NOAA Technical Memorandum NOS NGS-8

ESTABLISHMENT OF CALIBRATION BASE LINES

Rockville, Md.
August 1977

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and Raymond W. Tomlinson

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ABSTRACT. The calibration of electronic distance measuring instruments involves the determination or verification of instrument constants and the assurance that the measured distances meet accuracy specifications. Although it is not necessary to utilize a measured distance to determine or verify instrument constants, the verification effort is reduced when an accurately measured distance can be used. However, to assure that an instrument is measuring properly, a known distance of high accuracy or, preferably, a sequence of distances forming a calibration range or base line is required. Experience shows that a base line consisting of four on-line monuments spaced at intervals of 150 m, 400 to 430 m, and 1,000 to 1,400 m will meet the needs of the users. Specifications and recommendations on the establishment of calibration base lines are described in some detail.

INTRODUCTION

Since the beginning of the surveying profession, there have always been standards of length. Early in the 19th century, the Survey of the Coast adopted the meter as the standard for use in geodetic surveys of the United States. Land surveyors, on the other hand, employed the foot, as did most surveyors involved in engineering and associated surveying activities. For many years, the standardization or comparison of measuring devices with known values was, in general, very rudimentary. This continued to be the case, even after the National Bureau of Standards developed methods for determining very accurately the length of a tape or wire. Eventually, most surveyors had access to some means for ascertaining the length of their tapes to an acceptable degree of accuracy. A whole new dimension was added to the surveying profession when electronic distance measuring devices were invented. These instruments made feasible measurements that were not heretofore possible; but with this ability came the problem of assuring that the accuracy of the measurements was equivalent or better than those obtained previously.

BRIEF HISTORY

With the introduction of electronic distance measuring devices in the United States in 1952, the standardization problem was compounded, since the measurements are affected by meteorological conditions other than temperature and several instrumental uncertainties that require frequent periodic re-evaluations. The need for calibration base lines was evident, but a range specifically designed for such purposes was not available for more than a decade. In 1963 the Coast and Geodetic Survey measured a multi-monumented line in Beltsville, Maryland, using high precision taping techniques (Poling 1965). The total distance of the Beltsville base is about 1,800 m, but only 1,650 m is normally utilized. Later, a much longer line (about 9,050 m) near Culpeper, Virginia, was measured using similar procedures. Although no major restrictions were placed on the use of these base lines, few surveyors other than those from Federal agencies used them to calibrate their equipment.

As more and more surveyors acquired electronic distance measuring instruments (EDMI), a general concern arose in the profession as to the accuracy of the measurements obtained. It is true that the accuracy attributed by the manufacturer has been shown to be reliable. It is also true that due to usage and normal reduction in the efficiency of electronic and mechanical components, errors in the observations, often systematic, can result. Periodic maintenance, preferably by the manufacturer or his representatives, is required to minimize these errors. It is equally important, however, to verify the instrument constant and evaluate the measuring accuracy at more frequent intervals.

A known distance is not required to check the instrument constant. This can be achieved simply by measuring all distances between three points on line. A comparison is then made with the sum of the shorter lengths and the end-to-end measurement. To check the accuracy and operation of EDMI, a known distance, or preferably a sequence of known distances forming a calibration range, is required.

By 1970 a number of EDMI were available. Since that time, 20 or more models have been produced by various manufacturers. Most are short-range instruments. Inasmuch as this equipment has been used for almost every conceivable surveying problem, the need for assurance that the observations met the requirements became acute. The National Geodetic Survey (NGS) was aware of the situation and had held in-house discussions as to the best approach to solve this problem.

The original concept was to tape the distances between a number of monuments using several invar/lovar tapes and high precision measuring techniques. Four calibration base lines were measured using these techniques. Since this proved to be a time-consuming operation, another approach has been adopted. The present procedure is to tape a 150-m section, usually at the beginning of the range, using four invar/lovar tapes and high-precision methods. All sections are then measured in every combination using two high-accuracy short-range EDMI. Distances are observed on two days with both instruments employed on each occasion.

In 1977 the NGS measured a new base line at its Corbin, Virginia, facility. This base line, containing six monuments, was measured using high precision taping methods; it will replace the Beltsville base line for calibrating NGS equipment. The Beltsville base line has been remeasured using conventional calibration base line procedures and will continue to be available for use, as are the other ranges.

RESPONSIBILITY FOR BASE LINES AND COSTS

Initially, the base lines were cooperative ventures between the National Oceanic and Atmospheric Administration (NOAA) and local surveying societies, with the entire NOAA cost being absorbed by the NGS. The local societies were responsible for selecting the sites, setting the monuments, and assisting NGS personnel in carrying out the measurements. Generally, NGS personnel were involved in the initial phases, as well as during the period the measurements were secured.

It soon became apparent, primarily because of budgetary considerations, that while the calibration base line projects could continue to be cooperative arrangements, the NGS would have to be reimbursed for its participation. Payment includes the cost for NGS participation in performing the measurements, reduction and adjustment of the data, and publication of the results. Fees for these services are obtainable from the NGS.

A standard calibration base line consists of four monuments. Requests for measurements to additional monuments, other than those for the 100- and 200-foot standards, requires an additional reimbursement to the NGS above the regular fee for each additional monument. Under the present program, the NGS plans to verify the base lines at 5-year intervals without cost to the cooperating societies.

Local societies continue to be responsible for selecting the sites, setting the monuments, and providing experienced surveyors to aid NGS personnel in carrying out the observations. Obtaining necessary concrete, lumber, and any miscellaneous material remains the responsibility of the local societies.

Although this publication describes the establishment of calibration base lines in cooperation with the NGS, it should not deter any group of surveyors from measuring a base line independently (see appendices II and III for details). It must be emphasized that some special equipment not normally available, such as invar or lovar tapes in the quantity needed, high quality tension apparatus of particular design, and centering devices is required (see appendix I).

Adjustments will be performed by the NGS without cost, provided the data are prepared in a machine-readable format (on cards or tape). The NGS will furnish the format. However, if the data as submitted do not "run," they will be returned to the sender. Should unsatisfactory results be obtained, the NGS will review the adjusted data and attempt to ascertain the cause(s).

CALIBRATION RANGE

Design

The standard configuration consists of four monuments set in a straight line with a total length of about 1,400 m. In no instance should the range be significantly less than 1,000 m, or more than 1,400 m. The four-monument design provides six distinct distances when measured in either direction, and a combined total of 12 distances when a complete calibration test is carried out.

While it is possible to establish a calibration base line in which the monuments are not set on a straight line, this method should be used only as a last resort. When it is necessary to employ this procedure, in no instance can any of the monuments be off line by more than 5°. The primary reason for discouraging the setup of the so-called "broken" base line is the effort required to secure the angle observations necessary to project distances between the various monuments to common lines. There is little or no loss of accuracy when this method is properly employed.

For the conventional calibration line, monuments are located at 150 m, 400 to 430 m, and 1,000 to 1,400 m from the initial or "0-m" monument (fig. 1). The monuments at 400 to 430 m and 1,000 to 1,400 m are identified as intermediate and terminal points respectively. Normally the 150-m monument is established at that distance from the initial or "0-m" point. However, terrain restrictions or other conditions may require that the 150-m distance be established in relation to one of the other monuments. In either case, since this distance will be taped, the horizontal distance between the monuments should be accurate to within 0.02 m.

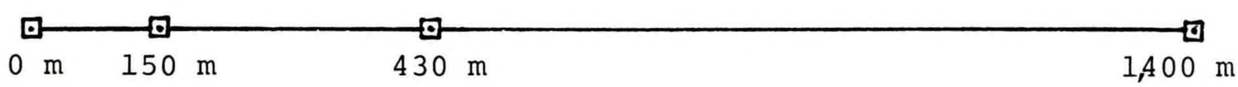

Figure 1.--Standard calibration base line configuration.

It is good practice to set the intermediate and terminal monuments within a few centimeters of the suggested distances. This is not a requirement, but is a recommended practice.

There will be occasions when it will not be possible to set the intermediate and/or terminal monuments at suggested distances from the initial point. In such cases, the monuments should be placed at distances, which are a multiple of 10 m, that approximate the recommended locations, e.g., the intermediate point could be at 420 m and the terminal monument 1,360 m from the initial mark.

The need for monumentation at 400 to 430 m rather than at 600 to 800 m, the intermediate spacing used in the past, has been brought about by the introduction of EDMI with ranges limited to 500 m. Where a longer distance is desired, another monument can be set on line at about 800 m. There is no need to know the distances to this point when only the instrument constants are to be determined (see technique described in the Brief History section).

There are no set rules for spacing the intermediate and terminal monuments other than that the intermediate point should not be more than about 430 m from the initial monument, as the terrain will generally dictate the locations. Nonetheless, it is desirable that the "multiple of 10 m" rule be adhered to whenever possible.

On request, a monument will be set 100 ft from another monument for use in calibrating tapes. Generally, these monuments would be established relative to the initial monument; but any other monument could also serve. The 100-ft monument need not be set on the line with the other marks; it could, in fact, be set at right angles to the line. There may be situations where separate monuments for the 100-ft line should be considered. Such a situation occurs when it is necessary to have the monuments protrude much higher than normal, or when permanent plumb benches are required to assure that tapes being calibrated under prescribed tension do not come in contact with the ground (see section on Monumentation for additional information).

The important consideration here is that the ground over which the measurements are to be made is reasonably level and seldom exceeds a 2% grade. Since this distance will be taped, the 100-ft monument must be set so that the length between the centers of the two marks (disks) involved does not differ from 100.00 ft by more than 0.05 foot.

On occasion, upon special request, ranges have been established for calibrating 200-ft tapes. The same comments and tolerances applicable to the 100-ft calibration lines apply.

Site Selection

Numerous considerations enter into the selection of a calibration base line site. Most are described in the following list:

1. Access--The location should be easy to reach with a minimum of restrictions.

2. Terrain--As a first consideration, it is particularly important that the terrain at the site be geologically stable and not susceptible to surface movement which could result from heavy rainfall or other conditions. Newly filled locations are to be avoided. Under no circumstances are marks to be set in concrete or macadam pavements, sidewalks, or strips which might be available at some airport sites or other locations.

The first choice would be a site with a gradual downward slope from the "0-m" monument to the middle of the line, then a gradual upward slope to the terminal point with the ends of the line at about the same elevation. The slope should not exceed a 1% grade between the 50-m segments of the 150-m section and should seldom exceed a 3% grade between other monuments. When these grades are exceeded, the published mark-to-mark distances often must be corrected for the differences in the heights of the instruments or reflectors.

As a second choice, a range over a gradual slope is satisfactory, providing the grade requirement is met.

In many cases, sites cannot be found that conform to the ideal terrain specifications, so some compromise is required. The essential consideration is that all monuments be intervisible.

If the monuments are set at 100 ft or at 200 ft, the comments concerning the terrain as given in the subsection on Design should be assigned a high priority in the selection of the point locations.

Both mark-to-mark and horizontal distances are published. When the suggested grade specifications are met, it is a relatively simple matter to place the instruments or reflectors at about the same height above the monuments. A direct comparison with the published mark-to-mark data can then be made. Unless steps are taken to set the instruments or reflectors such that the measured distances are in the horizontal plane between monuments, computations are required to compare the observed distances with the published horizontal values.

3. Man-made and natural obstacles--**A range should not be** established within 1/4 mile of high voltage transmission lines, microwave towers, or radio masts. The lines should not cross waterways, structures, or fences, particularly metal mesh

fences. In addition, the calibration base line should be more than 100 ft from such metal fences. Lines should not pass any closer than 20 feet to trees, telephone poles, and other obstructions. Most of these restrictions are required to insure that microwave instruments can be properly calibrated.

4. Location--Select a site at an abandoned or small airfield where there are no known plans to improve or subdivide the land, or on public property where there is little chance of construction. Sites along interstate highways may be satisfactory, providing clearance can be obtained and retained, and no plans exist which might make the base line useless in a few years.

BASE LINE LAYOUT

Prior to making a final decision on the selection of a site, it is often prudent to carry out preliminary observations to insure that the monuments can be located at the suggested distances from the initial point. The terrain should be examined to ascertain whether the recommended grade tolerances can be met. Ideally, the differences in elevations from the initial point should seldom exceed 1% of the distances involved. Finally, a careful examination should be made to be sure that no obstacles, as discussed earlier, are situated in the restricted zone. Once the decision is reached to proceed, the following procedure is recommended.

1. Set a stake at the initial point ("0 m") and mark the center.

2. Set up a theodolite or good quality transit over the stake at the initial point. If an EDMI which mounts atop a theodolite or transit is available and has sufficient range, install the instrument in place. When this equipment is not available, one procedure is to set the EDMI as close to the theodolite or transit as possible at a point normal to the line. Direct measurements to the aligned points will be within acceptable tolerances provided the EDMI is positioned 2 m or less from the initial point and the displacement from the perpendicular does not exceed 0.01 m. If these tolerances are exceeded, offset distances must be computed and the measured distances adjusted accordingly. There are several other approaches to resolving the alignment-distance problem. The procedures that are simplest to implement for the particular situation, or the method most familiar to the observer, should be used.

3. Aligning and setting the stakes at the monument sites, at the suggested distances, should proceed. Whether the terminal point or some other point is set first is left to the discretion of the observer. A mark should be placed on the stake to indicate the point of alignment.

4. After the stakes have been set, the alignment should be checked. One position (D and R) with a theodolite or direct and reverse observations with a 20" or better transit would suffice. No adjustments to the alignment marks on the stakes need be made if the points fall within 20 seconds of the theoretical straight line.

5. The distances should then be verified with the instrument centered over the initial stake, using whatever is considered to be one complete measurement with the particular EDMI employed. There is no need to take offset observations. Any adjustments for distance should now be made. The critical distance is the 150-m section.

6. Two temporary reference stakes are to be set at each monument site. One should be placed in the alignment and the other normal to the line. The distances from the stakes marking the points to the reference stakes at each location must be carefully taped.

7. Two steps should be taken prior to digging the holes for the monuments. First, check the distances from the stakes marking the points to the reference stakes. Second, erect plumb benches similar to that shown in figure 2.

MONUMENTATION

Standard Range

A calibration range without stable monumentation is obviously worthless. While concrete piers at about instrument height have their advocates, they are subject to a variety of conditions which might disturb the monumentation and so are not generally recommended. The heavy poured concrete monument, as illustrated in figure 2, is preferred. It is highly recommended that in addition to underground marks, two permanent reference marks be set at each location. Whether or not the monuments protrude depends on local circumstances. If grass cutting or snow removal equipment operate over the range, it might be best to set the monumentation two to three inches below the ground level or to protect the monuments in some fashion. Marks may also be set in drillholes in bedrock, rock outcrops, and large boulders. The NGS will furnish special calibration base line disks when requested. To assure positive identification, the disks should be stamped with identifying numbers and date. For a standard four-monument base line measured in 1977, the disks would be stamped:

0	150	430	1400
1977	1977	1977	1977

Disks or other marks used to reference the base line monuments will be provided by the local participants.

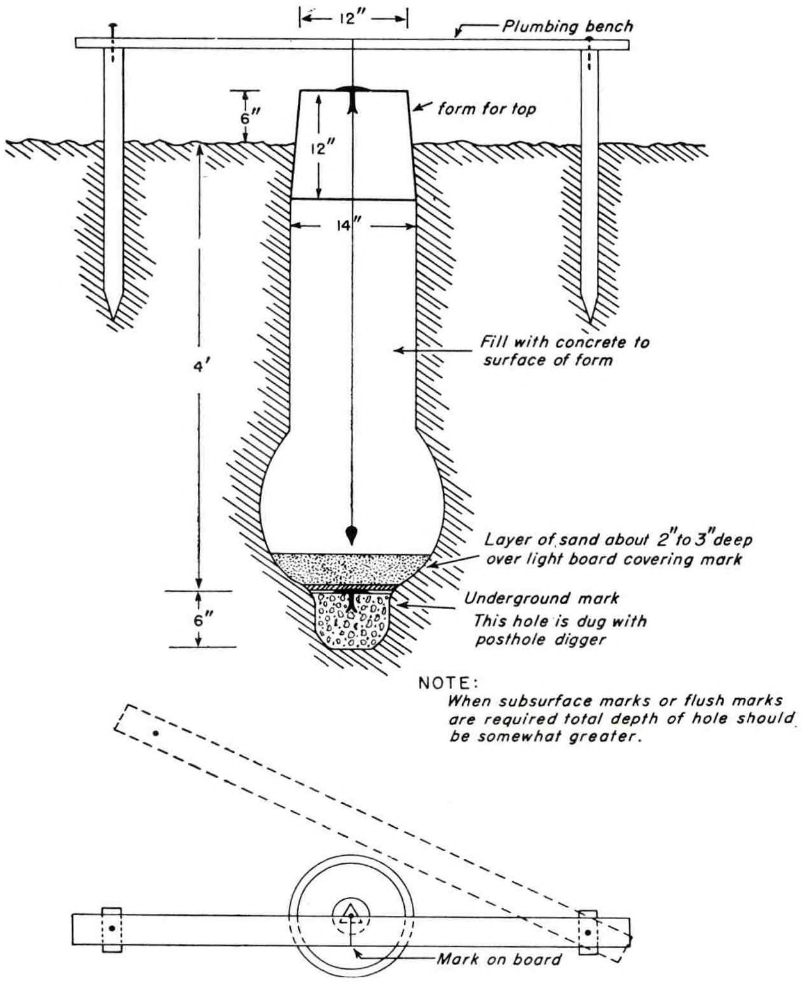

Figure 2.--Diagram of installation of typical calibration base line monument.

Setting the Base Line Monuments

1. Concrete monuments--The concrete monument is normally poured in place in a hole dug in the ground, using a top form only. The hole is dug to a depth of 3-1/2 to 5 feet (sufficient to extend below the frost line) with either a square or circular cross section (depending on shape of top form used), and about 14 inches or more in diameter, except that the lower 6-inch section is made about 10 inches in diameter for the underground station mark (fig. 2). The concrete is poured and tamped in the lower 6 inches of the hole for an underground mark and the disk is set. A point is plumbed directly over the center of the underground mark, on a plumb bench, signal stand, or collimator. This point is maintained during the pouring of the surface monument, so that the surface mark disk may be plumbed over the underground mark. The underground mark is covered by a thin board to prevent disturbing it and then by several inches of soil. The bottom of the hole for the surface monument is enlarged about 2 inches in radius, tapering upward for about 1/2 foot to make the bottom of the monument bell-shaped. Concrete is poured and tamped in the hole until a level is reached where the top form, when set on the concrete, will protrude from 2 to 6 inches above the ground, except where grass cutting or snow removal equipment may pass over sites. The top form may be in the shape of a frustum of a cone or a pyramid, or a cylinder. It is usually made of 1- by 12-inch boards with a 1-inch batter, a 12-inch square inside cross section at top of the form and a 14-inch square at the bottom. The form should be tried for fit before concrete is poured to avoid any shoulders or mushrooming effect near the top of the monument that might afford purchase for frost action. The pouring, tamping, and back-filling are completed, and the top of the monument is smoothed off and beveled with a trowel. The surface disk is then plumbed into position and set in the concrete monument. Great care should be exercised in carrying out the plumbing.

A paper cement bag may be used as a top form for a concrete monument. Use of the paper cement bag as a form has the advantage of greater economy in materials, and the smooth rounded surface is less susceptible to damage by frost or vehicles than a square top. When a cement bag is used as a top form, a cylindrical hole is dug about 14 inches in diameter and belled out as before to about 4 inches greater diameter at the bottom. The ends of the bag are trimmed, leaving about an 18-inch cylindrical section about 12 inches in diameter. After the hole is filled with concrete to within 1 foot of the surface, the bag is set on the poured concrete and then carefully filled with concrete, working it around the edges with a trowel to prevent honeycombing. Care is necessary to keep the cross section of the bag circular and the bag vertical. A pair of cylindrical metal forms may be used for this purpose. The outer form is about 18 inches long and about 12 inches in diameter, and the inner metal form is 9 inches long and 11 inches in diameter. Both forms have a 1-inch flange around their top rims. The bag is held in position between these two forms while the concrete is being poured. Immediately after the pouring, the inner form and then the outer form are lifted off.

2. Rock outcrop--The rock in which a mark is set should be hard and a part of the main ledge, not a detached fragment. The disk should be countersunk and well cemented in a drill hole.

3. Boulders--The boulder should be durable rock and as large or larger than a standard concrete monument. The boulder should be firmly imbedded in the ground. Unless the boulder is very large, a hole should be dug, and the boulder buried so as to protrude from the ground about 2 to 4 inches in the same manner as a concrete monument. In areas where boulders are prevalent, a truck and log chain can frequently be used to advantage in dragging a boulder to a point where a hole has been dug in a suitable location for a mark. The disk should be set in a drill hole in the same manner as in rock outcrop.

4. Rock ledges below surface--When the ledge is only slightly below the surface, a disk set in the usual manner in the ledge will be sufficient, provided two surface reference marks are established. Where the ledge is so far below the surface that a surface mark is required, a disk or copper bolt should be set in the ledge, the ledge carefully brushed or washed off for a space at least 18 inches in diameter, and a concrete surface monument placed above this underground mark. A disk should be set in the surface monument directly over the underground disk or bolt. If the rock ledge in which the underground mark is set is very smooth, it should be furrowed with a chisel to provide better anchorage for the concrete.

Setting the Reference Marks

Each monument should have two reference marks. Reference marks are stamped with the name (number) and date of the monument and are numbered serially clockwise from north. For example, reference mark no. 1 for the 150-m monument could be stamped

150
1977
RM 1

When needed, monuments are constructed similar to the surface monument but may be 2 inches smaller in diameter. They should be 30 inches or more in depth or as deep as is necessary to extend below the active frost line. The directions to the two reference marks should intersect at approximately 90°. Reference marks should be located where they are least likely to be disturbed, e.g., in or near fence lines. It is also necessary that reference marks be placed where direct unobstructed measurements can be made to them from the monument, and where the line of sight from the instrument to reference marks is clear. To facilitate taping, distances to reference marks from the monument should preferably be kept less than a 30-m tape length. Observations should be made at the monument to its reference marks, initialing on the most distant monument. Three positions with a one-second theodolite using a 20" rejection limit from the mean is satisfactory.

A transit may also be used if a sufficient number of observations are taken. Three direct and reverse pointings with a 20 or 30" transit will suffice. The distance to the reference marks should be measured using precise procedures. If possible, the distance between the reference marks should be determined in the same fashion. A side-angle-side computation should be made as soon as possible to insure that the measurements and observed angles are correct.

Material for Concrete Monuments

The main considerations in making concrete are: Have clean materials, mix them well before adding water, be certain the mixture is not too wet, and tamp well into the form. No dirt should be allowed in the mixture, as each streak of dirt in concrete means a line of cleavage. Where rough aggregate is available the proportions should be 1 part cement, 2 parts sand, and 3 parts gravel, with the top 12 inches of the mark of slightly richer mixture. Where only cement and sand are available, the lower part of the mark should be proportioned 1 part cement to 3 parts sand, and the upper part should be 1 part cement to 2 parts sand. Steel reinforcing rods may be used. To avoid cracking of the concrete due to rapid drying, the wet concrete should be covered with paper or plastic and then with earth or other material for at least 48 hours. The monuments should be set 60 to 90 days prior to beginning the base line measurements.

Tape Calibration Base Lines

In establishing 100-ft and 200-ft lines for calibrating tapes, vertical sag can be a problem. For example, a 100-ft lovar or steel tape weighing approximately 0.015 lb/ft would require about 2-ft clearance to insure that the tape does not touch the ground, when two supports and a tension (pull) of 10 pounds are used. Similarly, for a 200-ft tape weighing the same, using two supports and a tension of 20 pounds, would need a clearance of almost 4 feet. The formula for computing the vertical sag is:

$$\text{amount of sag} = y = w\ell^2/8t$$

where w is the weight of the tape, ℓ is the length between supports and t is the tension. w and t may be in pounds per foot (or per meter) and pounds, respectively, or in grams per foot (or per meter) and grams, respectively. ℓ must be in a corresponding unit.

It is very difficult to maintain the stability of monuments projecting 2 feet or more above the ground unless substantially larger monuments, set considerably deeper, are constructed. It is usually more advantageous to build and maintain permanent plumb benches than to construct larger monuments. For 100-ft lines, benches 2 feet above the ground surface are satisfactory; and when 200-ft lines are established, the plumb benches should extend about 4 feet.

As a general rule, standards or uprights, which are constructed of reinforced concrete, or metal set in concrete are considered best, although metal may be troublesome unless it is rust resistant or painted periodically. The bench (horizontal cross piece) should probably be of metal, since wood normally would be susceptible to weathering and cause warping and deterioration.

Some method for adjusting the benches is necessary so that the edge and engraved mark, or series of marks (or whatever is being employed) may be plumbed directly over the points marking the terminals of the line. Plumb bobs should not be used in the original centering of the benches, although they might be satisfactorily employed to check on the centering to insure no significant displacement has taken place since the benches were established. The original and subsequent centerings should be carried out using vertical collimators or two well-adjusted transits or theodolites. When transits or theodolites are used, they should be equally spaced from the monuments--one in the alignment, and the other perpendicular to the line.

Platforms

To facilitate equipment setups, it is useful to provide permanent supports for the tripod legs, so that when the legs are placed in them, the tripod head is positioned directly over the mark. A 1-ft long piece of 1-in. pipe driven in the ground (with a concrete collar if needed) at appropriate spacing is recommended. The building of large pads surrounding the mark is discouraged because their presence introduces temperature anamolies. In no case should such a structure be placed closer than one foot from the monument.

Procedures

General observing procedures, applicable to most EDMI, are described in NOAA Technical Memorandum NOS NGS-10, Use of Calibration Base Lines (Fronczek 1977).

APPENDIX I. SUGGESTED EQUIPMENT FOR A CALIBRATION BASE LINE PARTY

Following is a list of typical equipment to be used by a calibration base line party:

EDMI Equipment:

2 short-range EDMI $[\sigma^2 \leq (0.001\text{m})^2 + (D \cdot 10^{-6}\text{m})^2]$ and associated reflectors

2 adjustable tripods

2 optical plummet tribrachs

2 tribrach adapters

2 barometers

2 psychrometers

6 thermometers (Celsius scale)

2 thermistor sets (Celsius scale)

Tape Equipment:

5 50-meter standardized invar/lovar tapes

2 30-meter standardized steel tapes

3 100-foot standardized invar/lovar tapes

6 10-centimeter boxwood scales (0.5 mm divisions)

4 adjustable taping stands (bucks)

6 tape thermometers (Celsius scale)

1 spring balance, hand, 0-15 kg (for use with 30-meter tapes)

1 tape stretcher kit with circular spring balance (0-5 kg) and frictionless pulley apparatus (for use with 50-meter tapes)

1 tape clamp

2 magnifying glasses

Instrumentation:

2 theodolites (optical-reading to 1")

1 level instrument (2nd order)

2 adjustable tripods

2 optical plummet tribrachs

2 tribrach adaptors

2 level rods

Peripheral Equipment:

2 hand-held electronic calculators

2 two-way portable radios

2 combination pocket tapes (feet and meters)

1 8-amp battery charger

1 2-drawer filing cabinet

1 typewriter

2 umbrellas

1 optical plummet leveling adjusting kit

APPENDIX II. FIELD MEASUREMENT STANDARDS, SPECIFICATIONS, AND PROCEDURES

General

These instructions outline procedures for measuring a standard calibration base line with monumentation at 0, 150, 430, and 1,400 m. Procedures are also specified for establishing a 100-ft field standard, when requested by the participating organization.

Distance Observations, General

To insure that the desired accuracy for calibration base lines is met, great care must be taken during all phases of the operation. The following items will be checked for accuracy and completeness:

1. From station name
2. To station name
3. Instrument/tape model & serial no.
4. Reflector model & serial no.
5. Date & time of observation
   (local time - 24-hour clock)
6. Instrument/reflector constants (if known)*
7. Height of instrument/reflector/taping benches and/or stakes above marks*
8. Station elevations*#
9. Instrument/reflector eccentricity*
10. Atmospheric observations*
    a. Temperature
    b. Pressure
    c. Psychrometer
11. Weather conditions
12. Any unusual or problematic conditions, e.g., dust blowing across line, measuring across 100-ft wide by 10-ft deep gully, etc.

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* Units of measurement must always be shown.
# Vertical datum must be shown.

The elevation of all monuments, benches, and taping stakes will be determined and recorded. Elevation differences between monuments will be obtained using double-run, third-order procedures. Maximum allowable closures at any of the individual monuments will conform to third-order standards and specifications, as given in "Classification, Standards of Accuracy and General Specifications of Geodetic Control Surveys" (Federal Geodetic Control Committee, 1974), and "Specifications to Support Classification, Standards of Accuracy and General Specifications of Geodetic Control Surveys" (Federal Geodetic Control Committee, 1975).

Distance Observations, Tape

1. 150-m section--The 150-m section will be measured with 50-m standardized invar/lovar tapes using first-order taped base line procedures, as described in Special Publication No. 247 (Coast and Geodetic Survey, 1959) with the following exception. The copper strip and scribe will not be used. Instead, a 10-cm boxwood scale (0.5 mm divisions) will be attached to the taping stakes or benches. The 5-cm mark on the scale will be plumbed over the 0- and 150-m marks using two theodolites positioned so that the angle of intersection of the two lines of sight at the mark is approximately 90°. This procedure will be carried out before and after the distance measurements. If a check on the centering of the boxwood scales is not obtained, the taping will be repeated. Two additional boxwood scales will be positioned on line at 50 and 100 m from the 0-m mark. All boxwood scales are to be attached such that the zero end of the scales faces either the 0-m or 150-m monument. An explanatory statement, with sketch, is to be included in the taping records.

The rear contact will bring the standardized mark on the tape into coincidence with the 5-cm mark on the boxwood scale, and the front contact will read the value on the scale where coincidence occurs between the standardized tape mark and the scale. A magnifying glass should be used in reading the scale. The reading will be estimated to 0.1 mm. At least two readings of the scale are to be made with a spread (the difference between the highest value and the lowest value) not to exceed 0.3 mm. The mean value will be used in the computations.

In the event the above procedure is not feasible, a set-up or set-back may be made at the rear contact end of the tape. In either case, recordings of both front and rear boxwood scale readings will be made. A sketch showing exactly where the tape end was held should accompany the taping records whenever a set-up or set-back from the 5-cm mark on the scale is required. This will aid in resolving any confusion that tends to arise in such situations.

A complete set of observations over the 150-m section will consist of four measurements, once with each of four different tapes. The following scheme will be employed:

1. Forward measurement with one tape

2. Backward measurement with a second tape

3. Forward with a third tape

4. Backward with a fourth tape

To reduce the parallax effect, a single member of the base line taping team should be assigned the task of "front contact" for the forward and backward measurements. In no case are substitutions to be made at the "front contact" positions in measurements 1 and 2, or 3 and 4. The spread of the four observations over the 150-m section, after making tape and catenary corrections, should seldom exceed 1.0 mm and must not exceed 1.5 mm. If the tolerance is exceeded, additional measurements will be made until an acceptable spread is obtained. The acceptable measurements must include at least one complete taping with each tape.

2. 100-ft field standard--The 100-ft section will be measured with 100-ft standardized invar/lovar tapes to a temporary scribe on the 100-ft mark. The tension used during the standardization will also be used in the measurement. All measurements will be made mark-to-mark where possible, otherwise the previous procedure should be followed. A complete set of observations will consist of three measurements, carried out once with each of three different tapes. Temperature, tape and catenary corrections will be computed for each measurement, a mean computed, and a point stamped on the 100-ft mark at the distance of 100.000 ft from the "0" mark.

The spread of the three observations, after corrections, should seldom exceed 0.0005 foot and should not exceed 0.001 foot. If this tolerance is exceeded, the remeasurement requirements specified for the 0-m to 150-m segment apply here also.

Distance Observations, Electronic

The complete base line, except for the 100-ft section, will be measured with two high accuracy short-range EDMI on two separate days. (Note: See appendix III for high precision procedures for specific instruments.) Observations will be made such that all segments are measured, forward and backward, on each of the two days with both instruments.

The following procedure insures the greatest atmospheric variations in the limited time available:

> On the first day, starting at the 0-m monument and progressing to 150-, 430-, and 1,400-m monuments, measure all segments at each monument with both instruments. This will provide a total of 12 distinct observations with each instrument.

On the second day, at approximately the same starting time as the first day, begin measuring at the 1,400-m monument and work in reverse sequence from that used the first day. Remeasure all segments with both instruments. This will again provide a total of 12 distinct observations with each instrument.

In cases where additional monuments are set, the total number of measurements required for each of two instruments on each day is n(n-1), where n is the number of monuments.

No EDMI measurements are required, either to or from the 100-ft monument.

Descriptions

A standard NOAA Form 76-39 (Description of Triangulation Station - see fig. 3) should be filled out and included with the observations for each base line. It is not necessary to file a description card for each monument. However, the descriptions should be sufficiently detailed to enable a user to identify which of the monuments has been located. This is absolutely necessary in the case where no stampings have been made on the marks prior to the departure of the base line party from the area.

The title of the form should be changed from "Description of Triangulation Station" to "Description of Calibration Base Line." (See attached example.)

NOAA FORM 76-39
(12-70)

U.S. DEPARTMENT OF COMMERCE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
NATIONAL GEODETIC SURVEY

DESCRIPTION OF CALIBRATION BASE LINE

NAME OF STATION: URBANA BASE LINE **STATE:** Illinois **COUNTY:** Champaign
NEAREST TOWN: Savoy **QUADRANGLE NO.:**
CHIEF OF PARTY: M. D. Crabtree **YEAR:** 1976 **DESCRIBED BY:** CWW

NOTE.*	HEIGHT OF TELESCOPE ABOVE STATION MARK METERS,† HEIGHT OF LIGHT ABOVE STATION MARK METERS.				
	SURFACE-STATION MARK, UNDERGROUND-STATION MARK	DISTANCES AND DIRECTIONS TO AZIMUTH MARK, REFERENCE MARKS AND PROMINENT OBJECTS WHICH CAN BE SEEN FROM THE GROUND AT THE STATION			
	OBJECT	BEARING	DISTANCE		DIRECTION‡
			FEET	METERS	° ′ ″

Detailed description:

The base line is located at the University of Illinois Willard Airport, about 5 miles south of Champaign-Urbana and on the northeast side of the airport. The base line runs along the east boundary of the airport.

To reach the base line from the post office in Savoy, which is about 3 miles south of the Champaign City Limits, go east on Graham Drive for 0.1 mile to the junction with U. S. Highway 45. Turn right and go south on U. S. Highway 45 1.2 miles to the airport road on the right. Turn right and go west on a paved road for 0.7 mile to the entrance to the airport. Turn right and go north along the east boundary of the airport for 0.6 mile to a farm field and the 0-meter point on the left as described.

The 0-meter point is in the extreme northeast corner of the airport. It is 53 feet west of the center of a gravel road, 33 feet west of a white iron post and 3.6 feet south of a barbed wire fence and a corn field. The mark is on the west edge of a golf course that belongs to the University of Illinois.

All the marks are Illinois Registered Land Surveyors Association brass disks set in the top of round concrete monuments flush with the ground and have no stamping on them. The base line is a north-south line with the 0-meter point on the north end. It consists of the 0-, 150-, 400-, 800-, and 1400-meter points. There is a disk set 100 feet south of the 800-meter point to be used for tape calibration.

The base line was established in conjunction with the Illinois Registered Land Surveyors Association East Central Chapter. For further information contact Mr. Edward L. Clancey, Chapter President, at Burns, Clancey and Associates, 1101 East University Avenue, Urbana, Illinois 61801. His phone number is (217)384-1144.

*Refers to notes in manuals of triangulation and state publications of triangulation. ‡Direction-angle measured clockwise, referred to initial station.
†To nearest meter only, when no trigonometric leveling is being done.

☆U. S. GOVERNMENT PRINTING OFFICE: 1973--768075/1074 REGION NO. 6

Figure 3.--Sample of a description for a calibration base line. (Title of form has been altered to reflect changes in usage.)

APPENDIX III. HIGH PRECISION PROCEDURES USING A TELLUROMETER MA-100

To obtain the maximum accuracy with this instrument, the following procedures will be employed:

1. The optical plummets used for instruments and reflectors will be checked (and adjusted as necessary) before use on each base line. An adjustment kit will be provided to any party not so equipped.

2. Instruments will be allowed to warm up for 30 minutes before taking any measurements. Check the monitor to insure that the oven is operating.

3. When pointing an instrument toward a reflector, always sight above the reflector and use the tangent screws to bring the line-of-sight of the instrument down to the reflector. Use both tangent screws to obtain maximum light return.

4. If the external light return exceeds the internal light return, cover a portion of the reflectors to make the two light returns equal. In no case will the external light exceed the internal.

5. At short range, where a single prism is being used and the external light exceeds the internal light, attach the T-3 cap (with shutter) to reduce the external light return. When using the T-3 cap, make sure the instrument and reflector are at the same elevation; this eliminates transit time within the prism.

6. After maximum light return is obtained (in accordance with steps 4 and 5 above), take a coarse reading, followed by five fine readings. Then repoint on the reflector (noting this on recording form) and take five more fine readings. The spread of these ten readings should not exceed 20 units (2 mm) and must not exceed 30 units (3 mm).

7. Reflectors placed at stations along the line will be turned 90° off-line while measuring to another reflector in the same direction.

REFERENCES

Coast and Geodetic Survey, 1950, revised 1959, reprinted 1976: Manual of Geodetic Triangulation. Special Publication 247. U. S. Department of Commerce, Coast and Geodetic Survey (now National Oceanic and Atmospheric Administration, National Ocean Survey), National Geodetic Survey, Rockville, Md. 20852, 344 pp. National Technical Information Service Accession number COM-71-50406. (See inside front cover for address.)

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(Continued from inside front cover)

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