRAY                .0            .2
*703dcWGSXX                       TRAZ                .0            .1
*703dcWGSXX                       ROTZ                 -.01        0.01

*
*     Direction Observations:
*     Station From           Station To              Direction          Std. Dev
.
* 1   1001                   site A                   0  0  0.00000   0.70015
* 1   1001                   1004                   273 39 55.81000   0.70011
* 1   1001                   1005                   307 35 44.15000   0.70006
* 1   site A                 1001                     0  0  0.00000   0.70015
* 1   site A                 site B-2               168 56 24.90000   0.70008
* 1   site A                 1005                    89  7 46.95000   0.70009
* 1   site B-2               site A                   0  0  0.00000   0.70008
* 1   site B-2               1005                    47 52 52.20000   0.70005
* 1   site B-2               1006                    87 51 43.81000   0.70010
* 1   1004                   1001                     0  0  0.00000   0.70011
* 1   1004                   1005                   257 41  6.38000   0.70018
* 1   1004                   1007                   165  1 48.21000   0.70008
* 1   1005                   1001                     0  0  0.00000   0.70006
* 1   1005                   site A                 321 32  4.11000   0.70009
* 1   1005                   site B-2               269 13 30.41000   0.70005
* 1   1005                   1004                    43 45 22.67000   0.70018
* 1   1005                   1006                   223 47 36.15000   0.70013
* 1   1005                   1007                    97 32  3.44000   0.70005
* 1   1005                   1008                   137  6 52.31000   0.70010
* 1   1005                   1009                   180  0 39.45000   0.70005
* 1   1006                   site B-2                 0  0  0.00000   0.70010
* 1   1006                   1005                    94 35 13.50000   0.70013
* 1   1006                   1009                   191 24 35.41000   0.70011
* 1   1007                   1004                     0  0  0.00000   0.70008
* 1   1007                   1005                   326 26  1.39000   0.70005
* 1   1007                   1008                   278 17 28.81000   0.70013
* 1   1008                   1005                     0  0  0.00000   0.70010
* 1   1008                   1007                    92 16 37.74000   0.70013
* 1   1008                   1009                   269 24 40.25000   0.70011
* 1   1009                   1005                     0  0  0.00000   0.70005
* 1   1009                   1006                   320 36 12.55000   0.70011
* 1   1009                   1008                    46 30 55.20000   0.70011
```

```
*     The following record defines standard deviation information for
*     distances (a "sigma-distance" record).  Note how the identifier ds is
*     used in the distance observation records below.
 52 ds 0.05    1.0

*
*     Distance Observations:
*     Station From              Station To                 Distance      Sta. Dev.
   2  ntown                     hi65                       36107.181     0.01
   2  ntown                     nevada                     16670.030     0.01
   2  dot                       nevada                     14140.848     0.01
   2  dot                       hi65                       34702.142     0.01
   2  hi65                      nevada                     25931.517     0.01
   2  dot                       slater                     16175.778     0.01
   2  hi65                      boone                      50808.438     0.01
   2  ntown                     boone                      19538.726     0.01
   2  slater                    nevada                     24530.811     0.01
   2  ntown                     slater                     16389.439     0.01
   2  slater                    boone                      26326.905     0.01
   2  ntown                     dot                         2636.433     0.01
   2  dot                       betts                      87477.093     0.01
   2  ntown                     betts                      85314.548     0.01
   2  ntown                     hampt                      87284.004     0.01
   2  ntown                     105                           57.681     0.01
   2  105                       dot                         2592.534     0.01
   2  dot                       hampt                      86997.541     0.01
   2  dot                       boone                      22164.836     0.01
   2  oldtown                   bm09                       60740.216     0.01
   2  oldtown                   bm10                       61684.814     0.01
   2  oldtown                   bm11                       66467.667     0.01
   2  oldtown                   hardy                      95950.837     0.01
   2  oldtown                   humbota                    89089.271     0.01
   2  hardy                     humbota                    15204.226     0.01
   2  oldtown                   dodge                      36544.875     0.01
   2  oldtown                   slater                     16399.623     0.01
   2  oldtown                   ntown                         10.460     0.01

*     The following record defines a group name for the angles.  This name
*     will then be used in GeoLab printing, making it easier for you to
*     find certain observations (misclosure and residual listings).
*     Remember to end such a group of observations with either a new
*     group name, or a blank group name (see below).
*75   my angles
*
*     Angle Observations:
*     At         From       To                                Angle           Std. Dev
.
*48   1001       site A     1004                              273 39 55.8     0.9
*48   site A     1001       site B-2                          168 56 24.8     0.9
*48   1004       1001       1005                              257 41  6.4     0.9
*48   1006       site B-2   1005                               94 35 13.5     0.9
*48   1009       1005       1006                              320 36 12.6     0.9

*75

*     The following record defines standard deviation information for
*     azimuths (a "sigma-azimuth" record).  Note how the identifier AZ is
*     used in the azimuth observation records below.
*53 AZ 1.0
*
*75   my azimuths
```

```
*
*     Azimuth Observations:
*     Station From              Station To                    Azimuth           Std. Dev
.
* 3 AZsite B-2                  1001                          178 15  8.06      1.0
* 3 AZsite B-2                  1004                          205 46 47.50      1.0
* 3   1005                      1004                          175 51 33.33000   1.00012

*75

*
*     Vertical Angle Observations:
*     Station From              Station To                      Vert. Angle     Std. Dev
.
*44   1001                      site A                          0 29 58.8       2.0
*44   site B-2                  site A                          0 13 35.0       2.0
*44   site A                    1004                            0-25 18.77      2.0
*44   1004                      1001                            0-15  5.9       2.0
*44   site B-2                  1001                            0-15 44.0       2.0
*44   site B-2                  1004                            0-11 55.41      2.0

*
*     Zenithal Angle Observations:
*     Station From              Station To                    Zenithal Angle    Std. Dev
.
*47   1001                      site A                        89 30  1.2        2.0
*47   site B-2                  site A                        89 46 25.0        2.0
*47   site A                    1004                          90 25 18.77       2.0
*47   1004                      1001                          90 15  5.9        2.0
*47   site B-2                  1001                          90 15 44.0        2.0
*47   site B-2                  1004                          90 11 55.41       2.0

*
*     Height Observations:
*     Station                                                   Height          Std. Dev
.
 45   nevada                                                    305.511         0.001
 45   hi65                                                      340.091         0.001
 45   boone                                                     346.779         0.001
 45   bm11                                                      248.310         0.001
*45   1005                                                      1914.39         0.30
*45   1006                                                      2203.20         0.30
*45   1007                                                      1937.01         0.30
*45   1008                                                      2075.85         0.30
*45   1009                                                      2042.15         0.30

*
*     Height Difference Observations:
*     Station From              Station To                    Height Diff.      Std. Dev
.
 46   oldtown                   ntown                             0.238         0.01
*46   site B-2                  site A                          167.5           0.30
*46   site A                    1004                           -149.2           0.30
*46   1004                      1001                            -59.6           0.30
*46   site B-2                  1001                            -41.1           0.30
*46   site B-2                  1004                             18.9           0.30

*
*     2-D Coordinate Observations:
*
 75   2-D Coords
892dc
 96   slater                                   41 53  0.30116w 93 40 52.21372
 96   hampt                                    42 44 33.25579w 93 12 27.55318
 96   betts                                    41 47 27.08097w 94 37 47.90140
```

```
*96   1004                                    30  1 47.00543w 90 14  9.00026
*96   1005                                    30 11 48.01024w 90 14 58.99721
*96   1006                                    30 23 41.01226w 90 15 57.99611
*96   1007                                    30  0  2.00937w 90 30 52.00328
*96   1008                                    30 11 36.01429w 90 30 33.00049
*96   1009                                    30 24 17.01365w 90 30 55.99843
 97povdiagonal
 98       0.000001          0.000001          0.000001
 98       0.000001          0.000001          0.000001
*98       0.00009           0.00009           0.00009
*98       0.00009           0.00009           0.00009
*98       0.00009           0.00009           0.00009
*98       0.00009           0.00009           0.00009

*
*     2-D Coordinate Difference Observations:
*
 75   2-D Coord Diffs
*882dd
*96   1001                                    30  0  0.00020w 90  0  0.00005
*96   site A                                  30 10 54.00421w 89 58 58.99262
*96   site B-2                                30 25 40.00867w 90  0 53.98443
*96   1004                                    30  1 47.00542w 90 14  9.00017
*96   1005                                    30 11 48.01019w 90 14 58.99714
*97pdvdiagonal
*98       0.00009           0.00009           0.00009
*98       0.00009           0.00009           0.00009
*98       0.00009           0.00009

*
*     3-D Coordinate Observations:
*
 75   3-D Coords
*953dc
*96   site A                                  30 10 54.00463w 89 58 58.99257 2174.34
*96   site B-2                                30 25 40.00836w 90  0 53.98467 2006.78
*96   1004                                    30  1 47.00562w 90 14  9.00022 2025.09
*96   1005                                    30 11 48.01000w 90 14 58.99739 1924.03
*96   1006                                    30 23 41.01223w 90 15 57.99612 2213.07
*943dcWGSXX
*97povdiagonal
*98       0.0009            0.0009            0.0009
*98       0.0009            0.0009            0.0009
 98       0.09              0.09              0.09
 98       0.09              0.09              0.09
 98       0.09              0.09              0.09
 98       0.09              0.09              0.09
 98       0.09              0.09              0.09
 98       0.09              0.09              0.09
 98       0.09              0.09              0.09
 98       0.09              0.09              0.09
 98       0.09              0.09              0.09
 98       0.09              0.09              0.09
 98       0.09              0.09              0.09
 98       0.09              0.09              0.09
 98       0.09              0.09              0.09
 98       0.09              0.09              0.09
 98       0.09              0.09              0.09
 98       0.09              0.09              0.09
 98       0.09              0.09              0.09
 98       0.09              0.09              0.09
 98       0.09              0.09              0.09
 98       0.09              0.09              0.09
```

```
 98      0.09              0.09              0.09
 98      0.09              0.09              0.09
 98      0.09              0.09              0.09
 98      0.09              0.09              0.09
 98      0.09              0.09              0.09
 98      0.09              0.09              0.09
 75

*  The next record causes all data to the end of this file to be ignored.
 99

*
*     3-D Coordinate Difference Observations:
*
 75   3-DD Group2
 913dd
 96   1007                           30  0  1.94870w 90 30 52.04613 1937.020
 96   1008                           30 11 35.94621w 90 30 33.01558 2075.930
 96   1009                           30 24 16.94934w 90 30 56.02636 2042.170
 97pdvdiagonal
 98      0.00009           0.00009           0.00009
 98      0.00009           0.00009           0.00009
```

Appendix A1FIX.OUT

Your Company Name Incorporated
Trilateration for the Big Iowa Project using fixed dd
A= 6378137.000 B= 6356752.314 X0= 0.000 Y0= 0.000 Z0= 0.000

SOLVE:

Adjusted Values (Iteration Count = 9):

CODE	IDENT.	TYPE			INITIAL	DX			ADJUSTED
14	dodge	LATITUDE	41	42	10.845620	FIXED			
14	dodge	LONGITUDE	-93	42	24.664800	FIXED			
14	dodge	HEIGHT			277.81000	FIXED			
4	nevada	LATITUDE	42	1	21.473085	0.000000	42	1	21.473085
4	nevada	LONGITUDE	-93	27	5.417184	-0.000000	-93	27	5.417185
4	nevada	HEIGHT			276.37099	-0.00000			276.37099
4	hi65	LATITUDE	42	13	51.388483	0.000001	42	13	51.388484
4	hi65	LONGITUDE	-93	18	35.819606	-0.000001	-93	18	35.819607
4	hi65	HEIGHT			310.99096	-0.00000			310.99096
4	boone	LATITUDE	42	3	58.341212	-0.000000	42	3	58.341212
4	boone	LONGITUDE	-93	53	0.085097	-0.000000	-93	53	0.085097
4	boone	HEIGHT			318.40906	-0.00000			318.40906
4	bm09	LATITUDE	41	29	46.073407	-0.000005	41	29	46.073402
4	bm09	LONGITUDE	-93	29	29.066856	0.000042	-93	29	29.066814
4	bm09	HEIGHT			218.72170	0.00000			218.72171
4	bm10	LATITUDE	41	29	26.146255	-0.000005	41	29	26.146251
4	bm10	LONGITUDE	-93	28	24.200356	0.000042	-93	28	24.200314
4	bm10	HEIGHT			210.05416	0.00000			210.05416
4	bm11	LATITUDE	41	27	32.967404	-0.000005	41	27	32.967399
4	bm11	LONGITUDE	-93	24	38.537249	0.000042	-93	24	38.537207
4	bm11	HEIGHT			218.01999	0.00000			218.01999
4	105	LATITUDE	42	1	44.511661	0.000001	42	1	44.511662
4	105	LONGITUDE	-93	39	7.865518	-0.000000	-93	39	7.865518
4	105	HEIGHT			264.06012	-0.00000			264.06012
4	ntown	LATITUDE	42	1	45.891315	0.000000	42	1	45.891315
4	ntown	LONGITUDE	-93	39	9.281610	-0.000000	-93	39	9.281610
4	ntown	HEIGHT			285.35957	-0.00000			285.35957
4	dot	LATITUDE	42	1	20.065295	0.000000	42	1	20.065295
4	dot	LONGITUDE	-93	37	20.050290	-0.000000	-93	37	20.050291
4	dot	HEIGHT			262.71655	-0.00000			262.71655
4	slater	LATITUDE	41	53	0.301149	0.000000	41	53	0.301149
4	slater	LONGITUDE	-93	40	52.213746	0.000000	-93	40	52.213746
4	slater	HEIGHT			289.47199	-0.00000			289.47199

Your Company Name Incorporated
Trilateration for the Big Iowa Project using fixed dd
A= 6378137.000 B= 6356752.314 X0= 0.000 Y0= 0.000 Z0= 0.000

SOLVE:

CODE	IDENT.	TYPE			INITIAL	DX			ADJUSTED
4	hampt	LATITUDE	42	44	33.255885	0.000000	42	44	33.255885
4	hampt	LONGITUDE	-93	12	27.553122	0.000000	-93	12	27.553122
4	hampt	HEIGHT			320.37540	-0.00000			320.37540
4	betts	LATITUDE	41	47	27.080964	-0.000000	41	47	27.080964
4	betts	LONGITUDE	-94	37	47.901418	-0.000000	-94	37	47.901418
4	betts	HEIGHT			371.69719	-0.00000			371.69719
4	oldtown	LATITUDE	42	1	46.225256	-0.000005	42	1	46.225251
4	oldtown	LONGITUDE	-93	39	9.195996	0.000042	-93	39	9.195954
4	oldtown	HEIGHT			285.12229	-0.00000			285.12229
4	hardy	LATITUDE	42	49	48.576411	-0.000005	42	49	48.576406
4	hardy	LONGITUDE	-94	5	24.086542	0.000043	-94	5	24.086499
4	hardy	HEIGHT			328.98135	-0.00001			328.98134
4	humbota	LATITUDE	42	43	14.169859	-0.000005	42	43	14.169855
4	humbota	LONGITUDE	-94	12	4.906884	0.000043	-94	12	4.906841
4	humbota	HEIGHT			316.56396	-0.00001			316.56395

Your Company Name Incorporated
Trilateration for the Big Iowa Project using fixed dd
A= 6378137.000 B= 6356752.314 X0= 0.000 Y0= 0.000 Z0= 0.000

ELLIPSE:

2-D AND 1-D STATION CONFIDENCE REGIONS (95.000 %):

IDENT.	MAJOR SEMI-AXIS	MINOR SEMI-AXIS	AZ(MAJ)	VERTICAL
nevada	0.5219	0.1930	156.32	0.0208
h165	1.0746	0.1940	136.42	0.0208
boone	0.5155	0.2073	34.48	0.0208
bm09	8.5336	1.2514	80.95	6.6630
bm10	8.5236	1.3179	79.91	6.6630
bm11	8.4910	1.5134	76.81	0.0208
105	0.6966	0.3089	34.11	4.8905
ntown	0.2507	0.1465	120.30	2.3043
dot	0.2634	0.1499	129.54	2.7067
slater	0.0261	0.0258	97.63	3.0573
hampt	0.0259	0.0257	160.59	4.8904
betts	0.0261	0.0260	92.12	4.8905
oldtown	3.6542	0.1593	98.51	2.3072
hardy	6.5659	1.6271	76.19	5.6010
humbota	6.1100	1.9991	70.86	5.6010

Appendix Traverse

Traverse Summary

Using WGS 84 parameters of a = 6378137 meters and f = 1/298.25722201 various factors needed in the traverse were computed. From the Geolab and SP83 output an average latitude of 42 0′ 27", an elevation above mean seal level of 309.2 meters, and an average scale factor of 1.000011255 was computed. Other computed results include: R = 6364038.71 meters, Sea level factor = .999951416, Grid Factor = .999962671, and 1/G.F. = 1.00003733. This last constant is important when converting state plane coordinates to ground state plane coordinates. We found that the best results when computing the traverses occur when the azimuths from the observations are fixed in the input file of Geolab, in addition to the distances and the 3-d coordinate differences. The state plane coordinates were obtained from the SP83 program and hence the azimuths of NWPT-SWPT, NOPT-SOPT, and NEPT-SEPT lines determined. These were used to fix the beginning and ending azimuths in the various traverse computations. With the NWPT state plane coordinate fixed, the ground state plane coordinates of the other points found. Five various traverse computations were completed and their misclosures and differences summarized on the next couple of pages. The traverses were computed using a personal computer program called "READ" where an input file is set up first and then the program is run. I will describe the make up of the input file in later documentation. It might also be good to note that the azimuth between NOPT-SOPT may be less reliable because the GPS observation involved approximately only thirty minutes. This may have caused some of the larger misclosures in the traverses which begin at SOPT.

TRAVERSE SUMMARY

FROM	TO	ANGULAR (SECONDS)	MISCLOSURE N(Y) (METERS)	E(X)
NWPT	NEPT	-1.15	0.0786	-0.0273
WEST	NEPT	-2.36	0.0712	-0.0273
SEPT (EAST	NEPT LOOP)	0.0549	0.082	-0.00048
SOPT	NWPT	-6.48	0.0029	-0.105
SOPT	NEPT	-7.745	0.3599	-0.05664

USING PC PROGRAM READ

CONVERSION OF STATE PLANE TO GROUND STATE PLANE COORDINATES (NWPT FIXED) (AZIMUTHS FIXED)

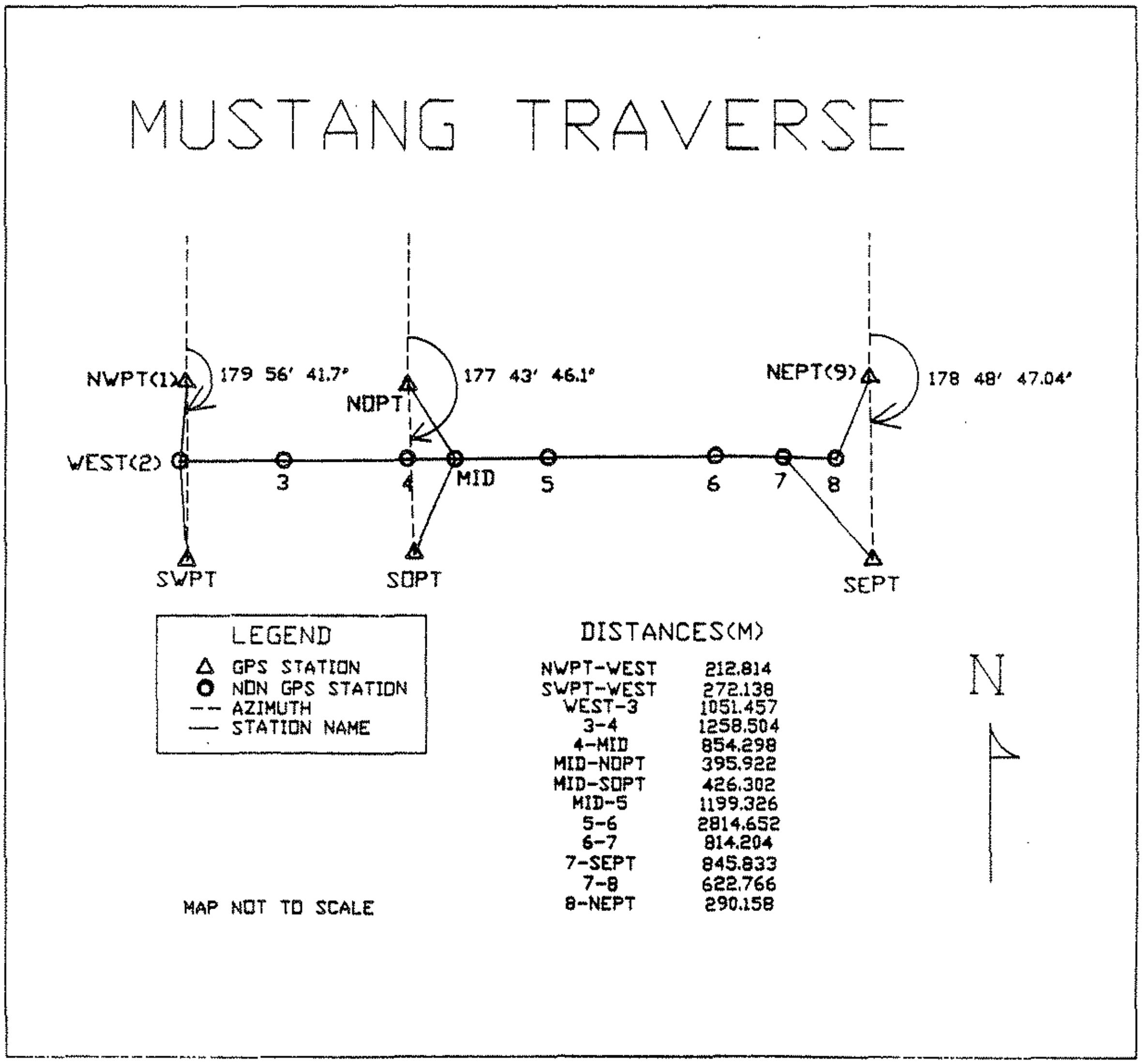
	STATE PLANE N(Y)	STATE PLANE E(X)	GROUND STATE PLANE N(Y)	GROUND STATE PLANE E(X)
NWPT	1056629.476	1507810.699	1056629.476	1507810.699
NOPT	1056598.090	1510612.600	1056598.089	1510612.705
NEPT	1056647.876	1516585.456	1056647.877	1516585.784
SEPT	1056144.576	1516595.882	1056144.558	1516596.210
SOPT	1056164.206	1510629.801	1056164.189	1510629.906
SWPT	1056144.732	1507811.165	1056144.714	1507811.165

1/G.F. = 1.0000373301

TRAVERSE SUMMARY

(IN METERS)

STATION	NWPT-> N(Y)	NEPT E(X)	WEST-> N(Y)	NEPT E(X)	SOPT-> N(Y)	NWPT E(X)	SOPT-> N(Y)	NEPT E(X)	EAST N(Y)	LOOP E(X)
NWPT	6629.476	7810.699			6629.476	7810.699				
1	6416.738	7805.106	6416.761	7805.106	6416.736	7805.106				
2	6413.65	8856.555	6413.671	8856.555	6413.606	8856.587				
3	6383.337	10114.69	6383.355	10114.69	6383.241	10114.76				
SOPT					6164.189	10629.90	6164.189	10629.90		
4			6423.824	10968.03	6423.678	10968.12	6423.702	10968.13		
5	6480.626	12166	6480.638	12166			6480.539	12166.06		
6	6472.661	14980.64	6472.666	14980.64			6472.624	14980.67		
7	6407.368	15792.21	6407.37	15792.21			6407.348	15792.21	6407.326	15792.216
8	6413.338	16414.95	6413.338	16414.95			6413.328	16414.95	6413.325	16414.952
NEPT	6647.877	16585.78	6647.877	16585.78			6647.877	16585.78	6647.877	16585.78
SEPT									6144.558	16596.21


MUSTANG TRAVERSE
NWPT(1)
179 56' 41.7"
NOPT
177 43' 46.1"
NEPT(9)
178 48' 47.04"
WEST(2)
3
4
MID
5
6
7
8
SWPT
SOPT
SEPT
LEGEND
GPS STATION
NON GPS STATION
AZIMUTH
STATION NAME
DISTANCES(M)
NWPT-WEST 212.814
SWPT-WEST 272.138
WEST-3 1051.457
3-4 1258.504
4-MID 854.298
MID-NOPT 395.922
MID-SOPT 426.302
MID-5 1199.326
5-6 2814.652
6-7 814.204
7-SEPT 845.833
7-8 622.766
8-NEPT 290.158
N
MAP NOT TO SCALE

Appendix Pseudo-Kinematic

USER'S MANUAL: PSUEDO-KINEMATIC GPS SURVEYING

REFERENCE: Ashtec XII Model L; Operations and Processing Manual, February, 1989.

USER ASSUMPTION: This document has been prepared based upon the assumption that the reader has working knowledge of Static Mode GPS surveying procedures to include post-processing procedures.

PSEUDO-KINEMATIC FIELD PROCEDURES:

One receiver will be set up on a known point and will remain on this point throughout the survey. The second receiver, or rover receiver, will be moved to all unknown points, occupying each point for a period of at least five minutes. Once the last unknown point has been occupied for five minutes, the rover is moved back to the first unknown point for five minutes and each other unknown point is re-occupied in the original sequence for five minutes. A key point here is that there must be at least one hour of elapsed time between the first and second occupation of a point. So, if you have finished your five minute occupation of the last unknown point and are ready to move back to re-occupy the first unknown point, check your time to ensure one hour has elapsed since you last occupied the original unknown point. If an hour has not elapsed, simply remain occupied on your current point until one hour has elapsed. The extra data collected will only help the solution. Two occupations of each point is all that is required.

The antenna heights over each point must be equal for each occupation. This requires tripods with tribrachs to be set up prior to the survey over each point and left there from the first to second occupation. Another technique is to mount the antenna onto an adjustable vertical staff fixed at a constant height so that this whole system may be moved from point to point. The tripod method provides a more stable platform for the antenna to rest on and is the preferred method. With this method, you must consider the requirement to guard the tripods at remote sites and is also limited by the number of points you need to occupy versus the equipment you have on hand. The staff method works well where you have more points to occupy than equipment, do not have enough equipment guards, or must occupy points where you cannot leave a tripod set up between occupations. (e.g. Points located on highways) The staff is less stable than the tripod, and becomes top-heavy when the antenna is mounted on it. These staffs can be found in locker #52 in the instrument room. The user should become familiar with these staffs before going to the field and using them for the first time. The actual HI of the antennae can be measured prior to the survey or afterwards.

RECEIVER SET UP

At screen four on both receivers, the user should enter 4 for minimum number of space vehicles (SV). For the base receiver,(the one occupying the known point), the operator should enter a 4-character site name at screen 9. There will be just one file with one site name for the base receiver. (Just like in Static Mode) The rover receiver will also have only one file, but each point occuppied will have a distinct 4-character site name entered at screen 9. The sequence is as follows:

At the first unknown station, the operator enters a 4-character site name for that point at screen 9. Once the signals from 4 satellites have been locked (can be checked at screen 0 or 1), the point is occuppied for at least 5 minutes. At the end of this 5 minute period, the operator turns to screen 9 and enters 4 question marks for the site name. This flags the software in post-processing to ignore data collected while ???? is the site name. The antenna and receiver are moved to the next point. The operator waits until 4 satellites are again locked, then goes to screen 9 and enters the unique 4-character site name for the point. Data is then collected for 5 minutes, 4 question marks are entered for site name, the antenna and receiver are moved to the next point where the sequence is repeated. The same 4-character site name must be used for each point during its re-occupation. The rover receiver only has one data file, but several site names will be associated with that file. Post processing software will utilize these different site names to provide solutions for each point.

Contrary to the true kinematic procedure, cycle slips during transit between points are acceptable in this procedure, but the points themselves should be unobstructed to avoid cycle slips while the point is occuppied.

At least two people, and optimally three people, are required to move the rover equipment from point to point. If the points are within walking distance, one person carries the antenna while one person carries the receiver and excess cable. A third person cold be present at the next station to assist in placing the antenna on the tribrach. If the points are to be driven to, an open bed truck is needed. In the bed of the truck should be a tripod with tribrach that the antenna can be mounted to while being transported to the next point. The tripod legs should be fit into a wooden triangle. If the vertical shaft is being used, the tripod supporting the shaft and the shaft itself can be secured in the wooden triangle. The receiver is placed carefully onto the bed of the truck and one person rides in the bed to stabilize the equipment. The equipment is transported in such fashion to the next point.

While in transit between points, operators must pay special attention the the cables. Avoid any sharp pulls or yanks on the connections at the receiver or antenna. This is a prime cause of cycle slips.

The survey is complete when the last unknown point has been occupied for the second time for a period of 5 minutes. Both receivers can be turned off at this point.

POST PROCESSING PROCEDURES FOR PSEUDO-KINEMATIC SURVEYS

The post processing of the pseudo-kinematic data is very similar to Static Mode post processing. One additional file will need to be created and the LINECOMP program will need to be run separately for each unknown point.

Begin the post processing by downloading the data from the receivers via the hose program as with static processing. At the template window, the operator may want to follow the naming convention of naming the file for the base receiver as BASdate.dat and the file for the rover receiver as ROVdate.dat. Of course, any naming convention will work. Next, run the comnav and makeufil programs as with static mode. At this point, the operator should run the genlog program. This program creates a file called the logtimes file which is used in further processing. The genlog program is called by typing 'genlog' at the dos prompt line. The user will be prompted to provide a navigation file to use. Enter the navigation file from the rover receiver. e.g. NROV521.dat. You will next be prompted to indicate which file is the fixed station file and which file is the rover receiver file. Enter 0 for fixed station and 1 for rover receiver. After you hit return to enter the 1 for rover receiver, the program will run to create the logtimes file. Although you do not need to look at it, you can view the logtimes file using the standard 'type logtimes' dos command. An example logtimes file is at enclosure 1. In this example, PT02 was the 4-character name given to the first unknown point. The rotation sequence in the field was from PT02 to PT01 to PT03 to PT04 and the same sequence on the second rotation.

You will next want to run the makeinp program. The first time through this program, you will create a new makeinput file which you will recall to edit for each additional unknown point you want to process.

Call the makeinp program as usual and begin by editing the known station parameters. Edit as usual, including data extraction code equal to 1 and list the base receiver Ufile in the proper location. YOU MUST also change the receiver identifier code to read 0000. This is different than in static mode processing. Be sure to enter the 4-character site name you used for your base point. This must match EXACTLY the site name you entered in your receiver in the field. This is also critical to the successful processing of your data. Next, edit unknown station parameters. Change the receiver identifier number to 0001 and enter the 4-character site name for your first unknown point in the proper location. Again, this must match EXACTLY with the site name you entered in the receiver in the field. Enter the rest of the data as usual, set data extraction code to 1 and enter the ufile for the rover in the last entry. Do not forget to enter the proper HI for the antenna in the proper location. Edit the rest of the run time parameters as with the static mode, and finally, give your input file a name. Use some type of recognizable convention. One that has been successful is to use combination of the base and unknown point site names. e.g. BASPT01.inp

You will next run the linecomp program, but instead of typing linecomp baseline.inp on the command line, just type 'linecomp'. This technique allows you to name your output file. Since you will be running linecomp for several points, this eliminates overwriting previously created output files. So, type 'linecomp'and hit return. You will be prompted for the input file. Enter the makeinp file you just created. You will next be prompted for the name of the output file you want the linecomp output to go to. Enter a name. A good convention to follow is to simply change the extension on your input file from .inp to .out. e.g. BASPT01.out. You will next be prompted to name the file to have the plotfile sent to. Again, you can give it any name you want, but one convention to follow is to simply add a P to the front of your output file. e.g. PBASPT01.out. After you hit the return to enter your plotfile name, linecomp will begin processing and the output will go to your specified output file.

To process the other unknown points, call the makeinp program again and use the option to read-in a baseline.inp file. Read-in your last previous baseline.inp file you created and you only need to edit the unknown station parameters. Edit the 4-character site name to match the name of your next unknown point and change the antenna height to the value for that unknown point. You will use the same rover ufile for all unknown points so there is no need to edit that entry. You will need to give this new makeinput file you created a new name. Use the 'Write input file' option as usual. Remember, the 4-character site name must match EXACTLY the name you used for that point in the field, to include any spaces, if you used them. I would not recommend using spaces in your names. The software searches in the logtimes file for these names and if they do not find a match, your processing will crash. Look at a logtimes file and this requirement will be more obvious.

After a successful processing, you can print the individual output files and you should see output that provides the same output for each unknown point as a static mode output would show. At enclosure 2 is a sample output from a pseudo-kinematic survey done for a portion of project Mustang just East of Nevada, IA. I've shown the output for PT01, one of the unknown points. The output shows all the output data between the known point where the base receiver was set up and the unknown point PT01. The output shown here is the same as if two receivers were used in a static mode between the base point and PT01. Note on the first page of the output the 4-character short name and also the receiver identifier code. The known station parameters show a 0000 for receiver identifier and unknown station parameters show a 0001 for receiver identifier code. The software uses these codes to match up the receivers in the logtimes file.

Enclosure 3 shows a flow chart for post-processing.

TROUBLE SHOOTING

The Pseudo-kinematic procedure is fairly forgiving to cycle slips and other types of mistakes and has a good track record of processing. However, not a perfect record. The most common error is the misspelling or mistyping of the 4-character site name in the unknown station parameters. Always use 4 characters when naming your sites. If you use only 2 or 3 the empty spaces will be read as blanks and you must enter spaces in your site names when editing the unknown station parameters. We have had one failure to process due to poor geometry of the satellites. The data was collected towards the end of the viewing window with low elevations of the satellites. Avoid this. Also, make sure there is 1 hour of elapsed time between occupation times on the points. The data may process, but the solutions will be poor.

Enclosures:

1. Logtimes file
2. Linecomp output
3. Post-processing flow chart

INT#	MJD	TSTART	TEND	R0	R1	R2	R3	R4	R5	R6	R7	R8	R9
0	48075	19:29:10	19:51:40	BASE	????	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
1	48075	19:51:40	19:57:20	BASE	PT02	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
2	48075	19:57:20	20:08:50	BASE	????	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
3	48075	20:08:50	20:14:40	BASE	PT01	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
4	48075	20:14:40	20:21:30	BASE	????	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
5	48075	20:21:30	20:27:30	BASE	PT03	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
6	48075	20:27:30	20:38:50	BASE	????	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
7	48075	20:38:50	20:44:10	BASE	PT04	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
8	48075	20:44:10	20:54:20	BASE	????	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
9	48075	20:54:20	20:59:20	BASE	PT02	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
10	48075	20:59:20	21:07:40	BASE	????	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
11	48075	21:07:40	21:12:50	BASE	PT01	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
12	48075	21:12:50	21:24:40	BASE	????	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
13	48075	21:24:40	21:29:50	BASE	PT03	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
14	48075	21:29:50	21:38:10	BASE	????	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
15	48075	21:38:10	21:44:20	BASE	PT04	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
16	48075	21:44:20	21:54:30	BASE	????	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
-1	99999	99:99:99	99:99:99										

```
Ashtech, Inc. GPPS-2          Program: LINECOMP        Version: 2.0.00
                            Fri Jul 06 06:38:10 1990

Project information
G   Survey               |25-character project name  [ The | is in column 26. ]
1239A                    |5-character session name
1989 01 11  00:00:00     |Baseline occupation calendar start date-time (UTC).
1989 01 11  00:00:00     |Baseline occupation calendar end date-time (UTC).
Project information

Known-station parameters
00000                    |Receiver identifier used in "LOGTIMES" file
00001                    |Project station number
base                     |4-character short name
FIXED STATION            |25-character long name
1                        |Position extraction (0=below,1=U-file,2=proj. file)
b  40.000000000          |N-Latitude degrees        (g=good;b=bad)
g  40  0  0.00000        |N-Latitude deg-min-sec    (g=good;b=bad)
b 280.000000000          |E-Longitude degrees       (g=good;b=bad)
b 280  0  0.00000        |E-Longitude deg-min-sec   (g=good;b=bad)
b  80.000000000          |W-Longitude degrees       (g=good;b=bad)
g  80  0  0.00000        |W-Longitude deg-min-sec   (g=good;b=bad)
g  100.0000              |Ellipsoidal height   (m)  (g=good;b=bad)
b    0.0000              |Geoidal height       (m)  (g=good;b=bad)
b    0.0000              |Mean-Sea-Level ht    (m)  (g=good;b=bad)
b   849623.0608          |Xecf  (m)                 (g=good;b=bad)
b -4818451.8184          |Yecf  (m)                 (g=good;b=bad)
b  4078049.8510          |Zecf  (m)                 (g=good;b=bad)
     0.0000              |North antenna offset(m)
     0.0000              |East antenna offset (m)
   .5240  0.1050  0.0000 |Vert antenna offset (m): slant/radius/delta_vertical
    32.8                 |Temperature (degrees C)
    51.0                 |Humidity (percent)
  1015.6                 |Pressure (millibars)
ubas7390.dat             |Measurement filename (restricted to 24 characters)
Known-station parameters

Unknown-station parameters
00001                    |Receiver identifier used in "LOGTIMES" file
00002                    |Project station number
PT01                     |4-character short name
UNKNOWN STATION          |25-character long name
1                        |Position extraction (0=below,1=U-file,2=proj. file)
b  40.000000000          |N-Latitude degrees        (g=good;b=bad)
g  40  0  0.00000        |N-Latitude deg-min-sec    (g=good;b=bad)
b 280.000000000          |E-Longitude degrees       (g=good;b=bad)
b 280  0  0.00000        |E-Longitude deg-min-sec   (g=good;b=bad)
b  80.000000000          |W-Longitude degrees       (g=good;b=bad)
g  80  0  0.00000        |W-Longitude deg-min-sec   (g=good;b=bad)
g  100.0000              |Ellipsoidal height   (m)  (g=good;b=bad)
b    0.0000              |Geoidal height       (m)  (g=good;b=bad)
b    0.0000              |Mean-Sea-Level ht    (m)  (g=good;b=bad)
b   849623.0608          |Xecf  (m)                 (g=good;b=bad)
b -4818451.8184          |Yecf  (m)                 (g=good;b=bad)
b  4078049.8510          |Zecf  (m)                 (g=good;b=bad)
     0.0000              |North antenna offset(m)
     0.0000              |East antenna offset (m)
  1.4325  0.0950  0.0000 |Vert antenna offset (m): slant/radius/delta_vertical
    24.0                 |Temperature (degrees C)
    51.0                 |Humidity (percent)
```

```
  1015.5                  |Pressure (millibars)
urov7390.dat              |Measurement filename (restricted to 24 characters)
Unknown-station parameters

F  -time parameters
    1                     |First epoch to process
   -1                     |Final epoch to process (-1 = last available)
  1.0                     |Approximate seconds for tlsq processing
 100.0                    |Tlsq a priori bad-residual criterion (i.e.,rms_cutoff)
15.0                      |Elevation cutoff angle (degrees)
1                         |Data to process (1=L1;2=L2;3=L1c;4=L1-L2;5=L1+L2)
3.0                       |Edit data with residuals greater than this*rms_cutoff
0.000100                  |Tlsq convergence criterion (meters)
00 00 00 00 00 00 00      |Omit these satellites (up to 7)
20                        |Auto SV omission criterion (Percent of Reference SV)
no                        |Display good residuals (bad are always displayed)
 5                        |Maximum iterations for tlsq and dlsq
fast                      |Speed: fast/slow
08 00 00 00 00 00 00      |Forbidden reference SVs (up to 7)
yes                       |Apply tropo delay correction
00:00:0000:9999           |SV:cycle-slip:epoch_begin:epoch_end
00:00:0000:9999           |SV:cycle-slip:epoch_begin:epoch_end
00:00:0000:9999           |SV:cycle-slip:epoch_begin:epoch_end
00:00:0000:9999           |SV:cycle-slip:epoch_begin:epoch_end
00:00:0000:9999           |SV:cycle-slip:epoch_begin:epoch_end
00:00:0000:9999           |SV:cycle-slip:epoch_begin:epoch_end
00:00:0000:9999           |SV:cycle-slip:epoch_begin:epoch_end
00:00:0000:9999           |SV:cycle-slip:epoch_begin:epoch_end
00:00:0000:9999           |SV:cycle-slip:epoch_begin:epoch_end
00:00:0000:9999           |SV:cycle-slip:epoch_begin:epoch_end
2                         |Data quality factor (10-40; default 20)
no                        |ASCII file (DD_OBS) of double differences
yes                       |Generate "PLOTFILE" for plotting residuals
-1.0                      |Int search data editing factor (1.0-3.0; auto = -1.0)
1                         |N=Extent of integer search: -N to +N for all DDs
yes                       |Demand fixed double difference processing
Run-time parameters
--------------------------------------------------------------------------------

LINECOMP 2.0.00 02/27/90
Common start of two UFILES: 1990/07/03 19:51:50
Common end   of two UFILES: 1990/07/03 21:44:20
    Selected first epoch:  1
    Selected last  epoch:  676
For SV  2 there are    33 triple-difference measurements.
For SV  6 there are    66 triple-difference measurements.
For SV  9 there are    58 triple-difference measurements.
For SV 11 there are    64 triple-difference measurements.
For SV 12 there are    31 triple-difference measurements.
For SV 13 there are    65 triple-difference measurements.
Epoch interval (seconds):  10

THE TRIPLE DIFFERENCE SOLUTION FOLLOWS:
TLSQ measure of geometry: 901.372573
r  _meas = 251   num_used = 249   rms_resid = 0.023879

  Sigmax (cm):     16.807870
  Sigmay (cm):      8.451824
  Sigmaz (cm):      4.276769
```

```
  x     y     z
x 1.00
y-0.77y 1.00
z 0.23z-0.51z 1.00

del_station: -0.000000 -0.000000 -0.000001

     Station1: FIXED STATION               Station2: UNKNOWN STATION
                (00001)    (base)                     (00002)    (PT01)
 Latitude:  42.00554261  42  0 19.95341          42.00785627  42  0 28.28258
 E-Long  : 266.62834011 266 37 42.02439         266.59313715 266 35 35.29373
 W-Long  :  93.37165989  93 22 17.97561          93.40686285  93 24 24.70627
 E-Height: 291.1690                              287.2881

 Baseline vector:      -2900.9788       346.9817       188.3692

 Mark1_xyz  :  -279171.8894  -4738586.8419   4246256.1744
 Az1 El1 D1 :      275.04773        -0.0891      2927.7222
 E1 N1 U1   :    -2916.4719       256.9977        -3.8809
 Mark2_xyz  :  -282072.8682  -4738239.8601   4246444.5437
 Az2 El2 D2 :       95.02417         0.0628      2927.7222
 E2 N2 U2   :     2916.3644      -256.9976         3.8809

Double-Difference Epochs:
  Prn:   2  Start epoch:  106  End epoch:  138
  Prn:   6  Start epoch:  104  End epoch:  487
  Prn:   9  Start epoch:  109  End epoch:  487
  Prn:  11  Start epoch:  106  End epoch:  487
  Prn:  12  Start epoch:  457  End epoch:  487
  Prn:  13  Start epoch:  105  End epoch:  487


THE FLOAT DOUBLE DIFFERENCE SOLUTION FOLLOWS:
Float-dlsq measure of geometry: 0.161639
num_meas = 260   num_used = 259  rms_resid = 0.043887

Reference SV:  6
amb[0] =      1560163.743   SV-02  Fit:  0.041  Num meas = 34
amb[1] =       383884.489   SV-09  Fit:  0.040  Num meas = 61
amb[2] =      1426729.970   SV-11  Fit:  0.048  Num meas = 65
amb[3] =      8518656.113   SV-12  Fit:  0.049  Num meas = 32
amb[4] =      1811891.933   SV-13  Fit:  0.042  Num meas = 67

  Sigmax (cm):      0.203660
  Sigmay (cm):      0.113306
  Sigmaz (cm):      0.045310
  SigmaN (cy):      0.049215
  SigmaN (cy):      0.028889
  SigmaN (cy):      0.022935
  SigmaN (cy):      0.049984
  SigmaN (cy):      0.044461
  x     y     z     N     N     N     N     N
x 1.00
y-0.87y 1.00
z 0.50z-0.60z 1.00
N  .98N-0.81N 0.43N 1.00
N-0.95N 0.93N-0.43N-0.91N 1.00
N 0.85N-0.54N 0.45N 0.89N-0.67N 1.00
N-0.94N 0.96N-0.48N-0.90N 0.98N-0.65N 1.00
N-0.98N 0.92N-0.57N-0.95N 0.96N-0.78N 0.97N 1.00
```

```
del_station: 0.000000 -0.000000 -0.000000

     Station1: FIXED STATION                Station2: UNKNOWN STATION
                (00001)     (base)                        (00002)     (PT01)
 Latitude:  42.00554261  42   0 19.95341          42.00785596  42   0 28.28146
 E-Long  : 266.62834011 266 37 42.02439          266.59313589 266 35 35.28922
 W-Long  :  93.37165989  93 22 17.97561           93.40686411  93 24 24.71078
 E-Height: 291.1690                               287.3675

 Baseline vector:     -2901.0874       346.9058       188.3966

 Mark1_xyz   :  -279171.8894  -4738586.8419   4246256.1744
 Az1 El1 D1  :      275.04688        -0.0875      2927.8226
 E1 N1 U1    :    -2916.5758       256.9630        -3.8015
 Mark2_xyz   :  -282072.9768  -4738239.9360   4246444.5710
 Az2 El2 D2  :       95.02332         0.0613      2927.8226
 E2 N2 U2    :     2916.4684      -256.9629         3.8015

    Top ten cases based on (O-C)-squared.
  0   0   0   0   0 Case:  121 --->  0.069228 ratio =    1.075
  0   1   0   0   0 Case:  124 --->  0.074448
 -1   0   0   0   0 Case:  120 --->  0.132459
 -1   1   0   0   0 Case:  123 --->  0.137679
  0   0   0   1   0 Case:  148 --->  0.164686
  0   1   0   1   0 Case:  151 --->  0.169906
  0   0   0  -1   0 Case:   94 --->  0.219923
  0   1   0  -1   0 Case:   97 --->  0.225143
 -1   0   0   1   0 Case:  147 --->  0.227917
 -1   1   0   1   0 Case:  150 --->  0.233137


THE FIXED DOUBLE DIFFERENCE SOLUTION FOLLOWS:
Fixed-dlsq measure of geometry: 0.004233
num_meas = 260   num_used = 260   rms_resid = 0.242972

Reference SV:  6
amb[0] =     1560164.000    SV-02   Fit:   0.169   Num meas = 34
amb[1] =      383884.000    SV-09   Fit:   0.294   Num meas = 61
amb[2] =     1426730.000    SV-11   Fit:   0.184   Num meas = 66
amb[3] =     8518656.000    SV-12   Fit:   0.269   Num meas = 32
amb[4] =     1811892.000    SV-13   Fit:   0.260   Num meas = 67

  Sigmax (cm):       0.066514
  Sigmay (cm):       0.143707
  Sigmaz (cm):       0.142025
  x     y     z
x 1.00
y-0.03y 1.00
z-0.13z-0.69z 1.00

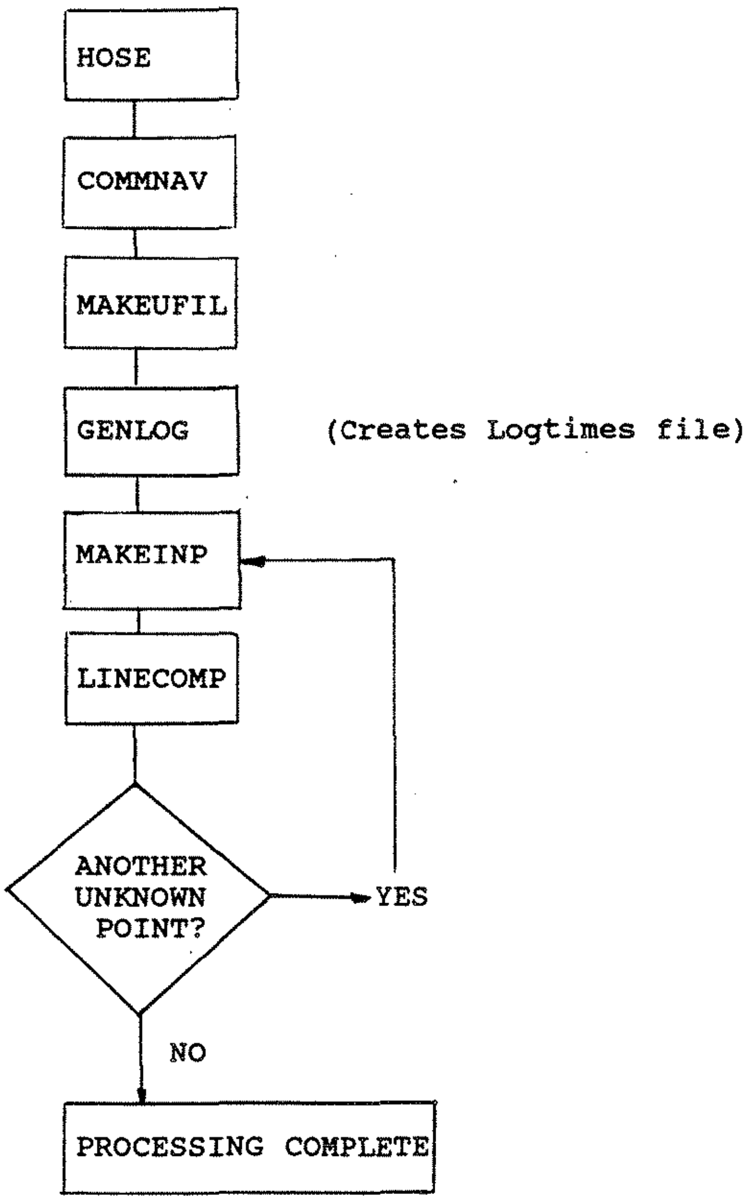
del_station: 0.000000 -0.000000 -0.000000

     Station1: FIXED STATION                Station2: UNKNOWN STATION
                (00001)     (base)                        (00002)     (PT01)
  titude:  42.00554261  42   0 19.95341          42.00785554  42   0 28.27996
 E-Long  : 266.62834011 266 37 42.02439          266.59313638 266 35 35.29095
 W-Long  :  93.37165989  93 22 17.97561           93.40686362  93 24 24.70905
 E-Height: 291.1690                               287.2798

 Baseline vector:     -2901.0455       346.9375       188.3034

 Mark1_xyz   :  -279171.8894  -4738586.8419   4246256.1744
 Az1 El1 D1  :      275.04604        -0.0892      2927.7788
   N1 U1     :    -2916.5358       256.9165        -3.8892
 Mark2_xyz   :  -282072.9349  -4738239.9043   4246444.4778
 Az2 El2 D2  :       95.02248         0.0630      2927.7788
 E2 N2 U2    :     2916.4284      -256.9165         3.8892
Fri Jul 06 06:40:52 1990
```

PSEUDO-KINEMATIC POST-PROCESSING SEQUENCE



Appendix Kinematic

USER'S MANUAL: GPS KINEMATIC SURVEYING

REFERENCE: Draft Documentation for ASHTECH GPPS Software, May 8,1989.

ASSUMPTION: It is assumed the reader has a working knowledge of static mode GPS surveying and associated post-processing procedures.

FIELD PROCEDURES FOR KINEMATIC GPS SURVEYING:

Let it first be said the documentation for the field procedures for GPS Kinematic Surveying in the reference document are very good and should certainly be read in addition to this document. I will attempt to cover points that have caused us special concern in our development of the kinematic technique.

The kinematic mode basically consists of one receiver remaining primarily static over a known position while a rover receiver occupies unknown points for a period of 2 minutes each to collect data. Unlike the pseudo-kinematic mode, each unknown station need only be occupied once.

The procedure requires that both receivers be locked on the signals of a minimum of 4 satellites (the same satellites at any one time on both receivers) for the duration of the survey.

Because of this, it is recommended that the survey only be conducted when 5 satellites are able to be viewed. This allows one satellite to slip while maintaining the minimum required 4 locked. This is the toughest requirement to meet in this procedure. Equipment must be in excellent working order, especially cables connecting the antennae and receivers.

The survey starts in one of two ways. Either with an antenna swap or with both receivers occupying known points on a baseline.

ANTENNA SWAP

The base (master) antenna starts over a known point and the rover starts over a nearby point. This nearby point should be only a few paces away and does not need to be a permanently established point. Data files are started in both receivers with unique 4-character site names entered at screen 9 for both the base and unknown point. Data is collected for 2 minutes, four question marks are entered at screen 9 on both receivers, and the antennae are swapped so that the master receiver is on the unknown point and the rover receiver is over the known point. The site name of each point is now entered into the receiver and data is collected for 2 minutes. The site name for each point must remain constant throughout the survey. At the end of the 2 minute period, question marks are again entered for the site name at screen 9, and the antennae are returned to their original positions. The appropriate site names are entered again. The antennae should remain in place again for 2 minutes, and at least one more complete swap should occur. After the rover has occupied the unknown swap point for 2 minutes at the end of the second swap (the third time on the point), it is moved on to the other unknown points for two minutes each. After the final unknown point has been occupied, the rover returns to the unknown swap point and one final complete swap should be done. The survey ends with the master antenna back over the original known point and the rover over the unknown swap point. Whenever an antenna, master or rover, occupies a new point, the unique 4-character site name for that point must be entered at screen 9. Whenever an antenna is being moved, 4 question marks (????) must be entered at screen 9 for the site name. This is a flag for the software in the post-processing to ignore this part of the data file. Each receiver will have one data file with several site names associated with it.

BASELINE START

To initiate the kinematic survey using this technique, the exact position of two points must be known very accurately. The master receiver occupies a known point and the rover occupies the other known point. The master remains on its known point and the rover moves sequentially to the other unknown points throughout the survey for 2 minutes each. Site names and question marks are entered at screen 9 following the same procedure outlined above. After the final unknown point has been occupied, the rover is returned to its first known point location for 2 minutes of data collection. That ends the survey.

CYCLE SLIPS: As mentioned above, the survey requires a minimum of 4 satellites to be locked at all times. If you fall below 4 satellites, you must return to your last point occupied, collect data for 2 minutes again, and continue your survey. The continuous counter on screen 1 will show if you have had a cycle slip. When a cycle slip occurs on a particular satellite, the counter will reset to 0 and begin accumulating again. Once the counter reaches 99, it will go no higher and continue to show 99. You can also enter the minimum number of space vehicles to 4 on screen 9 and if you are locked on less than 4 satellite signals, the receiver will beep a warning at you.

ANTENNA HEIGHT: The antenna height over a point must remain constant for every occupation of that point. (i.e. during antenna swaps or reoccupation of a point because of cycle slip) This can be achieved by setting up tripods with tribrachs over each point to be occupied or using some type of adjustable vertical shaft with a pre-set height. With the vertical shaft, the antenna is mounted directly to the shaft and the complete system, with supporting tripod, is moved from point to point. The tripods are more stable and should be used whenever possible. The shaft apparatus can be found in locker #52 in the equipment room and should be worked with prior to going to the field the first time. It is a useful device, but requires practice to become proficient with.

ANTENNA MOVEMENT: At least 2 and preferably 3 people should be used to move the antenna and receiver from point to point. If the points are within walking distance, one person carries the antenna above his head and parallel to the ground, and one person carries the receiver and excess cable. The third person is used to help place the antenna on the next tripod. If the points are far apart, the antenna and receiver should be transported via open-bed truck. A tripod with tribrach are placed in the back of the truck with the legs of the tripod placed in a wooden triangle. The antenna is then carried to the truck and placed on the tribrach and the receiver is also carefully placed in the bed of the truck. One person then rides in the back of the truck to help stabilize the equipment. The truck is driven to the next point. The route between points should be checked prior to the survey to avoid overhead obstructions which would cause cycle slips. Operators should not stick their heads above the plane of the antenna. Heads will block satellite signals as well as tree limbs and leaves. Also, the operators must be especially careful with the cable connecting the antenna and receiver. Any yanking or sudden movement will almost certainly cause all satellites to slip. This has been the greatest single downfall of our attempts so far to perfect this technique. As mentioned above, the cables themselves must be in excellent condition prior to starting the survey also.

POST-PROCESSING PROCEDURES FOR KINEMATIC GPS SURVEYING:

The documentation in the reference is well-written and should be read prior to this paper. My attempt is to fill in the few vagaries that exist in the ASHTECH manual.

Begin post-processing by transferring the data from both receivers via the hose program as in all other processing. Continue with the usual sequence of COMNAV and MAKEUFIL. The next step is to run the program 'genlog'. This program creates 3 files which are used by subsequent programs. The files are:logtimes, markpos.asc, and filename.obs. At the dos prompt line, enter 'genlog'. You will be first prompted to enter a navigation file. Enter the navigation file for the master receiver. You will then be prompted to enter the names of 2 Bendata files. Enter the name of the master receiver Bendata file followed by the name of the rover receiver Bendata file. Genlog then creates the three files:

1. Logtimes: (example at encl 1) This is a listing of the stations visited, at what time, and for how long. You will not need to edit this file, but you need to print out a hard copy to refer to later in the processing.

2. Filename.obs. (encl 2.) This file should be a simple 2 line file listing the ufile for the master and rover receiver. For some reason, occasionally genlog creates the file showing one ufile and one bendata file or 2 bendata files. Edit the file using any editor to show the ufiles for the master and rover.

3. Markpos.asc. (encl. 3) This is a file listing the points occupied starting with the master station, followed by the second known station and the sites located with the rover. The columns are explained well in the ASHTECH documentation with 2

exceptions: The column labeled 'ANT' is where you should enter the vertical height of the antenna for each point. This is the straight vertical height, NOT the slant height. When genlog creates this file, all entries in this column will be X's. (XX.XXXX) Column 'K' is the rating of how well the point is known from 0 to 9. 0 being absolutely known and 9 as totally unknown. If you used the baseline procedure to start the survey, then enter a zero in column K for both known points (first two rows) followed by the known Lat., Long., and Ellipsoidal Height. An example of the baseline markpos.asc is at encl. 3. <u>KEY POINT:</u> The software is very sensitive to the location of the known points in the baseline procedure. If you have previously conducted a static survey between the two points you are calling the known points, you must enter the values for Lat., Long., and E Ht shown in the linecomp output from the static processing for both of these points in the markpos.asc file. If these values are not used, the software will determine cycle slips have occurred and your data will not process. When using an antenna swap to initiate the survey, leave a 9 in column K for the swap point. The software will determine a solution for its position and update the 9 to a 1 in the ANTSWAP program. You still need to enter a 0 in the K column and known Lat., Long., and Ellipsoidal Height for the known point. When genlog creates the markpos.asc file, it will compute initial estimates for all the unknown points. These are the values indicated in the original file. There is no need to adjust these values before continuing in the processing. The software will do that. Finally, before moving on, make sure you have copied the correctly edited versions of filename.obs and markpos.asc back into your working directory from which you plan to run the processing programs.

ANTSWAP

If you started the survey with an antenna swap, your next step is to execute the ANTSWAP program. If you started with a baseline procedure, you can go right to the KINSRVY program. Both programs utilize the files described above. Again, the following discussion is meant only to fill in the few holes in the ASHTECH documentation describing the user interface with the programs.

To execute the ANTSWAP program, simply type 'ANTSWAP' at the dos prompt line. The program will prompt you for several self explanatory entries, and then will ask you if you want to set the reference satellite? The reference satellite should be the satellite that was viewed during the entire survey and had the highest elevation. Enter 'n' for no and the software will select the reference satellite for you. Unless you have any particular reason not to allow the software to do this, such as known poor health of a satellite, enter 'n' . You will next be prompted for home and away legs of the master antenna. A home leg is when the master antenna is on the known point during a swap and an away leg is when the master is on the unknown swap point being determined. Refer to the legs by the interval numbers shown on the logtimes file. (This is why you need to get a hard copy of this file prior to this point.)

Enclosure 1 shows a logtimes file for a survey that started with an antenna swap. The known point site name is Soth and the unknown swap point is PT01. A "swap" consists of one complete rotation of the master antenna on the known point and the rover over the unknown point, to the master over the unknown and rover over the known point, back to the master over the known point and rover over the unknown point. At encl 1, one swap occurs from interval 1 to interval 8, one swap from interval 8 to interval 14, and a final swap from interval 20 to 24. So, as can be seen, 2 swaps were run at the start of the survey (the minimum recommended number) and one swap at the end of the survey. (again, the minimum recommended number) Column RO is the master antenna and column R1 is the rover. All home legs,(1,8,14,20,24), and all away legs, (4,11,22) can be entered as one swap, but it is recommended to enter the data as at least 2 separate swaps: combine the swaps at the beginning of the survey as one and the swap at the end of the survey as one. Occasionally, the software will give an error message that a swap is not accepted. (Possibly caused by undetected cycle slips) This most often occurs when you combine two or more swaps into one swap. If this is the case, enter the swaps as separate entries and omit whichever swap the software will not accept. You only need one good swap to find the solution for the unknown swap point. When you enter two or more successful swaps, the software will compute separate solutions for each swap and display these solutions. You will be prompted if you want to disregard any solutions. The software will compute an average solution from the remaining solutions you do not disregard. Unless you have a special reason to disregard a solution, leave them all in.

The final result of the ANTSWAP program is a file called markpos.out that is nothing more than an updated markpos.asc file with a 1 in column K for the unknown swap point and improved Lat., Long., and Ht values. All the other unknown points will remain unchanged. See enclosure 4. You will be prompted whether or not to transfer Markpos.out to Markpos.asc. Answer 'Y' for yes. The next program, KINSRVY, utilizes the values in Markpos.asc and you want to ensure the updated values are placed in that file.

KINSRVY

The KINSRVY program is called by typing 'KINSRVY' at the dos prompt line. Two additional points of explanation are needed to round out the ASHTECH documentation:

1. When prompted to enter the start interval, refer to your logtimes printout. The start interval is the last interval of the last swap at the beginning of the survey where the master receiver is on the known point and the rover receiver is on the unknown swap point. The rover destination interval is the last interval listed on the logtimes file. You can also enter the interval where the last unknown point was occupied by the rover if you returned to do a swap at the end of the survey. At encl.

1, the start interval is 14 and interval 20 or 24 could be entered as the rover destination interval.

2. After you answer the prompt for setting the reference satellite, the screen will display several rows of large numbers in columns. It will then prompt you for 'The top how many are consistent?' The large numbers are the integer counts of the number of complete cycles counted between the satellite and antenna. The numbers are "consistent" if you can move downwards from row to row and round each number in each column to the same integer. When there is a change from one row to the next in the rounded integer, this represents a cycle slip and is "inconsistent". Therefor, the number of consistent solutions is the number of rows, from the top, before the row with the cycle slip. Also, if there are less than 3 columns, you were locked on less than 4 satellites and that row would be considered inconsistent. To check the number of consistent rows, be prepared to quickly hit the pause key because the numbers scroll by too fast to check. After entering the number of consistent rows, you'll be prompted to either append or start a new rover.trj file. This is a file that shows individual epoch solutions. For the first time run of the program start a new file. For subsequent runs, append the file. After you enter your answer to this prompt, the program will begin execution. Solutions for each epoch will scroll on the screen. If a cycle slip occurred on a particular satellite, the word 'slip' will appear at the appropriate epoch. As long as there are 3 good satellites showing for that epoch, you are OK. This means you

still had 4 good satellite counting the reference satellite. If you had less than 4 satellites, the program stops processing solutions at the point of the slip.

The output of the KINSRVY is an updated markpos.asc file called markpos.out. If the processing was successful, all unknown points will have a '2' in column K and upgraded solutions in the remaining columns. Enclosure 5 shows a final updated markpos.out file created by the KINSRVY program for a kinematic survey initiated with a baseline procedure at the East end of Project Mustang. Note the two zeroes in column K for the two known points, and the update for all unknown points indicated by 2's in column K.

Enclosure 6 shows a flow-chart for post processing.

TROUBLE SHOOTING

Many headaches in post-processing can be avoided by watching your satellite count in the field. If you drop below 4 satellites on lock, you simply have to return to the previous point where you had 4 good locked signals. Even if you think you may have lost lock on 4 satellites, take the time to revisit the last station in the field. The data simply will not process without 4 good satellite signals. If you see the word 'slip' for your satellites during the KINSRVY processing, there is no way to fix the problem. If you see "Cycle slip during start interval" displayed at the beginning of the KINSRVY processing, you need to check the locations of your known points. I've only seen this message while processing surveys beginning with the baseline method. You must be using the values for the known points that were provided on a static mode linecomp output. Always make sure you are inputting the most current updated filename.obs and markpos.asc files. Occasionally, in the confusion of editing and copying, you might forget to copy a newly edited file back into your working directory.

Enclosures:

1. Logtimes file
2. Filename.obs file
3. Markpos.asc file for baseline start
4. Markpos.out file from ANTSWAP program
5. Markpos.out file from KINSRVY program (from baseline survey)
6. Flowchart for post-processing

INT#	MJD	TSTART	TEND	R0	R1	R2	R3	R4	R5	R6	R7	R8	R9
0	48032	23:55:20	23:58:40	????	PT01	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
1	48032	23:58:40	00:11:00	SOTH	PT01	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
2	48033	00:11:00	00:13:20	????	????	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
3	48033	00:13:20	00:13:40	PT01	????	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
4	48033	00:13:40	00:17:00	PT01	SOTH	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
5	48033	00:17:00	00:17:20	????	SOTH	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
6	48033	00:17:20	00:19:00	????	????	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
7	48033	00:19:00	00:19:20	????	PT01	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
8	48033	00:19:20	00:21:40	SOTH	PT01	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
9	48033	00:21:40	00:24:20	SOTH	????	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
10	48033	00:24:20	00:26:00	????	????	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
11	48033	00:26:00	00:29:00	PT01	SOTH	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
12	48033	00:29:00	00:30:40	????	????	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
13	48033	00:30:40	00:31:00	????	PT01	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
14	48033	00:31:00	00:34:20	SOTH	PT01	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
15	48033	00:34:20	00:38:40	SOTH	????	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
16	48033	00:38:40	00:42:00	SOTH	PT02	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
17	48033	00:42:00	00:43:40	SOTH	????	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
18	48033	00:43:40	00:52:20	SOTH	PT03	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
19	48033	00:52:20	00:53:40	SOTH	????	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
20	48033	00:53:40	01:01:00	SOTH	PT01	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
21	48033	01:01:00	01:02:40	????	????	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
22	48033	01:02:40	01:07:00	PT01	SOTH	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
23	48033	01:07:00	01:08:40	????	????	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
24	48033	01:08:40	01:12:40	SOTH	PT01	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
25	48033	01:12:40	01:13:00	SOTH	????	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
-1	99999	99:99:99	99:99:99										

Umast521.dat
urov521.dat

NMBR	NAME	K	ANT	NORTH LAT	EAST LONG	E_HT
0000	TOWN	0	0.013	42 1 45.90276	266 20 50.86401	300.793
0001	NEPT	0	1.527	42 0 35.31759	266 42 0.89011	306.036
0002	MIDE	9	1.620	42 0 27.63068	266 41 53.47366	290.000
0 [illegible] 3	SEPT	9	1.523	42 0 18.49602	266 42 1.60018	290.000

NMBR	NAME	K	ANT	NORTH LAT	EAST LONG	E_HT
0000	SOTH	0	1.393	42 1 46.38631	266 20 46.27300	265.295
0001	PT01	1	1.377	42 1 46.78212	266 20 46.27464	265.241
0002	PT02	9	1.441	42 1 46.91310	266 20 46.21864	261.430
C 3	PT03	9	1.343	42 1 48.00515	266 20 44.64155	256.905

NMBR	NAME	K	ANT	NORTH LAT	EAST LONG	E_HT
0000	TOWN	0	0.013	42 1 45.90276	266 20 50.86401	300.793
0001	NEPT	0	1.527	42 0 35.31759	266 42 0.89011	306.036
0002	MIDE	2	1.620	42 0 27.73020	266 41 53.44198	305.090
0003	SEPT	2	1.523	42 0 19.00752	266 42 1.29240	301.534

KINEMATIC POST-PROCESSING SEQUENCE