SLAC-395

GEONET

Stanford Linear Accelerator Center
Survey and Alignment Workshop
on
Data Processing Using Geonet
For Accelerator Alignment

February 20–25, 1992

Prepared for the Department of Energy
under contract number DE-AC03-76SF00515

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CONTENTS

FIGURES

TABLES

PREFACE

This document started as the proceedings of the Geonet workshop held at SLAC in February 1992. All of the material for that workshop was written by Horst Friedsam. Horst's basic structure has been maintained, but the material has been updated to incorporate all the changes made to Geonet since the workshop.

The great majority of the programming for Geonet has been accomplished by Bill Crittenden, Bob Pushor and Catherine LeCocq, with minor contributions by several others in the SLAC Survey & Alignment group.

Bernard Bell
Metrology Department, SLAC
February 1995

INTRODUCTION

The Stanford Linear Collider (SLC) was scheduled to be finished within a three year time frame (1984–87). During this time the underground tunnels had to be constructed and about 1000 magnets positioned before commissioning the accelerator for the first physics run. This tight time schedule called for an automated flow of survey data to expedite the alignment process. We evaluated some commercial database programs including the mainframe system OPTUN and the PC system DBASE IV. Since neither of these met our requirements we started in 1985 to develop our own database system called GEONET, an acronym for Geodetic Networks. We began with a single-user version of GEONET and then enhanced it to a multiple-user version for a local area network. Later, when most of the SLC survey and alignment tasks were finished and other laboratories showed interest in using GEONET, we restructured and transformed the network version to its current state.

1. GEONET STRUCTURE

1.1. SURVEY DATA

1.1.1. Database Structure

GEONET is a flat file database. It structures survey data in a logical and straight forward way using a tree of subdirectories nested four deep (Fig. 1-1).

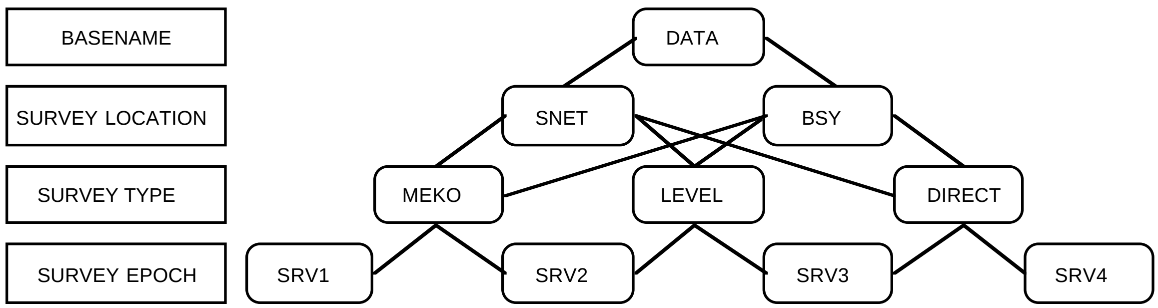

Figure 1–1. Geonet database structure

1.1.1.1. First Level: Basename

The first level of this tree is a generic basename for the type of data. For most installations there are two basenames: DATA for all survey field data, and IMS forall files created by an Industrial Measurement System. It is possible to use up to eight basenames, although there is no menu structure to guide the user through the initial set-up of Geonet. At SLAC the DATA basename has been replaced with 6 basenames covering different projects around the SLAC site. The options are contained in the CHOICES.SYS file in the INIT subdirectory (§1.1.2, Fig. 1-2).

1.1.1.2. Second Level: Survey Location

The second level of the subdirectory tree describes the survey location, *e.g.*, SNET for surface network or NETSIM for network simulations. In the case of IMS data this might be the name of an object to be measured, *e.g.*, a large detector. Up to sixteen entries are possible for this level.

1.1.1.3. Third Level: Survey Type

The third entry contains information about the kind of measurements, *e.g.*, the subdirectory MEKO contains Mekometer measurements and the associated elevation information necessary for the data reduction, while direction measurements are stored in the subdirectory DIRECT. Again, up to sixteen different measurement types are supported. The equivalent for IMS data are the individual parts of the detector which are measured as separate entities.

1.1.1.4. Fourth Level: Survey Epoch

The fourth entry shows the survey epoch where data are stored according to the date the measurements are recorded. Up to sixteen survey epochs are supported, usually named SRV1 to SRV16. This fourth and deepest level in the hierarchical structure is identical for IMS and survey DATA. For example, the subdirectory tree entry DATA\SNET\DIRECT\SRV5 contains direction sets measured as part of the surface network in the fifth epoch.

1.1.2. Configuration Files

The first-level subdirectory INIT contains configuration files defining the database of survey measurements. The first-level names of data bases currently in use are kept in the file CHOICES. SYS (Fig. 1-2). INIT contains four files for each basename defined in CHOICES.SYS (Table 1-1).

```
SNET      1 Surface Network
SLC       1 SLC East
LINAC     1 Linac (to sect 28)
YARD      1 Research Yard
BFACT     1 PEP/B factory
GEN       1 General Surveys
IMS       2 IMS Data
```

Figure 1–2. \INIT\CHOICES.SYS

Table 1–1. GEONET configuration files

Filename	*Description*	*Contents*
*.HST	History file:	information about each location/epoch in the structure (Fig. 1-5).
*.PTH	Path file:	database levels actually activated (Fig. 1-4).
*.STR	Structure file:	information about the 4 levels pertinent to the basename (Fig. 1-3).
*.TBL	Table file:	combined information of the structure and path files in binary form.

```
BFACT    PEP/B Factory

NIT      North Inj Tunnel
SIT      South Inj Tunnel
BRING    B Factory Ring
S4EXTR   Sector 4 Extract
S9EXTR   Sector 9 Extract

LEVEL    Leveling
DIRECT   Directions
DIST     Distances
INVAR    Distinvar
MEKO     Mekometer
OFFSET   Offsets
INTERF   Interferometer
GYRO     Gyroscope
ZENITH   Zeniths

SRV1     Survey 1
SRV2     Survey 2
SRV3     Survey 3
 ...       ...
SRV16    Survey 16
```

Figure 1–3. \INIT\BFACT.STR

```
*      BFACT    BRING    LEVEL    SRV1
*      BFACT    BRING    DIRECT   SRV1
*      BFACT    BRING    MEKO     SRV1
*      BFACT    NIT      LEVEL    SRV1
*      BFACT    SIT      LEVEL    SRV1
*      BFACT    BRING    LEVEL    SRV2
*      BFACT    S4EXTR   DIRECT   SRV1
*      BFACT    S9EXTR   DIRECT   SRV1
```

Figure 1–4. \INIT\BFACT.PTH

```
             BFACT FILESYSTEM HISTORY

Subdirectory                   Usage
----------------------         ---------------------------
BFACT\BRING\LEVEL\SRV1
    Created     05-03-93       B-factory ring survey - May 1993
BFACT\BRING\DIRECT\SRV1
    Created     05-03-93       B-factory ring survey - May 1993
BFACT\BRING\MEKO\SRV1
    Created     05-03-93       B-factory ring survey - May 1993
BFACT\NIT\LEVEL\SRV1
    Created     06-08-93       setup
BFACT\SIT\LEVEL\SRV1
    Created     06-08-93       setup
BFACT\BRING\LEVEL\SRV2
    Created     06-08-93       extra space
BFACT\S4EXTR\DIRECT\SRV1
    Created     06-29-93       Sector 4 Extraction Area
BFACT\S9EXTR\DIRECT\SRV1
    Created     06-29-93       Sector 9 Extraction Area
```

Figure 1–5. \INIT\BFACT.HST

A privileged user with a master password has access to the *.STR structure files in order to customize the GEONET setup for a particular survey site. Using the System Configuration option from the main menu and choosing the Initialization Files option of the following menu presents the user with eight different structure files that can be modified to suit individual needs. Usually only the entries describing the survey locations in the DATA.STR file need changing. Location names are limited by the DOS operating system to 8 characters, but it is recommended that location names be limited to four characters so as to avoid pathnames of unreasonable length.

The description of the type of measurements is fairly standard, showing the common survey methods used for accelerator alignment. These and the survey epoch entries should therefore require no change.

Once the data structure has been customized, survey epochs can be created using the System Configuration option of the main menu and choosing the Data File System option of the following menu. At that time a special subdirectory (ADJUST) that holds the input files for least-squares adjustments for a particular location will be created in the background.

In contrast to the easy task of adding a survey location to the DATA.STR file it is difficult to eliminate a location. One could delete a survey location name from the DATA.STR file with the effect that the subdirectory tree for this particular location stays intact and the location name does not appear in any of the menus. In case the subdirectory tree must be deleted, all files in subdirectories created for this particular survey location must be eliminated using GEONET functions to insure data integrity and safeguard from accidental destruction of important data.

1.2. COORDINATE DATA

GEONET uses a similar scheme for the coordinate and calibration databases. The coordinate database uses COORD as the basename and the name of the location as the second-level subdirectory, *e.g.*, COORD\SNET contains all database entries for the surface network. The necessary files for one-, two- and three-dimensional coordinate databases and ideal coordinates are automatically created when a survey epoch is added to a survey location. Additionally, a subdirectory BACKUP is created. Before a database is updated with new coordinate information the program creates a backup of the current status of the database in COORD\BACKUP which is used for automatic recovery in the event that something goes wrong during the update process.

COORD*n*.PTH and COORD*n*.STR files in the \INIT subdirectory hold subdirectory information. There are as many of each of these files as entries in the CHOICES.SYS file. The *n* in the filename refers to the order of basenames in CHOICES.SYS. In most installations of Geonet there are two of each file: COORD1.* for DATA coordinates and COORD2.* for IMS coordinates. The SLAC installation of Geonet has more: COORD1.* for SNET coordinates (Fig. 1-6), COORD2.* for SLC coordinates, COORD3.* for LINAC coordinates, *etc*. (see CHOICES.SYS in Fig. 1-2).

```
*    COORD    SNET     BNCHMARK
*    COORD    SNET     MONUMENT
*    COORD    SNET     IDEAL
*    COORD    SNET     3DIM
*    COORD    SNET     MAGNET
*    COORD    SNET     TRANS
*    COORD    BLINE    BNCHMARK
*    COORD    BLINE    MONUMENT
*    COORD    BLINE    IDEAL
*    COORD    BLINE    3DIM
*    COORD    BLINE    MAGNET
*    COORD    BLINE    TRANS
```

Figure 1–6. \INIT\COORD1.PTH

1.3. CALIBRATION DATA

The calibration database uses a hierarchy three layers deep for storing calibration data of individual instruments such as level rod offsets and Mekometer calibration results. The basename is CALIB. The second entry shows the measurement device, *e.g.*, LROD or MEKO. The third entry is CAL1 to CAL16 analogous to the survey epoch, thus providing space for up to sixteen different calibrations. However, this third level has not yet been implemented in GEONET: currently all programs which use calibration data expect to find it in CAL1, *e.g.*, the level reduction program expects to find the necessary offsets in CALIB\LROD\CAL1\OFFSET.IDX and the Mekometer reduction program searches for CALIB\MEKO\CAL1\CAL1.DAT. Adding the flexibility to chose between different calibration epochs would require creating another layer of menus. It has not yet been necessary to add this enhancement but the structure to do so is in place.

```
CALIB     Calibration Data

WIRE      Invar Wires
LROD      Leveling Rods
MEKO      Mekometer

CAL1      Calibration 1
CAL2      Calibration 2
CAL3      Calibration 3
  |            |
CAL16     Calibration 16
```

Figure 1–7. \INIT\CALIB.STR

The CALIB.PTH, CALIB.STR and CALIB.TBL files in the \INIT subdirectory contain the necessary subdirectory information for the Calibration database (Figs. 1-7, 1-8).

```
*       CALIB     LROD      CAL1
*       CALIB     MEKO      CAL1
*       CALIB     WIRE      CAL1
```

Figure 1–8. \INIT\CALIB.PTH

1.4. ARCHIVE SUBDIRECTORY

The ARCHIVE procedure allows the user to store onto floppy diskettes data sets that are no longer used, thus creating more space on the hard disk. Formerly the program wrote an archive catalog file to the ARCHIVE subdirectory. This file kept track of the amount of free space on each archive diskette. The new release of ARCHIVE no longer uses this feature; instead it provides two options to restore archived data:

a) Restore the data to the original subdirectory, which may have to be recreated before the restore process can begin.

b) Restore the data to the subdirectory ARCHIVE for temporary use only. In this case the user can view all of the restored files but cannot run any of the reductions or least-squares adjustments using these files.

1.5. GEONET SUBDIRECTORY

The GEONET subdirectory is subdivided as shown in Table 1-2.

Table 1–2. The Geonet subdirectory

Subdirectory	*Contents*
BIN	executable files
DOWNLOAD	data collection programs for downloading to field computers
PARAM	temporary parameter files to transfer information between programs
TDPREVU	Topdraw routines for error ellipse plots
WORK	intermediate work files
TEMP	output files created by the adjustment programs.

The subdirectory PARAM will be used only as long as some programs still require parameter files. Once all programs use command line arguments this subdirectory will be eliminated.

1.6. INIT SUBDIRECTORY

Besides the *.HST, *.PTH, *.STR and *.TBL files described above, the subdirectory INIT contains several other STR structure files (Table 1-3).

Table 1–3. Other Geonet STR structure files

Filename	*Contents*
DOWNLD.STR	information about downloadable data collection programs.
SYSCON.STR	system constant file defining the printer port and editor
TITLE.STR	title for the welcome screen
SPECIAL.STR	special program control file
BIAS.STR	bias information for the coordinate origin
PROTECT.STR	list of subdirectories to be hidden when passwords are chosen.

Fig. 1-9 shows an outline of the whole subdirectory structure used for Geonet.

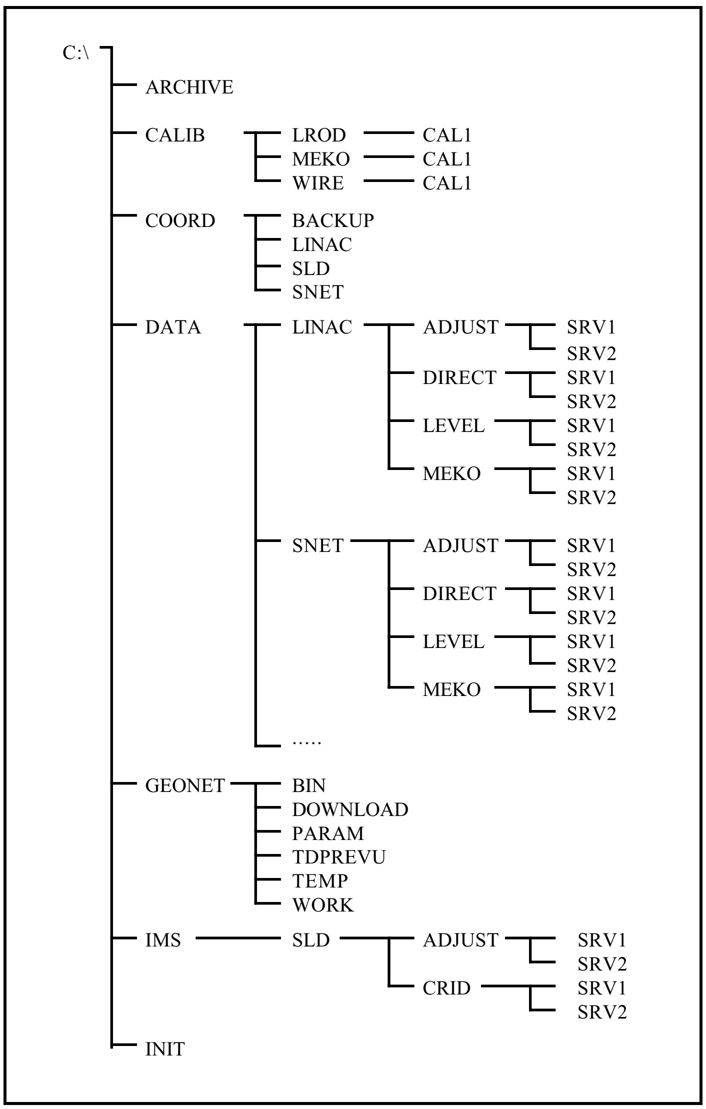

Figure 1–9. GEONET structure

2. GEONET INSTALLATION

2.1. INITIAL INSTALLATION

GEONET is installed by the batch file STARTUP located on the first of up to five diskettes containing the executable code. To begin installation type A:\STARTUP at the command prompt, whereafter a series of menus guides the user through the installation process. STARTUP determines the target hard disk drive that will hold the GEONET database. Drive letters C through H are supported. STARTUP then copies another batch file INSTALL.BAT to the hard disk which creates all the necessary subdirectories and copies all files from the floppy diskettes to their appropriate locations on the target disk. After completing these steps the user can customize GEONET to his needs.

The minimum requirements to run GEONET on a PC are 40 MB of hard disk space and 8 MB of RAM, in order to run the least-squares adjustment programs developed by Dr. Ingolf Burstedde. All least-squares adjustment programs are compiled with NDP Fortran and linked with a DOS Extender from PharLap. This can conflict with expanded memory managers like QEMM or EMM386 which set aside most of the available memory once initialized through CONFIG.SYS. Therefore *it is essential to disable these memory managers* before running GEONET. If different boot configurations are necessary we recommend a shareware program called BOOT.SYS which allows the PC to be booted with different configurations for different applications such as GEONET.

2.2. UPDATE INSTALLATION

If you receive an upgrade for GEONET the original STARTUP batch file will be used for the installation. In this case the batch file tests for existing structure files in the INIT subdirectory and preserves the DATA and IMS structure. Other structure files which have been changed will be renamed to *.BCK before the new version is copied from the floppy diskette. A note will appear on the screen instructing the user to modify the new files to reflect data which was stored in the old files. For example, the format for the BIAS.STR files has recently been changed to support more then one BIAS for different locations (Figs. 2-1, 2-2). This was necessary for SLAC where more than one origin is used for different sections of the Linac and the different storage rings like PEP and SPEAR.

```
Z-BIAS         90000
X-BIAS         70000
Y-BIAS          2000
```

Figure 2–1. BIAS.STR file: old format

```
        Z-BIAS    X-BIAS    Y-BIAS     MSE     YAW    PITCH      ROLL MOV NTM ORIGIN

BSY      90000.    70000.     2000.   77.6437  0.0 -0.004739965  0.0   L   1  STA 100
CID      11000.    70000.     1100.   77.6437  0.0 -0.005240000  0.0   L   1  Beg. sector 1
DRING    12000.    70000.     1200.   77.6437  0.0 -0.005210000  0.0   L   1  SB0
PXLINE   19000.    70000.     1900.   77.6437  0.0 -0.004950000  0.0   L   1  Beg. sector 19
SPEAR        0.0       0.0       0.0  77.6437  0.0  0.0          0.0   L   1  Center of ring

STDBIAS  90000.    70000.     2000.   77.6437  0.0 -0.004739965  0.0   R   1   B01
```

Figure 2–2. BIAS.STR file: new format

The bias entries should be copied into the new BIAS file using the new format. In most cases this file will contain only the line for the standard bias (STDBIAS) because one origin is sufficient for smaller accelerator projects.

2.3. DCAM INSTALLATION

The most recent GEONET release extends support for data collectors to laptop and handheld computers as well as the Hewlett-Packard Portable computers already supported. This enhancement was necessary after HP discontinued production of its Portable. Communication between the HP Portable and GEONET required a special HPIL (Hewlett-Packard Interface Loop) board in the PC and the program HPLINK running on the HP computer. Communication with a PC-compatible laptop is accomplished over a serial port with the program SPLINK running on the laptop. SPLINK is a SLAC-written program that handles all the upload/download functions of GEONET; it can be accessed through the Data Collection Application Manager (DCAM) which replaces the Personal Application Manager (PAM) of the HP Portable.

2.3.1. Installation

The installation diskettes for GEONET contain one 3.5'' floppy diskette which has all necessary files to install DCAM and SPLINK on a laptop equipped with a 3.5'' floppy drive. At the command prompt invoke A:\STARTUP on the laptop to start the installation process. The user is asked to define the hard disk partition to be used for the installation. A second batch file called INSTALL.BAT is copied to the hard disk where it creates the subdirectories FIELD\BIN to hold the executable files and FIELD\DATA to keep the collected measurements. It also copies an initial prototype menu DCAM.MNU (Fig. 2-3) into the FIELD\BIN subdirectory. This is done after the user has decided if an existing DCAM.MNU file can be overwritten or should be preserved. The DCAM.MNU file gives the minimum requirements to establish the link between GEONET and the laptop.

```
SPLINK
splink.exe
DOS Shell
command.com
```

Figure 2–3. Initial DCAM.MNU file

```
REM   Sample CONFIG.SYS file
REM
BREAK=ON
BUFFERS=20
FILES=40
LASTDRIVE=E
SHELL=C:\DOS\COMMAND.COM /P /E:512
DEVICE=C:\DOS\ANSI.SYS
INSTALL=C:\DOS\FASTOPEN.EXE C:=(50,25)
```

Figure 2–4. CONFIG.DCM: sample CONFIG.SYS file for DCAM

2.3.2. Modifying the AUTOEXEC.BAT file

After the installation is complete several modifications must be made to the AUTOEXEC.BAT file on the laptop: FIELD\BIN should be included in the PATH statement, an APPEND statement should be added, as should the environment variable DATADIR=C:\FIELD\DATA setting the path for the storage of measurements. If DCAM is to run automatically after boot-up a line containing DCAM should be added at the end of the AUTOEXEC.BAT file. These changes will not take effect until the laptop is re-booted. Fig. 2-5 shows a sample AUTOEXEC.BAT file.

```
@ECHO OFF
CLS
CD \
SET COMSPEC=C:\DOS\COMMAND.COM
VERIFY OFF
PATH C:\;C:\DOS;C:\FIELD\BIN
APPEND /E
APPEND C:\FIELD\BIN
PROMPT $P$G
VER
SET DATADIR=C:\FIELD\DATA
DCAM
REM  Under DCAM, the program and data directories are obtained
REM  from parameters in the DOS AUTOEXEC.BAT startup file.
REM  This permits independent paths to be specified for programs and
data
REM
REM  Program files are located by way of the PATH environmental
REM  variable; however, GWBASIC programs are considered to be
REM  DOS data files at load time and therefore are located through
REM  the APPEND variable.  The same is true for the DCAM menu file
REM  and any non-GWBASIC programs specified in it.
REM  Thus the data collection program directory must be specified
REM  in both the PATH and APPEND variables.
REM
REM  By convention, the name "FIELD" must appear as a 1st level
REM  directory in the program directory path.  The remainder of
REM  this path is arbitrary.  This allows a remote machine to locate
REM  the correct directory for downloading data collection programs.
REM
REM  The location of survey data files is specified in the DATADIR
REM  environmental variable, which is defined using the DOS SET
REM  command in the AUTOEXEC.BAT file. During DCAM program execution,
REM  the data file directory is made the current working directory.
REM  This directory may be changed exiting DCAM and issuing the
REM  command: SET DATADIR={newpath}.  The new data directory will
REM  become effective as soon as DCAM is restarted.
REM
REM  If DCAM is to be automatically invoked during system startup,
REM  its name must be placed in the last line of AUTOEXEC.BAT.
REM
REM  A valid prototype of the DCAM Menu file, "DCAM.MNU" must
REM  exist in the GWBASIC program directory at the time of DCAM
REM  startup.  This file provides menu names & startup commands for
REM  the field data collection programs.
```

Figure 2–5. Sample AUTOEXEC.BAT file for DCAM

2.3.3. Downloading programs

The last step requires downloading the necessary data collection programs from GEONET to the laptop, where all downloaded programs are kept in the FIELD\BIN subdirectory. At the same time, DCAM.MNU is updated to include the data collection programs available on the laptop and the parameters necessary to run each program.

2.4. CUSTOMIZING GEONET

The following files require customization for each site at which GEONET is installed:

Structure Files	*Names Files*	*CALIB Files*
DATA.STR	THEO.LST	OFFSET.IDX
IMS.STR	MEKO.LST	CAL1.DAT
BIAS.STR	RODNMS.LST	
SYSCON.STR	STATIONS.NMS	
TITLE.STR		
SPECIAL.STR		

2.4.1. *.STR structure files

Besides the DATA.STR, IMS.STR and BIAS.STR structure files already described, other features of GEONET require modification to meet the specific requirements of a given site. The title (TITLE.STR) should be changed to the name of the laboratory and/or project. The system constant file SYSCON.STR should be modified to reflect the current hardware setup.

Recently a new feature has been added to allow for incorporation into GEONET of custom written programs created by users. An example file called SPECIAL.STR is part of the INIT subdirectory and contains a description of the entries and their format.

2.4.2. *.LST and *.NMS names files

MEKO.LST, RODNMS.LST and THEO.LST in the GEONET\DOWNLOAD subdirectory contain the serial numbers of various instruments used by the data collection programs (Figs. 2-6, 2-7, 2-8). These files must be modified for each laboratory and/or project using Geonet.

2.4.2.1. MEKO.LST

MEKO.LST is an optional input file for the ME5000 program. If the file is present the program uses the information therein for the default serial numbers of the equipment. Otherwise these parameters must be entered by the user.

```
357089        Mekometer; default serial #'s - SLAC
450264        Instrument thermometer
450268        Target thermometer
0137          Barometer
375624        Prism     (Fields are extracted from columns 1-10)
```

Figure 2–6. MEKO.LST used by ME5000

2.4.2.2. RODNMS.LST

RODNMS.LST is a required input file for INVLEVEL and an optional input file for LEVEL. The file contains rod names, scale offsets, suffices to be appended to the rod names, and filenames for the output file. The list is divided into three sections, separated by `END` statements.

1. **Rod names and offsets**. The current version of INVLEVEL can handle up to 30 different level rods, but this can be increased if necessary. Columns 1–6 contain the rod name. Columns 10–18 contain the scale offset between left and right scales, in half-centimeters. 'N' in column 20 indicates that the rod name never takes a suffix. At SLAC suffices are never attached to 2m and 3m rods. The space beyond column 20 is available for comments. The line after the last rod must contain `END` in the first three columns.

2. **Rod suffices**. Up to nine suffices can be used; this number cannot be increased. Columns 1–30 contain information that will appear on the screen when selecting the suffix. Columns 33–35 contain the suffix itself. The suffix is restricted to a maximum of three characters, but the total name (rod name + suffix) can be no longer than 8 characters. Space beyond column 35 can be used for comments. The last suffix must be followed by a line with `END` in the first three columns.

3. **Output filename**. Up to nine different filenames may be used; like the number of suffices, this number cannot be increased. Columns 1–30 contain text that will be displayed when selecting the filename. Columns 33–44 contain the filename which must obey the standard DOS convention. `INVLEVEL.IVL` and `MEKLEVEL.IVL` must be included as options since the LEVRED and MEKRED reduction programs require these files. Space beyond column 44 is available for comments. There is no `END` line after this section.

For a fuller description of level rods, suffices and offsets see Bernard Bell, 'Level Rods', available from the SLAC Survey Group.

```
317139   592.500             Kern 1 meter leveling rods
317140    592.500
332882    592.500
332883    592.500
330131    592.500   N         Kern 2 meter leveling rods
330133    592.500   N
330134    592.500   N
330136    592.500   N
329528    592.500   N         Kern 3 meter leveling rods
329530    592.500   N
9201      592.500   N         Nedo 2 meter leveling rods
9202      592.510   N
MINI2     592.500             SLAC mini (.05 to .50 meter) leveling rods
MINI3     592.500
MINI9     592.500
MINI11    592.500
MINI12    592.500
MINI13    592.500
MINI14    592.500
MINI15    592.500
MINI16    592.500
MINI17    592.500
END
Levelling pin                   LP
Taylor-Hobson ball              TH
Tooling ball                    TB
In CERN socket                  CS
Nothing                         O
Inverse tooling ball            BT
END
Level runs and invar reduction   INVLEVEL.IVL
ARTU reduction                   RTULEVEL.IVL
Mekometer reduction              MEKLEVEL.IVL
```

Figure 2–7. RODNMS.LST used by invlevel

2.4.2.3. THEO.LST

THEO.LST is an optional input file for the distance (DIST) and direction (DIRECT) measurement programs. It contains a list of the Kern E2 theodolites and their ASB numbers. The ASB number is the electronic address set on a switch in the instrument. DIRECT and DIST are able to determine the address of the connected theodolite. If THEO.LST is present the program determines the serial number of that instrument without operator input.

The Wild theodolites are not included in the list because their serial numbers can be obtained directly from the instrument.

```
341378        ASB #1  Kern theodolite serial#'s, ordered by ASB#
341384        ASB #2
341337        ASB #3
327986        ASB #4  (SLAC has 6 Kern theodolites, ASB#'s 1-6 assigned)
346669        ASB #5
350964        ASB #6
none          ASB #7
none            ASB  #8   Replace  entry  with  serial#  if  ASB#  assigned.
Serial#
none          ASB #9  is extracted from columns 1-10.
```

Figure 2–8. THEO.LST used by DIRECT

2.4.2.4. STATIONS.NMS

Most of the data collection programs access a file called STATIONS.NMS, if it is present, to check station names entered during the data collection process, a most valuable feature since 90% of all mistakes can be attributed to misnamed points. Download has a special option to create a STATIONS.NMS list which is then automatically downloaded to the data collector.

2.4.3. CALIB files

Certain files within the CALIB nest of subdirectories contain important information that is required for data reduction. These files must be customized by the user.

2.4.3.1. LRODOFF.DAT

The subdirectory CALIB\LROD\CAL1 should be created for the file LRODOFF.DAT, formerly called OFFSET.IDX, which lists the offsets between level rods (Fig. 2-9). An example file is installed under GEONET\TEMP. A suffix can be added to the rod name to indicate the base on which the rod is used, *e.g.*, the suffix TH indicates that the level rod was used on a Taylor Hobson ball of 3.5-inch diameter. The history file OFFSET.HST shows the point to which the offset reduces the measurements, *e.g.*, the TH offset reduces the measurement to the center of the Taylor Hobson ball.

```
\CALIB\LROD\CAL1\OFFSET.IDX       13 Oct 1988

317139     -0.06652  1.0  KERN
317139BH  +0.01902  1.0  KERN  on Hubbs Ball (1.5 inch) upside down
317139BT   0.00632  1.0  KERN  on Tooling Ball upside down
317139HB  -0.01902  1.0  KERN  on Hubbs Ball (1.5 inch)
317139LD  -0.07421  1.0  KERN  on Linker D@#%
317139O   +0.00003  1.0  KERN  on Nothing
317139TB  -0.00632  1.0  KERN  on Tooling Ball (SPCL)
317139TH  -0.11436  1.0  KERN  on Taylor-Hobson ball
317140     -0.06644  1.0  KERN
317140BH  +0.01894  1.0  KERN  on Hubbs Ball (1.5 inch) upside down
317140HB  -0.01894  1.0  KERN  on Hubbs Ball (1.5 inch)
317140LD  -0.07413  1.0  KERN  on Linker D@#%
317140O   +0.00011  1.0  KERN  on Nothing
317140TB  -0.00624  1.0  KERN  on Tooling Ball
317140TH  -0.11428  1.0  KERN  on Taylor-Hobson ball
```

Figure 2–9. \CALIB\LROD\CAL1\LRODOFF.DAT file for Level reductions

For more information see Bernard Bell, "Level Rods", available from the SLAC Survey Group.

2.4.3.2. MEKO.DAT

The subdirectory CALIB\MEKO\CAL1 should be created for the file MEKO.DAT which contains the various site-specific parameters required for reduction of mekometer measurements (Fig. 2-10). An example of this file is installed under GEONET\TEMP. For more information consult §4.4.3. or 'The Proceedings of the Workshop on The Use and Calibration of the Kern ME5000 Mekometer,' SLAC, June 18-19, 1992, SLAC-403.

```
REFERENCE ELLIPSOID CONSTANTS
Major-Axis  6378206.4              semi-major axis of ellipsoid
Eccentricity      0.00676866       square of first eccentricity
Latitude         37.41684906       degrees
Refheight        77.6437           normal height, meters
Ellipsoidal    2000.000            Constant added to elevations
INSTRUMENT HEIGHT CONSTANT
Instrument    Dummy         Height const
357036        0.0           0.1020   CEBAF
357037        0.0           0.1020   LBL
357046        0.0           0.1020   FNAL
357075        0.0           0.1020   SSC
357081        0.0           0.1020   SSC
357086        0.0           0.1020   ANL
357088        0.0           0.1180   BNL
357089        0.0           0.1020   SLAC
PRISM HEIGHT CONSTANTS
Prism name    Constant      Height (including adapter)
365618        0.000054     0.412000      LBL
365619        0.000000     0.412000      FNAL
365630        0.000000     0.412000      CEBAF
374425        0.000000     0.412000      ANL
375608        0.000000     0.412000      SSC
375609        0.000000     0.412000      SSC
375624        0.000000     0.412000      SLAC
375630        0.000000     0.412000      SSC
375632        0.000000     0.412000      ANL
375651        0.000000     0.428000      BNL
SLAC-TH1      0.000000      0.070000
SLAC-TH2      0.000125      0.070000
```

Figure 2–10. \CALIB\MEKO\CAL1\MEKO.DAT file for Mekometer reductions

3. GEONET DATA COLLECTION PROGRAMS

Data collection programs and related files are provided with GEONET, Table 3-1.

Table 3–1. Geonet data collection software

Survey Programs	*Alignment Programs*	*Other Programs*	*Data Files*
DIRECT	BPM	GWBASIC.EXE	STATIONS.NMS
DIST	CCLAMP	HPBASIC.EXE	MEKO.LST
INVAR	CLASH	PCSUB.ASC	RODNMS.LST
INVLEVEL	DIALGAGE		THEO.LST
LEVEL	OFFSET		BENCHMARK.OUT
ME5000			IDEAL.OUT
			MONUMENT.OUT

3.1. BASIC INTERPRETER

All the data collection programs are written in BASIC and are provided in two forms: *.BAS for interpreted BASIC, and *.EXE compiled BASIC. The compiled versions can run as is, but the *.BAS versions require a BASIC interpreter. Two versions of the BASIC interpreter are supplied with Geonet in the GEONET\DOWNLOAD subdirectory: GWBASIC.EXE and HPBASIC.EXE.

a) **GWBASIC.EXE**. The standard basic interpreter is GW-BASIC supplied with dos. The download process checks the presence of GW-BASIC on the laptop, downloading it automatically if not found.

b) **HPBASIC.EXE**. The standard version of GW-BASIC will not run on the HP Portables due to their non-standard screens. HPBASIC.EXE is a version of GW-BASIC v.2.01 compatible with the HP-Portables.

PCSUB.ASC is a collection of common subroutines used by each data collection program. It is downloaded automatically if the download program does not detect it on the data collector.

3.2. DATA FILES

The data collection programs use various data files, some essential, others optional.

1. **STATIONS.NMS** is an optional file containing a list of valid station names. An option of the download program allows the user to assemble a names list which will be downloaded to the data collector and used for point name checking during the data collection process.
2. **THEO.LST**, **RODNMS.LST** and **MEKO.LST** are required by the programs that use them (see §2.4.2). Example files are provided; these should be customized for each laboratory.
3. **BNCHMARK.OUT**, **MONUMENT.OUT** and **IDEAL.OUT** are required input files for the program CLASH used to layout coordinates.

3.3. SURVEY PROGRAMS

Six programs cover the routine survey measurements at accelerator laboratories (Table 3–2).

Table 3–2. Geonet survey programs

Program	*Type of measurements*	*Instrument*
DIRECT	Directions	Kern E2; Wild T3000
DIST	EDM Distances	Kern DM503
INVAR	Invar wire distances	Distinvar + calibrated invar wires
INVLEVEL	Elevation differences	Optical level; Wild NA3000 digital level
LEVEL	Elevation differences	Optical level; Wild NA3000 digital level
ME5000	EDM distances	Kern ME5000 Mekometer

3.3.1. DIRECT

Required input files:	none
Optional input files:	THEO.LST, STATIONS.NMS
Output file:	*stn*.DIR
Formatting program:	DIRFORM
Data reduction program:	REDIR

DIRECT records direction measurements made with an electronic theodolite: either the Kern E2 theodolite (now discontinued by Leica) or the Wild T2000/T3000 series. For a full description on interfacing the computer and the theodolite see the document 'Cabling for Kern & Wild Instruments' (Bernard Bell, SLAC, latest revision March 10, 1993) available from the SLAC Survey Group.

Three rounds of observations are made, each round consisting of a direct and a reverse set. The observations of the direct set, first round are used to check for blunders in subsequent measurements. The tolerance level for gross error checking is set to ± 0.01 gon: if a subsequent target reading differs by more than ± 0.01 gon from the initial reading the measurement will be rejected. It is obviously important to use maximum care for the initial measurements.

After the third set a statistical analysis is made of all three sets. The standard deviation of one set σ_1 and of all sets σ_n are calculated

$$\sigma_1 = \sqrt{\frac{\sum v^2}{(n-1)(s-1)}} \tag{3–1}$$

$$\sigma_n = \frac{\sigma_1}{\sqrt{n}} \tag{3–2}$$

where n is the number of sets, s the number of targets and v the residuals. For the measurements to be accepted the standard deviation for all sets must be less than 0.3 mgon. If this tolerance is exceeded the program requests a fourth set.

The values for both error-checking tolerances can be changed by the operator at the start of the program. At SLAC we have found that the default tolerance values (10 mgon for blunder detection, 0.3 mgon for acceptance after three sets) require widening only for very short lines of sight measured with the Wild T3000.

Fig. 3-1 shows the *stn*.DIR output file; Fig. 3-2 the measurements as formatted by DIRFORM. This DIRFORM output enables the detection of stations where the theodolite has moved relative to the socket due to an insufficiently tightened locking pin. Such movement produces a large standard deviation and systematic changes in the final column of differences.

File Entry	*Description*
09-06-92	Measurement Date

15:03	Start time		
tk	Instrument operator		
dp	Helper 1		
none	Helper 2		
XS2208FF	Station Name (max. 8 characters)		
327986	Instrument s/n		
0.0100	Tolerance for gross errors (gon)		
0.3000	Tolerance for 1 direction after 3 sets (mgon)		
OVERCAST	Weather condition		
CALM	Wind condition		
XS2204FF	Target 1		
XS2205FF	Target 2		
XS2206FF	Target 3		
...	...		
END	End of targets		
118.01470	Set 1	Target 1	Direct
318.01600			Reverse
0.00000			Mean
117.74130		Target 2	Direct
317.74140			Reverse
399.72600			Mean
316.59240		Target 3	Direct
116.59340			Reverse
198.57755			Mean
...		...	
118.01370	Set 2	Target 1	Direct
318.01570			Reverse
0.00000			Mean
117.74020		Target 2	Direct
317.74100			Reverse
399.72590			Mean
316.59170		Target 3	Direct
116.59280			Reverse
198.57755			Mean
...		...	
118.01350	Set 3	Target 1	Direct
318.01500			Reverse
0.00000			Mean
117.74020		Target 2	Direct
317.74090			Reverse
399.72630			Mean
316.59130		Target 3	Direct
116.59260			Reverse
198.57770			Mean
...		...	
QUIT	End of measurements		
0.25	Accuracy of a direction after one set (mgon)		
0.15	Accuracy of a direction after 3 sets (mgon)		
0.00000	Target1	Final direction as	
399.72607	Target 2	average of all sets	
...	...		
+0.00	Residuals	Set 1	Target 1
+0.07			Target 2
+0.15			Target 3
...		...	
+0.00		Set 2	Target 1
+0.17			Target 2
+0.15			Target 3
...		...	
+0.00		Set 3	Target 1
-0.23			Target 2
-0.30			Target 3
...		...	
+0.00			
5552.0072	Sum of all reverse measurements		
15:20	End time		

Figure 3–1. Raw measurement file created by DIRECT.BAS

```
        Direction File: N:\SLC\NFF\DIRECT\SRV1\XS2208FF.250
-------------------------------------------------------------------------
-

Date        : 09-06-92                    Observer : tk

Start Time :  15:03                       Rman 1   : dp

End Time   :  15:20                       Rman 2   : none

Weather conditions   : OVERCAST
Wind Conditions      : CALM

Theodolite No.       : 327986

Gross Error Sigma    : 0.0100       M.S.E. of one set  : 0.2500 (mgon)
Iteration Sigma      : 0.3000       M.S.E. of all sets : 0.1500 (mgon)

No.  Target        Direct       Reverse      Reduced      Reduced      Differ
     Number         (gon)        (gon)        By Sets      All Sets     (mgon)
=========================================================================
=
1    XS2204FF    118.0147     318.0160       0.0000       0.00000      0.000
2    XS2205FF    117.7413     317.7414     399.7260     399.72607      0.070
3    XS2209FF    316.5924     116.5934     198.5776     198.57760      0.050
-------------------------------------------------------------------------
-
1    XS2204FF    118.0137     318.0157       0.0000                    0.000
2    XS2205FF    117.7402     317.7410     399.7259                    0.170
3    XS2209FF    316.5917     116.5928     198.5776                    0.050
-------------------------------------------------------------------------
-
1    XS2204FF    118.0135     318.0150       0.0000                    0.000
2    XS2205FF    117.7402     317.7409     399.7263                   -0.230
3    XS2209FF    316.5913     116.5926     198.5777                   -0.100
```

Figure 3–2. Formatted Direction measurement file created by DIRFORM

The files CALC.HP, CALC.INP and CALC.OUT are the program and example files for a modified version of DIRECT.BAS for the IBM-PC. It can be used to process incomplete direction data files. To use this program, one line containing the filename and type of the output file must be added to the beginning of the data file, and this file redirected to CALC.HP running in GWBASIC. The following command line is issued:

GWBASIC CALC.HP < CALC.INP

The 'less than' symbol is used to redirect the input file to be used by CALC.HP. This program has come in handy occasionally when there was not enough free disk space left on the data collector or the direction program was interrupted during the calculations for the statistics. Using this program it was possible to create a usable data file for GEONET.

D-ZEISS.BAS is a derivative of DIRECT.BAS for the Zeiss ETH-2 or other Zeiss electronic theodolite. Since SLAC does not use Zeiss theodolites this program has not been maintained since it was developed in 1990.

3.3.2. DIST

Required input files:	none
Optional input files:	STATIONS.NMS, THEO.LST
Output file:	*stn*.DST
Formatting program:	DSTFORM
Data reduction program:	REDIST

File Entry	*Description*
11-25-85	Date
08:00	Time
TED	Operator
JILL	Helper 1
NONE	Helper 2
M32	Instrument Station
327986	E2 theodolite #
325845	DM503 #
TEMPS	Thermometer #
TWETS	
TEMPT	
TWETT	
AJ02449	Barometer #
OVERCAST	Weather condition
CALM	Wind condition
0.00	
12.0	
747.0	Pressure (mmHg)
M33	Target
08:31	Time
0.0000	
9.60	
9.20	
9.60	
9.20	
219.512	1)
219.512	2) 3 measurements
219.512	3)
9.60	
9.20	
9.60	
9.20	
.....	More stations
END	
745.8	Pressure (mmHg)
11:35	

Figure 3–3. Raw measurement file created by DIST.BAS

DIST is the data collection program for the Kern DM503 EDM instrument, used at SLAC for the survey of the surface net monuments before the ME5000 was acquired.

```
Record  for  the  Distance  Measurements  on  Station  M32
    *********************************************************

  Date          : 11-25-85                Observer : TED

  Start Time    :    08:00                Rman 1    : JILL

  Air Pressure :    747.0                 Rman 2    : NONE

  Weather Conditions   : OVERCAST
  Wind Conditions      : CALM

  E-2    Inst. No. : 327986           Station Dry Probe : TEMPS
  DM503 Inst. No. : 325845                     Wet Probe : TWETS
  Barometer    No. : AJ02449          Target   Dry Probe : TEMPT
                                               Wet Probe : TWETT


  No.   Target      Distance    Residual   Dry Bulb Readings   Wet Bulb
Readings
       Number        (m)          (mm)      Station   Target     Station
Target
                                          [ deg C ] [ deg C ]  [ deg C]
[ deg  C]
=====================================================================
======

  1     M33         219.5120    -0.000
                    219.5120     0.000       9.60      9.60       9.20
9.20
                    219.5120     0.000       9.60      9.60       9.20
9.20
                     ------------------------------------------------
-------
  Mean Values      219.5120                  9.60      9.60       9.20
9.20
---------------------------------------------------------------------
-------

End  Air Pressure :    745.8  [ mm Hg]            End Time :   11:35
Mean Air Pressure :    746.4  [ mm Hg]
```

Figure 3–4. Formatted Distance file created by DSTFORM

3.3.3. INVAR

Required input files:	none
Optional input files:	STATIONS.NMS, WIRES.NMS
Output file:	*stntgt*.INV
Formatting program:	INVFORM
Data reduction program:	INVRED

INVAR.BAS/EXE records distance measurements made with the Distinvar. An invar wire of known length is stretched between two stations. One station is occupied by the Distinvar, the other station by the remote attachment head. The Distinvar contains a precision balance with a 1.5 kg counterweight mounted on a mobile carriage with a range of 50 mm. The instrument moves the carriage until the balance is in equilibrium with the tension on the wire. The reading is the position of the carriage. Three independent readings are recorded. The data reduction program INVRED adds the average of these readings to the calibrated wire length to obtain the distance. This procedure requires the pre- and post-calibration of the invar wire on a laser interferometer bench.

File Entry	*Description*
02-21-90	Measurement Date
17:42	Start Time
perry	Operator
mokski	Helper
1	Distinvar #
HNTB05	Station
HNTB10	Target
DG	Dial gages? DG/NODG
HL1809A	Wire #
14.30	1 Measurements
14.28	2
14.27	3
14.28	4 (if necessary)
0.05	1 Dial Gage readings
0.05	2
0.05	3
0.05	4
14.283	Mean reading
20.0	
MORE	Second wire
02-21-90	Date
17:50	Time
HL1809B	Wire #
25.24	1 Measurement
25.24	2
25.24	3
0.00	4
0.05	1 Dial Gage readings
0.05	2
0.05	3
0.00	4
25.240	Mean reading
QUIT	
17:54	End time

Figure 3–5. Raw measurement file created by INVAR.BAS

```
SLC SURVEY & ALIGNMENT

                    Distinvar File: HNTB0510.052

                                                  Instrumentation

Date            :  02-21-90               Instrument Number : 1
Starting Time  :  17:42                   Instrument Station:
HNTB05
Operator 1     :  PERRY                   Remote Station    :
HNTB10
Operator 2     :  MOKSKI                  Dial Gages        : DG
Temperature    :  20.0

                 -------------------------

                 Wire Number   :  HL1809A

Reading[ 1]   :     14.300                Deflection[ 1]  : 0.050
Reading[ 2]   :     14.280                Deflection[ 2]  : 0.050
Reading[ 3]   :     14.270                Deflection[ 3]  : 0.050
Reading[ 4]   :     14.280                Deflection[ 4]  : 0.050

      ---------------------                     -----

Average Reading   : 14.283
Mean Total        : 14.283

                 -------------------------

                 Wire Number   :  HL1809B

Reading[ 1]  2:     25.240                Deflection[ 1]  2: 0.050
Reading[ 2]  2:     25.240                Deflection[ 2]  2: 0.050
Reading[ 3]  2:     25.240                Deflection[ 3]  2: 0.050

      ---------------------                     -----

Average Reading   : 25.240
Mean Total        : 25.240

Ending Time    :  17:54
```

Figure 3–6. Formatted INVAR *measurements (*INVFORM*)*

3.3.4. INVLEVEL

Required input files:	RODNMS.LST
Optional input files:	STATIONS.NMS
Output file:	INVLEVEL.IVL, MEKLEVEL.IVL or RTULEVEL.IVL
Formatting program:	none
Data reduction program:	LEVRED

INVLEVEL.BAS/EXE is used for level runs in the accelerator housing, primarily to acquire the necessary elevation information for the reduction of distance measurements. The name of the output file is INVLEVEL.IVL, MEKLEVEL.IVL or RTULEVEL.IVL, according to whether the elevations are for invar, Mekometer or ARTU distance reductions. INVLEVEL differs from LEVEL in many respects: it does not require an even number of setups; the tolerance level which checks for blunders is set much smaller (±0.1 mm) due to the shorter lines of sight and the more stable environment in the beam housings; rod temperatures are not required.

The one required input file, RODNMS.LST, contains data for each level rod (§2.42.2., Fig. 2-7). The program CHECK.BAS can be used to calculate INVLEVEL loop closures.

```
Forward Stn.  Back Stn.   Elev. Diff.  Fwd Rod #   Bwd Rod #

RS221202, XS2204FF, +0.93391, 330136   , MINI9CS
XS2204FF, XS2205FF, +0.22110, MINI9CS  , MINI11CS
XS2205FF, XS2206FF, +0.18175, MINI11CS, MINI9CS
XS2206FF, XS2207FF, +0.21187, MINI9CS  , MINI11CS
XS2207FF, XS2208FF, +0.17213, MINI11CS, MINI9CS
XS2208FF, XS2209FF, +0.20193, MINI9CS  , MINI11CS
XS2209FF, XS2210FF, +0.16165, MINI11CS, MINI9CS
XS2210FF, RS221215, -1.29584, MINI9CS  , 330136
```

Figure 3–7. Output file created by INVLEVEL.BAS

3.3.5. LEVEL

Required input files:	none
Optional input files:	RODNMS.LST
Output file:	*stn*.LVL
Formatting program:	LVLFORM
Data reduction program:	

LEVEL.BAS/EXE is used for leveling between benchmarks on the surface net. It requires the use of double scaled invar level rods with half centimeter graduations. Error checking is done by reading the scales in a specific order. First the left scale of the forward rod is read then the left and right scale of the backward rod and finally the right scale of the forward rod again. This ensures the detection of any sudden elevation changes with either one of the level rods or the instrument. Effectively a double level run is performed which gives additional redundancy to check for blunders in reading the scales.

Two checks are performed. One compares the elevation difference calculated using the left scale readings and the right scale readings. The other compares the difference between the left and right scale reading of each level rod which mustmatch the offset constant (592.500 for Wild and Kern rods). Both of these checks must meet preset tolerance values before the instrument can be moved to the next station. Modern level instruments using telescopes with high magnification such as the Wild N3 allow scale readings with a line of sight of 20 m to an accuracy of ±0.1 mm. Therefore the tolerance level in LEVEL.BAS is set to ±0.25 mm, twice the theoretical possible accuracy.

Usually two different level rods are used to leapfrog from turning point to turning point. In this case the offset which exists between different level rods is introduced as error if the loop is not closed with the same rod used at the beginning of the line. Therefore the program requires an even set of instrument stations which ensures that the same level rod will be used at the beginning and end of a level line. The program originally called for the temperature of the invar scale at the top, middle and bottom to compensate for thermal expansion of the scale. This effect turned out to be negligibly small for the short level lines used at SLAC and other accelerator sites. For long level lines of high precision this effect should be taken into account. *This program should not be used* until an appropriate reduction program is implemented in the single-user version of Geonet.

File Entry	*Description*
01-10-92	Measurement Date
08:57	Start Time
MR	Operator
MP	Booker
JM	Rodman 1
JR	Rodman 2
1	
330136	Rod #
RED	
592.500	Scale Offset
330134	Rod #
BLUE	
592.500	Scale offset
0.0500	
0.0500	
OVERCAST	Weather condition
CALM	Wind condition
RR81	Start
RR101	Finish
9	No. turning points
1	1st leg
318.149	Back left scale
324.260	Forward left scale
916.771	Forward right scale
910.659	Backward right scale
RTP1	Fore stations
RR81	Back station
6.	Rod temperature
6.	
6.	
09:07	Time
6.	
6.	
6.	
09:07	
2	2nd leg
...	continues
10:01	End time
-1.0722925	
0	
0	
0	

Figure 3–8. Raw measurement file created by LEVEL.BAS

```
                       Level Line Data (Uncorrected)

                         Data File : rr81rr10.010


        From        : RR81                         Date       : 01-10-92
        To           : RR101                        Weather    : OVERCAST
        T.P.'s      :    9                                        CALM
         Start Time : 08:57


                 Survey Crew                                 Rod Data

        Observer    : MR                           Red  Serial #  :   330136
        Recorder    : MP                                Rod Const :  592.500
         Rodperson   : JM
        Rodperson   : JR                           Blue Serial #  :   330134
                                                        Rod Const :  592.500

        Instrument : 1                             Interrod Sigma :    0.050
                                                    Intrarod Sigma :    0.050
        -----


        Set Up :      1

         Back Left Scale      :   318.149
         Forward Left Scale  :   324.260           Left  Scale Delta    :    -
6.111
         Forward Right Scale :   916.771           Right Scale Delta    :    -
6.112
         Back Right Scale     :   910.659


        Back Target          :   RR81               For.  Target              :
RTP1
              Rod Temp (top) :     6.0                     Rod  Temp  (top)  :
6.0
              Rod Temp (mid) :     6.0                     Rod  Temp  (mid)  :
6.0
              Rod Temp (bot) :     6.0                     Rod  Temp  (bot)  :
6.0
             Time            :  09:07                     Time               :
09:07
             Height          :      0.000                 Height             :
-6.112


        -----


        Set Up :      2

… … … … … … … …

        Left  Back Sum       :   -1.07229            Right  Back  Sum         :
0.00000
        Left  For. Sum       :    0.00000            Right  For.  Sum         :
0.00000

        End Time             :  10:01
```

Figure 3–9. Formatted level file (LVLFORM)

3.3.6. ME5000

Required input files:	none	
Optional input files:	MEKO.LST, STATIONS.NMS	
	Output file:	*stn*.MEK
	Formatting program:	MEKFORM
	Data reduction program:	MEKRED

The Kern Mekometer ME5000 is now widely used for accelerator alignment. ME5000.BAS/EXE collects the necessary data to calculate horizontal distances. The data collector interfaces via a serial link with the ME5000. The default option is for two measurements per distance. The output file contains the frequencies; the uncorrected slope distance; temperature, humidity and barometric pressure for both station and target. For distances below 10 m the ME5000 an approximate distance is often required. For distances below 20 m an approximate distance is optional: if supplied the measurement time is reduced considerably. In this case the data collection program prompts the operator to enter an approximate distance which should be measured to ±2 cm. For a more detailed and comprehensive description of the working principal of the ME5000 and the data collection program refer to 'The Proceedings of the Workshop on The Use and Calibration of the Kern ME5000 Mekometer', SLAC, June 18-19, 1992, SLAC-403.

```
06-07-93  20:31:22                                                               DAT
Hans Imfeld           Bill Wagner           none                                 OBS
357089                                                                           INS
450268       450264       0137         OVERCAST    CALM                          THS
b20          0.000000                                                            ST1
b19          0.000000  375624      0.14200                                       ST2
13.90   73.7   757.8  13.60   79.0   757.8  RH  TOR                              MET
473.837036 481.298859 485.029907     3     40.022464   0.00 20:33:20 20:36:09 DIS
13.80   72.9   757.8  13.50   79.0   757.8  RH  TOR                              MET
473.836700 481.299011 485.029755     3     40.022473   0.00 20:38:47 20:41:52 DIS
                                                                                 FIN
b17          0.000000  375624      0.14200                                       ST2
13.80   72.8   757.8  13.30   77.3   757.8  RH  TOR                              MET
474.188812 481.668457 486.156219     8    100.036581   0.00 20:45:13 20:46:48 DIS
13.40   74.8   757.8  12.60   81.3   757.8  RH  TOR                              MET
474.188507 481.667816 486.155243     8    100.036714   0.00 20:48:53 20:50:36 DIS
                                                                                 FIN
...[cont.]
```

Figure 3–10. ME5000 raw measurement file

```
  ME5000 Mekometer Measurements File: N:\SNET\BLINE\MEKO\SRV2\B20.158
=============================================================================

 Station : B20                               Observer  : Hans Imfeld
                                             Rman1     : Bill Wagner
 06-07-93  20:31:22                          Rman2     : none
                                             OVERCAST, CALM
 Mekometer : 357089                          Stn Therm : 450268
 Height    : 0.0000                          Tgt Therm : 450264
                                             Barometer : 0137

Target : b19            T(C)  RH(%)  P(mm)     T(C)  RH(%)  P(mm)
Prism  : 375624         13.9  73.7   757.8     13.6  79.0   757.8
Tgt.ht.: 0.0000         13.8  72.9   757.8     13.5  79.0   757.8

Stime  Etime    F1(MHz)     F2(MHz)     F3(MHz)    Kval  ApxD(m)    Dis@STP(m)
20:33  20:36  473.837036  481.298859  485.029907  3                  40.022464
20:38  20:41  473.836700  481.299011  485.029755  3                  40.022473
=============================================================================

Target : b17            T(C)  RH(%)  P(mm)     T(C)  RH(%)  P(mm)
Prism  : 375624         13.8  72.8   757.8     13.3  77.3   757.8
Tgt.ht.: 0.0000         13.4  74.8   757.8     12.6  81.3   757.8

Stime  Etime    F1(MHz)     F2(MHz)     F3(MHz)    Kval  ApxD(m)    Dis@STP(m)
20:45  20:46  474.188812  481.668457  486.156219  8                 100.036581
20:48  20:50  474.188507  481.667816  486.155243  8                 100.036714
=============================================================================
...[cont.]
```

Figure 3–11. Formatted ME5000 measurement file (using MEKFORM)

3.4. ALIGNMENT PROGRAMS

Most, but not all, of these alignment programs are used for the mechanical adjustment of beam-line components. What they do all share in common is that, whereas the survey programs are generic measurement programs, the alignment programs are specifically tailored to needs at SLAC. They are therefore not necessarily of any use at other sites.

3.4.1. BPM

Required input files:	none
Optional input files:	RODNMS.LST
Output file:	*stn*.BPM
Formatting program:	none
Data reduction program:	none

BPM.BAS is used for the calibration and measurement of Beam Position Monitors in the SLC (Stanford Linear Collider). It has not been maintained since 1988.

3.4.2. C-CLAMP

Required input files:	ROLL.DAT
Optional input files:	none
Output file:	CCLAMP.CCL
Formatting program:	none
Data reduction program:	none

CCLAMP.BAS logs the pre-survey of C-clamps on the SLC arc magnets made to determine the precise location of each C-clamp on its magnet. The program is still maintained but is of no use to other labs.

3.4.3. CLASH

Required input files:	THEO.LST, IDEAL.OUT, MONUMENT.OUT, BNCHMARK.OUT
Optional input files:	none
Output file:	not fixed
Formatting program:	none
Data reduction program:	none

CLASH.BAS, the clashing laser alignment system was developed in 1985 to align magnet pedestals during the construction of the Stanford Linear Collider. It uses two laser theodolites (Kern E2 theodolites with laser attachments). The laser beams are propagated through the telescopes and pointed to the magnet pedestal which is to be positioned. When correctly aligned, the lasers intersect on a reference mark in the center of an opaque glass sphere. This marks the virtual vertex point of the magnet that will later sit on the pedestal.

The computer to which both theodolites are connected contains station coordinates (MONUMENT.OUT), rivet elevations (BNCHMARK.OUT), and ideal coordinates of the vertex points (IDEAL.OUT). Using the theodolites as a level instrument the elevation of each instrument station is determined from adjacent rivets. CLASH calculates, and displays in the upper two windows of the theodolites, the vertical and horizontal directions in which the two theodolites must be pointed to obtain intersecting laser beams at the vertex point. The magnet pedestal is then moved around until the intersecting laser beams coincide with the mark on the glass sphere.

CLASH enabled us to rapidly position about 1000 support stands for the magnets in the SLC arcs with an accuracy of about ± 2 mm. Even if the laser equipment is not available the system can still be used to set out two– or three–dimensional points. The two theodolite operators direct someone holding a pencil to the correct position. This is straightforward for the two-dimensional case but cumbersome for three-dimensional alignment.

We have recently abandoned CLASH, having found the Wild TC2002 total station to be sufficiently accurate to position pedestals using a single instrument and no extra equipment.

3.4.4. DIALGAGE

Required input files:	DELTA.DAT
Optional input files:	none
Output file:	DIALGAGE.OUT
Formatting program:	none
Data reduction program:	none

DIALGAGE.BAS monitors the adjustments made to individual beam components. Because of the cumbersome dial gage tree fixture this procedure was rarely used at SLAC, although the program has been maintained. Readings are recorded for archive purposes only.

3.4.5. OFFSET

Required input files:	none
Optional input files:	STATIONS.NMS
Output file:	*stn*.OFS
Formatting program:	none
Data reduction program:	none

For offset measurements a parallel plate micrometer is attached to the front of the telescope of the E2. With the micrometer of the parallel plate in *zero position*, a line of sight is established between two monuments. Perpendicular offsets from this reference line to tooling balls are measured using a K&E white face scale with 0.1 inch graduations. Micrometer readings are made in pairs: a reading to the nearest graduation to the left and a reading to the nearest graduation to the right. The sum of the left and right readings should equal the

File entry			*Description*
03-05-88			Measurement Date
13:30			Start time
BILL			Operator
MIKE			Helper
327986			Instrument Number
HSFF18			Station Name (Max 8 characters)
HSFF19			Target Name (Max 8 characters)
GS56BX	+0.75125	11.1559	Measurements: 3 entries per line:
GS56AX	+0.79456	11.1540	1. Offset point name (max. 8 characters)
......			2. Measured offset (m)
......			3. Direction (should be constant)
MORE			Another Target
HSFF20			New Target Name
GS56BX	+1.25583	2.4619	Offset Point Name etc
QUIT			End of measurements
13:46			End Time

Figure 3–12. Raw measurement file created by OFFSET.BAS

graduation pitch of the scale (0.1"). If it deviates by more than ±0.01 inch the readings are rejected. The average of three pairs of readings is recorded. The sign of the average reading is negative if the tooling ball is to the left of the line of sight looking from the theodolite towards the target; positive if to the right. The direction of the reference line is also recorded and compared with the initial direction. If the direction has changed by more than 0.0010 gon the program will stop and inform the operator that the original line of sight has been lost.

3.5. UPLOADING DATA

Having collected the measurements using one of these data collection programs, the next step is to upload the data to GEONET. Depending on the hardware setup this is done either through a serial port connection for laptops or via an HP-IL board which links the HP Portable to the PC. In either case the displayed menu options are the same. To link both computers one must run SPLINK, one of the menu items of DCAM on the laptop, or HPLINK on the HP Portable. Once the connection between the data collector and the PC running GEONET is verified the user makes menu selections to specify the data subdirectory which will hold the measurements. The upload process is initialized by entering the file name to be uploaded. If more than one file with a generic file type is to be uploaded it is usually easier to use wild cards like *.DIR which uploads all direction sets to the chosen subdirectory. This in turn will start the printing process using different formats depending on the kind of measurement type. At the same time the filename will be added to the index file (SRVxx.IDX) of the chosen subdirectory and the filetype will be changed to the Julian date of the day the measurements were taken. The filetype on the data collector will be changed to 999. This ensures that data files are uploaded only once. It also provides an easy way to erase the data to free space on the data collector after the upload process is finished.

Another important task of the upload routine is to check all point names recorded for their existence in any of the coordinate databases. The process starts with the search at the location which is currently selected for uploading. If a point name is not found all other coordinate databases will be checked. The search includes benchmarks, monuments, 3DIM coordinates and ideal coordinates. The user will be notified if a point name can not be found. Thereafter the option to view the log file (NEWPNT.LOG) containing entries for each point name not found is displayed. In case the point name is found in one of the databases the name will be recorded with the database location and database type in a file called POINTS.1D or POINTS.2D depending on the measurement type. These files are stored along with the input files for the adjustments under the subdirectory ADJUST. This feature allows an easy access to all points belonging to one survey epoch and will be used later to merge the data sets to create the input files for the least squares adjustments. The following tables show examples for the files NEWPNT.LOG, POINTS.1D and POINTS.2D.

```
Point         Name file        Upload file

                                Date 4-18-1990 - Time 13:29:58
PEP2095        POINTS.1D        E:\DATA\PEP\MEKO\SRV1\MEKLEVEL.IVL
                                Date 9-4-1991 - Time 17:27:27
PEP205NO       POINTS.2D        E:\DATA\PEP\DIRECT\SRV1\PEP203.353
                                Date 9-5-1991 - Time 9:55:49
PEP205NO       POINTS.2D        E:\DATA\PEP\DIRECT\SRV1\PEP203.353
```

Figure 3–13. NEWPNTS.LOG

Point Name	*Location*	*Coordinate Type*
PEP204	PEP	BNCHMARK
PEP207	PEP	BNCHMARK
PEP217	PEP	BNCHMARK
PEP2095	UNKNOWN	
RPEP201	SNET	BNCHMARK
PEP201	PEP	BNCHMARK
PEP216	PEP	BNCHMARK

Figure 3–14. POINTS.1D

Point Name	*Location*	*Coordinate Type*
PEP203	PEP	MONUMENT
PEP204	PEP	MONUMENT
PEP205	PEP	MONUMENT
PEP206	PEP	MONUMENT
PEP214	PEP	MONUMENT
PEP215N	UNKNOWN	
PEP216	PEP	MONUMENT
PEP217	PEP	MONUMENT

Figure 3–15. POINTS.2D

4. GEONET DATA REDUCTION PROGRAMS

Each measurement type has its own data reduction program, Table 4-1.

Table 4–1. GEONET reduction programs

Data Reduction Program	*Data Collection Program*	*Measurement Type*	*Measurement files*	*Output files*
INVRED	INVAR	Distinvar	*.IVL, *.INV	INVRED.LST, INVREDH.RES, INVREDS.RES
LEVEL	LEVEL	Leveling	*.LVL	
LEVRED	INVLEVEL	Leveling	*.IVL	HEIGHTS.DAT, LEVRED.LST
MEKRED	ME500	Mekometer	*.IVL, *.MEK	MEKRED.OUT, MEKREDH.RES, MEKREDS.RES
	OFFSET	Offsets	*.OFS	OFFSET.RES
REDIR	DIRECT	Directions	*.DIR	
REDST	DIST	DM503 distances	*.DST	REDIR.RES

The reduction programs require a survey epoch index file. Created when a new survey epoch is added to the database, this index file contains the file names of all data files and is updated each time a new file is uploaded. The survey epoch is used for the file name of the index files and IDX is used as filetype, *e.g.*, SRV9.IDX is the index file for survey epoch nine. The reduction programs open the IDX file and start processing each entry in the order they have been uploaded.

Also required is a parameter file in the GEONET\PARAM subdirectory, containing information about the location of all input and output files necessary to run a particular reduction program. The file name for the parameter file is defined by the measurement type while the file type is always PRM, *e.g.*, MEKO.PRM for mekometer reductions.

Each reduction program creates one or more result files with the filetype RES in the same sub-directory as the measurement data. These result files are later used to create the input files for the least-squares adjustments. Several programs also create a more detailed listing of the results in a file with filetype OUT.

4.1. REFERENCE SURFACES

Beam line coordinates are usually calculated in a cartesian coordinate system disregarding the earth's curvature. Since most survey instruments are leveled using a bubble, measurements are made with respect to gravity in a non-planar reference system. The discrepancy between the planar and non-planar systems grows exponentially with size. For small sites with radial distances less than 250 m from the origin the difference in length between the arc and the chord is negligible. For lengths in the range 250–1000 m, it is sufficient to approximate the gravity reference system with a sphere whose radius depends upon the latitude of the site. For distances beyond 1000 m an ellipsoid should be used as the reference surface (Fig. 4-1). For very large projects or for projects near major topographic discontinuities, account may be necessary of the deviations of the geoid from the ellipsoid.

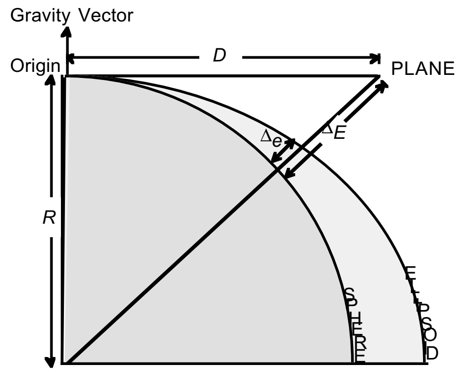

Figure 4–1. Survey reference surfaces

The elevation difference ΔE between a planar and spherical coordinate system grows with the square of the distance D from the origin (4-1): 0.8 mm at 100 m and 80 mm at 1000 m. R is the radius of the earth, approximately 6400 km.

$$\Delta E = \frac{D^2}{2R} \tag{4-1}$$

If the gaussian osculating sphere is used as the reference system, the difference between the ellipsoid and the sphere is

$$\Delta E = \frac{D^2 (K_1 - K_2)}{2} \tag{4-2}$$

with

$$K_1 = \frac{1}{\sqrt{MN}} \tag{4-3}$$

and

$$K_2 = \frac{\cos^2 A}{M} + \frac{\sin^2 A}{N} \tag{4-4}$$

where K_1 is the radius of curvature of the gaussian sphere, K_2 the curvature of the ellipsoid (Euler's Formula), A the azimuth, M the radius of curvature in the meridian, and N the radius of curvature in the prime vertical perpendicular to the meridian plane. Table 4-2 shows the discrepancy between sphere and ellipsoid depending on the azimuth and distance from origin.

Table 4–2. Sphere-ellipsoid separation Δe

Azimuth A	Separation Δe $D = 500$ m	$D = 1000$ m
0°	-0.04	-0.2
45°	0.0	0.0
90°	+0.04	+0.2

Since the area covered by the Stanford Linear Collider (SLC) is about 1 x 1 km, we use the gaussian osculating sphere as reference surface. The distance reduction is therefore independent of azimuth. Clark's ellipsoid is used for the calculation of the radius of the gaussian sphere (Table 4-3), because previous work by the National Geodetic Survey (NGS) was based on this figure.

Table 4–3. Clark's ellipsoid

semimajor axis	a	6 378 206.4 m
semiminor axis	b	6 356 583.8 m
latitude	ϕ	37.5°
mean radius	R	6 372 508.033 m

4.2. INVRED: DISTINVAR REDUCTIONS

Program Name : INVRED
Measurement file : *.INV
Results file : INVREDS.RES, INVREDH.RES
Detailed listing : INVRED.LST

INVRED reduces Distinvar measurements using the following steps:

1. *Obtain Calibrated Wire Length:* the calibrated wire length is obtained from the calibration data base (WIRES.DAT). The values contained in this data base are for the temperature at which they were calibrated. The calibrated length is reduced to 20°C. A check is made to ensure that there is a calibration both before and after the measurement in the field, and that these two calibrations agree to within 50 µm. The calibrations before and after measurement should be with the same distinvar as used for the measurement. If a different distinvar was used, the distinvar offsets are obtained from the file of offsets (OFFSET.IDX). The wire length used for subsequent steps is then the mean of the two calibrations.

2. *Temperature Correction:* using the expansion coefficient for the wire (contained in the file WIRES.REF), the calibrated length is reduced to the field temperature recorded at the time of measurement.

3. *Catenary Correction:* Under its own weight the wire sags in the form of a catenary curve, so that the length of the wire is greater than the straight-line distance. For level lines this poses no problem because the effect will be equal in calibration as in measurement, but for sloped lines the measurement conditions are no longer the same as the calibration conditions—the shape of the catenary for a sloped line is different than that of a level line (Fig. 4-2).

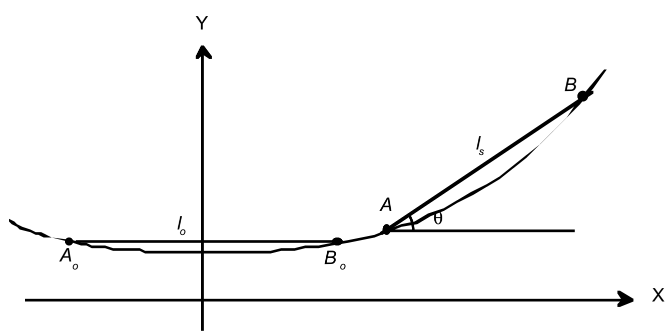

Figure 4–2. A catenary curve

There are two effects: because a different tension is imposed on the wire, the elongation of the wire is different; and the relationship of the catenary arc to the chord is different. Both corrections are given in brief below.[1]

[1] The equations are here presented only in summary; they are derived in full in M.Mayoud, Sloping Length Measurement with the CERN Distinvar, CERN Internal Report, SPS-SU/MM/Int./81-1, 1981.

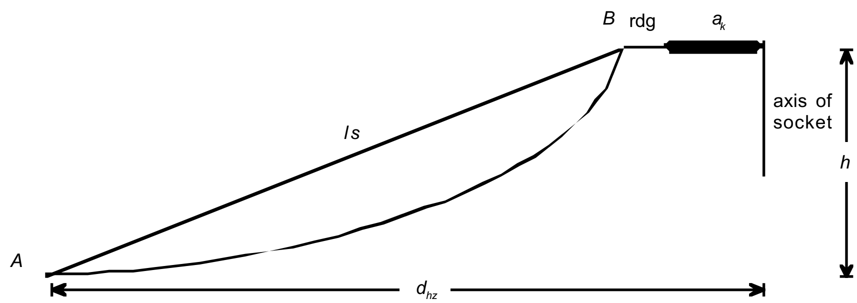

Figure 4–3. Sloped distinvar measurement

A sloped distinvar measurement can be analyzed as shown in Fig. 4-3. The calibrated length of the wire l_{cal} includes both the actual length of the wire l_w and a constant, here called the distinvar constant a_k, which is 65 mm for all instruments (4-5).

$$l_w = l_{cal} - a_k \tag{4-5}$$

Neither the reading nor the constant should be included in the catenary correction or the slope reduction.

a) Elongation of the wire. A wire elongates under tension. On a sloped line the tension imposed on the wire is different, so its elongation is not the same as that during calibration. The change in tension is determined by the change in location of the end points along the catenary curve. In Fig. 4-2 the endpoint has moved from B_0 to B, a change in elevation of Δy,

$$\Delta y = \frac{a \tan^2 h}{2} + \frac{h}{2} - \frac{h^2}{8a} \tag{4-6}$$

The change in elongation Δl is

$$\Delta l = \frac{l\,w\,\Delta y}{E\,\sigma} = 5.068 \times 10^{-7}\, l\, \Delta y \tag{4-7}$$

where E is Young's modulus (15970 kg/mm2), σ is the cross-section of wire (2.14 mm2), w the weight of wire per unit length (0.01732 kg/m).

b) Arc-to-chord correction. Assuming the same arc length, the chord across a sloped catenary will always be longer than the chord across a catenary where the ends are at equal height. Referring again to Fig. 4-2, the sloping chord l_s is always longer than the horizontal chord l_0 for the same arc length. The difference Δc in the catenary correction is

$$\begin{aligned} \Delta c &= \frac{l_w^3}{24a}(1 - \cos^4 \theta) \\ &= \frac{l_w^3}{17998944}(1 - \cos^4 \theta) \end{aligned} \tag{4-8}$$

where θ is the slope of the line, and a the catenary parameter (866 m).

These corrections, Δl and Δc, are not the absolute corrections, but rather the amount by which these corrections differ from those pertaining when the wire was calibrated in a horizontal position. The corrected slope distance is then the sum of the calibrated wire length plus the two corrections:

$$d_s = l_w + \Delta l + \Delta c \tag{4-9}$$

4. *Slope Reduction*: the simple Pythagorean geometrical reduction to the horizontal at h_m, the mean height of the line. To this is added the instrument constant a_k, and the distinvar reading rdg, to give the horizontal distance d_{hz},

$$d_{hz} = \left(d_s^2 - h^2\right)^{1/2} + a_k + rdg \tag{4-10}$$

5. *Reduction to the spheroid*: reduction to distance d_{ell} on the reference figure at height h_{ref} above the sphere of radius R,

$$d_{ell} = d_{hz} \frac{R + h_{ref}}{R + h_m} \tag{4-11}$$

The usual measurement procedure is to use a pair of wires. Each distance is measured independently with the two wires. This allows the detection of wire calibration problems.

4.2.1. INVRED Output Files

Three output files are produced: a detailed listing (INVRED.LST), a brief list of slope distances (INVREDS.RES), and a brief list of ellipsoidal distances (INVREDH.RES). On the *.RES lists, a series of stars is used to indicate problems that arose in the data reduction. A star is printed for any one of the following problems:

a) Agreement between before and after calibration of A wire exceeds 50 μm;

b) Agreement between before and after calibration of B wire exceeds 50 μm;

c) No calibration before measurement;

d) No calibration after measurement;

e) Final reduced distances for wires A and B differ by more than 50 μm.

```
INVAR  MEASUREMENT  &  REDUCTION   -  File IB3B4   .318

MEASUREMENT DATA :   B03       to  B04
11-14-85                                        CHRIS
21:58                                           JILL
Distinvar # 2                     Dial gauges used

Wire # C3000A   Distinvar  readings :   40.77  40.75  40.74
                Dial gauge readings :     .05    .05    .05
                Mean = 40.803 mm
Wire # C3000B   Distinvar  readings :   36.96  36.97  36.95
                Dial gauge readings :     .05    .05    .05
                Mean = 37.010 mm                DG diff. =  +.000
Temperature :  -.1 oC

HEIGHT INFORMATION  (geodetic heights)
   B03         95.4491 m
   B04         95.2968 m
   Ht. diff.    -.1523 m
   Gradient     -.5 %

Wire # C3000A      Composition : CERN lg
BENCH CALIBRATION DATA - lengths at 20 oC for #1
#1    10-30-1985  15:12       29.975006
#2    11-18-1985  09:20       29.974938
   Change in length            -.000068
No field calibration

Mean length at 20 oC          29.974304
Distinvar reading               .040803
Slope distance                30.015179
Ellipsoidal distance          30.014709

Wire # C3000B      Composition : CERN lg
BENCH CALIBRATION DATA - lengths at 20 oC for #1
#1    10-30-1985  15:13       29.978733
#2    11-18-1985  09:26       29.978712
   Change in length            -.000021     Rel. change =  +.000047
No field calibration

Mean length at 20 oC          29.978055
Distinvar reading               .037010
Slope distance                30.015136
Ellipsoidal distance          30.014666     Diff.       =  -.000043

CORRECTIONS & REDUCTIONS
Temperature correction         +.000071
Slope correction               +.000001
Slope reduction                -.000387
Ellipsoidal reduction          -.000084

**********  Reduced & Corrected Distance  =  30.014688 m  **********
```

Figure 4–4. INVRED.LST

```
B03     B04             30.01516   *
B04     B05             19.99688
B05     B06             40.01330   **
B06      B07                  49.98553
***
B07     B08             50.01980   **
B08      B09                  49.99121
***
B09      B10                  49.98668
***
B10     B11             20.00161
B11      B12                  50.00650
***
B12     B13             39.99190   *
```

Figure 4–5. INVREDS.RES

```
B03     B04             30.01469   *
B04     B05             19.99660
B05      B06                  40.01271
**
B06      B07                  49.98484
***
B07      B08                  50.01907
**
B08      B09                  49.99047
***
B09      B10                  49.98596
***
B10     B11             20.00132
B11      B12                  50.00578
***
B12     B13             39.99135   *
```

Figure 4–6. INVREDH.RES

4.3. LEVEL REDUCTIONS

Program Name : LEVEL
Measurement file : *.LVL
Results file : LEVEL.RES
Detailed listing : LEVEL.OUT

The level reduction program compensates for the offsets between the different level rods. LEVEL.RES contains a simple listing of the reduced elevations, while LEVEL.OUT contains a more detailed listing (Figs. 4-7, 4-8).

```
BM38    BMS6       -15.77663      .469
BMS7    BM6A       -13.75763      .316
BM36    BMS7       -12.24828      .316
SEAD    BMS6        -2.52950      .200
BMS6    BM6A        17.26812      .400
BMS8    BM36         3.48876      .200
```

Figure 4–7. LEVEL.RES

```
Level-Line :   BMS6     - BM38       Date          :   10-09-87

Distance   :  .440 (Km)              No of Setups :  22
Cal-Corr   :  -18.500 mue             Temp-Corr    : -146.040 mue
Uncorr dH  :   15.77663 m            Corr dH      :   15.77646 m


Level-Line :   BM38     - BMS6       Date          :   10-26-87

Distance   :  .440 (Km)              No of Setups :  22
Cal-Corr   :   -3.000 mue            Temp-Corr    :     6.151 mue
Uncorr dH  :  -15.77681 m            Corr dH      :  -15.77680 m


Average of For- and Backwards Run :
Uncorr dH  :  -15.77672 m            Corr dH      :  -15.77663 m

Differences (d) between For- and Backwards Run     :
d (Uncorr)  :   -.18000  (mm)             d  (Corr)      :   -.34139
(mm)

[dd]  uncorr    :    .03240  (mm)        [dd]  corr      :    .11655
(mm)
[dd/L]  uncorr  :    .07364  (mm)        [dd/L]  corr    :     .26488
(mm)
```

Figure 4–8. LEVEL.OUT

There are two common sources of problems:

a) if the input file contains work from several different days, the names TP1, TP2, etc., may be re-used for different turning points on different days. The data file should be edited so that each point name is unique.

b) if the the wrong suffix has been entered for the level rod (the suffix indicates what the rod is resting on), LEVEL.OUT will show large loop closures.

4.4. LEVRED: INVLEVEL REDUCTIONS

Program Name : LEVRED
Measurement file : *.IVL
Results file : HEIGHTS.DAT
Detailed listing : LEVRED.LST

LEVRED reduces INVLEVEL measurements of elevation differences necessary for reducing slope distances to the horizontal. The data reduction programs that require LEVRED output are INVRED invar reductions and MEKRED ME5000 reductions. LEVRED is automatically run prior to INVRED and MEKRED. INVLEVEL measurements for INVRED are contained in the data file INVLEVEL.IVL; measurements for MEKRED are in MEKLEVEL.IVL.

The INVLEVEL measuring sequence is unpredictable: it should be a series of interconnected loops, but can include dead-end traverses. The program separates the loops from the dead-ends, adjusting the former with a least-squares solution, and the latter by distributing any error equally along the line. At least one point of known elevation must be included. If this known point is a rivet name starting with 'R' its elevation will be automatically taken from the coordinate database. Otherwise one or more points of known elevation must be contained in the file BM.DAT in the same subdirectory as the INVLEVEL.IVL data file.

A detailed listing of the reduction is written to LEVRED.LST (Fig. 4-9). A list of the reduced elevations is written to the file HEIGHTS.DAT (Fig. 4-10). These elevations include the y-bias (ellipsoidal constant), which is later subtracted by INVRED and MEKRED.

The accuracy dΔH required in the height difference ΔH in order to obtain the accuracy dD in the distance D is

$$\mathrm{d}\,D = \frac{\Delta H}{D}\mathrm{d}\,\Delta H \tag{4-12}$$

For example, to obtain an accuracy of 0.1 mm in a 200 m distance with a 10 m elevation difference, the height difference must be known to an accuracy of 2 mm.

```
INVAR  REDUCTION  -  Preliminary level reduction

          File  :  l:\DATA\bline\INVAR\srv4\INVLEVEL.IVL


Legs in level net   =  30
BMs in level net    =   1

LOOPS      :  Loops                =   1
              Legs                 =  20
              BMs                  =   0
              Unknowns             =  20
              Convergence limit    =   .00010
              Iterations           =   2
              Residuals  :  Max.   =   .00004
                            Mean   =   .00001
                            Sum    =   .00028

DEAD-ENDS  :  Legs                 =  10

              Start     End        Legs   Misclosure

              SE19      212         2        open

New stations computed   =  29
```

Figure 4–9. LEVRED.LST

```
B03       2095.44909
B04       2095.29681
B05       2095.20329
B06       2095.00825
B07       2094.77254
B08       2094.52748
B09       2094.28040
B10       2094.03730
B11       2093.94040
B12       2093.69767
B13       2093.50909
```

Figure 4–10. HEIGHTS.DAT

4.5. MEKRED: ME5000 REDUCTIONS[2]

Program Name	:	MEKRED
Measurement file	:	*.MEK
Results file	:	MEKREDH.RES, MEKREDS.RES
Detailed listing	:	MEKRED.OUT

4.5.1. Reduction Process

4.5.1.1. Raw Distance from Frequencies

The raw data file contains both frequencies (up to three) and the distance calculated from those frequencies. Although the distance is saved in this file, the MEKRED program recalculates the distance afresh from the frequencies.

4.5.1.2. Atmospheric Reduction

All EDM instruments measure a length by emitting a beam of electro-magnetic radiation and determining the number of wavelengths in the round trip to the reflector and back. The wavelength is determined not only by the frequency but also by the refractive index of the air. The distance displayed on the ME5000 and recorded in the raw data file is calculated assuming a standard atmosphere (Table 4-4).

Table 4–4. Standard atmosphere for ME5000 measurements

Temperature	15°C
Pressure	760 mmHg, 1013.25 hPa
Moisture	none
Refractive Index	1.000 284 515

The refractive index is calculated using the formulae of Owen, Sprung and Goff-Gratch. Table 4-5 shows the accuracy required of the atmospheric measurements for an accuracy of $\pm 1.10^{-6}$ (1 ppm) in the refractive index and hence an accuracy of ± 1 ppm in the reduced distance. By far the major uncertainty is temperature.

Table 4–5. Required precision in atmospheric variables

Dry temperature	± 1°C
Moisture	± 40%
Pressure	± 3 mmHg / ± 4 mbar

The corrected distance D_A is the raw distance D multiplied by the ratio of the standard and actual refractive indices,

$$D_A = D\frac{n_s}{n_a} \tag{4-13}$$

[2] A more comprehensive treatment is available in Bernard Bell (ed.), *Proceedings of the Workshop on the Use and Calibration of the Kern ME5000 Mekometer*, SLAC, 1992, Report SLAC-403.

This correction for refractive index is also known as the first speed correction. For the sake of completeness two other corrections are applied: the second speed correction and the beam curvature correction; both are significant for microwave measurements over tens of kilometers, but neither is significant for infra-red EDM measurements below 10 km.

4.5.1.3. Geometric Reductions

Geometric reduction brings the slope distance D_S to the horizontal distance D_H at the mean height H_M

$$D_H = \sqrt{D_S^2 - (H_i - H_t)^2} \tag{4-14}$$

4.5.1.4. Geodetic Reductions

Reduction to the ellipsoidal distance on the reference figure (the curved arc distance along the reference surface at the reference height) is accomplished in two stages.

a) the horizontal distance D_H at the mean height H_M is reduced to the horizontal (chord) distance D_{REF} at the reference height H_{REF} (4-15 and Fig. 4-11)

$$D_{REF} = D_H \frac{R + H_{ref}}{R + H_m} \tag{4-15}$$

where R is the radius of the gaussian sphere.

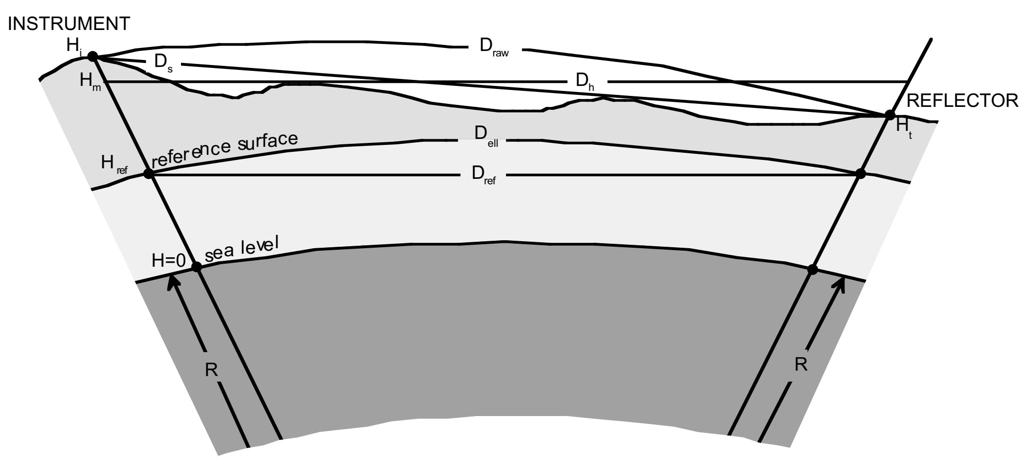

Figure 4–11. Geodetic Reductions

b) a curvature correction reduces the distance along the chord to that along the arc (4-16). The magnitude of this curvature correction is negligible for ME5000 distances, but is included for completeness.

$$D_{ELL} = D_{REF} \frac{D^2}{24(R + H_{REF})} \tag{4-16}$$

4.5.2. Input Files

When MEKRED is run in the Geonet environment, the names of the necessary input and output files are written to the file MEKO.PRM in response to selections made from various menus presented to the user. If the user wishes to run MEKRED outside the Geonet environment, it is only necessary to create the MEKO.PRM file and place it in the correct subdirectory.

4.5.2.1. Parameter File

As the user negotiates the Geonet data reduction menus, a file is prepared containing the names of all I/O files needed by MEKRED. MEKRED looks for this file as C:\GEONET\PARAM\MEKO.PRM. Lines 3-7 are used by LEVRED, the level reduction program that runs immediately prior to MEKRED. Lines 1-2, 7-11 are used by MEKRED. If the user wishes to run MEKRED in stand-alone mode, it is not necessary that the files referred to in lines 3-6 even exist, provided a file of elevations exists as described in line 7.

```
N:\DATA\BLINE\MEKO\SRV9\
N:\DATA\BLINE\MEKO\SRV9\SRV9.IDX
N:\DATA\BLINE\MEKO\SRV9\INVLEVEL.IVL
N:\DATA\BLINE\MEKO\SRV9\BM.DAT
N:\CALIB\SLC\LROD\CAL1\OFFSET.IDX
C:\GEONET\TEMP\LEVRED.LST
C:\GEONET\TEMP\HEIGHTS.DAT
N:\CALIB\SLC\MEKO\CAL1\CAL1.DAT
C:\GEONET\TEMP\MEKRED.OUT
C:\GEONET\TEMP\MEKREDH.RES
C:\GEONET\TEMP\MEKREDS.RES
```

Figure 4–12. MEKO.PRM

4.5.2.2. Raw Measurement File

MEKRED works its way through the index file (identified on the second line), taking one data file at a time. Two different formats have been used for these raw data files. The old format uses a fixed record length of 125 (125 characters per line). Since this was inconvenient for editing on a 80-column monitor, the format was changed to a fixed record length of 79 characters (79 characters per line) without the loss of any significant information. MEKRED can handle both formats. An example of the new format is given in §3.3.6.

4.5.2.3. Heights File

The heights file (usually called HEIGHTS.DAT) contains a list of elevations, including y-bias (ellipsoidal constant), for all instrument and target stations (Fig. 4-10).

4.5.2.4. Constants File

In the GEONET environment at SLAC this file is N:\CALIB\SLC\MEKO\CAL1\MEKO.DAT. The location of this file at other labs will depend upon the configuration of GEONET.

```
REFERENCE ELLIPSOID CONSTANTS
Major-Axis  6378206.4           semi-major axis of ellipsoid
Eccentricity      0.00676866    square of first eccentricity
Latitude         37.41684906    degrees
Refheight        77.6437        normal height, meters
Ellipsoidal    2000.000         Constant added to elevations
INSTRUMENT HEIGHT CONSTANT
Instrument    Dummy         Height const
357036        0.0           0.1020   CEBAF
357037        0.0           0.1020   LBL
357046        0.0           0.1020   FNAL
357086        0.0           0.1020   ANL
357088        0.0           0.1180   BNL
357089        0.0           0.1020   SLAC
PRISM HEIGHT CONSTANTS
Prism name    Constant      Height (including adapter)
365618        0.000000      0.412000
365619        0.000000      0.412000
365630        0.000000      0.412000
374425        0.000000      0.412000
375632        0.000000      0.412000
375624        0.000000      0.412000
LBL-TH1      -0.000650      0.070000
LBL-TH2      -0.000700      0.070000
ANL-TH1      -0.001600      0.070000
ANL-TH2      -0.001500      0.070000
ANL-TH3      -0.001600      0.070000
```

Figure 4–13. MEKO.DAT file for MEKRED

This constants file contains three types of data: geodetic, instrument and reflector constants.

1. Geodetic constants

The first six lines contain geodetic constants used by MEKRED. Of these, lines 2-4 are used to calculate the earth's radius. The nature of these parameters is as follows:

a) **Semimajor-Axis:** a, the semimajor axis of the reference ellipsoid, in meters. The reference figure used at SLAC is Clarke's ellipsoid of 1866, defined by its semimajor a and semiminor b axes,[3]

semimajor axis: a = 6 378 206.4 m
semiminor axis: b = 6 356 583.8 m

b) **Eccentricity:** $e2$, the square of the first eccentricity,

$$e^2 = \frac{a^2 - b^2}{a^2} \tag{4-17}$$

c) **Latitude:** ϕ, the latitude of the site, in degrees.

These first three parameters are used to calculate the earth's mean radius of curvature at the site. Since the reference surface is a spheroid not a sphere, the radius of curvature varies with latitude. At a given latitude the curvature is usually expressed in the form of the two principal radii of curvature, ρ (referred to as M in some of the literature) the radius of curvature in the meridian, and ν (or N in some of the literature) the radius of curvature in the prime vertical, perpendicular to the meridian (4-18, 4-19). SLAC is a sufficiently small site that it is adequate to ignore the azimuth of the line, taking instead the mean radius R_m which is the geometric mean of the two principal radii, (4-20).

[3] 'SLC Alignment Handbook,' in *SLC Design Handbook*, 1984, p. 8–31.

$$\rho = \frac{a(1-e^2)}{(1-e^2\sin^2\phi)^{3/2}} \tag{4-18}$$

$$\nu = \frac{a}{(1-e^2\sin^2\varphi)^{1/2}} \tag{4-19}$$

$$R_m = \sqrt{\rho\nu} \tag{4-20}$$

The latitude given in the example file above is for the origin ofthe SLAC coordinate system, station 100 at the east end of the linac.

latitude: ϕ = 37.4168°

mean radius: R_m = 6 372 508.16 m

d) **Refheight:** the reference height to which reduced ellipsoidal distances are projected. This is the normal height, in metres, above the ellipsoid.

e) **Ellipsoidal:** the constant added to elevations to avoid confusion between elevations and vertical cartesian coordinates (Z). The values in the elevations file read by MEKRED include this offset, which is subtracted by the program.

2. Instrument constants

The ninth line contains constants for the instrument. The first value is a dummy variable that is not used. The second value is the height offset. The program applies a vertical offset of 0.310 m, the height of the opto-mechanical center above the base of the instrument configured with the standard LMC0500 tribrach (the true Kern tribrach). The GDF21K tribrach (the Wild version of the Kern tribrach) is an additional 0.016 m higher. The offset listed in the file is the additional offset from the base of the LMC0500 tribrach to the vertical reference point. At SLAC we use the center of the CERN socket as the vertical reference. The Kern plate on top of the standard locking pin is 0.102 m above the center of the CERN socket, Fig. 4-14.

MEKRED now accepts offsets for up to ten instruments.

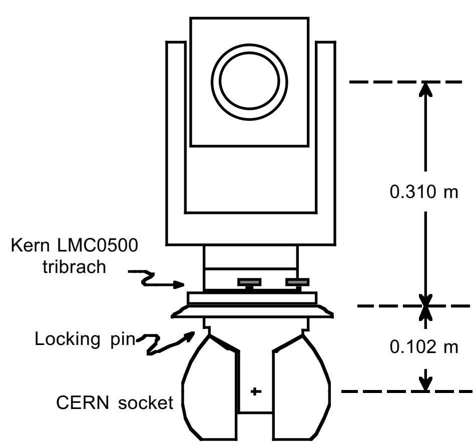

Figure 4–14. Vertical offsets for the ME5000

3. Reflector constants

Lines 12 onwards contain constants for the reflectors. MEKRED can handle up to thirty lines of such information. Each line has three fields. The first field is the reflector name. The second field is the horizontal addition constant. The third field is the vertical offset from the reference surface to the center of the reflector. Using SLAC's standard locking pins, the center of the regular ME5000 reflector is 0.412 m above the center of the CERN socket, Fig. 4-15. The center of a Taylor-Hobson ball is exactly 70 mm above the center of the CERN socket in which it sits.[4]

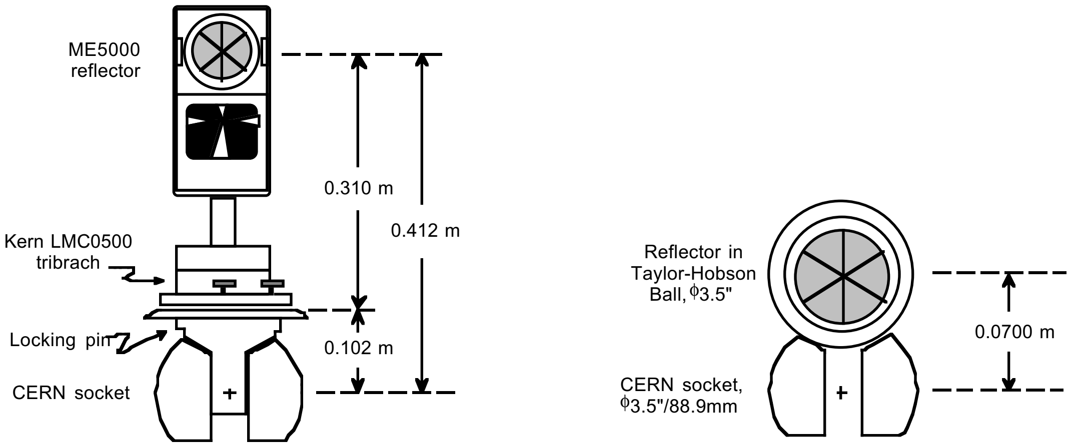

Figure 4–15. Vertical offsets for ME5000 reflectors

4.5.3. Output Files

Three output files are created on the users hard disk in the directory C:\GEONET\TEMP.

4.5.3.1. MEKREDS.RES

MEKREDS.RES (Fig. 4-16) contains a brief listing of the reduced slope distances and their standard errors. These slope distances incorporate the three atmospheric corrections.

4.5.3.2. MEKREDH.RES

MEKREDH.RES (Fig. 4-17) contains a brief listing of the reduced geodetic distances and their standard errors. These distances incorporate all atmospheric, geometric and geodetic corrections and reductions. They are therefore the ellipsoidal distances (arc distances along the ellipsoid) at the reference height.

4.5.3.3. MEKRED.OUT

MEKRED.OUT (Fig. 4-18) contains a full listing of the data reductions. The final reduced distance is the mean value for the ellipsoidal distance at the reference height. The atmospheric, geometric and geodetic corrections are listed separately for each distance.

[4] E. Menant, The New System of SPS Reference Targets, CERN Survey Group Technical Note, 22 June 1979.

```
B20       B19                 40.02356
.00003
B20       B17                100.03722
.00003
B20       B15                180.03935
.00001
B20       B14                210.03875
.00003
B20       B12                300.05123
.00022
B20       B10                370.06032
.00006
B20       B05                610.05718
.00010
B20       B03                660.06583
.00027
B20        B02              1190.08134
.00005
```

Figure 4–16. MEKREDS.RES

```
B20       B19                 40.02302
.00003
B20        B17               100.03586
.00003
B20        B15               180.03687
.00001
B20        B14               210.03586
.00003
B20        B12               300.04707
.00022
B20        B10               370.05513
.00006
B20        B05               610.04853
.00010
B20        B03               660.05646
.00027
B20         B02             1190.06357
.00005
```

Figure 4–17. MEKREDH.RES

```
ME5000 Mekometer Reduction File: C:\GEONET\TEMP\MEKRED.OUT
    Reduced: 07-06-92  09:07
    ======================================================================

    Station : B20                             Observer  : billo
                                              Rman1     : miker
    06-11-92   21:53:18                       Rman2     : none
                                              OVERCAST  CALM
    Mekometer : 357089                        Stn Therm.: 450264
    Add. const:  .1420                        Tgt Therm.: 450268
    Instr. Ht.:  .4120                        Barometer : 0137
    Elevation :   92.614                      Ref. Ht.  :   77.644

    ======================================================================

    Target : B19          T(C) HR(%)  P(mm)    T(C) HR(%)  P(mm)    RI
    Prism      : 375624   13.1  71.5  757.4    13.1  71.5  757.4  284994
    Add.Const.:  .000000  13.1  71.5  757.4    13.1  71.5  757.4  284994
    Tgt. Ht.  :  .41200
    Elevation :   92.802

    STime ETime   Dis@STP(m)  Reduced Dis        Corrections
    21:55 21:57    40.023600    40.023043        Met  :  -.00002
    21:58 22:00    40.023560    40.023002        Geom :  -.00044
                                                 Geod :  -.00009

                                 Mean =   40.023022  Std Dev =  .000029
    **********************************************************************

    Target : B17          T(C) HR(%)  P(mm)    T(C) HR(%)  P(mm)    RI
    Prism      : 375624   13.1  71.5  757.4    13.1  71.5  757.4  284994
    Add.Const.:  .000000  13.1  71.5  757.4    13.1  71.5  757.4  284994
    Tgt. Ht.  :  .41200
    Elevation :   93.088

    STime ETime   Dis@STP(m)  Reduced Dis        Corrections
    22:03 22:04   100.037244   100.035835        Met  :  -.00005
    22:05 22:06   100.037290   100.035881        Geom :  -.00112
                                                 Geod :  -.00024

                                 Mean =  100.035858  Std Dev =  .000033
    **********************************************************************
```

Figure 4–18. MEKRED.OUT

4.6. REDIR: DIRECTION REDUCTIONS

Program Name : REDIR
Measurement file : *.DIR
Results file : REDIR.RES
Detailed listing : none

This program is not a reduction program in the sense that it only manipulates the original data. It reformats and summarizes the reduced directions of all sets for each station into one file called REDIR.RES.

4.7. REDST: DM503 REDUCTIONS

Program Name : REDST
Measurement file : *.DST
Results file : REDIST.RES
Detailed listing : REFODI.OUT

This program is used to reduce distances measured with the Kern DM503 EDM instrument.

4.8. OFFSET REDUCTIONS

Program Name : OFFSET
Measurement file : *.OFS
Results file : OFFSET.RES
Detailed listing : none

Similar to the direction measurements this step only reformats and summarizes the measured offsets for each station. The result file is called OFFSET.RES.

5. LEAST SQUARES ADJUSTMENTS

After reducing the measured data sets the next step is usually to run a least-squares adjustment. The user is guided through this process by several series of menus.

5.1. CHOOSING THE ADJUSTMENT PROGRAM

The first series of menus guides the user through the selection of the appropriate least-squares adjustment program. The choice of program is determined by four variables: adjustment type, network dimension, input data and datum definition.

5.1.1. Adjustment Type

An adjustment may be either a one-norm or a two-norm adjustment.[1] The function to be minimized differs between these two forms: the one-norm adjustment minimizes the sum of the weighted absolute residuals (5-1); the two-norm adjustment minimizes the sum of the squares of the weighted residuals (5-2).

$$\text{(O) One Norm}: \sum |wr| = \min \tag{5-1}$$

$$\text{(T) Two Norm}: \sum wr^2 = \min \tag{5-2}$$

The one-norm adjustment is a suitable tool for blunder detection in geometrically well-defined and over-determined networks. It does not spread the blunders from bad observations among other good observations, and it identifies these blunders correctly in location and size.

5.1.2. Network Dimension

The next selection is whether the network to be adjusted is one-, two- or three-dimensional. One-dimensional networks are used for the determination of benchmark elevations and two-dimensional networks for the determination of monument positions. In these cases elevations and positions are treated independently. In a three-dimensional adjustment the position and elevation of a point are determined in one step.

5.1.3. Data Type

The third menu defines the data type: real observations (R), error propagation (E), and deformation analysis (D). Adjustment of real observed data is most common.

5.1.4. Datum Definition

The fourth and final menu defines the datum of the adjustment: unconstrained (F), constrained (A) or connected (C).

5.1.4.1. Unconstrained (Free) Network

An unconstrained or free network has no datum definition (Fig. 5-1). To solve the rank defect of the normal matrix an additional constraint is introduced, minimizing the sum of the

[1] Ingolf Burstedde, Adjustments of geodetic networks at SLAC, 1983.

differences between the approximate and adjusted coordinates. The result is a network best fitted to the approximate coordinates, which are usually derived from an earlier epoch.

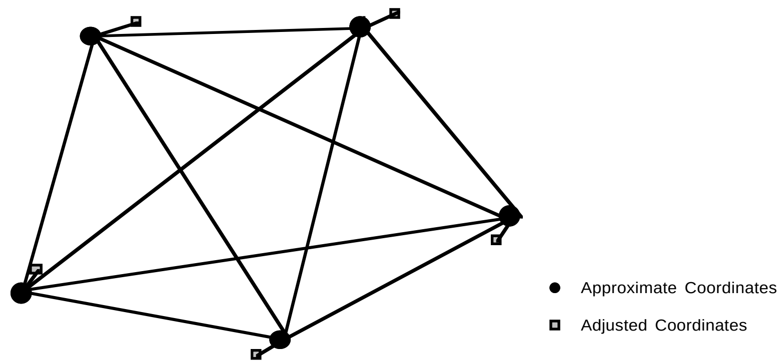

Figure 5–1. Unconstrained Network

5.1.4.2. Constrained Network

A constrained network (Fig. 5-2) can be either minimally-constrained or over-constrained to solve the normal equation without a rank defect. Minimally-constrained means that both coordinates of one point plus one coordinate of another point are fixed. Fixed in this context means these points are assumed to be error-free. If more than these minimum constraints are introduced the network is over-constrained.

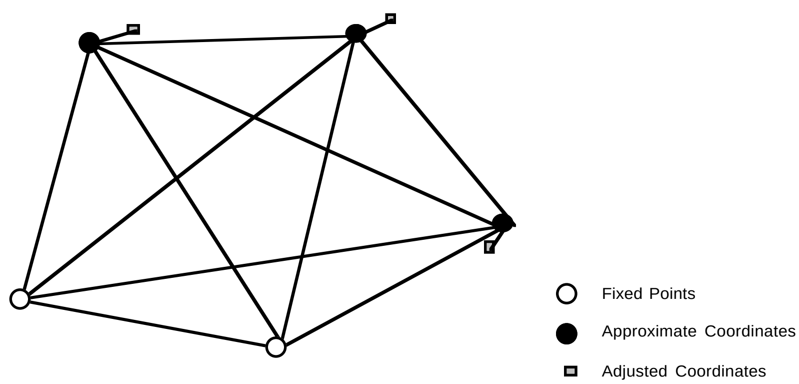

Figure 5–2. Constrained Network

5.1.4.3. Connected Network

A connected network (Fig. 5-3) requires the existence of a free net adjustment of a primary network. The secondary network will be connected via points common to both networks. The variance and covariance values for these points are used to calculate weights for the connecting points of the secondary network. A common application is the connection of a tunnel traverse to a surface network via survey shafts.

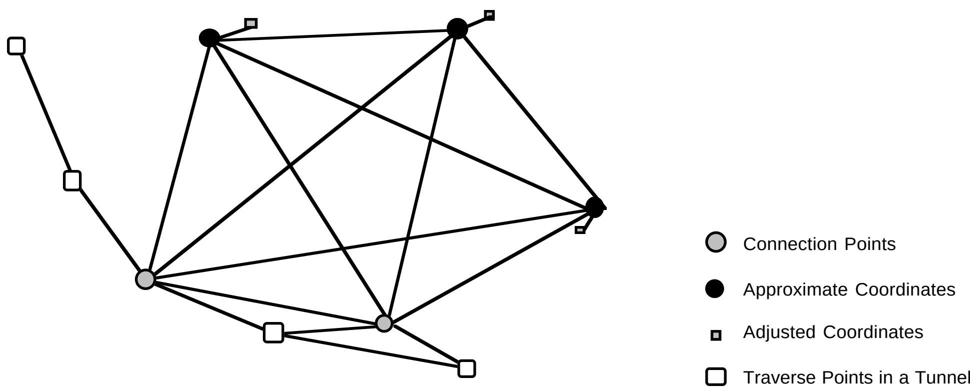

Figure 5–3. Connected Network

The Datum Definition menu offers two further options which are not actually related to the datum definition. Option (U) selects an appropriate blunder detection program. Option (P) selects a four-parameter transformation between the results of two unconstrained least-squares adjustments of two different survey epochs of the same location.

Successful navigation of these four menus should yield the name of a valid adjustment program. For example, T2RA is the program for a two-norm two-dimensional constrained adjustment using real observations. Not all combinations of the possible selections result in a valid name for an adjustment program. If the selection is invalid GEONET will notify the user and present a list of valid program names.

5.2. PREPARING THE INPUT FILE

After selecting the adjustment program the user chooses whether to use anexisting input file or to create a new input file. To create a new file the user is guided by a sequence of menus.

5.2.1. *A priori* Standard Error

After entering a title, the user selects the *a priori* mean square error which acts as a scale factor for the calculation of the weights. The default value of 0.0005 ensures a weight of one for distinvar distances. This parameter is located after the END statement of the section for fixed points in the example input file (Fig. 5-4).

5.2.2. Selecting Points

The next step is the selection of point names for the retrieval ofapproximate coordinates from the coordinate database. Two options are given:

1. **Coordinate List File.** The user eliminates unwanted point names from the coordinate list file, showing all point names for a certain location. .
2. **POINTS.1D and POINTS.2D files.** POINTS.1D or POINTS.2D, created during the upload process, contain names of all stations and targets occupied during a particular survey epoch—usually a subset of all point names for that particular location—plus information about the database from which approximate coordinates are to be retrieved.

```
TESTNET T2RA (APRIL 85) TUNNELNET NETPOINTS
APPROXIMATE COORDINATES
40           750.78927      750.58989
50           635.65957      700.02072
60           512.43354      535.99325
100          834.97100      501.58700
200          810.30200      476.22100
301          885.17600      428.07600
302          950.00000      375.00000
303         1014.78000      321.51100
END
FIXED COORDINATES
40       1
40       2
60       1
60       2
END
0.00050
WEIGHTED COORDINATES
50   1     0.00020
50   2     0.00020
END
HORIZONTAL DISTANCES
40      60            320.725     0.005
40      100           262.847     0.005
40      200           280.748     0.005
50      100           281.248     0.005
50      200           283.877     0.005
60      100           324.367     0.005
60      200           303.807     0.005
100     200            35.383     0.0005
100     301            89.019     0.0005
200     301            89.017     0.0005
301     302            83.781     0.0005
302     303            84.009     0.0005
END
HORIZONTAL DIRECTIONS
40
100          179.2453    0.0004
200          186.4017    0.0004
60           253.3361    0.0004
50           273.6522    0.0004
QUIT
50
100          149.8594    0.0004
200          157.8146    0.0004
60           241.0176    0.0004
40            73.6520    0.0004
QUIT
60
50            41.0176    0.0004
40            53.3360    0.0004
100          106.7654    0.0004
200          112.6073    0.0004
QUIT
100
40           379.2450    0.0004
301          161.8539    0.0004
200          249.1132    0.0004
60           306.7650    0.0004
50           349.8595    0.0004
QUIT
200
60           312.6073    0.0004
50           357.8147    0.0004
40           386.4017    0.0004
100           49.1133    0.0004
301          136.3795    0.0004
QUIT
301
200          336.3790    0.0004
100          361.8546    0.0004
302          143.6880    0.0006
QUIT
302
301            0.0000    0.0006
303          200.2443    0.0006
QUIT
END
GYRO MEASUREMENTS
301     302    143.6837    0.0020
302     303    143.9279    0.0020
END
OFFSET-MEASUREMENTS
302     303    301    0.1609    0.0005
END
RELATIVE ERROR ELLIPSES
302     303
END
ADJUSTED DISTANCES AS FUNCTION OF THE UNKNOWNS
301     302
302     303
END
ADJUSTED ANGLES AS FUNCTION OF THE UNKNOWNS
302     301    303
END
00       3.0
```

Figure 5–4. Input File for Least-squares Adjustment

The point names and their coordinates are listed under the section `APPROXIMATE COORDINATES` in the input file. Like all other sections this list is terminated by the `END` statement. Independent of the way the point names are selected, after the approximate coordinates have been retrieved the user has the opportunity to enter more approximate coordinates if necessary. This allows the user to create input files in overlapping areas.

If an unknown point is retained while creating the input file the program substitutes zero for the approximate coordinate values and attaches a comment stating that the point name could not be found. The unknown coordinates can be calculated by the adjustment program after replacing the zero values with some rough approximate coordinates. In this case the maximum number of iterations should be set fairly high.

5.2.3. Selecting Fixed and Constrained Points

Depending on the least-squares adjustment program selected, the next step involves the selection of fixed and weighted points. Only point names which are part of the adjustment are presented with an indicator for each coordinate. The user should eliminate all unwanted point names and should select whether one or both coordinates of the remaining points are fixed. Similarly all point names of the adjustment, minus the previously chosen fixed points, are presented for the selection of points which may be weighted. The weight for these points is preset to 0.0002 m and currently may be changed only by hand in the input file after the adjustment has been done once. The section for weighted points is terminated by `END`.

5.2.4. Selecting Measurements

The next series of menus presents a choice of measurement types to use as input. Only those measurement types defined in the DATA.STR file and with matching entries in the DATA.TBL file will be shown.

5.2.4.1. Distances

Distances are the first measurement type added to the input file. The user can choose mekometer distances, interferometer distances or distances calculated from approximate coordinates. Each type has its own mean square error which can be changed. If weighting of individual distances is necessary, this can be done manually by editing the input file after the first adjustment has been completed. The program selects only those distances from the reduced distance file whose station and target names are contained in the list of approximate coordinates

The option to use interferometer distances is provided for future use of laser tracker measurements. The appropriate reduction program is not yet in place.

The option to use distances calculated from approximate coordinates is useful for traverses measured on top of beam elements in which one is primarily interested in the deviations perpendicular to beamline. This technique has been used at SLAC for beam line smoothing. Only directions were measured and the calculated distances were input with a large mean square error.

The user is given the opportunity to select additional distances from a different location or epoch, allowing the creation of input files in overlapping areas.

5.2.4.2. Directions

The next menu offers input of direction measurements. The mean square error for directions is set to 0.0003 gon (0.3 mgon) and can be changed by the user before the data is selected from the result file using the point name list of the approximate coordinates. Each station is separated by a `QUIT` statement and the direction measurements are terminated by an `END` statement.

5.2.4.3. Other Measurements

Gyroscope and offset measurements are the final measurement types offered. Each section is terminated by an `END` statement.

5.2.5. Special Functions

Any of three special functions can be selected. Each section is terminated by `END`.

5.2.5.1. Relative error ellipses

The relative error ellipse will be calculated between the pairs of points specified.

5.2.5.2. Distances as a function of the unknowns

The adjusted distance and its expected mean square error will be calculated for the pairs of points specified.

5.2.5.3. Angles as a function of the unknowns

To obtain an angle as a function of the unknowns, specify the instrument station and two target stations. Both the angle and its expected accuracy will be calculated.

5.3. RUNNING THE ADJUSTMENT

Once the input file is complete, the user is asked for the number of iterations to be used to solve the adjustment. The default value is 7, but it can be increased to a maximum of 99.

After the least-squares adjustment is complete a number representing the quality of the survey is displayed on the screen. This number is the ratio of the mean square error *a priori* to the mean square error *a posteriori*. It should be close to one for an acceptable adjustment. A value significantly different from one suggests the presence of blunders or systematic errors. These should be eliminated before running the adjustment again.

A menu shows the output files created by the adjustment. Each file can be viewed using an editor and can also be printed. After exiting this menu the plot routine is invoked, presenting a graphical representation of the network geometry and the relative and absolute error ellipses. The observation plan for direction and distance measurements can also be plotted separately. All plots can be printed on a laser printer by pressing the 'P' key. Help is available through the 'H' key while running TDPREVU, a PC adaptation of TOPDRAW.

After viewing the results the user chooses either to redo the adjustment after modifying the input file or to return to the main menu, from where the same input file can be used to run any other adjustment including one-norm adjustments for blunder detection. This is possible because the input file is generic for all least-squares adjustment types of the same dimension.

5.4. THE OUTPUT FILES

The adjustment programs usually create three output files: ADJUST.OUT, ADJUST.DNM and ADJUST.DBS. These files are placed in the GEONET\TEMP subdirectory overwriting previous output files. Only the input files are kept, each in its appropriate subdirectory. Adjustments can be re-run at any time using these files. In the case of an unconstrained adjustment the DNM output file is stored with the input file. It contains the adjusted coordinates and the variance-covariance matrix and is required for deformation analysis, four-parameter transformation and connected net adjustment.

5.4.1. ADJUST.OUT

```
DATE : 02-10-92                    INPUT-FILENAME : ADJUST
TIME :    09:55                          FILETYPE : 2

PROGRAM  : T2RA
PATHNAME : \DATA\SNET\ADJUST\SRV1\

TESTNET T2RA (APRIL 85) TUNNELNET

APPROXIMATE COORDINATES
POINT             Z0              X0
40             750.78927       750.58989
50             635.65957       700.02072
60             512.43354       535.99325
100            834.97100       501.58700
200            810.30200       476.22100
301            885.17600       428.07600
302            950.00000       375.00000
303           1014.78000       321.51100

FIXED COORDINATES
40         1
40         2
60         1
60         2

WEIGHTED COORDINATES
50         1  0.00020
50         2  0.00020

STATISTICS
M0 = 0.00038     FACTOR = 0.76      F =   25    ITR =   2
SL = 0.00030     SU = 0.00053     F95 =  2.6

COORDINATE ADDITIONS AND ADJUSTED COORDINATES
POINT           DZ          DX            Z              X
40            0.00000     0.00000     750.78927      750.58989
60            0.00000     0.00000     512.43354      535.99325
50            0.00005    -0.00003     635.65962      700.02069
100           0.00008     0.00027     834.97108      501.58727
200          -0.00003     0.00026     810.30197      476.22126
301          -0.00016     0.00051     885.17584      428.07651
302          -0.00813    -0.00964     949.99187      374.99036
303          -0.00019     0.00006    1014.77981      321.51106

ABSOLUTE ERROR ELLIPSES
POINT         PHI         A           B
40             0.0     0.00000     0.00000
60             0.0     0.00000     0.00000
50            64.4     0.00015     0.00014
100          186.9     0.00097     0.00080
200          180.4     0.00093     0.00084
301           29.2     0.00113     0.00093
302           39.2     0.00151     0.00101
303           42.1     0.00208     0.00108

OBS. PARAMETERS         U            V            UA             MU
50      1           635.65957     0.00005    635.65962       0.00020
50      2           700.02072    -0.00003    700.02069       0.00020
```

—continued—

```
DISTANCES                S           V           SA            MS
40      60           320.72500     0.00101    320.72601      0.00500
40      100          262.84700     0.00064    262.84764      0.00500
40      200          280.74800     0.00083    280.74883      0.00500
50      100          281.24800     0.00079    281.24879      0.00500
50      200          283.87700    -0.00002    283.87698      0.00500
60      100          324.36700     0.00044    324.36744      0.00500
60      200          303.80700    -0.00066    303.80634      0.00500
100     200           35.38300     0.00060     35.38360      0.00050
100     301           89.01900    -0.00018     89.01882      0.00050
200     301           89.01700    -0.00007     89.01693      0.00050
301     302           83.78100     0.00000     83.78100      0.00050
302     303           84.00900     0.00000     84.00900      0.00050

DIRECTIONS              R          V            Z          TA          MR
40       100         179.24530   -0.00007      0.00015   179.24538
0.00040
40       200         186.40170    0.00002      0.00015   186.40187
0.00040
40       60          253.33610    0.00001      0.00015   253.33626
0.00040
40       50          273.65220    0.00003      0.00015   273.65238
0.00040
50       100         149.85940   -0.00006      0.00013   149.85946
0.00040
50       200         157.81460   -0.00003      0.00013   157.81470
0.00040
50       60          241.01760   -0.00016      0.00013   241.01757
0.00040
50       40           73.65200    0.00025      0.00013    73.65238
0.00040
60       50           41.01760   -0.00010      0.00007    41.01757
0.00040
60       40           53.33600    0.00019      0.00007    53.33626
0.00040
60       100         106.76540   -0.00005      0.00007   106.76542
0.00040
60       200         112.60730   -0.00003      0.00007   112.60734
0.00040
100      40          379.24500    0.00018      0.00019   379.24538
0.00040
100      301         161.85390   -0.00014      0.00019   161.85396
0.00040
100      200         249.11320   -0.00004      0.00019   249.11335
0.00040
100      60          306.76500    0.00022      0.00019   306.76542
0.00040
100      50          349.85950   -0.00023      0.00019   349.85946
0.00040
200      60          312.60730    0.00000      0.00003   312.60734
0.00040
200      50          357.81470   -0.00004      0.00003   357.81470
0.00040
200      40          386.40170    0.00013      0.00003   386.40187
0.00040
200      100          49.11330    0.00001      0.00003    49.11335
0.00040
200      301         136.37950   -0.00011      0.00003   136.37942
0.00040
301      200         336.37900    0.00078    399.99964   336.37942
0.00040
301      100         361.85460   -0.00029    399.99964   361.85396
0.00040
301      302         143.68800   -0.00049    399.99964   143.68715
0.00060
302      301           0.00000    0.00016    343.68699   343.68715
0.00060
302      303         200.24430   -0.00016    343.68699   143.93113
0.00060
```

```
GYROS                   RK          V           RA          MK
301     302         143.68370    0.00345   143.68715    0.00200
302     303         143.92790    0.00323   143.93113    0.00200

OFFSET       H          V           HA          MH
302     303    301    0.16090    -0.00014    0.16076    0.00050

RELATIVE ERROR ELLIPSES     PHI       A             B        E
302     303           43.9    0.00084      0.00038    0.00084

ADJUSTED DISTANCES AS FUNCTION OF THE UNKNOWNS
301    302  83.78100  0.00038
302    303  84.00900  0.00038

ADJUSTED ANGLES AS FUNCTION OF THE UNKNOWNS
302    301  303  200.24398  0.00042
```

Figure 5–5. ADJUST.OUT

5.4.1.1. Input Data

The top section of ADJUST.OUT shows the date and time of the adjustment, the input file name and type, the program name and the path name to the location of the input file. Thereafter follows a list of the approximate, fixed and weighted coordinates from the input file.

5.4.1.2. Statistical Evaluation

The section headed `STATISTICS` presents a statistical evaluation of the adjustment:

- `M0` mean square error (m.s.e.) *a posteriori*.
- `FACTOR` ratio of m.s.e. *a priori* to m.s.e. *a posteriori*. Indicates the quality of the data.
- `F` degree of freedom.
- `ITR` number of iterations required.
- `SL` lower limit of confidence interval of m.s.e. for α=5%, calculated using χ^2 table.
- `SU` upper limit.
- `F95` calculated as $F_{95} = \sqrt{2F_{2,f,95\%}}$ where F is the value from the 95% F-distribution with (2,f) degrees of freedom, f being the degree of freedom of the adjustment. The major and minor axes of the error ellipses are multiplied by F95 to obtain the confidence ellipses.

The results for SL, SU and F95 are valid only if the degree of freedom is greater than five since a polynominal approximation is used to calculate the values of the χ^2 and F-distribution.

5.4.1.3. Adjusted Coordinates

The section entitled COORDINATE ADDITIONS AND ADJUSTED COORDINATES shows the adjusted coordinates and the differences between these and the approximate coordinates. Usually the coordinates of the previous epoch are used as approximate coordinates so that the differences show changes between epochs.

5.4.1.4. Absolute Error Ellipses

This section lists the azimuth (PHI) of the major axis and the length of the major (A) and minor (B) axes for the error ellipse at each station of the network.

5.4.1.5. Observed Parameters

The lines show the approximate coordinate (U), the residual (V), the adjusted coordinate (UA) and the weight (MU) for all weighted coordinates.

5.4.1.6. Measurements

The next sections list for each measurement the raw measurement (S, R, RK or H), its adjusted value (SA, TA, RA or HA), its residual (V) and the estimated mean square error (MS, MR, MK or MH). The different measurement types are listed in the same order as the input file: distances, directions, gyroscope, offsets. For direction measurements an additional orientation unknown (Z) iscomputed for each station. Adding both the orientation unknown (Z) and the residual (V) to the measured direction (R) gives the adjusted azimuth (RA).

5.4.1.7. Special Functions

The final three sections show any special functions requested in the input file. The listing for each relative error ellipse shows the azimuth (PHI) of the major axis, the major (A) and minor (B) semi-axes and the size of the ellipse (E) perpendicular to the line between the end points (Fig. 5-6).

If requested, adjusted distances and angles calculated as functions of the unknowns are shown together with their respective mean square errors.

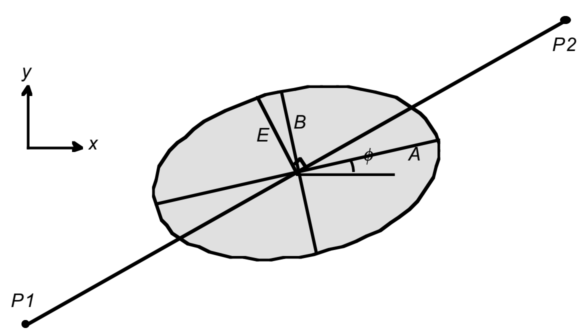

Figure 5–6. Relative error ellipse

5.4.2. ADJUST.DNM

```
3    1     0.00020
3    2     0.00020
1    2        320.72500   0.00500 320.72601  -0.00101
1    4        262.84700   0.00500 262.84787  -0.00087
1    5        280.74800   0.00500 280.74909  -0.00109
3    4        281.24800   0.00500 281.24898  -0.00098
3    5        283.87700   0.00500 283.87725  -0.00025
2    4        324.36700   0.00500 324.36739  -0.00039
2    5        303.80700   0.00500 303.80642   0.00058
4    5         35.38300   0.00050  35.38352  -0.00052
4    6         89.01900   0.00050  89.01915  -0.00015
5    6         89.01700   0.00050  89.01717  -0.00017
6    7         83.78100   0.00050  83.78074   0.00026
7    8         84.00900   0.00050  84.00906  -0.00006
1    4
4      179.24530   0.00040 179.24542   0.00005
5      186.40170   0.00040 186.40187  -0.00001
2      253.33610   0.00040 253.33626   0.00001
3      273.65220   0.00040 273.65240  -0.00004
3    4
4      149.85940   0.00040 149.85952   0.00003
5      157.81460   0.00040 157.81473   0.00002
2      241.01760   0.00040 241.01755   0.00020
1       73.65200   0.00040  73.65240  -0.00026
2    4
3       41.01760   0.00040  41.01755   0.00014
1       53.33600   0.00040  53.33626  -0.00017
4      106.76540   0.00040 106.76547   0.00002
5      112.60730   0.00040 112.60739   0.00000
4    5
1      379.24500   0.00040 379.24542  -0.00023
6      161.85390   0.00040 161.85392   0.00017
5      249.11320   0.00040 249.11323   0.00016
2      306.76500   0.00040 306.76547  -0.00028
3      349.85950   0.00040 349.85952   0.00017
5    5
2      312.60730   0.00040 312.60739  -0.00004
1      386.40170   0.00040 386.40187  -0.00013
4       49.11330   0.00040  49.11323   0.00012
6      136.37950   0.00040 136.37952   0.00003
6    3
5      336.37900   0.00040 336.37952  -0.00412
4      361.85460   0.00040 361.8539   -0.00292
7      143.68800   0.00060 143.67735   0.00705
7    2
6        0.00000   0.00060 343.67735   0.00949
8      200.24430   0.00060 143.94063  -0.00949

6    7    143.68370   0.00200   143.67735   0.00635
7    8    143.92790   0.00200   143.94063  -0.01273

7    8     6   0.16090   0.00050   0.17348  -0.01258
```

Figure 5–7. ADJUST.DNM

Each least-squares adjustment creates a temporary DNM output file (Fig. 5-7). In the case of a constrained adjustment this file can be edited after the adjustment is done. It contains the distances calculated using the approximate coordinates and the difference between these and the measured distances. Similar differences are calculated for the directions. This information can be useful if points have been misnamed. The upload procedure detects most naming errors where an invalid name has been used, but can not detect the case of a point misnamed with the valid name of a different station. If the approximate coordinates are already very well defined, the comparison of measured distances and directions to calculated ones will show immediately where the misnamed points are. This is especially useful in long and narrow tunnel networks where points can be easily misidentified and blunder detection programs do not work well because of the weak network geometry.

5.4.3. ADJUST.DNM database file

The third output file contains all the information to be updated in the coordinate database (Fig. 5-8). The first line contains the date of the adjustment and the location and survey epoch. Each subsequent line shows the point name, the difference between adjusted and approximate coordinates, the adjusted coordinates themselves and the parameters of the absolute error ellipses. All values except the differences from the approximate coordinates are used as entries to the database.

```
02-10-92  SNET       SRV1
50         0.00004648 -0.00003242   635.65962   700.02069  64.4 0.00015 0.00014
100        0.00007526  0.00026923   834.97108   501.58727 186.9 0.00097 0.00080
200       -0.00002580  0.00025987   810.30197   476.22126 180.4 0.00093 0.00084
301       -0.00015510  0.00050717   885.17584   428.07651  29.2 0.00113 0.00093
302       -0.00812872 -0.00963705   949.99187   374.99036  39.2 0.00151 0.00101
303       -0.00019356  0.00006265  1014.77981   321.51106  42.1 0.00208 0.00108
```

Figure 5–8. ADJUST.DBS database file

6. UPDATING AND RETRIEVING COORDINATES

6.1. DATABASE STRUCTURE

Each time a new location is added to the data structure the appropriate files to hold one-, two- and three-dimensional coordinate databases are created as well as a database for ideal coordinates. These four databases are given the following filenames:

1. BNCHMARK for elevation information
2. MONUMENT for two-dimensional positions
3. IDEAL for ideal coordinate information of the beam elements
4. 3DIM for three-dimensional coordinate information from a three-dimensional least-squares adjustment.

For each of these four categories three files are created with the following filetypes:

1. IDX index file
2. LST list file
3. DAT data file

Thus, when the SNET survey location was added, 13 files were automatically created in the \COORD\SNET\ subdirectory:

SNET.REF	BNCHMARK.IDX	MONUMENT.IDX	IDEAL.IDX	3DIM.IDX
	BNCHMARK.LST	MONUMENT.LST	IDEAL.LST	3DIM.LST
	BNCHMARK.DAT	BNCHMARK.LST	IDEAL.DAT	3DIM.DAT

Except Fig. 6-8, all the example files in this chapter are drawn from the \COORD\SNET subdirectory. In most cases only a portion of the file is shown. The IDX and DAT files are write protected; they should not be edited in any way lest the database be rendered unusable

6.1.1. IDX Index File

The IDX file contains the point names in alphanumerical order and a pointer to the last record entered in the data file for each point (Fig. 6-1). This facilitates a very fast and efficient binary search algorithm to look up a point name and its associated information, and provides an easy way to recall all database entries for a particular point. The first line of the index file contains the record length (fixed at 16), the number of data entries, and a zero to pad the line to the correct record length. Each subsequent line shows the point name and the pointer to the latest record in the database for that point.

```
 16     69   0
B01        108
B02        109
B20        118
BM20        32
BM32        33
BM33        34
BMN1        49
BMS2        42
R001        96
R025        97
SE19        28
```

Figure 6–1. \COORD\SNET\BNCHMARK.IDX (selection)

6.1.2. LST List File

The LST file has the same point name entries as the IDX file but not in alphanumerical order (Fig. 6-2). For beamlines it is convenient to order the points in the order of their appearance along the beam line. The file is used by MERGE to select individual points for a survey epoch. If a new point name is encountered during the upload process the program will automatically insert it at the correct place in the IDX file but only append it to the end of the LST file. The maintenance of the LST file is the responsibility of the GEONET user. The record length is not fixed.

```
BM20          BENCHMARKS SURFACE NET
BM32
BM33
BMS2
BMN1
R001          RIVETS ALONG THE LINAC
R025
B01           ELEVATION FOR BASELINE PILARS
B02
B20
```

Figure 6–2. \COORD\SNET\BNCHMARK.LST (selection)

6.1.3. DAT Data File

The first record of a DAT file contains the record length, which varies with the coordinate type; the number of records; and a zero to pad the line to the correct record length. Each subsequent line contains the point name, date of entry, coordinate data in meters and standard deviation(s) in mm. All coordinate information is stored in metric units. The last two columns show the pointer to a record in the reference file and the pointer to the previous data entry for the point. Data files for one-dimensional and two-dimensional data are shown in Figs. 6-3, 6-4.

```
 45    119                                    0
BMN1      052385  2089.56635 0.442  16        0
BMS2      052385  2091.14025 0.417  16        0
BM32      052385  2098.38927 0.502  16        0
BM20      052385  2096.59874 0.467  16        0
BM20      032486  2097.49336 0.427  17       23
BM32      032486  2098.38764 0.460  17       15
BMS2      032486  2091.13988 0.315  17        8
BMN1      032486  2089.56397 0.335  17        1
R001      070689  2101.94686 0.789  21        0
B01       070689  2102.78225 0.789  21        0
B20       070689  2092.20211 0.484  21        0
R001      011692  2101.94707 0.000  22       75
B01       011692  2102.77604 0.000  22       76
B20       011692  2092.20176 0.000  22       95
```

Figure 6–3. \COORD\SNET\BNCHMARK.DAT (selection)

```
 73    299                                                               0
M20       112185 90533.44940 69999.51166 118.2 0.00038 0.00033    1      0
M31       112185 90147.38343 70097.64697  55.9 0.00043 0.00030    1      0
M20       112185 90533.44918 69999.51191 120.0 0.00037 0.00032    2      2
M31       112185 90147.38299 70097.64723  56.2 0.00034 0.00027    2      3
M20       112285 90533.44923 69999.51349 105.7 0.00035 0.00031    7     68
M20       112285 90533.44979 69999.51289 137.2 0.00037 0.00033    8     96
M20       121185 90533.44913 69999.51350 110.8 0.00034 0.00031    9    124
M20       121985 90533.44918 69999.51354 185.1 0.00040 0.00028   10    136
M20       121985 90533.44913 69999.51333 183.3 0.00037 0.00027   11    164
M20       012886 90533.44911 69999.51340 183.3 0.00036 0.00027   12    177
M20       012886 90533.44922 69999.51346 181.4 0.00037 0.00028   13    205
M20       012786 90533.44920 69999.51354 182.9 0.00039 0.00029   14    233
M20       032686 90533.44932 69999.51327 182.1 0.00039 0.00031   18    254
```

Figure 6–4. \COORD\SNET\MONUMENT.DAT (selection)

6.1.4. REF Reference File

For each location a reference file is created, using the location as filename and REF as filetype (Fig. 6-5). The origin of each database entry is recorded in this file. The first line shows the record length (32) and the number of entries, terminated by a zero. Each subsequent line contains the reference number found in the data file, the date of entry and the survey location and epoch.

```
32     23                   0
 1  11-21-85  SURFNET1   T2RF
 2  11-21-85  SURFPEN1   T2RC
 3  11-21-85   SURFLIC   T2RF
 4  11-21-85  SURFPEN2   T2RC
 5  11-21-85  SURFNET2   T2RF
 6  11-22-85  SURFPEN4   T2RC
 7  11-22-85  SURFPEN4   T2RC
 8  11-22-85  SURFNET3   T2RF
 9  12-11-85  SURFPEN4   T2RC
10  12-19-85  SURFNET4   T2RF
11  12-19-85  SURFPEN4  T2RCM
12  01-28-86  SURFPEN4  T2RCM
13  01-28-86  NARCPEN4   T2RC
14  01-27-86   FFOCPEN   T2RC
16  05-23-85     LVL2C   T1RA
17  03-24-86     LVL2D   T1RA
18  03-26-86  SURFPEN5   T2RC
19  07-31-86  LVLARCS1   T1RA
20  06-22-88  T2RAPROX    DBS
21  07-06-89     LINAC   T1RA
22  01-16-92     BLINE    DBS
```

Figure 6–5. \COORD\SNET\SNET.REF

6.2. UPDATING THE DATABASE

Once the least-squares adjustments for real observations are done and the results are accepted, the coordinate database can be updated. All adjustment programs create a file in the subdirectory \GEONET\TEMP named ADJUST.DBS which contains the information to be updated in the database. Since this file is overwritten each time a new adjustment is run, the coordinate update should be done as soon as the adjustment results are accepted.

If an adjustment contains points from different locations, one should separate these in ADJUST.DBS prior to updating the appropriate coordinate database, lest the same point be placed in multiple databases. The database update process does not destroy the original ADJUST.DBS file and allows the user to repeat the procedure after the first update has been done. This allows the separation of point names according to their location and the selection of different coordinate databases between updates.

For easy recovery in case of failure, the update procedure makes a backup of the reference, list, index and data files in \COORD\BACKUP before attempting an update.

To perform a coordinate update select the option `Coordinate Database` from the GEONET main menu. The user will be guided by menus to define the location and database type for the update.

6.3. RETRIEVING COORDINATES

The reverse function to updating is retrieving data from a database, accessed through the same option on the main menu. Again the user defines the location and database type through menu selections. The option is given to retrieve all coordinate entries for the selected points or just the last entry. If all coordinates for a point are required the program will calculate the differences between the coordinate entries starting with the last record found in the database.

The user can select coordinate information in feet or inches rather than in meters. If feet or inches are chosen the program will automatically subtract the bias constants before the conversion in order to preserve significant digits in the output file.

The file of retrieved coordinates is placed in the \GEONET\TEMP subdirectory with the filename of the data type (BNCHMARK, MONUMENT, IDEAL, 3DIM) and a filetype of OUT.

```
     Output for N:\COORD\SNET\BNCHMARK.DAT in units Meter
     Retrieval date: 12-23-92

     Bias constant h=  2000.00000 included
----------------------------------------------------------
---

  Name       date         h+Ybias      mh (mm)        dh

BMN1          032486       2089.56397      0.335         -
1.57591
BMS2          032486       2091.13988      0.315         -
7.24776
BM32             032486           2098.38764         0.460
+21.76880
BM33          032486       2076.61884       0.571        -
20.87452
BM20         032486      2097.49336     0.427
```

Figure 6–6. BNCHMARK.OUT

```
     Output for N:\COORD\SNET\MONUMENT.DAT in units Meter
     Retrieval date: 12-23-92

     Bias constants z= 90000.00000 x= 70000.00000 included
-------------------------------------------------------------------------------
-

  Name    date     z+Zbias     x+Xbias   phi     A       B       dz       dx

M20      032686 90533.44932 69999.51327 182.1 0.00039 0.00031 +0.00012 -0.00027
         012786 90533.44920 69999.51354 182.9 0.00039 0.00029 -0.00002 +0.00008
         012886 90533.44922 69999.51346 181.4 0.00037 0.00028 +0.00011 +0.00006
         012886 90533.44911 69999.51340 183.3 0.00036 0.00027 -0.00002 +0.00007
         121985 90533.44913 69999.51333 183.3 0.00037 0.00027 -0.00005 -0.00021
         121985 90533.44918 69999.51354 185.1 0.00040 0.00028 +0.00005 +0.00004
         121185 90533.44913 69999.51350 110.8 0.00034 0.00031 -0.00066 +0.00061
         112285 90533.44979 69999.51289 137.2 0.00037 0.00033 +0.00056 -0.00060
         112285 90533.44923 69999.51349 105.7 0.00035 0.00031 +0.00000 +0.00000
         112285 90533.44923 69999.51349 105.7 0.00035 0.00031 +0.00008 -0.00013
         112185 90533.44915 69999.51362 112.7 0.00043 0.00036 -0.00017 +0.00180
         112185 90533.44932 69999.51182 121.7 0.00036 0.00031 +0.00014 -0.00009
         112185 90533.44918 69999.51191 120.0 0.00037 0.00032 -0.00022 +0.00025
         112185 90533.44940 69999.51166 118.2 0.00038 0.00033

N1       032686 90156.62905 70023.39345 135.6 0.00050 0.00044 -0.00034 +0.00019
         012886 90156.62939 70023.39326 153.0 0.00066 0.00047 +0.00190 -0.00048
         012886 90156.62749 70023.39374 111.5 0.00068 0.00038 +0.00013 -0.00001
         121985 90156.62736 70023.39375 111.4 0.00069 0.00039 -0.00157 -0.00017
         121185 90156.62893 70023.39392 108.6 0.00062 0.00032 +0.00046 -0.00003
         112285 90156.62847 70023.39395 108.1 0.00062 0.00032 +0.00000 +0.00000
         112285 90156.62847 70023.39395 108.1 0.00062 0.00032
```

Figure 6–7. MONUMENT.OUT

```
Output for N:\COORD\FFTB\3DIM.DAT in units Meter
     Retrieval date: 12-23-92

     Bias constants z= 90000.00000 x= 70000.00000 y=  2000.00000 included
------------------------------------------------------------------------
-

  Name    date     z+Zbias     x+Xbias    y+Ybias    phi     A        B       my
3DTB05    100492  90176.75734  69998.64993   2077.35198     0.0  0.00000  0.00000
.00000
3DTB10    100492  90181.18259  69998.66388   2077.34479     0.0  0.00000  0.00000
.00000
3DTB15    100492  90184.51213  69998.65633   2077.35357     0.0  0.00000  0.00000
.00000
```

Figure 6–8. 3DIM.OUT

7. ERROR PROPAGATION

Geonet includes error propagation programs which provide an estimate of the error distribution across a given network for a given observation plan. These programs are useful in developing an observation plan achieving the required accuracy with a minimum number of observations.

7.1. INPUT FILE

Required input data are the approximate coordinates, which can be scaled from a drawing, and an observation plan. The format of the input file (Fig. 7-1) is similar to the other least-squares adjustment programs.

```
CONTROL NET FOR BOOSTER RING
NETPOINTS
N10           10000.00000     21273.23955
N1010         10900.31632     20900.31632
N2010         11273.23955     20000.00000
END
FIXED COORDINATES
END
0.001
WEIGHTED COORDINATES
END
HORIZONTAL DISTANCES        0   0.10000    .01414      -.50000
N10     N1010      0.00100
N10     N2010      0.00100
N10     N3010      0.00100
N10     N4010      0.00100
N10     N5010      0.00100
N10     N6010      0.00100
N10     N7010      0.00100
N1010   N10        0.00100
END
HORIZONTAL DIRECTIONS       0      .0001 0.08    10.0  0.3   200.0
END
GYROS
END
OFFSETS
END
RELATIVE ERROR ELLIPSES
END
DISTANCES AS FUNCTION OF THE UNKNOWNS
N10       N1010
END
ANGLES AS FUNCTION OF THE UNKNOWNS
END
```

Figure 7–1. Input file for error propogation study

The estimated accuracy for each anticipated observation may be entered or it can be calculated by the program according to a given formula. The values after the headlines `HORIZONTAL DISTANCES` and `HORIZONTAL DIRECTIONS` are used to calculate weights for distances and directions depending on the distance between instrument and target. The estimated accuracy for each distance must be entered in meters.

7.1.1. Horizontal Distances

The accuracy m_D of a distance D is

$$m_D = \sqrt{a^2 + (bD^H)^2} \tag{7-1}$$

where a is the constant term in millimeters, b the distance-dependent term in mm/km and H an exponent which indicates the distance dependence of the accuracy. If H is greater than zero the accuracy decreases with increasing distance. If H is less than zero the accuracy decreases with decreasing distance. The following line is read in with the format A25,3X,I2,3F10.5:

```
HORIZONTAL DISTANCES        0    0.10000    .01414   -.50000
```

The first value after the text is a switch which determines the source of weights. If it is non-zero the weights are calculated using (7-1). If it is zero, the individual entries provided by the user are used. The next three values are a, b and H of (7-1). If a is chosen to be zero, then the individual entries provided by the user are substituted for a. The default values were derived empirically using mekometer calibration measurements made on a baseline. They reflect a decrease in accuracy for short distances below 10 m. These values are:

$$\begin{aligned} a &= 0.1 \text{ mm} \\ b &= 0.1414 \text{ mm/km} \\ H &= -0.5 \end{aligned}$$

The planned distance measurements are read in using the format 2A8,F10.5,3X,A1. The first two entries are the station and target name followed by the estimated accuracy for the distance. The last entry is an optional '*' which indicates that for this particular distance the user provided value and not (7-1) should be used. This allows the user to study the effect of eliminating certain measurements by using large values for the accuracy.

7.1.2. Horizontal Directions

A similar function dependent on the distance between station and target has been implemented for the calculation of weights of directions. In this case transverse offsets for a short and a long distance are assumed. The offset for any other distance is calculated by linear interpolation and expressed in gons.

The accuracy of a direction m_R is calculated as

$$m_R = \sqrt{a^2 + \left[\frac{S}{D}\frac{200}{\pi}\right]^2} \tag{7–2}$$

where a is the constant term, S the distance-dependent part, and D the distance between the station and the target. S is calculated as a linear interpolation:

$$S = \left(\frac{T_{\max} - T_{\min}}{D_{\max} - D_{\min}}\right)\left(D - D_{\min}\right) + T_{\min} \tag{7-3}$$

where $D_{\min}$ is the short distance with an offset of $T_{\min}$ and $D_{\max}$ the long distance with its estimated offset of $T_{\max}$, (Fig. 7-2).

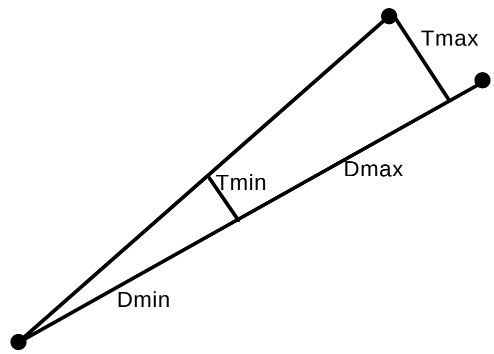

Figure 7–2. Weights for Directions

The following line is read with the format A25,3X,I2,F10.5,2(F5.3,F8.3).

```
HORIZONTAL DIRECTIONS       0    0.0001 0.08    10.0  0.3   200.0
```

The first value after the text determines the source of weights. If it is non-zero the weights are calculated using (7-2). If it is zero, the individual entries provided by the user are used. The other five values on this line show the constant term a, the estimated offset T_{min} in mm for the short distance, the short distance D_{min} in meters, the estimated offset T_{max} in mm for the long distance and the long distance D_{max} in meters. The default values, determined empirically, are :

a	=	0.0001 gon			
D_{min}	=	10 m	T_{min}	=	0.08 mm
D_{max}	=	200 m	T_{max}	=	0.30 mm

The planned observations are read using the format 2A8,F10.5,1X,A1. The first three entries are the station and target names followed by the accuracy of the directions. The fourth entry, an optional '*' serves the same purpose as for distance measurements.

Fig. 7-3 shows the relationship between the two functions used to calculate estimated accuracy for distances and directions. For distances of 10–30 m, which are typical in tunnel networks, an accuracy of 0.1–0.4 mm is estimated.

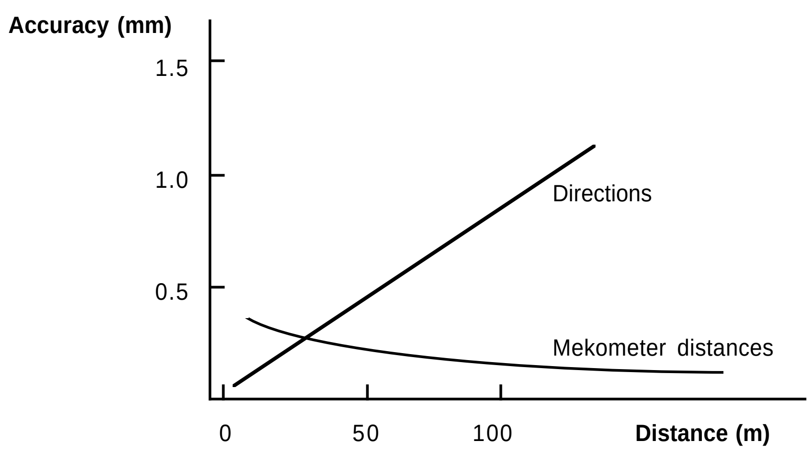

Figure 7–3. Weights for Distances

7.2. OUTPUT FILES

The output file (Fig. 7-4) created by the error propagation programs contains the same information as the output of a least squares adjustment using real observations. Error ellipses and the observation plan are displayed with TOPDRAW after the adjustment is done.

```
DATE :     10-09-91              INPUT-FILENAME : ERRORP
TIME :     12:44                       FILETYPE : 2

PROGRAM : T2EF

PATHNAME : \DATA\SNET\ADJUST\SRV3\

CONTROL NET FOR BOOSTER RING

APPROXIMATE COORDINATES

POINT         Z0         X0

N10         10000.00000     21273.23955
N1010       10900.31632     20900.31632
N2010       11273.23955     20000.00000

HORIZONTAL  DISTANCE  PROGRAM   0      0.10000       0.01414      -
0.50000

N10      N1010          0.00100
N10      N2010          0.00100
N10      N3010          0.00100
N10      N4010          0.00100
N10      N5010          0.00100
N10      N6010          0.00100
N10      N7010          0.00100
N1010    N10        0.00100

STATISTICS

M0 = 0.00100    F = 43

SU = 0.00083        SO = 0.00126     F95 = 2.5

ABSOLUTE ERROR ELLIPSES

POINT       PHI          A          B

N10         200.0      0.00032    0.00031
N1010        50.0      0.00032    0.00031

ADJUSTED DISTANCES AS FUNCTION OF THE UNKNOWNS
N10     N1010        974.49536        0.00050
```

Figure 7–4. Output file from error propogation study

8. DEFORMATION ANALYSIS

The one- and two-dimensional deformation analysis programs[1] used for GEONET require the unconstrained least-squares adjustments for two epochs of the same location. Furthermore, both adjustments must include the same point name list. The program is not able to detect movements of multiple points at a time. If a point with a large movement is detected, all observations to this point must be removed from both unconstrained adjustments, and the adjustments redone. Only then is another deformation analysis possible. Using this procedure one can detect movements one point at a time.

8.1. DEFORMATION ANALYSIS

8.1.1. Input Files

```
TESTNET T2RF (APRIL 1985) SURFACE NET
   9    0.00129   56.
20    508.55079    1278.48136
10    322.80570    1337.65475
70    354.91821     718.94557
30    605.00023     907.13006
40    750.78927     750.58989
50    635.65957     700.02072
60    512.43354     535.99325
11    418.30961     740.84719
61    300.03810     470.47721
   0.168697D+01      -0.248654D+00         0.487020D+01       -0.129874D+01
0.420283D+00
   0.206274D+01         0.133282D+00      -0.653839D+00       -0.991421D+00
0.395490D+01
  -0.616774D-01      -0.555982D+00         0.522317D-01       -0.900405D-01
0.106054D+01
  -0.823639D-01     -0.151167D+00      -0.684349D-01      -0.578263D+00   -
0.305256D+00
   0.150510D+01        0.239399D-03         0.334931D+00       -0.587104D+00
0.194010D+00
```

```
TESTNET T2RF (APRIL 1985) SURFACE NET (70Y +3CM)
   9    0.00137   52.
20    508.55151    1278.48000
10    322.80557    1337.65477
70    354.94687     718.94198
30    605.00037     907.12965
40    750.78919     750.59060
50    635.65974     700.02167
60    512.43401     535.99449
11    418.31027     740.84837
61    300.03746     470.47848
   0.169092D+01       -0.251527D+00        0.488314D+01       -0.129177D+01
0.416573D+00
   0.207930D+01          0.141546D+00     -0.658432D+00       -0.971471D+00
0.397910D+01
  -0.588717D-01       -0.569081D+00        0.595267D-01       -0.808148D-01
0.107719D+01
  -0.960122D-01      -0.147726D+00    -0.988456D-01       -0.614770D+00   -
0.313395D+00
   0.156360D+01       -0.112584D-01        0.313513D+00       -0.616382D+00
0.159187D+00
```

[1] Dr. Ing. Ingolf Burstedde, Adjustments of geodetic networks at SLAC, 1983.

Figure 8–1. Input files for deformation analysis

Fig. 8-1 shows two input files for deformation analysis. The first line is the title. The second line contains the number of points, the mean square error achieved by the adjustment, and the degree of freedom. The next lines show the names and adjusted coordinates for each point. The final group of lines contains the variance co-variance matrix used for the deformation analysis. The upper diagonal elements of this matrix (8-1) are listed by column starting with the first element. The values on the main diagonal are the variances for each point. The off-diagonal elements are the co-variances.

$$\begin{bmatrix} Q^{1}_{xx} & Q^{1}_{xz} & Q^{12}_{xx} & Q^{12}_{zx} \\ & Q^{1}_{zz} & Q^{12}_{xz} & Q^{12}_{xx} \\ & & Q^{2}_{xx} & Q^{2}_{xz} \\ & & & Q^{1}_{zz} \end{bmatrix} \tag{8-1}$$

8.1.2. Output File

The output file (Fig. 8-2) lists the coordinates from the two input files, and continues with the following information:

8.1.2.1. Common M0 and F

M_0, the common mean square error of the two adjustments, and F, the common degree of freedom, are derived from the values for the individual adjustments (f_1, m_{01}; f_2, m_{02}).

$$M_0 = \sqrt{\frac{f_1 m_{01}^2 + f_2 m_{02}^2}{F}} \tag{8-2}$$

$$F = f_1 + f_2 \tag{8-3}$$

8.1.2.2. Number of Independent Unknowns

U, the number of independent unknowns, is taken from NP the number of points.

$$U = NP - 3 \tag{8-4}$$

8.1.2.3. Standardized Gaps

Each line in this section lists five values:

a) Point name

b) Ordinate axis, z or x.

c) D_J the coordinate difference between the two epochs is the difference between the vectors of adjusted coordinates of the first (X_1) and second (X_2) epochs,

$$D_J = X_2 - X_1 \tag{8-5}$$

d) Q_{JJ} the associated sum of the variances, calculated separately for each ordinate,

$$\begin{aligned} Q_{xx} &= Q_{x1x1} + Q_{x2x2} \\ Q_{zz} &= Q_{z1z1} + Q_{z2z2} \end{aligned} \tag{8-6}$$

where Q_{x1x1} is the variance in the x-direction of a point in the first epoch and Q_{x2x2} the variance for the same point in the second epoch. Q_{z1z1} is the variance in the z-direction.

```
PROGRAM T2DF                          DATE :  02-14-92
                                      TIME :  11:33

1. NET  (READ FROM : \DATA\SNET\ADJUST\SRV14\T2RF.DNM)
TESTNET T2RF (APRIL 1985) SURFACE NET

M0 =   0.00129      F = 56

POINT         Z             X
20        508.55079     1278.48136
10        322.80570     1337.65475
70        354.91821      718.94557
30        605.00023      907.13006
40        750.78927      750.58989
50        635.65957      700.02072
60        512.43354      535.99325
11        418.30961      740.84719
61        300.03810      470.47721

2. NET  (READ FROM : \DATA\SNET\ADJUST\SRV15\T2RF.DNM)
TESTNET T2RF (APRIL 1985) SURFACE NET (70Y +3CM)

M0 =    0.00137   F = 52

POINT         Z             X
20        508.55151     1278.48000
10        322.80557     1337.65477
70        354.94687      718.94198
30        605.00037      907.12965
40        750.78919      750.59060
50        635.65974      700.02167
60        512.43401      535.99449
11        418.31027      740.84837
61        300.03746      470.47848

COMMON M0 AND F
M0  =   0.00133
F   =   108

NUMBER OF INDEPENDENT UNKNOWNS
U  =  15

STANDARDIZED GAPS

POINT          DJ         QJJ      SJ
20     Z    0.00072    3.37789   0.3
20     X   -0.00136    9.75334   0.3
10     Z   -0.00013    4.14204   0.0
10     X    0.00002    7.93400   0.0
70     Z    0.02866    2.13773  14.7
70     X   -0.00359    3.06870   1.5
30     Z    0.00014    2.47556   0.1
30     X   -0.00041   10.46853   0.1
40     Z   -0.00008    6.29889   0.0
40     X    0.00071    3.11512   0.3
50     Z    0.00017    2.34289   0.1
50     X    0.00095    2.34259   0.5
60     Z    0.00047    1.82907   0.3
60     X    0.00124    3.21659   0.5
11     Z    0.00066    5.09224   0.2
11     X    0.00118   19.72335   0.2
61     Z   -0.00064    5.26554   0.2
61     X    0.00127    5.45540   0.4

MAXIMUM : POINT  70   Z,    S =  14.7

MEAN GAP

THETA  =    0.00811
FAK    =   37.21
```

Figure 8–2. Output file for deformation analysis

e) S_J the standardized gaps between epochs, also calculated separately for each coordinate,

$$S_J = \frac{|D_J|}{M_0 \sqrt{Q_{JJ}}} \tag{8-7}$$

where D_J is the coordinate difference, M_0 the common mean square error for both adjustments and Q_{JJ} the combined variance for z or x. These values are used for a statistical test which is a local test for point movements. If S_J is greater than $\mathbf{S}_{(1-\alpha),U,F}$ of the t-distribution then one can deduce that this station has moved. The maximum shift is identified at the end of the list.

8.1.2.4. Mean Gap

The last section describes a statistical test which is a global test to determine if the network shows any deformations.

$$\theta = \sqrt{\frac{D^T Q_{JJ}^{-1} D}{U}} \tag{8-8}$$

where D is the difference vector between the coordinates of both epochs, U the number of independent unknowns, and Q_{JJ} the matrix of the sum of both variance co-variance matrices. The value FAK is calculated for the comparison with the $\boldsymbol{F}$ distribution,

$$FAK = \frac{\theta^2}{M_0^2} \tag{8-9}$$

The network deformations are indicated if FAK is greater than $\boldsymbol{F}_{(1-\alpha),U,F}$.

8.2. FOUR PARAMETER HELMERT TRANSFORMATION

A related topic is the comparison of two networks using a four parameter transformation which can also be used to detect point location differences between two epochs. Again an unconstrained least-squares adjustment for both epochs of a location are required. The four parameters calculated are the scale, rotation and the shifts in both coordinate directions which minimize the coordinate differences between two epochs.

The same input files as for the deformation analysis are used. The user is given a choice to do the transformation either with or without the calculation of a scale factor. The coordinate differences shown in the column V and U of the table for transformed coordinates are plotted. The output file (Fig. 8-3) shows the results for the scale, rotation and the two shifts. These four parameters are derived from a least squares adjustment. It is therefore possible to calculate statistics for each of the unknowns if more than two identical points for the computation of the transformation parameters are used.

The error equations for each coordinate direction are:

$$U = X^* - X \tag{8-10}$$

$$V = Z^* - Z \tag{8-11}$$

where U and V are the coordinate residuals to be minimized, X^* and Z^* are the coordinates of the first epoch and X and Z the coordinates of the second epoch after the transformation,

$$X = a + bx - cz \tag{8-12}$$

```
PROGRAM HELMERT           DATE:  02-14-92
                          TIME:  18:38
HELMERT TRANSFORMATION BETWEEN NET1 AND NET2
*********************************************************************
***
COORDINATE-SYSTEM TO BE TRANSFORMED :    (z,x)
COORDINATE-SYSTEM IN WHICH WILL BE TRANSFORMED : (Z,X)
*********************************************************************
***
1. NET (READ FROM : /DATA/SNET/ADJUST/SRV14/T2RF.DNM) :

TESTNET T2RF (APRIL 1985) SURFACE NET

M0 = 0.00129    F = 56

POINT      Z              X

20     508.55079     1278.48136
10     322.80570     1337.65475
70     354.91821      718.94557
30     605.00023      907.13006
40     750.78927      750.58989
50     635.65957      700.02072
60     512.43354      535.99325
11     418.30961      740.84719
61     300.03810      470.47721

2. NET  (READ FROM : /DATA/SNET/ADJUST/SRV15/T2RF.DNM ) :

TESTNET T2RF (APRIL 1985) SURFACE NET (70Y +3CM)

M0 = 0.00137      F = 52

POINT        z             x

20       508.55151    1278.48000
10       322.80557    1337.65477
70       354.94687     718.94198
30       605.00037     907.12965
40       750.78919     750.59060
50       635.65974     700.02167
60       512.43401     535.99449
11       418.31027     740.84837
61       300.03746     470.47848

IDENTICAL POINTS USED FOR THE COMPUTATION OF THE
TRANSFORMATION-PARAMETERS : 9

TRANSFORMED COORDINATES AND RESIDUALS :

NP        Z*            X*            -V*          -U*
-----------------------------------------------------

20     508.54988    1278.48243       -0.00091     0.00107
10     322.80312    1337.65819       -0.00258     0.00344
70     354.94241     718.94186        0.02420    -0.00371
30     604.99796     907.12969       -0.00227    -0.00037
40     750.78704     750.58926       -0.00223    -0.00063
50     635.65677     700.02045       -0.00280    -0.00027
60     512.42978     535.99280       -0.00376    -0.00045
11     418.30624     740.84815       -0.00337     0.00096
61     300.03182     470.47718       -0.00628    -0.00003

STATISTICS :
STANDARD DEVIATION :     0.00709 (m)
POINT ACCURACY :         0.01003 (m)

TRANSFORMATION-PARAMETERS :
SHIFT IN X-DIRECTION :  0.004101474    +/- 0.07803
SHIFT IN Z-DIRECTION :  0.065619310    +/- 0.07803
```

```
SCALE-FACTOR :            1.000005538     +/- 0.00001
ROTATION ANGLE (DEG) :   0.000202539     +/- 0.00043 (DEG)
```

Figure 8–3. Output file for a four-parameter transformation

$$Z = d + bz + cx \tag{8-13}$$

where a and d are the unknowns for the coordinate shift between both systems, and b and c contain the rotation and scale factor in form:

$$b = m \cos \theta \tag{8-14}$$

$$c = m \sin \theta \tag{8-15}$$

where m is the scale factor and θ the rotation angle (Fig. 8-4).

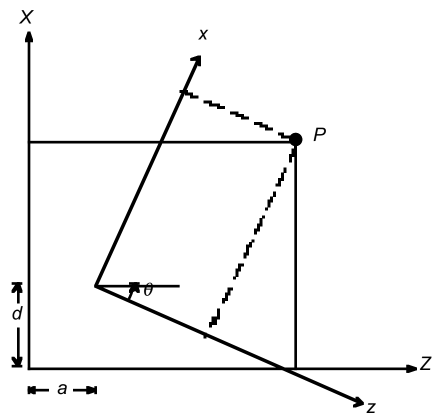

Figure 8–4. Four-parameter transformation

The standard deviation is a measure for the mean square error of the coordinate residuals,

$$m_0 = \sqrt{\frac{\sum\left(V^2 + U^2\right)}{2n - 4}} \tag{8-16}$$

where V and U are the coordinate residuals and n is the number of identical points.

The point accuracy for the identical points is,

$$m_p = m_0 \sqrt{2} \tag{8-17}$$

9. BLUNDER DETECTION

GEONET provides blunder detection programs for one-, two- and three-dimensional networks.[1] Since undetected blunders distort the solution of a least-squares adjustment and significantly bias the statistical estimates, it is necessary to detect blunders before attempting an adjustment. Two methods are commonly used. The first uses least-squares adjustments and statistical testing methods.[2] This approach has the disadvantage that blunders are distributed into good observations, making detection and isolation of blunders difficult. This method is usually only suitable for the detection ofone blunder at a time. The second method uses the one norm adjustment,[3] a robust estimation technique more sensitive to blunders than the least squares approach.[4]

The target function of the L1–norm minimizes the sum of the weighted residuals,

$$\sum |wr| = \min \tag{9–1}$$

This expression can be transformed into a linear programming problem which can be solved using the simplex algorithm. The goal is to find u observations of the data set which solve for the u unknowns without inconsistencies while at the same time minimizing the absolute sum of the weighted residuals. These u observations are found in iterative steps and their residuals will naturally be zero. These observations are assumed to be free of blunders, a reasonable assumption given that blunders occur only occasionally. Blunders in the remaining observations can be easily detected by the size of their residuals, because these observations are not used for the calculation of the adjusted coordinates. The more over-determination that is provided and the better the network geometry is defined, the more reliable will be the results of this procedure.

Fig. 9-1 shows an example output file for a two dimensional L1–norm adjustment. It shows the general output information used for the least-squares adjustments, a section for the approximate coordinates, and a summary of the number of observations, netpoints and fixed coordinates. The following lines contain the iteration steps and the result of the absolute sum of the weighted residuals in the last column. The iteration steps are split into two sections. The first shows the results during the search for those u observations which solve for the u unknowns without inconsistencies. The second part shows the results after rearranging the remaining observations to obtain the minimum of the target function. The iteration process will stop when the minimum of the target function has been reached. The process converges very slowly in cases of unfavorable network geometry. Therefore the iteration process will also stop when the iteration number reaches the number of observations in order to avoid unnecessary long computation times. This is indicated by the statement `END OF REDUCTION : IT = NO` in the output file. This criteria can be changed to unlimited iterations if the first entry of the last line of the input file is changed to 99.

The next section displays the coordinate additions according to the adjustment, followed by the adjusted observations. The text `MULTIPLIER = 3.0` means that all residuals greater than three times their entered mean square error will be flagged to be checked. The multiplier can also be changed to any other number by altering the second entry of the last line of the input file.

---

[1] Dr. Ing. Ingolf Burstedde, Adjustments of geodetic networks at SLAC, 1983.

[2] Baarda, W., A test procedure for use in geodetic networks, New Series 2, Netherlands Geodetic Commisiion, Delft, The Netherlands (1968), 5.
Pope, A.J., The statistics of residuals and the detection of outliers, NOAA Technical Report NOS 65, NGS 1, U.S. Dept. of Commerce, Rockville, MD, 1976.

[3] Fuchs, H., 'Untersuchungen zur Ausgleichung durch minimieren der absolut Summe der Verbesserungen,' thesis presented to Technical University Graz in Austria, 1980.

[4] Gao Y., Krakiwsky E. J. ,and Czompo J., 'Robust Testing Procedure for Detection of Multiple Blunders,' *Journal of Surveying Engineering*, Vol. 118, No. 1, 1992.

The following sections show the observations, their estimated mean square error, the difference between the measured and calculated observation and the residual.

```
DATE : 02-16-92                         INPUT-FILENAME : ADJUST
TIME : 21:34                                  FILETYPE : 2

PROGRAM : O2RU

PATHNAME  : \DATA\SNET\ADJUST\SRV15\

TESTNET O2RU  (APRIL 85)  TUNNELNET

APPROXIMATE  COORDINATES

POINT         Z0            X0
40         750.78927     750.58989
50         635.65957     700.02072
60         512.43354     535.99325
100        834.97100     501.58700
200        810.30200     476.22100
301        885.17600     428.07600
302        950.00000     375.00000
303       1014.78000     321.51100

8      NETPOINTS
3      FIXED COORDINATES
12     DISTANCES
7      DIRECTION SETS
27     TOTAL DIRECTIONS
2      GYROS
1      OFFSETS

20 UNKNOWNS
42 TOTAL OBSERVATIONS

IT    IS    IR       C0

1      18    73   -0.09442
2      25    71   -0.08736
3       9    49   -0.08687
4      31    93   -0.08650
5      30   119   -0.08574
6      19   120   -0.05642
7      20    79   -0.04182
8      35    99   -0.04155
9      36   106   -0.04150
10      7   100   -0.04149
11     24    54   -0.04132
12     34    45   -0.04105
13     33    76   -0.04085
14     28    50   -0.03976
15     26    56   -0.03852
16      1   108   -0.03803
17     17    70   -0.03775
18      3    46   -0.03768
19     22    72   -0.03753
20     12    94   -0.02965

1      57   105   -0.01887
2     106   109   -0.01883
3      92    95   -0.01881
4     114    97   -0.01859
5      55    62   -0.01853
6      63    60   -0.01833
7      96   111   -0.01828
8     109    48   -0.01812
9      58    41   -0.01811
10     71   106   -0.01801
```

11	64	65	-0.01793
12	87	64	-0.01793
13	64	87	-0.01793
14	46	64	-0.01793
15	62	103	-0.01793
16	45	71	-0.01779
17	106	45	-0.01779
18	87	101	-0.01779
19	107	87	-0.01779
20	45	106	-0.01779
21	106	45	-0.01779
22	87	107	-0.01779
23	107	87	-0.01779
24	45	106	-0.01779
25	106	45	-0.01779
26	87	107	-0.01779
27	107	87	-0.01779
28	45	106	-0.01779
29	106	45	-0.01779
30	87	107	-0.01779
31	107	87	-0.01779
32	45	106	-0.01779
33	106	45	-0.01779
34	87	107	-0.01779
35	107	87	-0.01779
36	45	106	-0.01779
37	106	45	-0.01779
38	87	107	-0.01779
39	107	87	-0.01779
40	45	106	-0.01779
41	106	45	-0.01779
42	87	107	-0.01779

END OF REDUCTION : IT=NO

COORDINATES ADDITIONS

	DZ	DX
40	0.00000	0.00000
50	0.00000	0.00412
60	-0.00626	0.00846
100	-0.00760	0.00325
200	-0.00819	0.00196
301	-0.01045	0.00502
302	-0.02056	0.01777
303	0.00038	0.02373

ADJUSTED OBSERVATIONS : (MULTIPLIER = 3.0)

DISTANCES

		S(M)	MS(MM)	L(MM)	V(MM)
40	60	320.72500	5.00	1.01	0.00
40	100	262.84700	5.00	-0.87	1.52
40	200	280.74800	5.00	-1.09	1.27
50	100	281.24800	5.00	-0.98	0.79
50	200	283.87700	5.00	-0.25	0.00
60	100	324.36700	5.00	-0.39	0.30
60	200	303.80700	5.00	0.58	-0.42
100	200	35.38300	0.50	-0.52	0.00
100	301	89.01900	0.50	-0.15	0.00
200	301	89.01700	0.50	-0.17	-0.08
301	302	83.78100	0.50	0.26	0.00
302	303	84.02900	0.50	19.94	0.00

HORIZONTAL DIRECTIONS

		R(GON)	MR(GON)	L(MGON)	V(MGON)
40	100	179.24530	0.40	0.05	0.00
40	200	186.40170	0.40	-0.01	-0.03
40	60	253.33610	0.40	0.01	0.12
40	50	273.65220	0.40	-0.04	0.00

```
50      100     149.85940   0.40    0.03    0.20
50      200     157.81460   0.40    0.02    0.10
50      60      241.01760   0.40    0.20    0.00
50      40       73.65200   0.40   -0.26    0.00

60      50       41.01760   0.40    0.14    0.00
60      40       53.33600   0.40   -0.17    0.02
60      100     106.76540   0.40    0.02    0.07
60      200     112.60730   0.40    0.00    0.00

100     40      379.24500   0.40   -0.23    0.00
100     301     161.85390   0.40    0.17    0.00
100     200     249.11320   0.40    0.16    0.00
100     60      306.76500   0.40   -0.28    0.37
100     50      349.85950   0.40    0.17    0.00

200     60      312.60730   0.40   -2.04    0.00
200     50      357.81470   0.40   -1.98    0.00
200     40      386.40170   0.40   -2.13   -0.23
200     100      49.11330   0.40   -1.88    0.00
200     301     136.38950   0.40    8.03   -9.57    CHECK

301     200     336.37900   0.40   -4.12    1.53    CHECK
301     100     361.85460   0.40   -2.92    0.00
301     302     143.68800   0.60    7.05    0.00

302     301       0.00000   0.60    9.49    0.00
302     303     200.24430   0.60   -9.49    0.00

GYROS
                  RK GON)   MK(MGON)  L(MGON)   V(MGON)
301     302     143.69370   2.00    16.35   -3.99
302     303     143.92790   2.00    12.73    6.11     CHECK

OFFSETS
                        H(M)     MH(MM)    L(MM)     V(MM)
302     303      301    0.16090    0.50    -12.58    0.09
```

Figure 9–1. Output file for two-dimensional L1–Norm adjustment

10. ARCHIVING AND SPECIAL FUNCTIONS

10.1. ARCHIVING

The archive function has been provided to unload obsolete data sets in order to free hard disk space. This option combines two features: data compression and archival to floppy disk.

10.1.1. Compression

Data is compressed by combining selected data files from one epoch into one large compressed file. The gain in free hard disk space can exceed 50% when used on numerous small files. This compression ratio is displayed on the screen. The filename of the resulting compressed file is the survey epoch, and the filetype is CMP.

10.1.2. Backup to Floppy Disk

The compressed files are then archived to a floppy disk, thus freeing hard disk space. If all data files including the index file have been selected for compression, the subdirectory will be made reusable for new data. Two files are left in the subdirectory: an empty index file ready to be used for new data, and an archive file with a one line entry pointing to the name of the archive floppy. If the index file is not part of the compressed file the subdirectory will not be made reusable.

During the archive process the user is asked to insert a floppy diskette. If the diskette is not formatted the program invokes the formatting routine. It also checks for an existing label to be used. If no label is found the program will assign a sequential archive label starting with ARCH001 and ending with ARCH400. This provides the capability to archive 480 MB of data on high density floppies. The label is the only entry in the file SRVxx.ARC which resides in the data subdirectory and is necessary for the data recovery process. The user is instructed to label the floppy with the archive number. This must be done so that the appropriate diskette can be located during the recovery procedure.

With each compression and archive task the appropriate history file for the chosen base name will be updated (Fig. 10-1). Option 5 of the archive menu allows editing and viewing of the history file. The file shows the subdirectory and the creation date including a comment line. Subsequent entries show the dates when files were compressed, archived, recovered, expanded, or the whole subdirectory deleted.

Due to the recent changes made to the archive procedure the currently used history files will be automatically rewritten the first time a new epoch is added to the data structure. Since the creation date for existing subdirectories is unknown, the program assigns question marks. Existing comments are replaced by the word 'unknown' and should be entered again using the backup file DATA.BAK.

```
DATA FILESYSTEM HISTORY

DATA\SNET\DIRECT\SRV1
  Created          ??-??-91    Unknown
DATA\SNET\LEVEL\SRV1
  Created          ??-??-91    Unknown
  Compressed       02-18-92
  Archived         02-18-92    testing only
  Recovered        02-18-92
  Expanded         02-18-92
  Compressed       02-18-92
  Archived         02-18-92    test
  Recovered        02-18-92
  Expanded         02-18-92
DATA\SNET\LEVEL\SRV7
  Created          ??-??-91    Unknown
  Deleted          02-06-92
  Created          02-06-92    testing again
  Deleted          02-06-92
  Created          02-07-92    test new history file format & comment length
  Deleted          02-07-92
  Created          02-07-92      test  ability  to  enter  comments  until  end  of
lines.
  Compressed       02-07-92
  Archived         02-07-92      archiving  to  ARCH001  for  test  purposes  only
today.
  Recovered        02-07-92
  Expanded         02-07-92
  Compressed       02-07-92
  Expanded         02-07-92
  Compressed       02-07-92
  Expanded         02-07-92
  Deleted          02-07-92
  Created          02-07-92    testing only
  Deleted          02-07-92
  Created          02-07-92    test
DATA\EXP1\LEVEL\SRV1
  Created          02-07-92    testing
  Deleted          02-07-92
DATA\SLNC\LEVEL\SRV1
  Created          02-07-92    test
  Deleted          02-07-92
```

Figure 10–1. A data file system history file

10.1.3. Data Recovery

The recover option is used to retrieve any previously archived data set. Having selected the subdirectory to be used for the recovered data, the user is prompted to insert the appropriate archive diskette. After the compressed data file is copied to the hard disk it is uncompressed to its original constituent files. If duplicate file names are found during this process a message will be displayed warning of a naming conflict. Duplicate file names are recorded in the file FILELIST.DUP in the ARCHIVE subdirectory. The duplicate files should be renamed or removed before attempting to run the program again. If duplicate files are found an option is given to recover the data to the ARCHIVE subdirectory. This is useful if only some files have to be reviewed and no further data processing is necessary.

10.2. SPECIAL FUNCTIONS

A recent addition to GEONET is the incorporation of custom programs written by the user. A file called SPECIAL.STR (Fig. 10-2) is part of the GEONET installation. The entries of this file are used to run special programs. The comment section on top of the file provides information about the usage. Subsequent lines contain up to sixteen program name entries, the name of the executable program, some flags and up to three explicit parameters. The flags used can be 'D' for data filesystem subdirectory path, 'E' for the editor name and 'P' for the printer name. Flags are optional and and preceded by a single '/' following the program name. If 'P' and 'E' are used, the printer port and the name of the editor will be passed to the calling program. If 'D' is used GEONET will prompt the user for the location, measurement type and survey epoch. The pathname is then passed on to the calling program. Up to three explicit arguments may be specified after the flags. All executable programs must be located in the subdirectory GEONET\BIN.

```
;SPECIAL.STR - SPECIAL PROGRAM CONTROL FILE
;
;  Users may incorporate their own programs into Geonet and invoke them
;  using the Special Programs menu selection.  This file defines the
menu
;  of programs available, program names and their parameters.  It is the
;   responsibility of the user to update this file and to put his
executable
;  program module into the GEONET\BIN subdirectory.
;
;  Each program entry occupies one line.  Lines beginning with ';' or '
'
;  are treated as comments.  A typical entry consists of the following
;  fields, separated by spaces:
;
; Menu descriptor -
;   Text which appears in the menu of available special programs.
;   Up to 17 characters (no spaces).
;
; Program name/flags -
;   Name of executable file + implicit parameter flags.  Use .EXP
;   extension for NDP Fortran programs.  Flags are used to pass Geonet
;   system information to the program.  The flags are as follows:
;     D - Data filesystem subdirectory path
;     P - Printer name
;    E - Editor name
;   Flags are optional & are preceded by a single '/' following the
;   program name.  Parameters are passed in the order that the flags
;   are specified.
;
; Explicit parameters -
;   Up to three parameters may be specified explicitly, each separated
;   by spaces.  These follow any implicit parameters.
;

Dial_gage  GAGES3.EXE/DE arg1 arg2 arg3       (example only)
```

Figure 10–2. SPECIAL.STR for Special Functions