NOAA Technical Memorandum NOS NGS-12

TRAV10 HORIZONTAL NETWORK ADJUSTMENT PROGRAM

Rockville, Md.
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NOAA geodetic publications

Classification, Standards of Accuracy, and General Specifications of Geodetic Control Surveys. Federal Geodetic Control Committee, John O. Phillips (Chairman), Department of Commerce, NOAA, NOS, 1974, reprinted 1975, 1976, 12 p. (PB265442). National specifications and tables show the closures required and tolerances permitted for first-, second-, and third-order geodetic control surveys.

Specifications to Support Classification, Standards of Accuracy, and General Specifications of Geodetic Control Surveys. Federal Geodetic Control Committee, John O. Phillips (Chairman), Department of Commerce, NOAA, NOS, 1975, reprinted 1976, 30 p. (PB261037). This publication provides the rationale behind the original publications, "Classification, Standards of Accuracy, ...".

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Charles R. Schwarz

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UNITED STATES DEPARTMENT OF COMMERCE
Juanita M. Kreps, Secretary

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
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National Ocean Survey
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PREFACE

The TRAV10 program is the result of contributions from many individuals within the National Geodetic Survey (NGS). John G. Gergen laid out the groundwork by designing and coding the first eight programs in the TRAV series. TRAV10 uses many of his routines without change. Robert H. Hanson programmed the HERESI routine for solving the normal equations. The storage structure used in this routine dictates the logic for the rest of the program. David E. Alger wrote the preprocessor and Anna-Mary B. Miller wrote the postprocessor. Richard A. Snay contributed the algorithm and program for the reordering of the unknowns. Primary credit for the program belongs to John F. Isner, who acted as lead programmer and analyst, wrote the main processor, and integrated all the parts. This memorandum was prepared by Charles R. Schwarz, who also converted the program from the CDC 6600 computer to an IBM 360 version.

TRAV10 HORIZONTAL NETWORK ADJUSTMENT PROGRAM

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ABSTRACT. The TRAV10 adjustment program is the major tool for the adjustment of horizontal survey networks at the National Geodetic Survey. It performs a two-dimensional adjustment on the ellipsoid. Many features are similar to those of other programs used by other agencies. The handling of the normal equations, especially for large networks, is the most important design criterion. The TRAV10 program uses the Cholesky solution method with a variable band storage scheme. The normal equations are partitioned into variable sized blocks, stored on random access secondary storage, and paged into main memory as needed. A reordering of the unknowns is used to reduce both the required storage and the number of arithmetic operations.

1. INTRODUCTION

The TRAV10 adjustment program is the major tool for the adjustment of horizontal survey networks at the National Geodetic Survey. It has been implemented both on the NOAA CDC 6600 running under SCOPE 3.3, and on the NOAA IBM 360/195, running under OS/MVT. With only very minor exceptions, the two implemented versions of the program are identical.

TRAV10 has grown out of an evolving series of computer programs used at NGS to adjust horizontal survey networks since 1972. Each version has been named after the first major application--the adjustment of the transcontinental traverse of the United States.

The TRAV programs are similar in that they all use observation equations, perform a least-squares adjustment, and iterate the solution to convergence. In purpose they are similar to the GALS program of the Geodetic Survey of Canada, the HAVOC program of the Geodetic Survey Squadron of the U.S. Defense

Mapping Agency, and others. These are all single-pass horizontal adjustment programs, designed to accomplish a complete adjustment from the editing of input observations to the computation of residuals and statistics.

The NGS TRAV programs have differed from each other primarily in the methods they use to form and solve the normal equations. TRAV05, the first version to be put into large-scale operation, used a banded matrix structure completely contained in core memory. It was implemented in three versions, the only difference being the size of the network that could be solved. The controlling factor was generally the amount of central memory allocated to the storage of the normal equations. The small version was configured so that its use of central memory allowed it to run at the highest priority used by the computer center in normal operations. The medium and large versions were configured to use more memory, solve large networks, and run at correspondingly lower priorities.

TRAV06, the second operational program, was used for about one year. It was designed around a variable band storage structure for the normal equations, which were completely contained in central memory. TRAV08 was a larger version of TRAV06.

TRAV07 was a first attempt at partitioning the normal equations and storing the partitions on secondary storage. The partitioning was such that each row of the normal equations was a separate block. Although this scheme allowed the adjustment of much larger networks in a limited area of central memory, the program incurred abnormally high input/output charges and often ran in an I/O bound mode on NOAA's CDC 6600. It was never made operational.

All TRAV programs through TRAV08 were almost independent of the number of observations. Although there were a few fixed size arrays used to index the observations, the number of observations in a network was seldom the limiting factor. The controlling consideration was the limited number of unknowns for which the program could solve.

The operational programs TRAV05, TRAV06, and TRAV08 could handle the majority of projects processed by NGS. However, the few very large projects that exceeded the limitations, and the need for operational efficiency, necessitated a new TRAV program.

2. DESIGN CRITERIA

2.1 Limitations

The first and most important design criterion for TRAV10 was that the program should not place limits on the number of stations or observations that could be processed, or on the size of the normal equation matrix. Specifically, a partitioning scheme was needed to avoid limitations of in-core solutions experienced in TRAV05, TRAV06, and TRAV08. At the same time, the partitioning scheme had to be more efficient than the experimental TRAV07.

It was recognized that the computer on which the program runs will eventually place a hardware limit on the size of the network that can be handled. There could always be a network so large that all the disk storage space on the machine would not be sufficient to hold the normal equation partitions. Similarly, there could be so many stations or partitions that even the necessary indices would not fit in the central memory. Thus the objective was that even though the hardware resources placed a limitation, the program itself should not. TRAV10, therefore, has no fixed size in terms of observations, stations, normal equation elements, or partitions. If hardware resources are increased, the size of the network that can be adjusted will increase correspondingly and without limit.

The limitations imposed by finite hardware resources are at least an order of magnitude larger than those which would apply to in-core solution schemes. The hardware limitations are almost never the operative consideration because other factors are of primary consideration.

The first consideration is that the facility operation procedures practiced by the computer center usually define the largest region available under multiprogramming operations. The size of this region is usually smaller than the total multiprogramming area. Of course, it is possible to run in a single thread mode using the whole multiprogramming area, and even to enlarge the multiprogramming area by reconfiguring the operating system. However, this would require that special arrangements be made with the computer center, that the run be made only after all other work of the computer center is completed, and that the special arrangements are valid only on a "one-time" basis. Such special arrangements are seldom worth the effort if the problem can be solved otherwise.

A second consideration concerns human engineering: there is a point at which the output of an adjustment is both physically and conceptually too big to be handled by a human being. When this point is passed, people tend to become cavalier in their analysis of the output, rejecting observations without proper consideration and failing to notice important weaknesses in the network to be adjusted.

A third consideration is the risk that an entire run could be lost if the computer system fails near completion of a run. In general, the longest time a program should ever run without checkpoint safeguards is about 10-20 minutes CPU (about one hour wall clock) time.

All of these considerations point to the same practical limit: about 1,000-2,000 stations. This range was selected as the design objective for TRAV10.

To handle even larger networks, NGS has also been developing a series of programs using the Helmert block technique to partition the normal equation system. This partitioning technique affords a natural checkpoint/restart system. The original concept was that the Helmert block scheme would be used only for adjustments that exceeded the 1,000-2,000 station practical limit of TRAV10, and that the size of each Helmert block would be about the same as the largest network handled by TRAV10. Recently it has been suggested that the Helmert block scheme may be used advantageously for networks as small as several hundred stations.

2.2 Specification of Parameters

The user should be required to specify as few parameters as possible to the program. For instance, the program should relieve the user of the responsibility for counting the number of stations and the number of observations. Redundant specification of parameters should be avoided. In TRAV10, this criterion is met by requiring the user to specify only a single parameter in the control cards: the size of the region in which the program is to run. (This is done with the REGION parameter on the IBM 360 and the Request Field Length (RFL) statement on the CDC 6600.) The program reads the input and decides how best to use the available core area. The core area is normally divided among the various arrays in the program in such a way that no core space is wasted. Since FORTRAN programs are normally fixed in size, special assembly language interfaces have been used in both the CDC 6600 and the IBM 360 versions to enable the program to access all the central memory in the region in which it runs. In the 6600 version, unused core (should there be any) is returned to the operating system. In the IBM 360 version, the user also preallocates secondary (disk) storage space by estimating the number of stations, observations, and normal equation elements. These estimates may be very approximate and have no effect on the program's execution priority.

2.3 Efficiency

The program should be efficient for small and large networks. It should be possible to run small problems with smaller amounts of computer resources. For NGS, as well as for most program users, the efficiency of a program can only be judged with reference to the scheduling algorithm implemented by the computer center. Fewer resource demands by the program means higher priority processing, faster turnaround, more throughput, and higher productivity. TRAV10 achieves this kind of efficiency by attempting to use all the core space available to it and by avoiding time-consuming algorithms that are applicable to only large networks. For a given network, TRAV10 allows a trade-off to be made between core size and time. To run the program in a small core size, the user pays in terms of the time spent to partition the normal equations and to transfer the partitions to and from secondary storage. The user is advised to make this trade-off so as to place his/her run in a job class of as high priority as possible. Exactly how this is done depends on the scheduling algorithm of the computer center.

2.4 Transparency

Details of the data and file structures used by the program and techniques used to handle the normal equations should be transparent to the user. In TRAV10, the user is largely unaware of the reordering and partitioning of the unknowns. The program takes care of these matters automatically so that the user is left free to concentrate on the geodetic aspects of the problem.

2.5 Abnormal Terminations

Data errors should not cause the program to terminate abnormally without producing a message to the user in geodetic terms. For TRAV10, this is accomplished by a program that performs a complete edit of the input data before numerical processing begins.

2.6 Program Modularity

The program should be modular so that functions can be clearly separated and modifications easily made. For this reason, TRAV10 is actually a process or sequence of programs rather than a single program. It consists of a choice of two preprocessors, a main processor (also called TRAV10), and a postprocessor. In the IBM 360 version, the main processor and postprocessor are combined into a single program.

All editing of the input data is performed by a preprocessor. This allows for a thorough editing of all data fields. Serious data errors can be trapped at an early stage. When fatal errors are found, all numerical processing is suppressed, although the edit process is carried to conclusion.

The main processor incorporates all the numerical functions concerned with the observation and normal equations. It is the only processor that is cognizant of the method used to partition, store, and solve the normal equations.

The postprocessor reports the residuals, computes their statistics, produces other information to be used in analyzing the results, and writes a file of card images with the adjusted geodetic coordinates.

2.7. User's Options

The program should be designed as a production tool for processing large amounts of data in a stable environment. As such a tool, NGS management uses TRAV10 to specify how computations will be performed. Practices that are considered the prerogatives of management are compiled into the program and cannot be changed by the individual user. Such practices include the editing checks applied by the preprocessor, the default weighting scheme, the numerical values of datum parameters, and the methods used to reorder the unknowns and control the number of iterations. The user is given some options, but most of these are used for controlling printed output and preparing the specification of output reports. In no case can the user's options affect the adjustment model or the numerical results of the adjustment.

3. HANDLING OF NORMAL EQUATIONS

The most important consideration in a geodetic least-squares adjustment program is the set of algorithms used to accumulate, store, and solve the normal equations. These algorithms often dictate the logic and structure of the other parts of the program. They determine the program limitations in terms of the number of observations or parameters, and usually whether it is efficient enough to be used for large problems or in a production environment. Designing a good least-squares adjustment program requires some knowledge of the problem to be solved; general purpose programs designed to handle any or all least-squares adjustment problems are not desirable. A distinguishing feature of many adjustment problems in geodesy is that the normal equations are sparse (i.e., there are many more zero than nonzero elements), and algorithms are often designed to take advantage of the a priori knowledge of the location of the zero elements. Normal equation systems arising in horizontal adjustments are sparse, since an off-diagonal element is nonzero only if the two stations to which it corresponds are related by an observation. Furthermore, the percentage of nonzero elements decreases as the size of the network increases.

In TRAV10, the normal equations are solved by subroutine HERESI, which is based on a routine described by Poder and Tscherning (1973).

3.1 Solution Algorithm

HERESI implements the Cholesky algorithm (Schmid 1973). The normal equations are decomposed into the product of an upper triangular matrix and its transpose in the form

$$N = C^T C.$$

The first stage, the triangular factorization or forward solution process, transforms the normal equation system

$$NX = U$$

into the system

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

The back solution process solves the triangular system for the solution vector

$$X = C^{-1}\left(C^T\right)^{-1}U.$$

The algorithm can also be easily extended to yield an inverse of the original matrix, although this is not used in TRAV10.

The basic equations for the forward solution are

$$c_{ij} = \begin{cases} (n_{ij} - \sum_{k=1}^{i-1} c_{ki}\, c_{kj})/c_{ii}, & i < j \\ (n_{ij} - \sum_{k=1}^{i-1} c_{ki}\, c_{kj})^{\frac{1}{2}}, & i=j \\ 0, & i > j \end{cases} \qquad (1)$$

Examination of these equations discloses the following properties used by HERESI:

1. Once n_{ij} is used to develop c_{ij}, it is no longer needed. Thus the matrix C can be developed in the space occupied by matrix N. Since there is no need to store the lower part of C, only the upper triangular part of the symmetric matrix N is stored.

2. The triangular matrix C can be developed either row by row or column by column. The HERESI algorithm develops one column at a time, from the first element in the column to the diagonal element.

3. The solution vector can be developed in the same space occupied by the right-hand side of the original equations. Thus the storage requirements are determined only by the size of the original equations; no new storage locations are needed for the solution processes.

3.2 Variable Bandwidth

Further examination of eq. (1) shows that if element n_{mj} is the highest nonzero element in column j of N, then c_{mj} is the highest nonzero element in column j of C. No new nonzero elements are generated above position m in column j.

The column profile of a matrix is a graphical display of the position of the highest nonzero element in each column. Figure 1 shows the profile of the upper triangular part of a typical normal equation matrix. The bandwidth of an individual column is the distance of the highest nonzero element from the diagonal. The matrix bandwidth is the largest of the individual column bandwidths. The number of elements within the matrix profile (also called the profile) is obviously the sum of the individual bandwidths.

For many algorithms designed to be operated on banded matrices, the critical measure is the bandwidth. The algorithm in HERESI considers the bandwidth of each column separately. Only elements within the variable band (or profile) are stored, accumulated, and operated upon. Elements outside the profile are known to be zero, and no nonzero elements are generated outside the profile during the Cholesky decomposition. The critical measure, determining the number of locations required for storage and the number of arithmetic operations required for decomposition, is the profile. The processing of each column starts with the first nonzero element, since all those above it remain zero.

The variable bandwidth scheme of matrix storage obviously requires an additional index giving the individual bandwidth of each column. This extra effort is worth the potentially large saving of storage.

3.3 The Parititioning Scheme

In TRAV10 the normal equation matrix is divided into partitions or blocks. Each partition consists of some number of pairs of columns of the normal equation matrix. Pairs are used so that the columns corresponding to the latitute and longitude unknowns of a given station are always in the same block. The right-hand side of the normal equations is always a block by itself. Each partition, together with its column index, is stored as a record on random access secondary storage (usually disk) and brought into main memory as needed.

The size of the individual partitions depends on the amount of real memory workspace available to the program. The workspace is divided into two frames. The program automatically partitions the matrix by putting as many pairs of columns into a block as

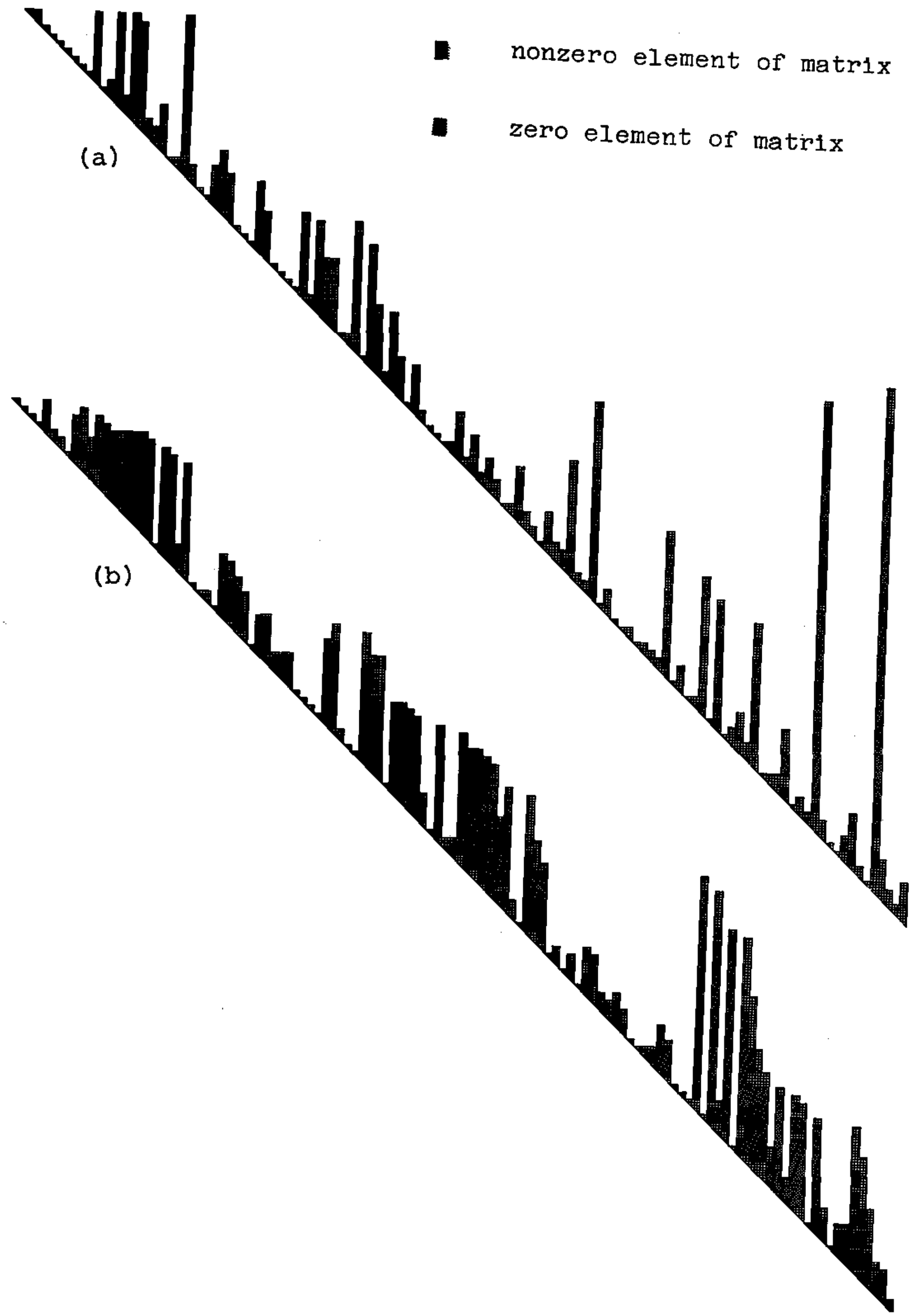


Figure 1.--Typical matrix profile structures showing the ordering of unknowns by (a) a profile minimization scheme and (b) a bandwidth minimization scheme.

it can without exceeding the size of a frame. The minimum frame size with which the program can work is 4n + 3 locations, where n is the number of stations. This minimum guarantees that the right-hand side vector (used in computing accuracies) can be held in a frame.

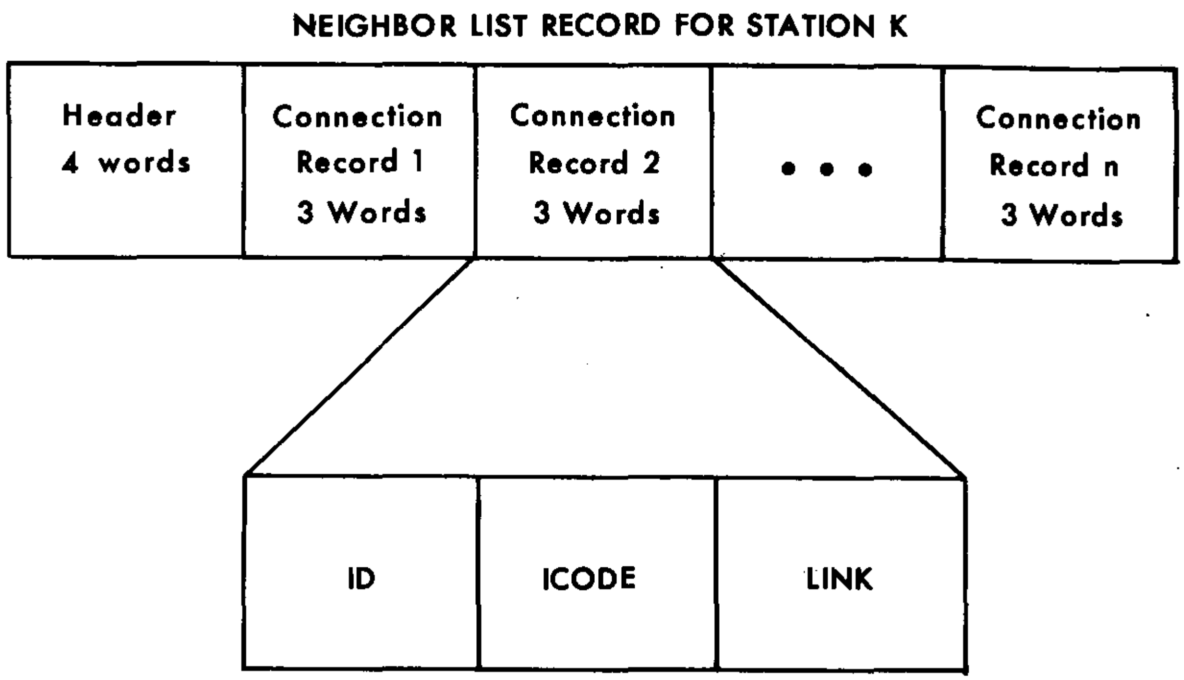
3.4 Reordering of Unknowns

The computational and storage savings to be gained from the variable bandwidth approach depend on the size of the matrix profile. In TRAV10, the unknowns are reordered in such a way as to reduce the profile of the matrix, using the algorithm described by Richard Snay (1976). In practice, the profile of the normal equation matrix requires significantly less storage than a fixed size band, and far less than the upper triangle. For networks comprised of between 30 to 100 stations, the profile is almost always less than 15% of the elements of the upper triangle. For larger networks, the savings are even more dramatic, since the profile tends to grow only linearly with the number of stations.

The reordering algorithm operates on a machine representation of the network graph. In TRAV10 this graph is represented by a neighbor list for each station. Each neighbor list consists of a variable length sequence of connection records, each of which both identifies the connected station and also indicates the type of observations causing the connection (fig. 2). Since the neighbor lists must be accessed randomly by the reorder routines, they are stored (one physical record per station) on direct access secondary storage and brought into main memory as needed by various routines. Connection records are formed only for observations that are valid in the adjustment. Those formed by observations that will be deleted (i.e., single direction lists) are ignored. When the neighbor lists are formed, all connection records for a given pair of stations are merged together. Connections arising from the elimination of orientation unknowns are also represented, so that the merged neighbor lists provide a representation of the internal structure of the normal equations.

3.5 Formation of Normal Equations

The normal equations are accumulated by considering the observation equations one at a time. Rounds of directions (abstracts) are considered as single entities; otherwise, the ordering of the observation equations is immaterial.



ID station number. A connection of some sort exists between station K and station ID.

ICODE bit flags indicating type of connection

rightmost bit - a direction from K to ID
next bit to left - a direction from ID to K
next bit to left - an azimuth between K and ID
next bit to left - a distance between K and ID
next bit to left - latitude constraint (ID=K)
next bit to left - longitude constraint (ID=K)
NOTE: no bit flags set indicates that the connection arises indirectly from z elimination.

LINK pointer to next connection record in the list. The pointers allow the list to be accessed by ascending order of station number rather than by sequential location. The beginning-of-list pointer is the fourth word of the header.

Figure 2.--Structure of connection records and neighbor list.

3.5.1 Elimination of Orientation Unknowns

The orientation unknowns (z's), which arise from each round of directions, are eliminated by the method attributed to Schreiber (Jordan-Eggert 1935, sections 100 and 110). The relationship of this scheme to elimination by matrix partitioning is discussed in section 4. It affords an easy, automatic way of eliminating the orientation unknowns at the earliest opportunity.

Because of the elimination of z's, only the latitudes and longitudes are left as unknown parameters. The size of the normal equations is reduced, but the meaning of "connection" is changed. Two stations are now connected (i.e., there are nonzero elements in the corresponding rows and columns of the normal equations) whenever there is a direct observation between the two stations, or a third station observes both of them in a single round of directions.

3.5.2 Accumulation of Partial Normal Equations

The criterion governing the design of the normal equation partitioning scheme is that two partition frames fit the program's real memory workspace. This is a requirement of the Cholesky factorization routine HERESI.

During the accumulation of partial normal equations, one half of the available memory serves as a frame for transient partitions while the other half is used as a staging area for partial normal equation terms computed when the appropriate partition is not available.

The staging area must be structured such that each partial normal equation term is tagged with its destination. A further requirement is that terms destined for the same location must be ordered on a first-in, first-out basis.

To satisfy the above requirements, the staging area is allocated among as many queues as there are partitions. All space initially "belongs" to an availability list, and all queues are empty. Figure 3 shows this condition for a 3-partition system.

Each list element is large enough to hold the coefficient value, a row and column number, and a pointer to the next element (indicated by an arrow in the figure).

Suppose that partition two currently occupies the paging area. All terms which belong in partition two will be immediately accumulated as they arise. Those belonging to any of the other partitions will be saved in the staging area, linked to the queue corresponding to the partition to which they belong. Figure 4 illustrates the situation after several "normalizations."

If the partition experiencing the greatest "demand" is in the paging area, data movement is minimized and the efficiency of normal equations formation is improved. This is insured if the observations are sorted into the order of elimination of the "from" station, since stations connected by observations are generally close in order of elimination (banding effect). Sorting was judged uneconomical for networks containing more than a few hundred observations, because the sorting expense becomes greater than the cost of doing the solution itself.

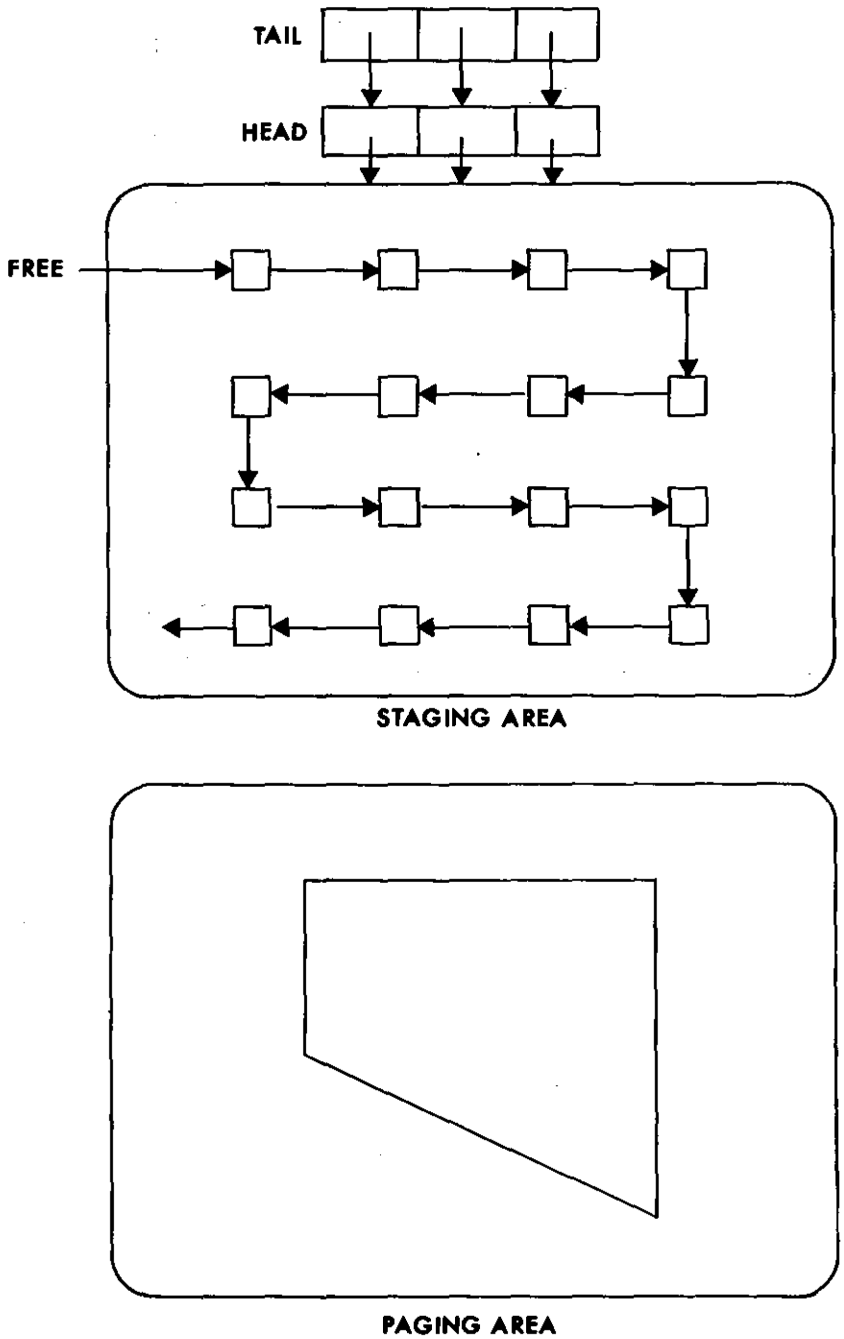


Figure 3.--Allocation of memory for normal equation accumulation before processing.

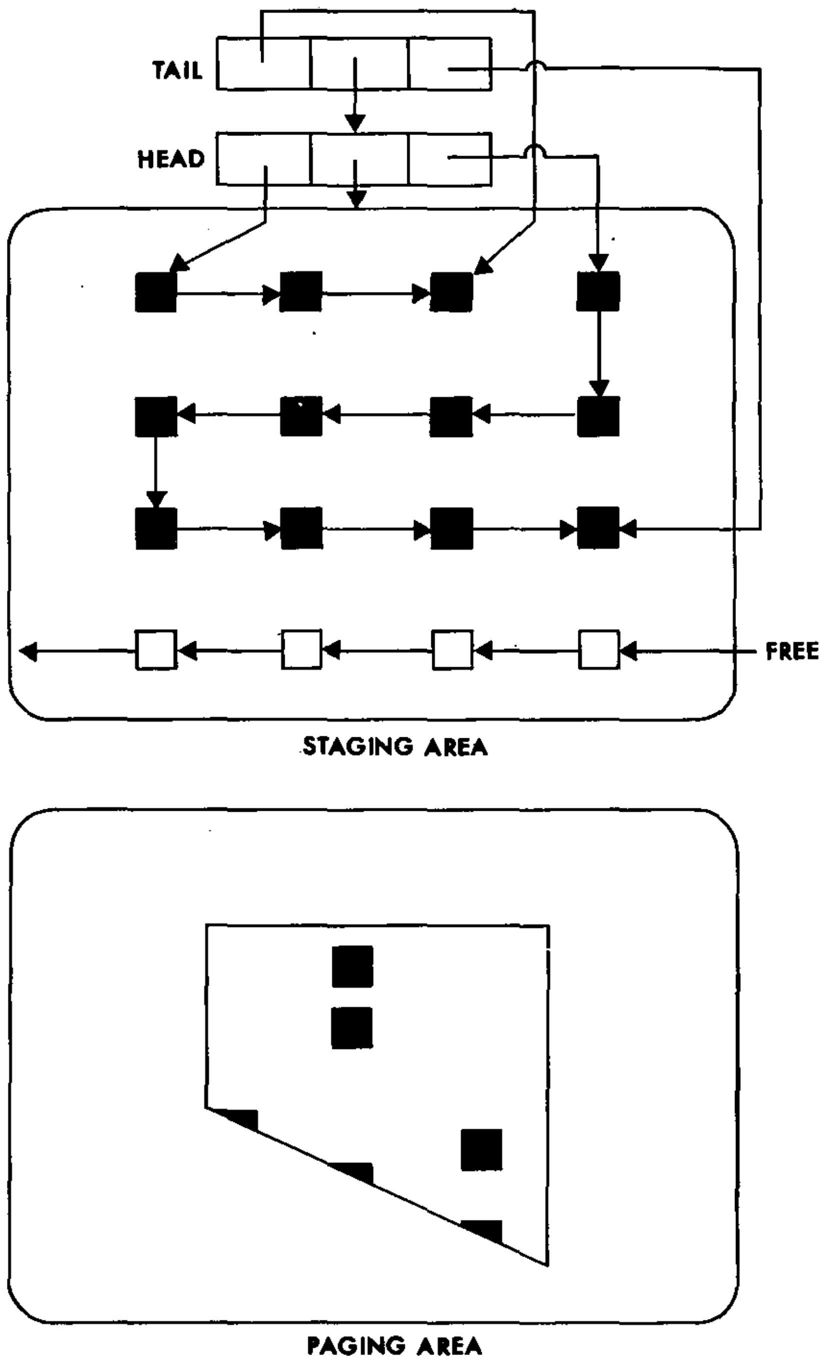


Figure 4.--Allocation of memory for normal equation accumulation after processing.

Localization of demand is observed even when sorting is not performed. This phenomenon is attributed to rounds of directions, which are entered as input in an unbroken sequence of direction observations. Localization is enhanced by the concatenation of rounds observed from the same station.

Over any small time interval, localization of demand has the net result that either the partition in the paging area is experiencing heavy demand, or one of the queues in the staging area is lengthening rapidly.

The process described above may be interrupted in two possible ways:

a. The observations are depleted.

b. The staging area runs out of free space (all space being taken up by the collection of queues).

In the first case, each partition for which there is a non-empty queue element in the staging area must be recalled to the paging area so that the contents of the respective queue may be "flushed" into the partition. This operation consists of adding each queued partial normal equation term into the proper location in the normal equations.

The second case is referred to as an "overflow." Overflows require immediate remedial action before any processing can continue. The partition currently in the paging area is rewritten on the disk, and the partition corresponding to the longest queue is fetched in its place. The longest queue is then flushed into the new partition and the liberated queue elements are returned to the availability list. The process is then allowed to resume at the point where the overflow condition occurred.

When the system of equations fits into a single partition, the staging area is unused, since all partial coefficients accumulate in their final places. In this case, no wasted movement of data into and out of the staging area occurs, and no input/output of the partition is required. Data movement and input/output will both increase as the number of partitions increases. For a given network, the number of partitions depends on the available memory space, which is determined by the user's field length or REGION parameter. This allows the user to make the trade-off between time, input/output, and core, in order to maximize the job priority under a given scheduling algorithm.

4. MATHEMATICAL SPECIFICATIONS

4.1 Notation

The following notations and adopted values are used in this section:

a	=	equatorial radius	
f	=	flattening	
c	=	$a/(1-f)$	
e'^2	=	$f(2-f)/(1-f)^2$	second eccentricity
ρ	=	$180*3600/\pi$	206264.8062471
M_i	=	$c/(1+e'^2\cos^2\phi_i)^{3/2}$	radius of curvature in the meridian at point i
N_i	=	$c/(1+e'^2\cos^2\phi_i)^{1/2}$	radius of curvature in prime vertical at point i
α_{ij}	=	geodetic azimuth from i to j	
R_{ij}	=	$\dfrac{M_i N_i}{N_i\cos^2\alpha_{ij} + M_i\sin^2\alpha_{ij}}$	radius of curvature in azimuth α_{ij}
s or s_{ij}	=	geodetic distance from i to j	
ϕ, λ	=	geodetic latitude and longitude	

Φ, Λ = astronomic latitude and longitude

ξ = $\Phi - \phi$ component of the deflection of the vertical in the meridian

η = $(\Lambda - \lambda) \cos\phi$ component of the deflection in the prime vertical

R = 6,371 kilometers mean earth radius

N_i = geoid height at point i (distinguished by radius of curvature in prime vertical by context)

H = orthometric height

D = observed distance

k = a factor used to determine the algebraic sign of certain quantities. k=+1 is used for the North American Datum, with longitude measured positive west and azimuth measured clockwise from South. k=-1 is used with other datums, with longitude measured positive to the east and azimuths measured clockwise from North

4.2 Observations and Reductions

TRAV10 accepts direction, azimuth, and distance observations, as well as position (latitude, longitude) constraints. Most observation types are interpreted as being performed by an instrument at a point on the Earth's surface, leveled in the real gravity field, to another point on the Earth's surface. For the purposes of computation, these observations are reduced to the corresponding inferred observations on the ellipsoid. Tables 1, 2, and 3 indicate which corrections are applied. In general, they are applied prior to adjustment and not changed. An exception is the Laplace correction to astronomic azimuths, which is updated after each iteration to take into account the most recent estimate of the geodetic longitude.

Table 1.--Direction observations

Code	Definition	Weight factor[1]	Corrections Geodesic[2]	Skew normal[3]	Deflection[4]
1	First-order	0.6	X	X	X
2	Second-order	0.7	X	X	X
3	Third-order	1.2	X	X	X
4	Fourth-order	3.0	X	X	X
R	Direction to reference mark	3.0	X	X	X
Z	Direction to azimuth mark	3.0	X	X	X

[1] The default standard error of a direction observation is computed from the formula

$$\sigma^2 = S_D^2 + 2*(\rho*0.001/D)^2,$$

where D is the approximate distance between the points and S_D is the weight factor from the table. The second term in the formula accounts for a mis-centering error of 1 mm of both theodolite and target.

[2] All directions receive the geodesic correction.

[3] Directions to stations with an orthometric height receive the skew normal correction. If the geoid height is missing, the orthometric height is used as an approximate height above the ellipsoid.

[4] Directions from the stations with both astronomic coordinates and both orthometric and geoid height, to stations with both orthometric and geoid height, receive the deflection correction.

Table 2.--Azimuth observations

Code	Definition	Default std.error[1]	Corrections Geodesic	Laplace	Deflection[2]
A	First-order astro(NGS)	(1)	X	X	X
B	Lower-order astro	2"0	X	X	X
J	Geodetic azimuth	2"0			

[1] The default standard error of a first-order astronomic azimuth is computed from

$$\sigma^2 = (.45)^2 + (.80)^2 + (\tan\phi/.80)^2 + (.40*\sin\phi)^2 ,$$

where ϕ is the latitude.

[2] The deflection correction is applied only if the occupied station has both orthometric and geoid heights given.

Table 3.--Distance observations

Code	Definition	Weight factor[1] S_1	S_2	Corrections: Sea level[2]	Arc	Geoid height[3]	2nd velocity
C	Electro-optical infrared	15mm	1.0ppm			X	
G	Electro-optical infrared	15	1.0			X	X
X	Electro-optical mark to mark	15	1.0	X	X		
F	Reference marks, feet	10	0.5			X	
M	Reference marks, meters	10	0.5			X	
T	Taped, sea level	10	0.5			X	
U	Taped, mark to mark	10	0.5	X	X		
E	Microwave, sea level	30	3.0			X	
Y	Microwave, mark to mark	30	3.0	X	X		

[1] The standard error of a distance observation is computed from the weight factors by the formula

$$\sigma^2 = S_1^2 + (DS_2)^2 + (0.00005(h_2 - h_1)/3)^2 ,$$

where D is the distance and h_1 , h_2 are the heights.

[2] Mark to mark distances must have both orthometric and geoid heights at both ends of the line; otherwise, they are rejected.

[3] Geoid height corrections are made only if geoid heights are available for both ends of the line.

The corrections to directions and azimuths are taken from Bomford (1971, pp. 121-122). As applied in TRAV10, these are:

a. Geodesic correction

$$-\frac{\rho}{12}\ \frac{e'^2 s^2}{N^2} \cos^2 \phi \ \sin 2\alpha$$

b. Skew normal correction

$$\frac{\rho\, h_2}{2N}\, e'^2 \quad \cos^2 \phi \ \sin 2\alpha$$

c. Deflection correction

$$\rho(\xi \sin\alpha + \eta \cos\alpha)\ \frac{h_2 - h_1}{D}$$

The Laplace correction, which transforms astronomic azimuths to geodetic azimuths, is computed in the form

$$\eta \tan \phi \ .$$

When the adjustment is performed on the North American Datum, the observatory correction of 0".51 is added to all astronomic (west) longitudes before the computation of the deflection in the prime vertical. This correction is applicable to astronomic longitudes referred to the U. S. Naval Observatory and observed on or after January 1, 1962. The effect of the correction is to make all astronomic longitudes consistent with the adopted origin of the North American Datum, which is based on the adopted longitude of the U. S. Naval Observatory prior to 1962.

The corrections for distance observations are taken from Meade (1972). As applied in TRAV10, these are

a. Sea level correction

$$\left(\frac{D^2 - (h_2 - h_1^2)}{(1+\frac{h_1}{R_{12}})\,(1+\frac{h_2}{R_{21}})} \right)^{\frac{1}{2}} - D$$

b. Arc correction

$$\frac{D^3}{24R}$$

c. Geoid height correction

$$-\frac{D}{R}\ \frac{N_1 + N_2}{2}$$

d. Second velocity correction

$$\frac{C_r(C_r-2)\ D^3}{24R}$$

Position observations (constraints) require no corrections. The standard deviations of latitude and the standard deviations of longitude may be specified at the discretion of the user. Default values are $\sigma_\phi = \sigma_\lambda = 10^{-10}$ second of arc. The default values are intended to serve as a means of effectively fixing a station's coordinates.

4.3 Observation equation coefficients

An observation equation is formed for each observed quantity. No observation equation involves more than five unknown parameters, so that the matrix of observation equations is sparse. Symbolically, each observation equation is written:

$$a_1\ \delta\phi_1 + a_2\ \delta\lambda_1 + a_3\ \delta\phi_2 + a_4\ \delta\lambda_2 + a_5\delta z = \ell + v\ .$$

The units of the coordinate corrections $\delta\phi$, $\delta\lambda$ are seconds of arc. The units of angular and position observations are seconds of arc, and distance observations are in meters.

The observation equation coefficients are based on the forms given by Bomford (1971, p. 145).

For direction observations, the coefficients are

$$a_1 = -k\frac{M_1}{S}\ \sin\alpha_{12} \qquad a_3 = -k\frac{M_2}{S}\ \sin\alpha_{21}$$

$$a_2 = \frac{N_2}{S}\ \cos\phi_2\ \cos\alpha_{21} \qquad a_4 = -a_3$$

$$a_5 = 1\ .$$

For astronomic azimuth observations, the coefficients are

$$a_1 = -k\frac{M_1}{S}\sin\alpha_{12} \qquad a_3 = -k\frac{M_2}{S}\sin\alpha_{21}$$

$$a_2 = \frac{N_2}{S}\cos\phi_2\cos\alpha_{21} + \sin\phi_1 \qquad a_4 = \frac{N_2}{S}\cos\phi_2\cos\alpha_{21}$$

$$a_5 = 0$$

For distance observations, the coefficients are

$$a_1 = k\frac{M_1}{\rho}\cos\alpha_{12} \qquad a_3 = k\frac{M_2}{\rho}\cos\alpha_{21}$$

$$a_2 = \frac{N_2}{\rho}\cos\phi_2\sin\alpha_{21} \qquad a_4 = -a_2$$

$$a_5 = 0.$$

For a direct observation of latitude, $a_1 = 1$ and $a_2 = a_3 = a_4 = a_5 = 0$. For a direct observation of longitude, $a_2 = 1$ and $a_1 = a_3 = a_4 = a_5 = 0$.

The coefficient a_5 is never formed explicitly in the program nor is space ever allocated for it.

The right-hand side in the equation, ℓ, is taken in the sense "observed minus computed" where the "observed" value is the input value plus the correction discussed in section 4.2. The "computed" values of the geodetic azimuth and distance are obtained from the geodetic inverse problem

$$\begin{pmatrix} \alpha_{12} \\ \alpha_{21} \\ S_{12} \end{pmatrix} = f(\phi_1, \lambda_1, \phi_2, \lambda_2) ,$$

where the values for the latitudes and longitudes are either the input values or the values from the most recent iteration. The Helmert iterative method with the computational arrangement presented by Vincenty (1975, 1976) is used to solve the geodetic inverse problem.

For direction observations, the constant term is computed as $d^b - \alpha^c - z^0$, where α^c is the "computed" azimuth, d^b is the "observed" direction, and z^0 is an approximation to the orientation unknown for the round of directions. The approximation z^0 is obtained from the equation $z^0 = d^b - \alpha^c$ using the direction and azimuth for the first direction in the round. This causes the constant term in the first observation equation of each round of directions to be zero, and the constant term in the other equations to be generally small. This is done as a convenience to the geodesist who is interested in treating a large misclosure as an indicator of a large error or blunder. Otherwise, since the observation equation is linear in this unknown, we could just as easily use $z^0 = 0$.

4.4 Weights

Weights are always computed as the inverse of the square of the standard deviation of the observation. The standard deviation may be specified together with the observation. A single standard deviation is given for angular and position observations. For distance observations, both a constant part and a part proportional to the distance must be specified. If no standard deviation is given, the default observational standard deviation shown in tables 1, 2, 3, and section 4.2 are used. The observational standard deviations are in the same units as the corresponding observations, except for positional constraints when the standard deviations of latitude and longitude are specified in meters.

4.5 Rejections

The following observations are rejected by the program:

1. Any observations for which the stations at both ends of the line are not in the input list of geodetic positions. These observations cannot be processed, since approximate values are not available for all the unknowns involved.

2. Any single direction list. These observations can add nothing to the adjustment.

3. Any astronomic azimuth with a Laplace correction in excess of 10 minutes of arc.

4. Any mark to mark distance for which the difference in endpoint elevations is greater than the distance itself.

5. Any mark to mark distance for which both the orthometric height and the geoid height are not available for both ends of the line.

4.6 Normal Equations

Each azimuth, distance, and position observation generates an observation equation that can be written

$$A_k X = L_k + V_k ,$$

where X is a vector containing corrections to all latitudes and longitudes. A_k is a row matrix, all of whose elements except four will always vanish. L_k and V_k are single elements. If P_k is the weight of the observation, the corresponding partial normal equation is

$$N_k X = U_k ,$$

where $N_k = A_k^T P_k A_k$

and $U_k = A_k^T P_k L_k$.

Direction observations require special consideration because of the presence of the orientation unknowns. The method of Schreiber (Jordan-Eggert, sections 100 and 110) is used. Let the group of observation equations generated by the k^th^ abstract be written as

$$A_k X + E_k \delta Z_k = L_k + V_k \quad .$$

The matrix A_k and the vectors L_k and V_k now have as many rows as there are directions in the abstract; E_k is a vector of ones. If P_k is the weight matrix for this group of observations, the following partial normal equations are generated:

$$\begin{pmatrix} A_k^T P_k A_k & A_k^T P_k E_k \\ E_k^T P_k A_k & E_k^T P_k E_k \end{pmatrix} \begin{pmatrix} X \\ \delta z_k \end{pmatrix} = \begin{pmatrix} A_k^T P_k L_k \\ E_k^T P_k L_k \end{pmatrix}$$

Since all observations involving the orientation unknown δz_k have been processed, it can be eliminated at the partial normal equation stage. This leads to the following reduced partial normal equation:

$$(A_k^T P_k A_k - A_k^T P_k E_k (E_k^T P_k E_k)^{-1} E_k^T P_k A_k) \quad X$$

$$= A_k^T P_k L_k - A_k^T P_k E_k (E_k^T P_k E_k)^{-1} E_k^T P_k L_k , \qquad (2)$$

which is similarly written

$$N_k X = U_k .$$

The column matrix E_k and the terms containing it are never generated explicitly. Instead, the direction observation equations are processed while ignoring the orientation unknown, generating the terms $A_k^T P_k A_k$ on the left and $A_k^T P_k L_k$ on the right. As the observations are processed, the "Schreiber equation" is formed. This is written

$$E_k^T P_k A_k X = E_k^T P_k L_k, \qquad \text{weight} = -(E_k^T P_k E_k)^{-1},$$

or in a more intuitive form,

$$(\sum_i P_{ki} A_{ki}) X = \sum_i P_{ki} L_{ki} , \qquad \text{weight} = -(\sum_i P_{ki})^{-1} ,$$

where the sum is taken over all directions in the abstract.

After all directions in the round are processed, a partial normal equation is formed from the Schreiber equation as if it were an actual observation equation. This is added to the contributions from the actual direction observations, giving rise to the second term on each side of the reduced partial normal equation for the abstract (eq. 2).

All contributions to the normal equations are accumulated as partial normal equations are generated. After all observations are processed, the final normal equations take the form

$$NX = U,$$

$$\text{where } N = \sum_k N_k$$

$$\text{and } U = \sum_k U_k .$$

4.7 Iterations

The normal equations are solved for the corrections X to the latitude and longitude unknowns. After this, the entire process of forming observation and normal equations is repeated with the updated approximations to the unknowns. The iterative process is terminated when any of the following conditions exists:

1. Satisfactory convergence is achieved. This occurs whenever the root mean square (rms) corrections to both latitude and longitude are less than 0".0001, i.e.,

$$\left(\frac{\Sigma(\delta\phi)^2}{n}\right)^{\frac{1}{2}} \le 0.''0001 \text{ and } \left(\frac{\Sigma(\delta\lambda)^2}{n}\right)^{\frac{1}{2}} \le 0.''0001 \ .$$

2. The number of iterations exceeds 4 (the first solution is counted as iteration zero).

3. The solution diverges on two iterations. Divergence is detected when the rms residual increases between two successive solutions. This is allowed to happen once, but iterations are terminated if it occurs a second time.

4.8 Accuracies

TRAV10 has the capability of computing the relative error between any two specific points. The relative error is expressed as the standard error of the adjusted azimuth σ_α, the standard error of the adjusted distance σ_d, and the covariance between them $\sigma_{\alpha d}$.

Let X^a denote all the adjusted latitudes and longitudes. Symbolically, we can write the azimuth and distance as

$$\begin{pmatrix} \alpha \\ d \end{pmatrix} = g(X^a),$$

even though only two latitudes and two longitudes are acutally involved. We further let

$$G = \frac{\partial g(X^a)}{\partial X^a} = \frac{\partial(\alpha, d)}{\partial X^a}$$

The covariance matrix of the azimuth and distance is symbolically propagated from the covariance matrix of the latitude and longitude unknowns:

$$\Sigma_{\alpha d} = G\,\Sigma_X\,G^T = \sigma_0^2 G\,N^{-1}\,G^T = \sigma_0^2 G(C^T\,C)^{-1} G^T$$

$$= \sigma_0^2\,G\,C^{-1}(C^T)^{-1}\,G^T$$

$$= \sigma_0^2\,\left((C^T)^{-1} G^T\right)^T\,\left((C^T)^{-1}\,G^T\right).$$

The product $\left((C^T)^{-1} G^T\right)$ is computed by solving the equation $C^T U = G^T$ with the HERESI subroutine. The computations are equivalent to performing a forward solution for the last two columns of the original normal equations augmented with the two columns G^T.

TRAV10 does not explicitly compute terms of the inverse of the normal equations. The point uncertainty of the coordinates of any station can be found by computing the accuracy of the desired station relative to any fixed point in the adjustment. This approach avoids superfluous computations that are not of interest to the analyst and allows all computations to be contained within the matrix profile.

5. GEODETIC ANALYSIS AIDS

5.1 Detection of Blunders

The magnitude of the right-hand side or constant term in the observation equation is often a good indicator of blunders in the data. This is especially true when the input coordinates are very accurate (as is often the case in horizontal surveys) or when there are few blunders and a heavily overdetermined system. The program displays those observations for which the constant term is large. The definition of "large" for each type of observation is given in section 12.10 of the user instructions (appendix).

5.2 Solvability Analysis

A logical solvability analysis is performed as part of the reordering process. Based on the observations used, the stations read as part of the input are grouped into components. Each component is an independent network, unconnected to any other component. To be solvable, each component requires a definition of the origin, orientation, and scale of the coordinate system. This is normally supplied by fixing one or more points in each component.

An analysis of the observations at each station is produced. The number of unique independent observations at a station is counted by the formula

L + MAX(0,NDFROM-1) + NDTO + NAZI + NDIST ,

where

NDFROM is the number of directions emanating from the station,

NDTO is the number of directions to the station, NAZI is the number of azimuths either from or to the station, and

NDIST is the number of distances either from or to the station.

If $L < 2$, the station is flagged as undetermined. If $L=2$, it is flagged as a no-check station.

The counts of the number of observations are based on the connection records (fig. 2). Because all connection records for a given pair of stations are merged, repeated observations of the same type over the same line are counted only once. Thus, for a station to be considered possibly determinable, it must be involved in at least two unique observations.

When undetermined stations are detected, the matrix of normal equation coefficients is known to be singular and the program suppresses any attempt to solve the normal equations. In the practical adjustments of horizontal networks at NGS, missing observations and undetermined stations have been found to be a very frequent cause of singular normal equation systems. Thus, the solvability analysis is frequently able to identify the cause of the singularity.

There are, however, certain unusual configurations which can cause the normal equations to be singular even though no undetermined stations are detected. For example, consider an intersection station seen from two other points where all three points lie on a straight line. Only one component of the intersection station's position can be determined even though the number of observations meets the minimum required for determining both components.

5.3 Analysis of Residuals

The reporting and analysis of the residuals are performed by the postprocessor phase of the adjustment. This phase is implemented only after the solution phase has iterated to convergence.

Residuals are computed only after the last iteration of the solution process. Both the linear residuals ($v_i = A_iX-\ell_i$) and the normalized residuals (v_i/P_i) are displayed. The user of the program is offered the following tools for analysis:

1. On option, only the observations are listed for which the absolute value of the normalized residual is greater than 1.0. This serves to highlight the potentially troublesome observations.

2. Observations are flagged when the absolute value of the normalized residual is greater than the tau statistic at the 95% confidence level (5% probability of type 1 error). The use of the tau statistic for screening residuals from an adjustment is described by Allen Pope (1976).

3. On option, the residuals are sorted by observed station and all the residuals for each intersection station are displayed as a group.

4. The minimum, maximum, and mean absolute value residual is displayed for each of the observation codes. This is done both for the total population of residuals and for the limited population of observations over short lines.

5. The range, minimum, maximum, mean, and average absolute value of the normalized residuals are displayed.

6. The observation sequence numbers for the 20 largest normalized residuals are displayed. This immediately guides the user to the largest residuals.

7. The 95% confidence interval of the χ^2 statistic is displayed for the testing of the estimated variance of unit weight.

5.4 Detection of Singularities

If the normal equations are singular, then a zero will be generated by the Cholesky triangular factorization process for some diagonal element. Once this occurs, no more elements in the row corresponding to that element can be processed, since the algorithm requires division by the diagonal element of the row being processed.

In practice, roundoff errors and other effects cause small nonzero numbers to appear on the diagonal during factorization of singular matrices, so that the test for zero must be replaced by a comparison against a tolerance. In the program, each squared diagonal element of the triangular matrix factor is normalized by division by the corresponding element of the normal equation matrix before comparison to the tolerance, i.e.,

$$g_i = \frac{c_{ii}^2}{n_{ii}}$$

This normalization was suggested to NGS by William D. Googe of the Defense Mapping Agency Topographic Center, and is, therefore, called the "Googe number." It allows selection of a tolerance which is independent of network size, observation types, or weights.

In the program, the tolerance is set equal to 0.000001. Whenever a column is reduced and $g_i < 0.000001$, a message is produced indicating that the solution breaks down at that point. The corresponding row and column of the normal equations (and triangular factor) are set equal to zero and the solution is continued. In effect, this procedure finds the solution that would be obtained if the offending unknown were set equal to its a priori (approximate) value. It allows the geodesist to see all, not only the first, of the unknowns that cannot be determined from the given data.

The Googe number can be given an interesting geometrical interpretation. Let A_{i-1} denote the matrix consisting of the first i-1 columns of the matrix of coefficients of the observation equations, and let a_i denote the $i^{\underline{th}}$ column, i.e.,

$$A_i = (A_{i-1} \quad a_i)$$

and

$$A = A_u$$

where u is the total number of unknowns.

The portion of the normal equations corresponding to the first i columns is

$$N_i = \begin{pmatrix} N_{i-1} & \beta_i \\ \beta_i^T & \gamma_i \end{pmatrix},$$

where

$$N_{i-1} = A_{i-1}^T P \, A_{i-1},$$

$$\beta_i = A_{i-1}^T P \, a_i \, ,$$

and

$$\gamma_i = a_i^T \, P \, a_i \, .$$

After the Cholesky triangular factorization procedure has been applied to the first i-1 columns of the normal equations, the space originally occupied by the upper triangular part of N_i contains

$$\begin{pmatrix} C_{i-1} & \beta_i \\ & \gamma_i \end{pmatrix} ,$$

where $C_{i-1}^T \, C_{i-1} = N_{i-1}$.

After reduction of column i (but before taking the square root of the diagonal element), this space contains

$$C_i = \begin{pmatrix} C_{i-1} & \left(C_{i-1}^T\right)^{-1} \beta_i \\ & \gamma_i - \beta_i^T C_{i-1}^{-1} \left(C_{i-1}^T\right)^{-1} \beta_i \end{pmatrix}$$

The lower right corner of the matrix is

$$\begin{aligned} c_{ii}^2 &= \gamma_i - \beta_i^T C_{i-1}^{-1} \left(C_{i-1}^T\right)^{-1} \beta_i \\ &= \gamma_i - \beta_i^T N_{i-1}^{-1} \beta_i \\ &= a_i^T P a_i - a_i^T P A_{i-1} (A_{i-1}^T P A_{i-1})^{-1} A_{i-1}^T P a_i \\ &= a_i^T P^{\frac{1}{2}} \left(I - P^{\frac{1}{2}} A_{i-1} \left[(P^{\frac{1}{2}} A_{i-1})^T P^{\frac{1}{2}} A_{i-1}\right]^{-1} (P^{\frac{1}{2}} A_{i-1})^T\right) P^{\frac{1}{2}} a_i \\ &= \bar{a}_i^T (I - \bar{A}_{i-1} (\bar{A}_{i-1}^T \bar{A}_{i-1})^{-1} \bar{A}_{i-1}^T) \bar{a}_i \ , \end{aligned}$$

where $P^{\frac{1}{2}}$ is the square root of the weight matrix and the overbars indicate normalization by $P^{\frac{1}{2}}$.

Let

$$S_{i-1} = I - \bar{A}_{i-1} (\bar{A}_{i-1}^T \bar{A}_{i-1})^{-1} \bar{A}_{i-1}^T \ .$$

Then

$$c_{ii} = \bar{a}_i^T S_{i-1} \bar{a}_i$$

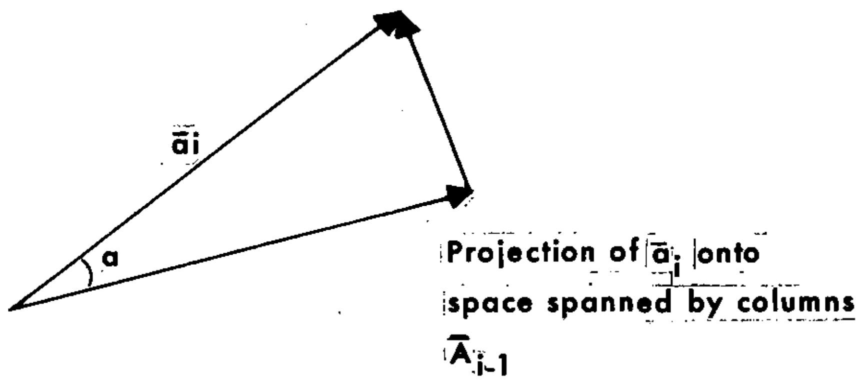
or, since S is idempotent,

$$c_{ii}^2 = (S_{i-1}\bar{a}_i)^T (S_{i-1}\bar{a}_i) = \left|S_{i-1} \bar{a}_i\right|^2 .$$

The matrix S_{i-1} is a projector onto the orthogonal complement of the sub-space spanned by the columns of $\bar{A}_{i-1}$. It may also be viewed as a projector in the space with metric P onto the orthogonal complement of the sub-space spanned by the columns of A_{i-1}. The number c_{ii}^2 is the square of the length of the projection of $\bar{a}_i$ onto this space. We also have

$$n_{ii} = \gamma_i = a_i^T P a_i = \left|\bar{a}_i\right|^2 .$$

The Googe number $g_i = c_{ii}^2/n_{ii}$ can now be given the following interpretation: When $g_i=0$, the i^{th} column of the observation equations is a linear combination of the first i-1 columns; when $g_i=1$, the i^{th} column is orthogonal to the first i-1 columns. Thus g_i is a measure of the independence of the i^{th} column from the first i-1 columns. Geometrically, it may be interpreted as the square of the sine of the angle α in the following drawing:



Since $0 \leq g_i \leq 1$, the magnitude of g_i is independent of the number of unknowns, number of observations, units used, or weights used. In practice, the test for $g_i < 0.000001$ has proven to be a reliable indicator of problems in the set of data being adjusted.

6. TRAV10 PERFORMANCE

Figure 5 provides a general indication of the performance of TRAV10 on the NOAA CDC 6600. For small networks, about 150-200 stations can be adjusted per minute of central processor time. For larger networks, one can process 100-150 stations per minute. On the NOAA IBM 360/195, roughly two and one-half times as many stations per minute can be processed as on the CDC 6600.

The time required to adjust any given network is remarkably well approximated by a linear function of the number of stations. Other factors, of course, may be considered. The CPU time required depends very strongly on the number of observations to be processed, but the number of observations tends to be a linear function of the number of stations. The matrix profile tends to grow somewhat faster than a linear function of the number of stations, which accounts for the observation that somewhat fewer stations per minute can be processed for large networks. Other factors, such as the number of normal equation partitions, have very little effect on the CPU time, although they may affect the charges a job incurs for input/output activity.

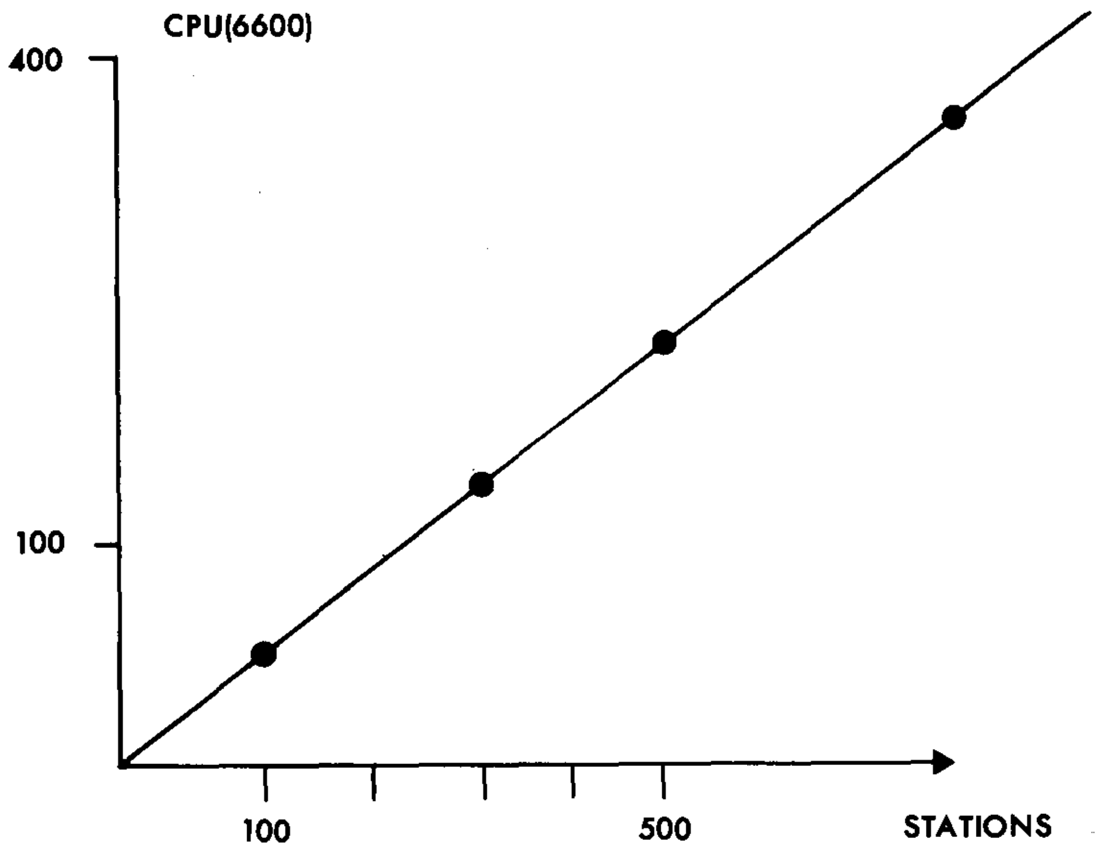


Figure 5.--TRAV10 run time as a function of the number of stations.

The following representative sampling of jobs (table 4) was used to construct figure 5.

Table 4.--TRAV10 performance

Number of stations	Observations/station	Profile/station	CPU seconds
100	6	50	30
300	6	80	135
500	6	200	220
800	6	220	370

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APPENDIX.--USER INSTRUCTIONS

User operating instructions, which are maintained in machine-readable form, appear on the following pages. This sample is for the IBM 360 version of the program. Instructions for the CDC 6600 version differ only in details concerning the use of control cards. In general, a TRAV deck will run the same and produce identical answers on either machine.

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    DATE OF DOCUMENTATION  NOVEMBER, 1975
    DATE OF REVISION       JANUARY,  1977

1.PURPOSE

    TO ADJUST A HORIZONTAL SURVEY NETWORK BY THE METHOD
    OF OBSERVATION EQUATIONS ON THE ELLIPSOID

2. FEATURES

    TRAV10 IS WRITTEN TO BE THE PRIMARY PRODUCTION TOOL OF
    THE HORIZONTAL NETWORK BRANCH OF THE NATIONAL GEODETIC
    SURVEY. IT IS DESIGNED SO THAT BOTH VERY LARGE AND VERY
    SMALL NETWORKS CAN BE ADJUSTED, WHILE STILL MAINTAINING
    EFFICIENT USE OF COMPUTER TIME AND CORE MEMORY. THE USER
    COMMUNICATES THE SIZE OF THE NETWORK TO BE ADJUSTED TO
    THE PROGRAM THROUGH A MINIMUM NUMBER OF PARAMETERS.
    THE EDITING OF INPUT DATA AND ERROR MESSAGES IS DESIGNED
    TO BE COMPREHENSIVE.

3. PROGRAM HISTORY

    SINCE 1972, THE NATIONAL GEODETIC SURVEY HAS USED A SERIES
    OF PROGRAMS NAMED TRAVXX ON A CDC6600. VERSION 8/76
    OF TRAV10 IS AN IBM 360 VERSION OF TRAV10 ON THE
    CDC6600, CURRENT AS OF FEBRUARY 1977.
    IT IS SIMILAR TO THE CDC 6600 VERSION OF THE PROGRAM IN
    MOST RESPECTS, THE PRIMARY DIFFERENCE BEING THAT THE
    POST-PROCESSOR HAS BEEN MADE AN INTEGRAL PART OF TRAV10
    AND NO LONGER REQUIRES A SEPARATE JOB STEP.

4. PREPROCESSORS

    TRAV10 MUST BE RUN IN CONJUNCTION WITH A PREPROCESSOR,
    WHICH PERFORMS THE NAME NUMBERING FUNCTION AND PASSES
    90 CHARACTER RECORDS TO THE MAIN PROCESSOR.
    TWO PREPROCESSORS ARE PROVIDED FOR THIS PURPOSE
    PREPROC - THE FULL PREPROCESSOR PERFORMS A COMPLETE
              EDIT OF THE INPUT TRAVDECK, CHECKING FOR
              BOTH VALID FIELD CONTENTS AND VALID DECK
              STRUCTURE.
       QUIKPROC- THE QUICK PREPROCESSOR PERFORMS THE NAME
              NUMBERING FUNCTION ONLY. IT DOES ABSOLUTELY
              NO CHECKING FOR INVALID FIELDS OR DECK STRUCTURE
              ERRORS. IT SHOULD BE USED ONLY WHEN THE USER
              IS ABSOLUTELY CERTAIN THAT HIS TRAVDECK CONTAINS
              NO ERRORS.

5. PROCEDURES

    THREE PROCEDURES ARE PROVIDED
       5.1 CCTRAV10 - EXECUTES THE FULL PREPROCESSOR AND THE MAIN
           PROGRAM.
       5.2 CCTRAVQ - EXECUTES THE QUICK PREPROCESSOR AND THE MAIN
           PROGRAM.
```

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        5.3 CCTRAVED - EXECUTES THE FULL PREPROCESSOR ONLY,
                AND IS USED ONLY TO EDIT TRAVDECKS.

     FOR ALL THREE PROCEDURES, THE PROCEDURE STEPS ARE NAMED AS
        PREPROC  - THE STEP THAT EXECUTES THE FULL PREPROCESSOR
        QUIKPROC - THE STEP THAT EXECUTES THE QUICK PREPROCESSOR
        TRAV10   - THE STEP THAT EXECUTES THE MAIN PROCESSOR TRAV10



 6. INPUT

     THE INPUT TO ALL THREE PROCEDURES IS THE STANDARD TRAVDECK,
     DESCRIBED IN THE NGS 6600 PROGRAM LIBRARY USER'S WRITE-UPS,
     IN THE STANDARD OPERATING PROCEDURES OF THE HORIZONTAL
     NETWORK BRANCH OF NGS, AND IN APPENDIX B.

     INPUT IS PASSED TO THE PROCEDURES THROUGH ONE OF TWO FILES
     (BUT NOT BOTH)
        CARDIN   - FOR 80 CHARACTER CARD IMAGES
        UPDATEF  - FOR 100 CHARACTER IMAGES (CARD IMAGES IN CC 1-80
                   AND RECORD IDENTIFIERS IN CC 81-100).

     EXAMPLES
        FOR DATA SUBMITTED THROUGH THE RUN STREAM, INCLUDE THE CARD
       //CARDIN DD *

        FOR DATA PREPARED WITH THE SNAPUP UTILITY IN A PREVIOUS
        STEP OF THE SAME JOB, USE
       //CARDIN DD DSN=++IMAGES,DISP=(OLD,DELETE)

        FOR DATA PREPARED WITH R. MILLER'S ROUTINE FOR SIMULATING
        THE CDC 6600 UPDATE SYSTEM (CCRJMUPD), USE
       //UPDATEF DD DSN=++COMPILE,DISP=(OLD,DELETE)

7. PROGRAM SIZE - NUMBER OF STATIONS.

     7.1 THE FULL PREPROCESSOR IS FIXED IN SIZE AT 1500 STATIONS.
         IF IT IS NECESSARY TO PROCESS MORE STATIONS, SEE THE
         PROGRAMMING STAFF TO HAVE A SPECIAL VERSION OF THE
         PREPROCESSOR COMPILED.

     7.2 THE QUICK PREPROCESSOR AND THE TRAV10 PROGRAM ARE VARIABLE
         IN SIZE, SO THAT THE NUMBER OF STATIONS WHICH CAN BE PROCESSED
         IS LIMITED ONLY BY THE SIZE OF THE REGION IN WHICH THE
         PROGRAM RUNS.

 8. CALCULATING REGION SIZE

     ANY JOB EXECUTING ONE OF THE PROCEDURES SHOULD CONTAIN THE REGION
     PARAMETER ON THE JOB CARD, WHERE THE REGION SIZE FOR EACH
     PROCEDURE IS COMPUTED AS DESCRIBED BELOW

     8.1 CCTRAVED   -  USE REGION=140K

     8.2 CCTRAVQ   -  USE ONE OF THE TWO METHODS BELOW

         8.2.1   COMPUTE THE REGION SIZE IN UNITS OF K (I.E.,UNITS
             OF 1024 BYTES) FROM THE FORMULA
                 REGION SIZE = WS + 90K
             WHERE 90K IS THE PROGRAM SIZE (INCLUDING ALL CODE,FIXED
             LENGTH ARRAYS, BUFFERS, ACCESS METHOD ROUTINES, LOADER
             ROUTINES, ETC.) FOR VERSION  8/76 OF PROGRAM TRAV10,
             AND WS IS THE AMOUNT OF WORK SPACE NEEDED BY TRAV10.

             WS IS COMPUTED IN UNITS OF WORDS USING THE METHOD BELOW.
```

TO CONVERT TO UNITS OF K, MULTIPLY BY 4 AND DIVIDE BY 1024.

THE EXACT NUMBER OF WORDS NEEDED BY TRAV10 FOR WORKSPACE IS

14*NGP + 4*NEL + 5*NR + 4*M + 125

WHERE

- NGP IS THE NUMBER OF GP CARDS IN THE TRAVDECK
- M IS THE MAXIMUM NUMBER OF DIRECTIONS IN ANY ABSTRACT
- NR IS THE NUMBER OF BLOCKS INTO WHICH THE NORMAL EQUATIONS ARE PARTITIONED.
- NEL IS THE NUMBER OF NORMAL EQUATION ELEMENTS IN THE LARGEST PARTITION.

ALTHOUGH THE PARAMETERS NGP AND M ARE FIXED FOR ANY ONE ADJUSTMENT PROBLEM, THE USER CAN EXERCISE SOME CONTROL OVER THE PARTITIONING OF THE NORMAL EQUATIONS BY THE REGION SIZE HE ALLOWS THE PROGRAM TO RUN UNDER. TRAV10 ATTEMPTS TO PUT ALL THE NORMAL EQUATION ELEMENTS INTO A SINGLE PARTITION (NR=1 AND NEL = THE MATRIX PROFILE). IF THIS RESULTS IN A LARGER WORK SPACE THAN CAN BE ACCOMMODATED IN THE REGION IN WHICH THE JOB IS RUNNING, THE NORMAL EQUATIONS ARE PARTITIONED INTO BLOCKS WHICH ARE AS LARGE AS POSSIBLE. EACH PARTITION IS A SET OF COLUMNS OF THE NORMAL EQUATION MATRIX.
THE PARAMETER NEL CAN BE NO SMALLER THAN 2*NGP + 3 NORMAL EQUATION ELEMENTS; A SMALLER VALUE WILL PRODUCE THE MESSAGE *REGION SIZE REQUESTED CANNOT SUPPORT MINIMAL PARTITION** AND TERMINATE THE JOB.

THE TOTAL NUMBER OF PARTITIONS IS APPROXIMATELY

PROFILE/NEL

IN GENERAL, THE USER SHOULD GIVE THE PROGRAM AS MUCH CORE AS POSSIBLE, UP TO THE CASE WHERE NR=1 AND NEL = THE MATRIX PROFILE, WHICH IS THE MAXIMUM THE PROGRAM CAN USE. WHEN A SPECIFIED REGION SIZE IS SMALLER THAN THE MAXIMUM THE PROGRAM CAN USE, RUNNING TIME WILL INCREASE SOMEWHAT DUE TO THE INPUT AND OUTPUT OF THE NORMAL EQUATION PARTITIONS FROM AND TO AUXILIARY STORAGE. HOWEVER, THE USER MAY DESIRE TO ALLOCATE A REGION SMALLER THAN THE MAXIMUM THE PROGRAM CAN USE SO THAT THE JOB CAN BE RUN IN A HIGHER PRIORITY JOB CLASS (OR SO THAT A LARGE JOB WILL FIT ON THE MACHINE AT ALL). IN THIS CASE, ALLOCATE THE MAXIMUM REGION ALLOWED FOR THE JOB CLASS BEING USED.

8.2.2 IF THE PROFILE OF THE NORMAL EQUATION COEFFICIENT MATRIX IS NOT KNOWN, USE THE ESTIMATES BELOW. ASSUMING M=50 AND PROFILE=0.15*(NUMBER OF UNKNOWNS)**2 YIELDS

MINIMUM WORK SPACE = 31*NGP + 125

MAXIMUM WORK SPACE = 2.4*NGP*NGP + 14*NGP + 133

THESE APPROXIMATIONS YIELD THE FOLLOWING APPROXIMATE REGIONS

	REGION SIZE	
NUMBER OF GPS	MINIMUM	MAXIMUM
30	93K	99K
50	95	115
100	101	188
150	107	307
200	113	474
500	150	
1000	210	
1500	270	
2000	331	

```
          2500                  392
          3000                  453
```

8.3 CCTRAV10

USE THE LARGER OF 140K AND THE REGION SIZE COMPUTED ACCORDING TO THE METHODS OF PARAGRAPH 8.2

9. PARAMETERS PASSED TO THE PROCEDURES

THE FOLLOWING KEYWORD PARAMETERS CAN BE PASSED TO THE PROCEDURES

GPS - THE NUMBER OF GP'S IN THE JOB
OBS - THE NUMBER OF OBSERVATIONS
PROFILE - THE PROFILE OF THE NORMAL EQUATION MATRIX

DEFAULT VALUES ARE GPS=50,OBS=300,PROFILE=1000

THESE PARAMETERS ARE USED ONLY FOR THE CALCULATION OF THE AUXILIARY (DISK) STORAGE NEEDED WHILE RUNNING THE PROGRAM, BUT HAVE NO EFFECT ON THE PROGRAMS THEMSELVES OR THE JOB CLASS UNDER WHICH THE PROGRAM WILL RUN. THEREFORE, TO PREVENT THE PROGRAMS FROM TERMINATING DUE TO INSUFFICIENT DISK SPACE, IT IS WISE TO BE GENEROUS IN ESTIMATING THESE PARAMETERS. THE PROFILE PARAMETER IS NOT PERTINENT AND SHOULD BE OMITTED WHEN RUNNING THE PROCEDURE CCTRAVED.

10. OUTPUT

ERROR MESSAGES FROM THE PROGRAMS ARE LISTED IN APPENDIX C. MOST ARE SELF EXPLANATORY.

IF REQUESTED BY A '1' PUNCH IN CC 70 OF THE OPTION CARD, TRAV10 PRODUCES A FILE OF GP CARD IMAGES CONTAINING ADJUSTED GP'S. THIS FILE IS PASSED TO SUBSEQUENT STEPS IN THE SAME JOB, BUT IS LOST AT THE END OF THE JOB. TO ACCESS THIS FILE IN A SUBSEQUENT JOB STEP, USE

```
//YOURDDNAME  DD  DSN=++NEWGPS,DISP=OLD
```

11. JCL EXAMPLES

11.1 PERFORM AN ADJUSTMENT OF A TRAVDECK WHICH EXISTS ON CARDS, WITH 30 GP'S AND 500 OBSERVATIONS, ALREADY EDITED.

```
//JOBNAME  JOB  ACCOUNTING INFO.....,REGION=100K,TIME=1
//        EXEC   CCTRAVQ,GPS=30,OBS=500,PROFILE=1000
//CARDIN  DD *

               TRAVDECK

/*
//
```

11.2 A TRAVDECK IS IN THE MEMBER NAMED DATA01 OF THE CATALOGUED DATASET NAMED NOS.NGS.MYDATA. THE JOB HAS 200 GPS,2000 OBS, AND A PROFILE OF 5000 ELEMENTS. CORRECTIONS ARE TO BE MADE USING SNAPUP, AND AN ADJUSTMENT DONE. THE NEW GP CARDS ARE TO BE WRITTEN ON TAPE.

```
//JOBNAME  JOB  ACCOUNTING INFO....,REGION=200K,TIME=1
//       EXEC    SNAPUP,DATASET='NOS.NGS.MYDATA(DATA01)'
//SYSIN DD *
          SNAPUP DIRECTIVES
/*
//        EXEC   CCTRAV10,GPS=200,OBS=2000,PROFILE=5000
//CARDIN  DD  DSN=++IMAGES,DISP=OLD
//        EXEC   PGM=IEBGENER
```

```
     //SYSUT1  DD  DSN=++NEWGPS,DISP=OLD
     //SYSUT2  DD  UNIT=TAPE9,VOL=SER=XXXXX,DCB=*.SYSUT1,DISP=NEW
     //SYSIN DD DUMMY
     //SYSPRINT DD  SYSOUT=A
     //

12. SPECIAL FEATURES - - SPECIAL FEATURES OF THE PROGRAM WITH WHICH
    THE USER SHOULD BE FAMILIAR ARE DISCUSSED BELOW.


    12.1  REORDERING OF UNKNOWNS - - THE PROGRAM DEALS WITH TWO
          DIFFERENT ORDERINGS OF THE STATIONS. THE FIRST, KNOWN AS
          INPUT ORDER, IS THE ORDER IN WHICH THE STATIONS APPEAR IN
          THE GP CARD PORTION OF THE INPUT TRAVDECK. THE SECOND
          ORDERING, THE ORDER OF ELIMINATION, IS DETERMINED BY THE
          PROGRAM. FOR THE MOST PART, USERS NEED NOT BE CONCERNED
          WITH THE ORDER OF ELIMINATION OR EVEN THAT A SECOND
          ORDERING EXISTS. MOST MESSAGES ARE KEYED TO THE INPUT ORDER
          OR THE STATIONS. ONLY THE MESSAGE ***SINGULAR SOLUTION***,
          ***SOLUTION BROKE DOWN AT STATION XXX***,
          *********EXECUTION TERMINATING*********, USES THE ORDER OF
          ELIMINATION TO IDENTIFY THE STATION (IN THE FIELD XXX).THE
          CORRESPONDENCE BETWEEN THE INPUT ORDER AND THE ORDER OF
          ELIMINATION IS  GIVEN WITH THE OBSERVATIONAL SUMMARY AND
          SOLVABILITY ANALYSIS.

           THE REORDERING OF THE UNKNOWNS IS PERFORMED TO REDUCE THE
           NUMBER OF COMPUTATIONS INVOLVED IN SOLVING THE NORMAL
           EQUATIONS, AND IS BASED ON THE METHOD IN NOAA TECHNICAL
           MEMORANDUM NOS NGS-4 'REDUCING THE PROFILE OF SPARSE
           SYMMETRIC MATRICES,' BY RICHARD A. SNAY.

           UNLESS SUPPRESSED BY A '1' PUNCH IN CC 63 OF THE OPTION CARD
           REORDERING WILL PROCEED AUTOMATICALLY. USE OF THE REORDER
           FEATURE IS GENERALLY RECOMMENDED. THE PAYOFF, IN TERMS OF
           REDUCING THE RUNNING TIME FOR SOLVING A GIVEN NETWORK, IS
           MARGINAL FOR SMALL NETWORKS BUT EXTREMELY SIGNIFICANT FOR
            LARGE NETWORKS (UNLESS THE INPUT ORDER ALREADY REPRESENTS
            AN ORDER WHICH MINIMIZES THE PROFILE OF THE NORMAL EQUATION
            COEFFICIENT MATRIX).

      12.2 TABLE OF CONNECTIONS
           AS A BY-PRODUCT OF THE REORDERING PROCESS, A TABLE OF
           CONNECTIONS IS BUILT AND DISPLAYED TO THE USER. THE ITEMS
           DISPLAYED FOR EACH STATION ARE
            INPUT ORDER
            ORDER OF ELIMINATION
            COMPONENT TO WHICH THE STATION BELONGS
            NUMBER OF UNIQUE DIRECTIONS ORIGINATING FROM THE STATION
                 (SINGLE DIRECTION LISTS ARE NOT COUNTED)
            NUMBER OF UNIQUE DIRECTIONS WHICH SEE THE STATION
                 (SINGLE DIRECTION LISTS ARE NOT COUNTED)
            NUMBER OF UNIQUE AZIMUTHS HAVING THE STATION AT ONE END
                 (ASTRO AZIMUTHS MUST HAVE ASTRO LONGITUDE)
            NUMBER OF UNIQUE DISTANCES HAVING THE STATION AT ONE END.
            SOLVABILITY NOTE (SEE BELOW)

            THE WORD UNIQUE ABOVE MEANS THAT OBSERVATIONS OF THE SAME
            KIND OVER THE SAME LINE ARE COUNTED ONLY ONCE.

            AN ELEMENTARY SOLVABILITY ANALYSIS IS PERFORMED AT EACH
            STATION.  THE ANALYSIS IS BASED SOLELY ON THE UNIQUE NUMBER
            AND KINDS OF OBSERVATIONS INVOLVING THE STATION. THE RESULT
            OF THE ANALYSIS IS POSTED IN THE TABLE OF CONNECTIONS
            WHENEVER ONE OF THE FOLLOWING THREE CONDITIONS IS MET
                     FIXED STATION
```

NO-CHECK STATION
UNDETERMINED STATION

DUE TO THE SIMPLICITY OF THE ANALYSIS, THERE MAY BE STATIONS WHOSE POSITION IS NOT DETERMINED OR IS NOT OVERDETERMINED BUT WHICH ARE NOT FLAGGED.

12.3 SUMMARY OF CONTROL INFORMATION BY COMPONENT.

A COMPONENT IN TRIANGULATION IS A SUBNETWORK WITHIN WHICH EVERY POINT HAS A PATH TO EVERY OTHER POINT. NORMALLY, ONE ATTEMPTS TO ADJUST A SINGLE NETWORK, OR A SINGLE COMPONENT; HOWEVER, BECAUSE OF MISSING OBSERVATIONS, THE NETWORK MAY ACTUALLY BREAK DOWN INTO TWO SUBNETWORKS. WHEN THIS HAPPENS EITHER NEW OBSERVATIONS MUST BE SUPPLIED OR FIXED CONTROL, SCALE, AND ORIENTATION MUST BE SUPPLIED FOR EACH COMPONENET.

12.4 POSITIONAL CONSTRAINTS.

POSITIONS ARE CONSTRAINED AT THEIR INPUT GP BY WEIGHTED CONSTRAINTS. THE WEIGHTS ARE COMPUTED FROM THE STANDARD DEVIATIONS IN LATITUDE AND LONGITUDE GIVEN ON THE CONSTRAINED POSITION CARD. HOWEVER, IF THE STANDARD DEVIATION FIELD FOR EITHER LATITUDE OR LONGITUDE IS BLANK OR ZERO, A STANDARD DEVIATION OF 0.0000000001 SECONDS OF ARC WILL BE ASSIGNED, THUS EFFECTIVELY FIXING THE COORDINATE.

12.5 OBSERVATIONS

EVERY OBSERVATION TAKES PART IN THE ADJUSTMENT AS LONG AS BOTH END POINTS ARE IN THE GP SECTION OF THE TRAVDECK AND WITH THE EXCEPTION OF SINGLE DIRECTION ABSTRACTS AND UNREASONABLE OBSERVATIONS. UNREASONABLE OBSERVATIONS WHICH MAY BE REJECTED INCLUDE THE FOLLOWING

1. ASTRO AZIMUTHS WITH LAPLACE CORRECTIONS IN EXCESS OF 10 MINUTES OF ARC.
2. MARK-TO-MARK DISTANCES WITH ENDPOINT ELEVATION DIFFERENCES GREATER THAN OR EQUAL TO THE DISTANCE ITSELF.
3. MARK-TO-MARK DISTANCES FOR WHICH BOTH THE ORTHOMETRIC AND GEOID HEIGHT ARE NOT AVAILABLE FOR BOTH ENDS OF THE LINE.

REJECTED OBSERVATIONS ARE FLAGGED BY THE MESSAGE

DELETED OBSERVATION++++++++++++++++++

IF EITHER END OF THE LINE IS A STATION NOT FOUND IN THE GP SECTION OF THE TRAVDECK, THE OBSERVATION IS FLAGGED BY THE MESSAGE

DELETED OBSERVATION ******************

DELETION OF DIRECTIONS OFTEN RESULTS IN ONLY A SINGLE ACTIVE DIRECTION REMAINING, WHICH IS THEN REJECTED AS A SINGLE DIRECTION LIST. SINGLE DIRECTION LISTS ARE NOT FLAGGED EXPLICITLY, BUT THEIR OBSERVATION SEQUENCE NUMBER IS REASSIGNED TO THE NEXT OBSERVATION

12.6 WEIGHTS

THE WEIGHT ASSOCIATED WITH AN OBSERVATION IS THE INVERSE OF THE SQUARE OF THE STANDARD ERROR OF THE OBSERVATION. THE STANDARD ERROR IS EITHER PUNCHED ON THE OBSEVATION CARD OR COMES FROM INTERNAL DEFAULTS. THE DEFAULT WEIGHTING SCHEME IS DOCUMENTED ON THE FIRST PAGE OF THE TRAV10 OUTPUT.

12.7 ABSTRACTS

MULTIPLE ABSTRACTS OF DIRECTIONS AT THE SAME STATION MAY BE USED, BUT MUST BE DISTINGUISHED BY VARYING THE LIST NUMBER. ALL DIRECTIONS IN AN ABSTRACT MUST BE

```
      TOGETHER IN THE INPUT, BUT DIFFERENT ABSTRACTS AT THE
      SAME STATION CAN BE SEPARATED BY OTHER ABSTRACTS.

   12.8  ASTRONOMIC LONGITUDES
      ALL ADJUSTMENTS ON NAD 1927 USE ASTRONOMIC LONGITUDES
      REFERRED TO THE U.S. NAVAL OBSERVATORY. SINCE ASTRO
      LONGITUDES OBSERVED AFTER JAN 1, 1962 ARE BASED ON
      THE 1968 BIH SYSTEM, THE PROGRAM ADDS 0.51 SECONDS
      TO ALL INPUT LONGITUDES.
    12.9  TRIANGLE CLOSURES
       TRIANGLE CLOSURES ARE NOT COMPUTED

    12.10  MISCLOSURES
       AN ATTEMPT HAS BEEN MADE TO SCREEN OUT TRULY
        TROUBLESOME OBSERVATIONS BY DISPLAYING THOSE FOR
        WHICH THE 'OBSERVED MINUS COMPUTED' TERM IS LARGE.
        THE PROGRAM COMPUTES LINEAR MISCLOSURES FOR ALL
        OBSERVATIONS. FOR ANGULAR OBSERVATIONS, THE LINEAR
        MISCLOSURE IS GIVEN BY D*TAN(L), WHERE D IS THE
        LINE LENGTH AND L IS THE ANGULAR MISCLOSURE
        (OBSERVED MINUS COMPUTED TERM).

        THE FOLLOWING RULES GOVERN THE PRINTING OF
        MISCLOSURES

        FOR ANGULAR OBSERVATIONS, PRINT THOSE FOR WHICH
            1. ANGULAR MISCLOSURE IS GREATER THAN 30 SECONDS, OR
            2. LINEAR MISCLOSURE IS GREATER THAN 5 METERS.

        FOR LINEAR OBSERVATIONS, PRINT THOSE FOR WHICH
            1. THE MISCLOSURE IS GREATER THAN 0.5 METER AND
               THE DISTANCE IS LESS THAN 500 METERS, OR
            2. THE MISCLOSURE IS GREATER THAN 5 METERS AND
               THE DISTANCE IS GREATER THAN 500 METERS.

       IN ADDITION, ANY MISCLOSURE GREATER THAN 10000 METERS
       (SIGNIFYING GROSS BLUNDERS IN INPUT POSITIONS)
        WILL TERMINATE THE RUN WITH THE MESSAGE
         RUN ABORTED DUE TO EXCESSIVE N-TERMS************


     12.11  ACCURACIES
        TRAV10 WILL COMPUTE THE STANDARD DEVIATION OF THE
         ADJUSTED AZIMUTH AND DISTANCE BETWEEN ANY PAIR OF
         POINTS, AS REQUESTED IN THE ACCURACY REQUEST PORTION
         OF THE TRAVDECK. IT IS NOT NECESSARY THAT THERE BE
         ANY ACTUAL OBSERVATIONS BETWEEN THE TWO POINTS.
         STANDARD DEVIATIONS OF COORDINATES ARE NOT COMPUTED.

     12.12  INPUT
        THE STRUCTURE OF THE INPUT DECK IS DESCRIBED IN
         APPENDIX B.
****************************************************************

              APPENDIX A  -  JCL EXPANSIONS
                    DELETED

            TO GET A LISTING OF ANY ONE OF THE PROCEDURES,
                 SIMPLY EXECUTE THE PROCEDURE.

*****************************************************************

            APPENDIX B  -  TRAVDECK  SPECIFICATIONS

B.1  TRAV DECK FORMAT SPECIFICATIONS ***********
     RESPONSIBLE PARTY   JOHN G GERGEN
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```
****
1.1  OPTION CARD
       CC01-09        RESERVED FOR DECK NAME
       CC10-15        RESERVED FOR PROJECT VARIANCE OF UNIT WEIGHT
       CC16-50        NOT USED
       CC51-62 ARE RESERVED FOR FUTURE APPLICATION TO HELMERT BLOCKING
        CC43           RESTART OPTION FOR HELMERT BLOCKING
        CC51-54        SEQUENCE NUMBER OF LAST INTERIOR GP
        CC55-58        SEQUENCE NUMBER OF LAST INSIDE JUNCTION POINT
        CC59-62        SEQUENCE NUMBER OF LAST OUTSIDE JUNCTION POINT
****
      CC63      =  1 SUPPRESS INTERNAL REORDERING OF UNKNOWNS
      CC64-68         MINIMUM G-NUMBER OF NEW POSITIONS (TURNS ON MOVEMENT
                      VECTORS FOR NON-INTERSECTION, NON-FIXED GPS WITH
                      LOWER G-NUMBERS)
      CC69      =  1 DO NOT COMPUTE FINAL INVERSES
      CC70      =  1 ADJUSTED POSITIONS OUTPUT ON TAPE15
      CC71            NOT USED BY TRAV10
      CC72      =  1 ADJUSTMENT PERFORMED ON EUROPEAN DATUM,INTERNATIONAL
                      ELLIPSOID,AZIMUTHS FROM NORTH,EAST LONGITUDES
      CC73      =  1 RESIDUALS GROUPED AROUND INTERSECTION STATIONS.
                      CONDITION  ORDER AND TYPE IN GP CARDS MUST BE
                                 34   OR...
                                 44   OR...
                                 4
                      ALL OBSERVATION TYPES WILL BE GROUPED.
      CC74      =  1 SUPPRESS PRINTING OF DELETED OBSERVATIONS
                =  2 SUPPRESS PRINTING OF ALL OBSERVATIONS.
      CC75      =  1 PRINT ONLY RESIDUALS WHOSE NORMALIZED VALUE
                      EXCEEDS 1.0
      CC76-80         DESIGNATE NEW ACCESSION NUMBER TO BE USED WITH
                      ALL SUPERSEDED (READJUSTED) POSITIONS
****
1.2   GEODETIC POSITION CARD
      CC01     CARD TYPE CODE
      CC02-06  G NUMBER (SOURCE DOCUMENT IDENTIFICATION)
      CC07-36  STATION NAME
      CC37-47  GEODETIC LATITUDE DEG-MIN-SEC TO 5 DECIMAL PLACES
               DECIMAL POINT IMPLIED BETWEEN CC42-43
      CC48-59  GEODETIC LONGITUDE DEG-MIN-SEC TO 5 DECIMAL PLACES
               DECIMAL POINT IMPLIED BETWEEN CC54-55
      CC60-65  ELEVATION, METERS TO 2 DECIMAL PLACES,DECIMAL POINT
               IMPLIED BETWEEN CC63-64
      CC66-69  GEOID HEIGHT, METERS TO 1 DECIMAL PLACE, DECIMAL
               POINT IMPLIED BETWEEN CC68-69
      CC70-78  PLANE COORDINATE ZONE CODES. THREE FIELDS, 3 COLUMNS
               LONG, WHERE FIRST TWO COLUMNS REPRESENT STATE CODE AND
               THIRD COLUMN PLANE COORDINATE CODE. (ALSO SEE TABLE OF
               STATE PLANE COORDINATE ZONE CODES IN DECK CALLED STPCZNS.
      CC79-80  ORDER AND TYPE OF STATION (SEE ALLOWABLE CODES IN
               FULL PREPROCESSOR SPECIFICATIONS).

****
1.3   CONSTRAINED POSITION CARD
      CC01-06  BLANK
      CC07-36  STATION NAME
      CC37-66  BLANK
      CC67-69  LATITUDE STANDARD ERROR IN METERS
               (IMPLIED DECIMAL POINT BETWEEN CC68 AND CC69)
      CC70-72  LONGITUDE STANDARD ERROR IN METERS
               (IMPLIED DECIMAL POINT BETWEEN CC71 AND CC72)

****
1.4   ASTRONOMIC POSITION CARD
      CC01     CARD TYPE CODE
      CC02-06  A NUMBER (SOURCE DOCUMENT IDENTIFICATION)
```

```
      CC07-36  STATION NAME
      CC37-44  ASTRONOMIC LATITUDE DEG-MIN-SEC TO 2 PLACES,DECIMAL
               POINT IMPLIED BETWEEN CC42-43
      CC48-56  ASTRONOMIC LONGITUDE DEG-MIN-SEC TO 2 PLACES, DECIMAL
               POINT IMPLIED BETWEEN CC54-55
      CC70-71  STATE CODE

****
1.5   OBSERVATION CARD
      CC01     CARD TYPE CODE
      CC02-06  G NUMBER (SOURCE DOCUMENT IDENTIFICATION)
      CC07-30  OBSERVING STATION NAME
      CC31-36  JULIAN DATE OF OBSERVATION DAY-YEAR, WHERE DAY=3 DIGIT
               JULIAN DAY NUMBER, AND YEAR=3 DIGIT YEAR.
               EXAMPLE  14 MAY 1886 BECOMES  134886
      CC37-66  OBSERVED STATION NAME
      CC67-71 AS FOLLOWS

**    A N G U L A R  OBSERVATIONS

      CC67-68  STANDARD ERROR IN SECONDS, TO ONE DECIMAL
      CC69-70  ABSTRACT (LIST) NUMBER
      CC71     VISIBLE FROM THE GROUND CODE V

**    D I S T A N C E   OBSERVATIONS

      CC67-69  STANDARD ERROR, CONSTANT PART IN MM TO TENTHS OF MM
      CC70-71  STANDARD ERROR, PROPORTIONAL PART, IN PPM, TO ONE DECIMAL
**
      CC72-80  OBSERVED VALUE

**    A N G U L A R   OBSERVATIONS
               DEG-MIN-SEC TO 2 DECIMALS, DECIMAL POINT IMPLIED BETWEEN
               CC78-79

**    D I S T A N C E   OBSERVATIONS
               METERS TO 3 DECIMAL PLACES, DECIMAL POINT IMPLIED
               BETWEEN CC77-78


 1.6  ACCURACY REQUEST CARD
       CC07-30   FROM STATION NAME
       CC37-66   TO STATION NAME

******

B.2    TRAV DECK STRUCTURE
            OPTION CARD (ONE ONLY)
            GEODETIC POSITION CARDS
              BLANK CARD
            CONSTRAINED POSITION CARDS
              BLANK CARD
            ASTRONOMIC POSITION CARDS
              BLANK CARD
            OBSERVATION CARDS FOR DIRECTIONS
             BLANK CARD
            OBSERVATION CARDS FOR AZIMUTHS
              BLANK CARD
            OBSERVATION CARDS FOR DISTANCES
              BLANK CARD
            ACCURACY REQUEST CARDS
               END OF FILE

******

    *******************************************************************
```

APPENDIX C - THE FULL PREPROCESSOR - PREPROC

C.1 GENERAL FLOW

PREPROC IS A TWO PASS PROGRAM. ERROR MESSAGES ARE NOTED IN SEC. 2.2 FOR EACH PASS THROUGH THE DATA. ALL MESSAGES NOTED ARE FATAL. PASS 1 MESSAGES CAUSE IMMEDIATE TERMINATION OF EDITING AT THE END OF THAT SECTION. ANY MESSAGES CONCERNING IMPROPER DECK STRUCTURE (MESSAGES 1 THROUGH 10 OF PASS 1) WILL SHOW THE FIRST 10 ERRORS. IF THE NUMBER OF ERRORS EXCEED 10 THE OUTPUT IS CANCELLED (THE MESSAGE WILL GIVE TOTAL COUNT OF RECORDS IN ERROR). ALL OTHER MESSAGES ARE DESCRIBED IN MESSAGES 11 AND 12. THESE ARE NOTED BY UNDERSCORING BY X FOR FATAL AND W FOR WARNING.

DURING PASS 2, MESSAGES 1 AND 2 WILL TERMINATE CHECKING AT THE END OF THE GEOGRAPHIC POSITIONS. MESSAGES OF TYPE 1 AND 3 PRODUCED AFTER THE GPS WILL CAUSE TERMINATION AT END OF DATA. THESE MESSAGES ARE NOTED IN SEC. 2.3.

PREPROC CAN ACCEPT BOTH CARD DECKS AND UPDATE FORMAT DECKS. ERRORS ARE FLAGGED AND THE CARD INPUT SEQUENCE NUMBER IS GIVEN OR THE UPDATE SEQUENCE NUMBER IS GIVEN TO ALLOW FOR EASIER CORRECTION OF ERRORS.

C.2 ERROR MESSAGES

2.1 SEVERITY OF ERRORS

W - WARNING ISSUED, BUT EXECUTION WILL CONTINUE

F - FATAL. DECK SCANNING CONTINUES, BUT NO OUTPUT FILE (TRAVIN) WILL BE GENERATED. A DUMP WILL BE CALLED AFTER SCANNING DECK FOR ADDITIONAL ERRORS.

2.2 MESSAGES - PASS I

1. OPTION CARD IN ERROR
2. NO GPS IN DECK
3. GPS OUT OF ORDER OR ALL (NO. OF GPS) IN ERROR.
4. NO FIXED POSITIONS IN DECK
5. FIXED POSITIONS OUT OF ORDER OR ALL (NO. OF FIXED POSITIONS) FIXED POSITIONS IN ERROR.
6. ASTRO DATA OUT OF ORDER OR ALL (NO. OF ASTRO POSITIONS) ASTRO POSITIONS IN ERROR
7. DIRECTIONS OUT OF ORDER OR ALL (NO. OF DIRECTIONS) DIRECTIONS IN ERROR.
8. AZIMUTHS OUT OF ORDER OR ALL (NO. OF AZIMUTHS) AZIMUTHS IN ERROR.
9. DISTANCES OUT OF ORDER OR ALL (NO. OF DISTANCES) DISTANCES IN ERROR.
10. IMPROPER DECK STRUCTURE PREMATURE END OF DATA.
11. FATAL ERRORS IN DATA HAVE TERMINATED ANY FURTHER PROCESSING OF THIS JOB. PASS I OF PROGRAM WILL LIST THE FATAL ERRORS GENERATED BY EACH SECTION OF THE INPUT FILE. THESE ERRORS ARE FLAGGED BY UNDERSCORING AN X IN THE COLUMN IN ERROR.

2.3 MESSAGES - PASS II

1. ILLEGAL CHARACTER IN FIRST TWO CHARACTERS OF NAME FIELD. THIS MESSAGE DESCRIBES THE ERROR IN THE NAME FIELD OF THE PREVIOUSLY LISTED DATA RECORD. THE FIELDS WHERE POSSIBLE ILLEGAL CHARACTERS MAY BE ARE UNDERSCORED BY AN X. THE JOB IS TERMINATED IF THE ERROR OCCURS IN THE GP DECK AT THE END OF THE GPS.
2. DUP GP IN DECK. FATAL ERROR, STOPS PROCESSING BEFORE OBSERVATIONS ARE NUMBERED.
3. FROM AND TO STATION SAME. ANY OBSERVATION WITH THE NAME

FIELDS EQUAL (EXCEPT BLANK NAMES IN ACCURACY CARDS) WILL TERMINATE ON A FATAL ERROR.

NOTE ALL DATA RECORDS LISTED AS ERRORS SHOW A SEQUENCE NUMBER OF 20 CHARACTERS ON THE RIGHT.

A. CARD DECK INPUT - SEQ. NO. IS SEQUENTIAL WITHIN INPUT DECK.

B. UPDATE FILE - SEQ. NO. SHOWS THE DECK NAME AND RECORD NUMBERS RELATIVE TO THE INPUT DECK.

C.3 NAMES

GP CARDS, FIXED POSITION CARDS AND ASTRO POSITION CARDS HAVE ONE NAME ONLY IN CC7-36. OTHER CARD TYPES HAVE TWO NAMES, A FROM-STATION-NAME (FSN) IN CC7-30 AND A TO-STATION-NAME (TSN) IN CC37-66. NOTE THAT FSNS ARE ALWAYS 24 OR FEWER CHARACTERS IN LENGTH. IT IS UNDERSTOOD THAT FSNS ARE PADDED WITH SIX BLANKS ON THE RIGHT BEFORE COMPARISON WITH THE TABLE OF NAMES.

NAMES MUST BEGIN IN THE PROPER COLUMNS OR F ERRORS WILL OCCUR. NAMES MUST ALSO START WITH A LETTER (A-Z) OR NUMBER (0-9) AND THE SECOND CHARACTER MUST BE EITHER A LETTER (A-Z) OR NUMBER (0-9) OR ONE OF THE FOLLOWING SPECIAL CHARACTERS

BLANK
PERIOD
HYPHEN

OR ELSE THE MESSAGE ILLEGAL CHARACTER IN NAME FIELD WILL BE DISPLAYED ALONG WITH A FATAL ERROR FLAG.

C.4 SPECIFICATIONS FOR PREPROC FIELD CHECKING BY CARD TYPE

4.1 OPTION CARD

COLUMN	ALLOWABLE CONTENTS	SEVERITY
07	BLANK	F

4.2 GP CARD

COLUMN	ALLOWABLE CONTENTS	SEVERITY	
01	BLANK OR L	F	CODE
07-08	LEGAL NAME CHARS	F	
37--38	INTEGER)= 90	F	LATITUDE DMS
39--40	INTEGER)= 60	F	,,
41--47	INTEGER)= 6000000	F	,,
48--50	INTEGER)= 360	F	LONGITUDE DMS
51--52	INTEGER)= 60	F	,,
53--59	INTEGER)= 6000000	F	,,
60--63	SIGNED INTEGER (*)	F	ELEVATION (***)
64--65	INTEGER OR SC	F	,,
66--68	SIGNED INTEGER (*)	F	GEOID HEIGHT****
69	INTEGER	F	,,
70--72	ALLOWABLE PCZ (**)	W	
73--78	ALLOWABLE PCZ OR BLANK	W	
79--80	ALLOWABLE CLASS/ ORDER CODE	W	

(*) FOR SIGNED INTEGERS, THE + SIGN MAY BE OMITTED

(**) SEE TABLE OF VALID STATE PLANE COORDINATE ZONES DOCUMENTED ELSEWHERE.

(***)MUST CONTAIN VALUE EXCEPT WHEN CLASS/ORDER CODE EQUALS 34, 45, OR 49

(****)MUST BE IN RANGE OF - 50 TO 50 . MUST CONTAIN A VALUE EXCEPT WHEN CLASS/ORDER CODE EQUALS 44 OR 49

4.3 ASTRO POSITION CARD

COLUMN	ALLOWABLE CONTENTS	SEVERITY	
01	P	F	CODE
07--08	LEGAL NAME CHARS	F	
37--38	INTEGER)= 90	F	ASTRO LATITUDE
39--40	INTEGER)= 60	F	DMS
41--44	INTEGER)= 6000	F	,,
48--50	INTEGER)= 360	F	ASTRO LONGITUDE
51--52	INTEGER)= 60	F	DMS
53--56	INTEGER)= 6000	F	,,
70--71	LEGAL STATE CODE	W	

NOTE IT IS ALLOWED TO HAVE LAT OR LONG MISSING, BUT NOT BOTH

4.4 FIXED POSITION CARD

COLUMN	ALLOWABLE CONTENTS	SEVERITY
01	BLANK	F

4.5 DIRECTION CARD

COLUMN	ALLOWABLE CONTENTS	SEVERITY	
01	1,2,3,4,R,Z	F	CODE
07--08	LEGAL NAME CHARS	F	
31--33	DAY CODE (*)	W	DATE
34--36	800)=INTEGER)= 977	W	,,
37--38	LEGAL NAME CHARS	F	
67--68	INTEGER	F	STANDARD ERROR
69--70	INTEGER	F	ABSTRACT NO.
71	BLANK OR V	W	
72--74	INTEGER)= 360	F	DIRECTION DMS
75--76	INTEGER)= 60	F	,,
77--80	INTEGER)= 6000	F	,,

(*) DAY CODES ARE BASICALLY INTEGERS BETWEEN 001 AND 366 BUT THE SYMBOL X MAY BE USED TO DENOTE THE PRECISION OF THE DATE AS THE FOLLOWING EXAMPLE ILLUSTRATES

231 ACTUAL DAY OF OBSERVATION WAS KNOWN
23X DATE ACCURATE TO WITHIN 3 TO 30 DAYS
2XX DATE KNOWN TO WITHIN 1 TO 6 MONTHS
XXX 6 MONTH PRECISION OR WORSE

4.6 AZIMUTH CARD

COLUMN	ALLOWABLE CONTENTS	SEVERITY	
01	A,B,J	F	CODE
07--08	LEGAL NAME CHARS	F	
31--33	DAY CODE (*)	W	DATE
34--36	800)=INTEGER)= 977	W	,,
37--38	LEGAL NAME CHARS	F	
67--68	INTEGER	F	STANDARD ERROR
72--74	INTEGER)= 360	F	AZIMUTH DMS
75--76	INTEGER)= 60	F	,,
77--80	INTEGER)= 6000	F	,,

(*) SEE EXPLANATION OF DAY CODE IN SECTION 4.5

4.7 DISTANCE CARD

COLUMN ALLOWABLE CONTENTS SEVERITY

```
            01          F,M,T,G,C,U,X,Y,E    F           CODE
            07--08      LEGAL NAME CHARS     F
            31--33      DAY CODE (*)         W           DATE
            34--36      800 )=INTEGER )= 977 W            ,,
            37--38      LEGAL NAME CHARS     F
            70--71      INTEGER              F           STANDARD ERROR
            72--80      NONZERO INTEGER      F           DISTANCE

         (*)  SEE EXPLANATION OF DAY CODE IN SECTION 4.5

         4.8 ACCURACY CARD

            COLUMN      ALLOWABLE CONTENTS   SEVERITY
            07--08      LEGAL NAME CHARS     F
            37--38      LEGAL NAME CHARS     F

C.5  ALLOWABLE CLASS/ORDER CODES

    TT  20  31  44  50  60  71  85  90
    10  21  32  45  51  61  72      91
    11  22  34      53  62  74      93
    13  23  35      54  63  75      94
    14  24  36      55  64  76      95
    15  25  38      57  65  78      97
    17  26  39      58  66  79      98
    18  27              67
        28              68
        29              69


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            APPENDIX D  -   TRAV10 OUTPUTS

D.1  OUTPUT FROM THE INPUT AND ADJUSTMENT PHASES
     1. STANDARD ERRORS AND OPTIONS USED IN THIS RUN
     2. INPUT STATION POSITIONS, ELEVATIONS, ETC.
     3. FIXED POSITIONS WITH THEIR ASSIGNED SEQUENCE NUMBER.
     4. LIST OF INPUT ASTRONOMICAL POSITIONS.
     5. INPUT DIRECTIONS; COMPUTED CORRECTIONS FOR DEFLECTION OF THE
        VERTICAL, NORMAL SECTION TO GEODESIC CORRECTION, AND
        SKEW NORMAL ( FOR ELEVATION OF THE FOREPOINT); CORRECTED
        DIRECTION. DIRECTIONS FOR WHICH BOTH END POINTS ARE NOT
        IN THE GP LIST ARE DELETED. SINGLE DIRECTION LISTS ARE
        DELETED.
     6. OBSERVED AZIMUTHS; LAPLACE CORRECTION; GEODETIC AZIMUTH.
        AZIMUTHS FOR WHICH BOTH ENDS OF THE LINE ARE NOT IN THE
        GP LIST ARE DELETED WITH ASTERIKS IN THE ELLIPSOIDAL AZIMUTH
        FIELD. AZIMUTHS FOR WHICH THE LAPLACE CORRECTION IS LARGER
        THAN 600 SECONDS OF ARC (WHICH IS USUALLY AN INDICATION THAT
        THE ASTRONOMIC LONGITUDE EITHER WAS NOT INPUT OR WAS INPUT
        INCORRECTLY) ARE DELETED WITH PLUS SIGNS IN THE ELLIPSOIDAL
        AZIMUTH FIELD.
     7. INPUT DISTANCES; CORRECTIONS FOR REFRACTION AND GEOID HEIGHT;
        ELLIPSOIDAL GEODESIC DISTANCE. IF BOTH END POINTS OF THE
         LINE ARE NOT IN THE GP LIST, THE DISTANCE IS DELETED WITH
          ASTERISKS IN THE ELLIPSOIDAL DISTANCE FIELD.
          FOR MARK TO MARK DISTANCES, IF BOTH STATIONS DO NOT HAVE
           BOTH ELEVATIONS AND GEOID HEIGHTS, OR IF THE HEIGHT
          DIFFERENCE IS GREATER THAN THE MARK TO MARK
          DISTANCE BETWEEN THE POINTS, THE OBSERVATION IS
           DELETED WITH PLUS SIGNS IN THE ELLIPSOIDAL DISTANCE
           FIELD.
     8. PARAMETERIZATION OF NORMAL EQUATION STRUCTURE AND SIZE.
        OBSERVATIONAL SUMMARY AND SOLVABILITY ANALYSIS. ORDER OF
        ELIMINATION OF EACH STATION AFTER REORDERING OF UNKNOWNS.
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          SUMMARY BY COMPONENT.
       9. FOR EACH ITERATION
          A. OBSERVATIONS FOR WHICH THE √OBSERVED MINUS COMPUTED√
             TERM IS LARGE. TERMS WHICH WILL BE PRINTED ARE
              DISCUSSED IN SECTION 12.10
          B. RMS CORRECTION TO LATITUDE AND LONGITUDE (IN SECONDS
             OF ARC), VARIANCE OF UNIT WEIGHT AND DEGREES OF FREEDOM.
      10. STANDARD DEVIATION OF THE AZIMUTH AND DISTANCE BETWEEN PAIRS
          OF POINTS, AS REQUESTED IN THE ACCURACY SECTION OF THE
          TRAVDECK.
      11. JOB STATISTICS; TIME AND CENTRAL MEMORY USAGE..

D.2  POSTPROCESSOR AND RESIDUAL ANALYSIS PHASE
 OUTPUT... THE PROGRAM OUTPUTS THE FOLLOWING INFORMATION IN ALL CASES.
            1. ADJUSTED POSITIONS IN DEGREES, MINUTES, AND SECONDS,
               WITH STATION SEQUENCE NUMBER, G-NUMBER, NAME, ELEVATION,
               GEOID HEIGHT, STATE PLANE COORDINATE ZONE(S), AND ORDER/
               TYPE.
            2. ADJUSTED OBSERVATIONS, WITH SEQUENCE NUMBER, FROM- AND
               TO-STATION NUMBERS AND NAMES, WEIGHT, RESIDUAL, RESIDUAL
               TIMES SQUARE ROOT OF WEIGHT, AND ORIGINAL OBSERVATION
               (SECONDS ONLY, IN THE CASE OF DIRECTIONS AND AZIMUTHS).
               SEE OPTION 11 BELOW.
            3. MAXIMUM RESIDUAL, MEAN RESIDUAL, AND MEAN ABSOLUTE VALUE
               OF RESIDUAL, FOR EACH CATEGORY OF OBSERVATION REPRESENTED
               IN THE ADJUSTMENT, FOR LONG AND SHORT LINES.
            4. THE NUMBER OF NO-CHECK OBSERVATIONS.
            5. NUMBER OF OBSERVATIONS, MAXIMUM AND MINIMUM NORMALIZED
               RESIDUAL AND RANGE, MEAN NORMALIZED RESIDUAL, MEAN ABSO-
               LUTE VALUE OF NORMALIZED RESIDUAL.
            6. SEQUENCE NUMBERS OF OBSERVATIONS WITH NORMALIZED RESI-
               DUALS GREATER THAN 2. IF THERE ARE MORE THAN 20 SUCH
               OBSERVATIONS, ONLY THE 20 WITH THE GREATEST ABSOLUTE
               VALUE OF NORMALIZED RESIDUAL ARE PRINTED.
            7. VALUE OF TAU, USED FOR COMPARISON WITH NORMALIZED
               RESIDUALS (SEE NOTE ON REJECTS BELOW).
            8. VARIANCE OF THE UNIT WEIGHT, DEGREES OF FREEDOM, AND
               ACCEPTABLE RANGE OF VARIANCE USING A CHI-SQUARE TEST.
            9. STATION NAMES IN ALPHABETICAL ORDER, WITH THEIR SEQUENCE
               NUMBERS.

        ... OPTIONAL OUTPUT (ONLY IF SIGNALS IN INPUT ARE ACTIVATED).
            10. OLD FREE STATIONS HAVE G-NUMBER CHANGED.
            11. NORMALLY ALL ADJUSTED OBSERVATIONS ARE PRINTED.
               OPTIONALLY, ONLY THOSE OBSERVATIONS FOR WHICH THE
               NORMALIZED RESIDUAL IS GREATER THAN 1 ARE PRINTED.
            12. FOR EVERY OLD FREE STATION, THE DIFFERENCES BETWEEN
               INPUT AND ADJUSTED POSITIONS IN LATITUDE, LONGITUDE,
               DISTANCE, AND AZIMUTH, ARE PRINTED.
            13. FOR EVERY INTERSECTION STATION, ALL OBSERVATIONS WHICH
               HAVE THAT STATION AS A TO-STATION ARE PRINTED, INCLUDING
               TYPE OF OBSERVATION, SEQUENCE NUMBER, FROM- AND TO-
               STATION NUMBERS AND NAMES, RESIDUAL, FORWARD AZIMUTH AND
               DISTANCE.
             14. FOR EVERY PAIR OF STATIONS BETWEEN WHICH OBSERVATIONS
                  EXIST, THE FROM AND TO STATION NAMES ARE PRINTED
                  TOGETHER WITH THE ADJUSTED FORWARD AZIMUTH, BACK
                  AZIMUTH, AND DISTANCE.
            15. ALL INFORMATION MENTIONED IN POINT 1 UNDER BASIC
               OUTPUT (EXCEPT SEQUENCE NUMBER) IS WRITTEN TO DATA SET
               NEWGPS IN GP-CARD FORMAT.

 REJECTS...NO DATA IS REJECTED IN POSTPRC. HOWEVER, THE RESIDUALS ARE
            COMPARED AGAINST A TAU VALUE WHICH IS A FUNCTION OF THE
            VARIANCE, DEGREES OF FREEDOM, AND NUMBER OF OBSERVATIONS
            IN THE ADJUSTMENT (FORMULATION BY A. POPE). IF ANY NORMAL-
```

IZED RESIDUAL (RESIDUAL TIMES SQUARE ROOT OF WEIGHT) IS GREATER THAN TAU, IT IS MARKED WITH AN ASTERISK NEXT TO THE PRINTED NORMALIZED RESIDUAL IN SECTION 2 ABOVE. THIS MEANS THE OBSERVATION SHOULD BE LOOKED AT. THE OBSERVATION IS N O T REMOVED FROM THE DATA FILE BY THE PROGRAM.

D.3 ABNORMAL TERMINATIONS

IN CASE OF FATAL ERRORS, TRAV10 WILL ABEND, PREVENTING ANY FURTHER PROCESSING OF THE JOB. THE JCL LOG WILL INDICATE A COMPLETION CODE OF USER 240, WHICH IS ISSUED BY THE FORTRAN ERROR MONITOR. THE IHN240I MESSAGE WILL INDICATE THE USER COMPLETION CODE ISSUED BY TRAV10. THE MEANINGS OF THESE CODES ARE

101 THE KORE ROUTINE CANNOT OBTAIN CENTRAL PROCESSOR MEMORY SPACE. THIS MESSAGE SHOULD NEVER BE ISSUED. IF IT OCCURS, SEE THE PROGRAMMING STAFF.

104 A PROGRAM LOGIC ERROR OCCURRED WHEN READING THE NORMAL EQUATION PARTITIONS FROM MASS STORAGE. SEE THE PROGRAMMING STAFF.

105 A PROGRAM LOGIC ERROR OCCURRED WHEN WRITING THE NORMAL EQUATION PARTITIONS FROM MASS STORAGE. SEE THE PROGRAMMING STAFF.

106 AN ERROR OCCURRED WHEN WRITING A NORMAL EQUATION PARTITION ON MASS STORAGE. THE ERROR IS PROBABLY DUE TO A HARDWARE PROBLEM ON THE DISK. RESUBMIT THE JOB. IF THE ERROR PERSISTS, SEE THE PROGRAMMING STAFF.

200 TRAV10 PURPOSELY ABORTS A RUN BECAUSE OF INSUFFICIENT WORK SPACE OR BECAUSE OF A DIVERGING OR SINGULAR SOLUTION. THE MESSAGE √THE FOLLOWING DUMP IS STRICTLY INTENTIONAL√ IS PRODUCED ON THE OUTPUT LISTING. THE EXACT REASON FOR THE ABORT IS FOUND PRECEDING THE JOB STATISTICS.
IF THE REASON IS INSUFFICIENT SPACE, INCREASE THE REGION PARAMETER ON THE JOB CARD AND RESUBMIT THE JOB. THE OTHER ERROR MESSAGES INDICATE THAT THE PROBLEM LIES WITH THE DATA. SEE SECTION D.4.

201 THE HERESI ROUTINE DID NOT HAVE ENOUGH SPACE TO GENERATE A BACK SOLUTION. THIS IS A PROGRAM LOGIC ERROR AND SHOULD NEVER OCCUR IN TRAV10. IF IT DOES, SEE THE PROGRAMMING STAFF.

301 LOGIC ERROR IN THE REORDER ALGORITHM. SEE THE PROGRAMMING STAFF.

D.4 DATA DEPENDENT MESSAGES

4.1 TRAV10 DID NOT FIND ANY DATA.
SELF EXPLANATORY. USUALLY CAUSED BY A JCL ERROR SUCH THAT THE INPUT TRAVDECK IS NOT PROPERLY PASSED TO TRAV10.

4.2 ERROR
TOO MANY POSITIONS
THE MAXIMUM NUMBER OF POSITIONS IS XXX

THE REGION SIZE UNDER WHICH THE PROGRAM IS RUNNING IS TOO SMALL TO SUPPORT EVEN THE INPUT OF GP CARDS. RERUN THE JOB IN A LARGER REGION. SEE SECTION 8 FOR A GUIDE TO CALCULATING THE PROPER REGION SIZE.

4.3 ERROR
SYSTEM LACKS DEGREES OF FREEDOM, ADJUSTMENT IMPOSSIBLE.

THE DEGREES OF FREEDOM CALCULATED FROM THE EQUATION
DF = MAXIMUM OBS SEQUENCE NO. - (2* NUMBER OF GPS
+ NUMBER OF ABSTRACTS)
INDICATES THAT THERE ARE NOT ENOUGH OBSERVATIONS TO SOLVE FOR ALL THE UNKNOWNS IN THE SYSTEM.

4.4 ERROR
REGION SIZE REQUESTED INADEQUATE FOR AUTO. REORDER
REQUIRED REGION IS XXXXXXK MORE THAN THIS RUN,
INTERNAL REORDER OPTION CANCELED*******

THE SOLUTION PROCEEDS WITHOUT THE BENEFIT OF REORDERING. ON SUBSEQUENT RUN, INCREASE THE REGION SIZE BY THE AMOUNT INDICATED.

4.5 ERROR
MAXIMUM NUMBER OF CONNECTIONS EXCEEDED
MAXIMUM NUMBER OF CONNECTIONS IS XXXX
STATION YYYY EXCEEDS THIS MAXIMUM

THE NUMBER OF CONNECTIONS AT STATION YYYY EXCEEDS THE MAXIMUM FOR WHICH THE REORDERING ROUTINES WERE DESIGNED. THE NUMBER OF CONNECTIONS IS THE SUM OF THE NUMBER OF STATIONS CONNECTED DIRECTLY TO STATION YYYY BY OBSERVATIONS AND THE NUMBER OF INDIRECT CONNECTIONS. (ALL PAIRS OF STATIONS SEEN BY STATION YYYY WITHIN A GIVEN ABSTRACT ARE INDIRECTLY CONNECTED). IF THIS MESSAGE OCCURS, SEE THE PROGRAMMING STAFF TO HAVE A SPECIAL VERSION OF TRAV10 COMPLIED WITH A LARGER MAXIMUM NUMBER OF CONNECTIONS.

4.6 ERROR
REGION SIZE REQUESTED CANNOT SUPPORT MINIMAL PARTITION.
PLEASE RECOMPUTE REGION SIZE.

THE REGION IN WHICH THE PROGRAM IS RUNNING IS NOT LARGE ENOUGH TO ALLOW WORK SPACE FOR EVEN THE SMALLEST POSSIBLE PARTITION OF THE NORMAL EQUATIONS. SEE SECTION 8 FOR A GUIDE TO CALCULATING THE REGION SIZE. RECOMPUTE THE REGION SIZE AND RESUBMIT.

4.7 CONGRADULATIONS
REQUESTED REGION SIZE ADEQUATE FOR IN-CORE SOLUTION

PARTITIONING OF THE NORMAL EQUATIONS IS NOT NECESSARY AND THE SOLUTION IS PERFORMED IN-CORE. IT MAY BE POSSIBLE TO RUN THE JOB IN A SMALLER REGION AND THUS OBTAIN BETTER TURNAROUND. SEE SECTION 8.

4.8 SYSTEM TOO LARGE FOR IN-CORE SOLUTION
NORMAL EQUATIONS WILL BE WRITTEN OUT IN XXXX RECORDS ON DISK

WITH THE REGION SIZE WITHIN WHICH THE PROGRAM IS RUNNING, PARTITIONING OF THE NORMAL EQUATIONS HAS BEEN NECESSARY. THE SOLUTION PROCEEDS NORMALLY.

4.9 ERROR
RUN BEING KILLED DUE TO PREVIOUS ERRORS
UNDETERMINED (U) STATIONS HAVE BEEN DETECTED

THE SOLVABILITY ANALYSIS (SEE SECTION 12.2) HAS INDICATED THAT THERE IS AT LEAST ONE UNDETERMINED STATION AND THE NORMAL EQUATIONS MUST THEREFORE BE SINGULAR. ALTHOUGH THE SOLVABILITY ANALYSIS CANNOT GUARANTEE SOLVABILITY, THE EXISTENCE OF UNDETERMINED STATIONS GUARANTEES LACK OF SOLVABILITY. THE UNDETERMINED STATIONS MUST BE REMOVED OR FIXED OR ELSE MORE DATA MUST BE ADDED TO DETERMINE

THEM.

4.10 ERROR
RUN ABORTED DUE TO EXCESSIVE N-TERMS.

USUALLY INDICATES A GROSS ERROR IN THE INPUT POSITIONS. SEE SECTION 12.10 FOR THE DEFINITION OF EXCESSIVE N-TERMS

4.11 ERROR
SINGULAR SOLUTION
SOLUTION BROKE DOWN AT STATION XXXX LATITUDE (OR LONGITUDE)

THE SOLUTION BREAKS DOWN DURING THE REDUCTION OF THE NORMAL EQUATIONS, INDICATING A SINGULAR SYSTEM CAUSED BY ONE OR MORE UNDETERMINED COORDINATES. THIS CONDITION MAY ARISE BECAUSE OF A SUBTLE TRUE SINGULARITY OR BECAUSE OF WEAK GEOMETRY. FIND THE CAUSE OF THE SINGULARITY AND REMEDY BY ADDING MORE DATA OR CONSTRAINTS. THE STATION NUMBER XXXX REFERS TO THE ORDER OF ELIMINATION OF THE STATIONS.

4.12 SLOWLY CONVERGING OR DIVERGING SOLUTION.

CHECK FOR BAD PRELIMINARY POSITIONS. THIS CONDITION MAY ALSO BE CAUSED BY A COMBINATION OF CRITICAL GEOMETRY AND UNREALISTIC WEIGHTS, PARTICULARLY OVER SHORT LINES.

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(Continued from inside front cover)

NOAA Technical Memorandums National Ocean Survey
National Geodetic Survey subseries

NOS NGS-1 Use of climatological and meteorological data in the planning and execution of National Geodetic Survey field operations. Robert J. Leffler, December 1975, 30 p. (PB249677). Availability, pertinence, uses, and procedures for using climatological and meteorological data are discussed as applicable to NGS field operations.

NOS NGS-2 Final report on responses to geodetic data questionnaire. John F. Spencer, Jr., March 1976, 39 p. (PB254641). Responses (20%) to a geodetic data questionnaire, mailed to 36,000 U. S. land surveyors, are analyzed for projecting future geodetic data needs.

NOS NGS-3 Adjustment of geodetic field data using a sequential method. Marvin C. Whiting and Allen J. Pope, March 1976, 11 p. (PB253-967). A sequential adjustment is adopted for use by NGS field parties.

NOS NGS-4 Reducing the profile of sparse symmetric matrices. Richard A. Snay, June 1976, 24 p. (PB258476). An algorithm for improving the profile of a sparse symetric matrix is introduced and tested against the widely used reverse Cuthill-McKee algorithm.

NOS NGS-5 National Geodetic Survey data: availability, explanation, and application. Joseph F. Dracup, June 1976, 45 p. (PB258475). This publication summarizes the data and services available from NGS, reviews survey accuracies, and illustrates how to use specific data.

NOS NGS-6 Determination of North American Datum 1983 coordinates of map covers. T. Vincenty, October 1976, 8 p. (PB262442). Predictions of changes in coordinates of map corners are detailed.

NOS NGS-7 Recent elevation change in Southern California. S.R. Holdahl, February 1977, 19 p. (PB265940). Velocities of elevation change have been determined from Southern Calif. leveling data for 1906-62 and 1959-76 epochs.

NOS NGS-8 Establishment of calibration base lines. Joseph F. Dracup, Charles J. Fronczek, and Raymond W. Tomlinson, August 1977, 22 p. (PB277130). Specifications are given for establishing calibration base lines.

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NOS NGS-9 National Geodetic Survey Publications on surveying and geodesy 1976. September 1977. 17 p. (PB275181). This compilation lists publications authored by NGS staff in 1976, sources of availability of out-of-print Coast and Geodetic Survey publications, and information on subscriptions to the Geodetic Control Data Automatic Mailing List.

NOS NGS-10 Use of calibration base lines. Charles J. Fronczek, December 1977, 38 p. A detailed explanation is given for evaluating electronic distance measuring instruments.

NOS NGS-11 Applicability of Array Algebra. Richard A. Snay, February 1978, 22 p. Conditions required for the transformation from matrix equations into computationally more efficient array equations are considered.

NOAA Technical Reports National Ocean Survey
National Geodetic Survey Subseries

NOS 65 NGS 1 The statistics of residuals and the detection of outliers. Allen J. Pope, May 1976, 133 p. (PB258428). A criterion for rejection of bad geodetic data is derived on the basis of residuals from a simultaneous least-squares adjustment; subroutine TAURE is included.

NOS 66 NGS 2 Effect of Geoceiver observations upon the classical triangulation network. R. E. Moose, and S. W. Henriksen, June 1976, 65 p. (PB260921). The use of Geoceiver observations is investigated as a means of improving triangulation network adjustment results.

NOS 67 NGS 3 Algorithms for computing the geopotential using a simple-layer density model. Foster Morrison, March 1977, 41 p. (PB265421). Several algorithms are developed for computing the gravitational attraction with high accuracy of a simple-density layer at arbitrary altitudes. Computer program is included.

NOS 68 NGS 4 Test results of first-order class III leveling. Charles T. Whalen and Emery Balazs, November 1976, 30 p. (PB265-421). Specifications for releveing the National vertical control net were tested and the results published.

NOS 70 NGS 5 Selenocentric geodetic reference system. Frederick J. Doyle, Atef A. Elassal, and James R. Lucas, February 1977, 53 p. (PB266046). Reference system was established by simultaneous adjustment of 1,244 metric-camera photographs of the lunar surface from which 2,662 terrain points were positioned.

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NOS 71 NGS 6 Application of digital filtering to satellite geodesy. C. C. Goad, May 1977, 73 p. (PB270192). Variations in the orbit of GEOS-3 were analyzed for M_2 tidal harmonic coefficient values which perturb the orbits of artificial satellites and the Moon.

NOS 72 NGS 7 Systems for the determination of polar motion. Soren W. Henriksen, May 1977, 55 p. Methods for determining polar motion are described and their advantages and disadvantages compared.

NOAA--S/T 78-108