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ESTABLISHMENT OF CALIBRATION BASE LINES

Rockville, Md.
Revised June 1982

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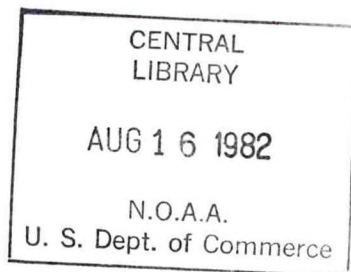
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Joseph F. Dracup, Charles J. Fronczek,
Raymond W. Tomlinson

Revised by: Paul R. Spofford

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June 1982



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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 the measuring capabilities of an instrument have not significantly deteriorated, 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 1000 to 1400 m will meet the needs of most users. Specifications and recommended procedures for establishing calibration base lines are described in 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 [subsequently named the Coast and Geodetic Survey (C&GS), now the National Ocean Survey (NOS)] 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 rudimentary, even after the National Bureau of Standards developed methods for accurately determining the length of a tape or wire. Eventually, however, most surveyors had access to some means for ascertaining the length of their tapes to an acceptable degree of accuracy. A new dimension was added to the surveying profession when electronic distance measuring devices were invented. Use of these instruments introduced the capability of performing measurements with speed and a degree of precision not previously possible. But with this ability came the problem of assuring that the accuracy of the measurements was equivalent to or better than those obtained previously.

BRIEF HISTORY

With the introduction of electronic distance measuring instruments (EDMI) in the United States in 1952, the standardization problem was compounded since EDM measurements are affected by meteorological conditions other than temperature and by several instrumental uncertainties which require frequent periodic reevaluations. Although the need for calibration base lines was evident, a test range specifically designed for such EDM reevaluations was not available for more than a decade. In 1963, C&GS (now NOS' National Geodetic Survey) measured a multimonumented line in Beltsville, Md., using high-precision taping techniques (Poling 1965). The distance of the Beltsville base totals about 1800 m, but only 1650 m is normally utilized. Later, a much longer line (about 9050 m) near Culpeper, Va., 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 calibrated their equipment at these facilities.

As more surveyors acquired EDM, the surveying profession became concerned about the accuracy of their measurements. It has been shown that the accuracies attributed by the manufacturers to the instruments are reliable. It is also known that errors in the observations, which are often systematic, can result from normal usage due to a reduction in the efficiency of electronic and mechanical components. Periodic maintenance, preferably by the manufacturer or a designated representative, is required to minimize such 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 operating precision of the EDM, a known distance, or preferably a sequence of known distances forming a calibration range, is required.

By 1970, a number of EDM were available. Since that time, more than 50 models have been produced by various manufacturers. Most are short-range instruments. Because this equipment was being used for almost every conceivable surveying problem, the need for assuring that the observations met the required project accuracies became acute. To resolve the problem NGS held in-house discussions and investigated several solutions.

The original concept was to tape the distances between a number of monuments using several Invar type tapes¹ and high precision measuring techniques. Four calibration base lines were measured with these techniques

¹Invar is a steel-nickel alloy developed in France about 1900. Its unique property is that its coefficient of thermal expansion is about 1/25 that of pure steel. Similar alloys are known commercially by such names as LO-VAR^R and MINVAR^R.

before the time-consuming operation was discontinued. The present procedure employed by NGS is to tape a 150-m section, usually at the beginning of the range, using four calibrated Invar type tapes and high precision methods. All sections are then measured in every combination with two high accuracy short-range EDM. Distances are observed on 2 days with both instruments employed on each occasion.

In 1977, the NGS measured a new base line at its Corbin, Va., facility. This base line, containing six monuments, was measured using high precision taping methods and has replaced 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, in addition to the other range.

RESPONSIBILITY FOR BASE LINES AND COSTS

Initially, the base lines were established as cooperative ventures between the National Oceanic and Atmospheric Administration (NOAA) and local surveying societies. The local societies were responsible for selecting the sites, setting the monuments, and assisting NGS personnel in executing the measurements. Generally, NGS personnel were involved in the initial phases such as site selection and monument installation, as well as during the period when measurements were secured.

As a result of budgetary restrictions it soon became apparent that, while the calibration base line projects would continue under cooperative arrangements, NGS would have to be reimbursed by the requesting societies for part of its participation. Payment by the participating society includes the cost of NGS participation in performing the measurements, reducing and adjusting the data, and publishing the results. A fee schedule for these services is available from NGS at the following address:

National Geodetic Survey, Attn: OA/C111
National Ocean Survey, NOAA
Rockville, MD 20852

A standard calibration base line consists of four monuments. Measurements to extra monuments require additional reimbursement to NGS for each monument set. NGS plans to periodically remeasure a number of selected base lines to test the long-term (i.e., multiyear) stability of the monumentation or to reestablish the base lines as necessary.

Local societies continue to be responsible for selecting the sites, setting the monuments, and providing experienced surveyors to assist NGS personnel in carrying out the observations. The requesting organization is also responsible for procuring necessary supplies such as concrete, lumber, and miscellaneous materials.

Although this publication is intended to describe the establishment of calibration base lines in cooperation with NGS, it should not deter private surveyors from establishing their own calibration base line. However, such an undertaking requires specialized equipment which is not normally avail-

able, such as Invar or LO-VAR tapes, high quality tension apparatus of particular design, and centering devices. To ensure that consistent procedures are followed by the individual surveyor, NGS requests that it be informed when a private calibration base line is established.

Least-squares adjustments of privately measured data will be performed by NGS without cost to the originator, provided the data are prepared and submitted in machine-readable format (i.e., 80 column punch cards or computer readable tape). NGS will furnish the keypunch specifications upon request. However, if the data submitted are not adjustable, they will be returned to the sender. Should unsatisfactory results be obtained, NGS will review the adjusted data and attempt to ascertain the cause.

CALIBRATION RANGE

Design

The standard base line configuration consists of four monuments set in a straight line with a total length of about 1400 m. In no instance should the range be significantly less than 1000 m or more than 1400 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 performed.

While it is possible to establish a calibration base line in which the monuments are not set on a straight line, this method is discouraged and 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 1000 to 1400 m from the initial or "0-m" monument (fig. 1). The monuments at 400 to 430 m and 1000 to 1400 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 of 150 m to ensure that the full calibrated tape lengths can be used.

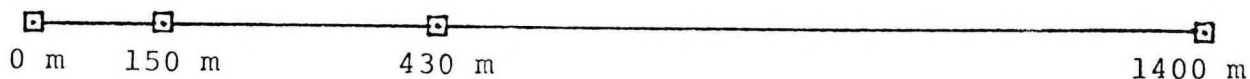


Figure 1.--Standard calibration base line configuration.

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 a recommendation.

Occasionally, it will not be possible to set the intermediate and/or terminal monuments at the suggested distances from the initial point. In such cases, the monuments should be placed at distances, on a multiple of 10 m, that approximate the recommended locations; e.g., the intermediate point could be at 420 m and/or the terminal monument 1360 m from the initial mark or some other similar variation.

The need for monumentation at 400 to 430 m rather than at 600 to 800 m, the intermediate spacing used in the past, has resulted from the introduction of EDM, with ranges limited to 500 m. Where a longer distance is desired, another monument can be set on line at about 800 m. It is not necessary to know the accurate distances to this point when only the instrument constants are to be determined. (See technique described under Brief History.)

There are no set rules for spacing the intermediate and terminal monuments, other than the intermediate point should not be more than about 430 m from the initial monument and the "multiple of 10 m" rule be adhered to whenever possible.

The "multiple of 10 m" rule is advised in order to obtain the best results from the original measurement and subsequent use of the calibration range. Most EDM are designed such that the basic "yard stick" (wavelength) for the instrument is 10 or 20 m. A distance is measured by counting the number of full wavelengths and adding the final (usually partial) wavelength. The component of the instrument which determines (resolves) the partial wavelength is called the resolver. In modern instruments the resolver, itself, may generate a small (± 5 mm) measurement error. (The error in older instruments was as much as ± 0.3 m.) To avoid contaminating subcentimeter level calibration measurements with varying resolver errors, the same section of the resolver should be used for each measurement. Setting the monuments on a multiple of 10 m will enforce this requirement. Any resolver error included in the computation then becomes nearly a constant for all measurements. The error can be disregarded in the determination of the instrument constant, but must be compensated for if a subcentimeter level length measurement or calibration is desired. The test for resolver error has been described in professional journals (Couchman 1974, Rueger 1978).

Many existing base lines with extra monuments for calibrating tapes have been established. In cooperation with the National Bureau of Standards, most States have facilities to calibrate surveying tapes to an accuracy of 1:250,000--a value difficult to achieve in the field without practice and proper supplemental equipment. This service is sometimes performed without charge at the State agency which controls weights and measures.

On request, NGS will set a monument 30.48 m (100 ft) from another monument for use in calibrating tapes. Generally, such a monument would be established relative to the initial monument, but any other monument could also serve the purpose. The 30.48-m monument is not an integral part of the base line and need not be set on 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 30.48-m line should be considered; for example, when it is necessary to have the monuments protrude above ground level 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 Monumentation for details.)

The important consideration here is that the ground over which the tape measurements are to be made is reasonably level and seldom exceeds a 2-percent grade. Since the distance will be taped, the 30.48-m (100 ft) monument must be set so that the length between the centers of the two marks (disks) involved does not differ from 30.48 m by more than 0.015 m (0.05 ft).

On special occasions ranges have been established for calibrating other length tapes. The same comments and tolerances applicable to 30.48-m calibration lines apply.

Since the calibration range is designed for length calibration only, a knowledge of the exact orientation and position of the monuments is not needed. For this reason NGS does not connect calibration ranges to the National Networks of Geodetic Control. Bench mark type elevations are published, but these usually are not tied to a vertical datum. The data are published only to provide the differential heights between the marks.

Site Selection

Numerous considerations enter into the selection of a calibration base line site. These considerations follow:

1. Access. The location should be easy to reach, with minimum restrictions. When Federal funds are used in the project, the adjusted distances will be a matter of public record and the base line site must be accessible to the public.

2. Terrain. As a first consideration, it is important that the terrain at the site be geologically stable and not susceptible to surface movement, resulting 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 similar strips, which might be available at some airport sites or other locations.

The ideal choice for a site would have 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. This profile of an ideal grade would allow intervisibility between monuments while measuring without need to take down intervening instrumentation. The slope should not exceed a 1-percent grade between the 50-m segments of the 150-m section and should seldom exceed a 3-percent 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 can be established over a gradual slope if the grade requirement is met.

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

If monuments are set at 30.48 m or at other lengths, information on the terrain, as stated 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 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. Manufactured and natural obstacles. A range should not be established within 0.4 km (0.25 mi) of high-voltage transmission lines, microwave towers, radio masts, or radar facilities. At an airfield, a site may run parallel to but not across a runway or taxiway. Otherwise ground and air heat problems will result. The lines should not cross waterways, structures, or fences, particularly metal mesh fences. The calibration base line should be more than 30 m (100 ft) from a metal fence. In addition, base lines should not pass closer than 6 m (20 ft) to trees, telephone poles, or other obstructions. Most of these restrictions are required to ensure that microwave instruments can be properly calibrated.

4. Location. A possible site could also be at an abandoned or small airfield, with no known plans to improve or subdivide the land, or public property where there is little chance of construction. Sites along interstate highways may be satisfactory if permission for access can be obtained and retained, and no plans exist to render the base line useless in a few years. As a matter of policy, NGS will not generally measure a new base line closer than 120 km (75 mi) from a previously measured base line.

BASE LINE LAYOUT

Before selecting a permanent site, it is prudent to carry out preliminary observations to ensure 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 percent of the distances involved. Finally, a careful examination should be made to be sure that no obstacles 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 EDM which mounts atop a theodolite or transit is available and has sufficient range, install the instrument. When this type of equipment is not available, another acceptable 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 EDM 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 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 then 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. With a theodolite one position (D and R) is sufficient. With a 20" transit, direct or reverse observations are satisfactory. No adjustments to the alignment marks on the stakes are needed if the points fall within 20" of the theoretical straight line.

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

6. Two temporary reference stakes are 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 before the holes are dug for the monuments. First, check the distances from the stakes, marking the points to the reference stakes. Second, erect plumb benches similar to the illustration shown in figure 2.

MONUMENTATION

Standard Range

Without stable monumentation a calibration range is obviously worthless. For this reason, NGS will not perform measurements over ranges with sub-standard monumentation. Experience has shown that monuments with significant mass placed in relatively undisturbed soil have the best long-term stability. Precast monuments usually have a slim profile, relatively small mass, and must be secured in place with fill dirt, making them susceptible to horizontal movement when the fill dirt compacts. Concrete piers, while massive, have a significant portion of their mass protruding unsupported and are subject to a number of conditions which might cause movement. For this reason, the heavy, poured concrete monument (fig. 2) is required.

Monuments can either protrude slightly above the ground or be set below ground level, depending on specific circumstances. If grass-cutting or

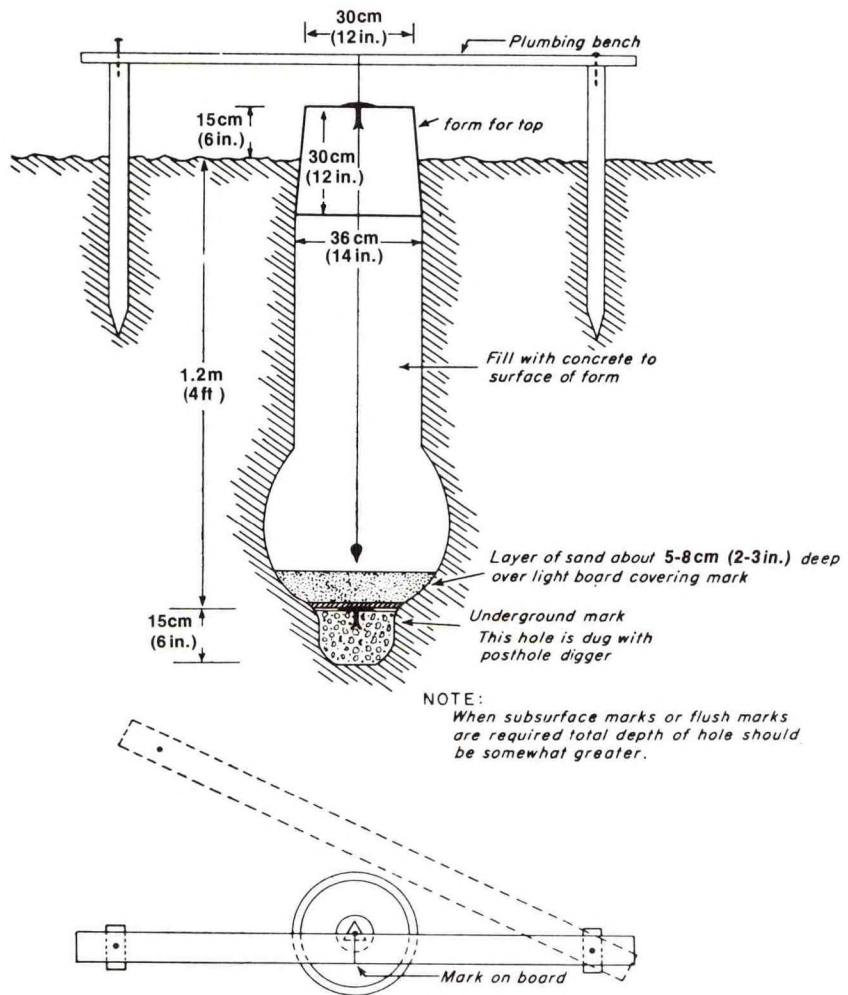


Figure 2.--A typical calibration base line monument with optional underground monument.

snow removal equipment operates on the range, it might be best to set the monumentation about 5 cm (2 to 3 in.) below the ground level, or to protect the monuments in some other way. Marks may also be set in drill holes in bedrock or rock outcrops. NGS will furnish special calibration base line disks when requested. To assure positive identification, the disk should be stamped with identifying numbers and the date of establishment. For example, the disks for a standard four-monument base line measured in 1977 would be stamped:

0	150	430	1400
1977	1977	1977	1977

Reference marks or underground marks are no longer recommended, as neither are sufficiently well located to be used in restoring a moved or destroyed surface mark. Disks or other marks used to reference the base line monuments are provided by the local participants.

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 1.1 to 1.5 m (3.5 to 5 ft) (sufficient to extend below the frost line) with either a square or circular cross section (depending on the shape of the top form used), and about 0.36 m (1.2 ft) or more in diameter. If an underground mark (fig. 2) is set, the bottom 0.15 m (0.5 ft) section of the hole is made about 0.25 m (0.8 ft) in diameter, the concrete is poured and tamped in the lower 0.15 m (0.5 ft) of the hole, 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 surface mark disk may be plumbed over the underground mark. The underground mark is covered by a thin board to prevent disturbances and then covered by several inches of soil. The bottom of the hole for the surface monument is enlarged about 5 cm (2 in.) in radius, tapering upward for about 0.30 m (1.0 ft) to make the bottom of the monument bell-shaped. Concrete is poured and tamped in the hole until the level is reached where the top form, when set on the concrete, will protrude from 5 to 15 cm (2 to 6 in.) above the ground. An exception to this is where grass cutting or snow removal equipment may pass over the site.

The top form may be in the shape of a frustum of a cone, pyramid, or cylinder. It is usually made (using 1 x 12 in. boards) with a 30.5-cm (12-in.) square inside cross section at top of the form and a 36-cm (14-in.) square at the bottom, producing a 2.5 cm (1 in.) batter. The form should be tried for fit before concrete is poured to avoid any shoulder or mushrooming effect near the top of the monument that might allow frost action to move the mark. Then, after the pouring, tamping, and back-filling are completed, 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 the concrete monument. Use of a 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 0.36 m (1.2 ft) in diameter and belled out as before, to about 10 cm (4 in.) greater diameter at the bottom. The ends of the bag are trimmed, leaving about a 0.46-m (1.5-ft) cylindrical section about 0.30 m (1 ft) in diameter. After the hole is filled with concrete to within 0.30 m (1 ft) 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 0.46 m (1.5 ft) long and about 0.30 m (1 ft) in diameter, and the inner metal form is 0.23 m (0.75 ft) long and 0.28 m (0.9 ft) in diameter. Both forms have a 2.5-cm (1-in.) flange around their top rims. The bag is held in position between these two forms while the concrete is being poured. Immediately after pouring the concrete, 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. 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 far below the surface, the rock ledge becomes the location for an optional underground mark and a surface mark is required. A disk or copper bolt may be set in the ledge, the ledge carefully brushed or washed off to create a space at least 0.46 m (1.5 ft) in diameter, and a concrete surface monument placed above this underground mark using the method for concrete monuments. A disk should be plumbed in the surface monument directly over the underground disk or bolt.

Setting the Optional Reference Marks

Each monument may have two optional reference marks. Reference marks are stamped with the name (number) and date of the monument; they are numbered serially clockwise from north. For example, reference mark Number 1 for the 150-m monument could be stamped:

150
1977
RM 1

When needed, reference monuments are constructed similar to the surface monument but may be 5 cm (2 in.) smaller in diameter. They should be set 0.76 m (2.5 ft) or more in depth or as deep as is necessary to extend the monuments 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 advisable that reference marks be placed where direct, unobstructed measurements can be made to them from the base line monument, and where the line of sight from the instrument to the reference marks is

clear. To facilitate taping, distances to reference marks from the monument should preferably be kept to 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 1" 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 are sufficient.

Material for Concrete Monuments

The main considerations in making concrete are the following: 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. The top 0.3 m (1 ft) of the mark should contain a slightly richer mixture. Where only cement and sand are available, the lower part of the mark should consist of 1 part cement to 3 parts sand, while the upper part should be 1 part cement to 2 parts sand. Steel reinforcing rods may be used. To avoid cracking as a result of 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 to allow for movement of the marks as the concrete cures and the surrounding soil settles.

Tape Calibration Base Lines

In establishing 30.48-m (100-ft) lines or other lengths for calibrating tapes, vertical sag can be a problem. For example, a 30.48-m Invar or steel tape weighing about 0.21 g/m (0.015 lb/ft) would require about 0.6 m (2 ft) clearance at each end to ensure that the tape does not touch the ground when two supports and a tension (pull) of 4.5 kg (10 lb) are used. Similarly, for a 61.0-m (200-ft) tape weighing the same per unit length, using two supports and a tension of 9.1 kg (20 lb), a clearance of almost 1.2 m (4 ft) would be needed. 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 per unit of length, 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 0.6 m (2 ft) 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 30.5-m (100-ft) lines, benches 0.6 m (2 ft) above the ground surface are satisfactory; when 61.0-m (200-ft) lines are established, the plumb benches should extend about 1.2 m (4 ft).

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

Some method for adjusting the benches is necessary so that the edge and engraved mark, or series of marks (whichever 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 ensure 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 setting up the equipment, 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 0.3-m (1-ft) long piece of 2.5-cm (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 anomalies. In no case should a structure be placed closer than 0.3 m to the monument.

Procedures

General observing procedures that are applicable to most EDM are described in NOAA Technical Memorandum NOS NGS-10, Use of calibration base lines (Fronczek 1977).

APPENDIX A.--SUGGESTED EQUIPMENT FOR ESTABLISHING A CALIBRATION
BASE LINE

The following list contains typical equipment to be used by a calibration base line party:

EDMI equipment:

- 2 short-range EDM [$\sigma^2 < (0.001 \text{ m})^2 + (D \cdot 10^{-6} \text{ m})^2$]
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-m standardized Invar (LO-VAR, MINVAR, etc.) tapes
- 2 30-m standardized steel tapes
- 3 100-ft standardized Invar (LO-VAR, MINVAR, etc.) tapes
- 6 10-cm 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-m tapes)
- 1 tape stretcher kit with circular spring balance (0-5 kg continuous scale) and frictionless pulley apparatus (for use with 50-m 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 adapters
- 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
- 2 umbrellas
- 1 optical plummet leveling adjusting kit

APPENDIX B.--FIELD MEASUREMENT STANDARDS,
SPECIFICATIONS, AND PROCEDURES

General

These instructions outline procedures for measuring a standard calibration base line with monumentation at 0 m, 150 m, 430 m, and 1400 m. Procedures are also specified for establishing a 30.48-m (100-ft) field standard, when requested by the participating organization.

General Distance Observations

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

1. From station name (occupied point)
2. To station name (observed point)
3. Instrument/tape model and serial no.
4. Reflector model and serial no.
5. Date and time of observations
(local time - 24-hour clock)
6. Instrument/reflector constants (if known)¹
7. Height of instrument/reflector/taping benches and/or stakes above marks, recorded to millimeter accuracy¹
8. Station elevation^{1,2}
9. Instrument/reflector eccentricity, recorded to millimeter accuracy¹
10. Atmospheric observations¹
 - a. Temperature
 - b. Pressure
 - c. Psychrometer
11. Weather conditions
12. Any unusual or problematic condition, e.g., dust blowing across line, measuring across a 30.5 m (100 ft) wide by 3 m (10 ft) deep gully, etc.

The elevation differences of all monuments, height of benches, and height of 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 stated in Classification, Standards of Accuracy and General Specifications of Geodetic Control Survey (Federal Geodetic Control Committee 1974), and Specifications to Support Classification, Standards of Accuracy and General Specifications of Geodetic Control Survey (Federal Geodetic Control Committee 1980).

¹ Units of measurement must always be shown.

² Vertical datum must be shown.

Taped Distance Observations

1. 150-m section. The 150-m section will be measured with 50-m standardized Invar(LO-VAR, etc.) tapes using first-order taped base line procedures, as described in Special Publication No. 247 (Coast and Geodetic Survey 1959), except for the following changes: The copper strip and scribe will not be used. Instead, a 10-cm boxwood scale (0.5 mm divisions) will be attached to each taping stake or bench and aligned with the base line. The 5-cm mark on the scale will be plumbed over the 0-m 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 plumbing and taping will be repeated. Two additional boxwood scales will be positioned on line at 50 m and 100 m from the 0-m mark. All boxwood scales are to be attached such that the zero ends of the scales face either the 0-m or 150-m monument. An explanatory statement, with sketch of the boxwood scale orientation, 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 to allow the full tape length to be used. In either case, recordings of both front and rear boxwood scale readings must 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, i.e., once with each of four different tapes. The following scheme will be employed:

- a. Forward measurement with the first tape.
- b. Backward measurement with a second tape.
- c. Forward with a third tape.
- d. 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 measurement. In no case are substitutions to be made at the

"front contact" positions in measurements 1 and 2, 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. 30.48-m (100-ft) field standard. The 30.48-m section will be measured with 100-ft standardized Invar (LO-VAR, MINVAR) tapes to a temporary scribe on the 30.48-m mark. The tension used during the tape 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 a distance of 30.480 m from the "0-m" mark.

The spread of the three observations, after corrections, should seldom exceed 0.00015 m (0.0005 ft) and should not exceed 0.00030 m (0.001 ft). If this tolerance is exceeded, the remeasurement requirements specified for the 0-m to 150-m segment also apply here.

Electronic Distance Observations

The complete base line except for the 30.48 (100-ft) section will be measured with two high accuracy short-range EDM on 2 separate days. (See appendix C for high precision procedures for specific instruments.) Observations will be made such that all segments are measured, forward and backward, on each of the 2 days with both instruments.

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

On the first day, starting at the 0-m monument and progressing to 150-m, 430-m, and 1400-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 1400-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.

The spread between the mean of the observations with each instrument for each line segment, after corrections and on the same reference surface (i.e., mark-to-mark or horizontal), should not exceed:

$$\delta = [0.0017^2 + (D \cdot 10^{-6})^2]^{\frac{1}{2}}$$

where D = segment length, and all units are in meters.

The spread between each day's mean for each line segment, after corrections and on the same reference surface, should not exceed:

$$\delta = [0.0015^2 + (D \cdot 10^{-6})^2]^{\frac{1}{2}}.$$

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 EDM measurements are required either to or from the 30.48-m (100-ft) monument.

Descriptions

Figure 3 shows a typical description of a calibration base line.

US DEPARTMENT OF COMMERCE - NOAA
NOS - NATIONAL GEODETIC SURVEY
ROCKVILLE MD 20852 - MAY 18, 1982

CALIBRATION BASE LINE DATA
BASE LINE DESIGNATION: RALEIGH
PROJECT ACCESSION NUMBER: G15482

QUAD: N350784
NORTH CAROLINA
WAKE COUNTY

DESCRIPTION OF RALEIGH BASE LINE
YEAR MEASURED: 1982
CHIEF OF PARTY: WJR

THE BASE LINE IS LOCATED ABOUT 13.4 KM (8.3 MI) SOUTHWEST OF WAKE FOREST, 11.3 KM (7.0 MI) NORTHEAST OF RALEIGH AND 3.7 KM (2.3 MI) NORTHEAST OF THE JUNCTION OF UNITED STATES HIGHWAYS 1 AND 401 ALONG THE EAST SIDE OF THE FRONTAGE ROAD IN FRONT OF THE PLANTATION INN ON THE WEST SIDE OF ROUTE 1.

TO REACH THE BASE LINE FROM THE JUNCTION OF UNITED STATES HIGHWAY 1 BRIDGE OVER UNITED STATES HIGHWAY 401 ON THE NORTH SIDE OF RALEIGH, GO NORTH ON UNITED STATES HIGHWAY 1 FOR 3.5 KM (2.3 MI) TO THE INTERSECTION OF UNITED STATES HIGHWAY 1 AND OLD WAKE FOREST ROAD. TURN LEFT ON OLD WAKE FOREST ROAD AND THEN RIGHT ON TO THE FRONTAGE ROAD TO THE 0 METER POINT ON THE EAST SIDE OF FRONTAGE ROAD NEAR ANGLE IN THE RIGHT OF WAY FENCE. CONTINUE NORTH ALONG EAST SIDE OF FRONTAGE ROAD FOR 0.16 KM (0.1 MI) TO THE 150 METER POINT ON THE RIGHT, CONTINUE NORTH ALONG FRONTAGE ROAD FOR 0.24 KM (0.15 MI) TO THE 400 METER POINT ON THE RIGHT, CONTINUE NORTH ALONG FRONTAGE ROAD FOR 1.04 KM (0.65 MI) TO THE 1400 METER POINT ON THE RIGHT.

THE BASE LINE IS A NORTHEAST-SOUTHWEST LINE WITH THE 0 METER POINT ON THE SOUTHWEST END. IT IS MADE UP OF THE 0, 150, 400 AND 1400 METER POINTS. ALL OF THE MARKS ARE SET ON A LINE BETWEEN THE EAST EDGE OF THE FRONTAGE ROAD AND THE RIGHT OF WAY FENCE. THE LINE RUNS FROM ABOUT 28 FEET NORTHWEST OF THE ANGLE IN THE RIGHT OF WAY FENCE AT THE JUNCTION OF UNITED STATES HIGHWAY 1 AND OLD WAKE FOREST ROAD TO THE MILL OUTLET VILLAGE ON THE NORTHEAST END OF THE BASE LINE. THE 0, 150, AND 400 METER POINTS ARE ACROSS FROM THE PLANTATION INN ON THE EAST SIDE OF THE FRONTAGE ROAD.

THE 0 METER POINT IS A STANDARD NCGS DISK STAMPED---RALEIGH 000---SET INTO THE TOP OF A ROUND CONCRETE MONUMENT 28 CM (11 IN) IN DIAMETER FLUSH WITH GROUND LOCATED 43.46 M (142.6 FT) SW FROM A POWER POLE WITH AN ALUMINUM TRIANGLE TAG, 35.05 M (115.0 FT) SE FROM THE CENTER OF THE FRONTAGE ROAD, 32.00 M (105.0 FT) NW FROM THE CENTER OF THE SOUTH BOUND LANE OF UNITED STATES HIGHWAY 1, AND 8.41 M (27.6 FT) WNW FROM THE CENTER POST OF BRACED SECTION AT CORNER OF FENCE. THE 150 METER POINT IS A STANDARD NCGS DISK STAMPED---RALEIGH 150---SET INTO THE TOP OF A ROUND CONCRETE MONUMENT 28 CM (11 IN) IN DIAMETER FLUSH WITH GROUND LOCATED 17.28 M (56.7 FT) SE FROM THE CENTER OF FRONTAGE ROAD, 10.06 M (33.0 FT) WSW FROM THE POWER POLE AT THE JUNCTION OF POWER LINES, AND 8.26 M (27.1 FT) NW FROM THE RIGHT OF WAY FENCE. THE 400 METER POINT IS A STANDARD NCGS DISK STAMPED---RALEIGH 400---SET INTO THE TOP OF A ROUND CONCRETE MONUMENT 28 CM (11 IN) IN DIAMETER FLUSH WITH GROUND 9.48 M (31.1 FT) W FROM A POWER POLE WITH AN ALUMINUM TRIANGLE TAG, 7.80 M (25.6 FT) NW FROM THE RIGHT OF WAY FENCE, 6.83 M (22.4 FT) SE FROM THE CENTER OF THE FRONTAGE ROAD, AND 5.76 M (18.9 FT) SW FROM THE POWER POLE ANCHOR CABLE. THE 1400 METER POINT IS A STANDARD NCGS DISK STAMPED---RALEIGH 1400---SET INTO THE TOP OF A ROUND CONCRETE MONUMENT 28 CM (11 IN) IN DIAMETER FLUSH WITH GROUND LOCATED 56.69 M (186.0 FT) SSE FROM THE CENTER OF THE SOUTH DRIVE TO MILL OUTLET VILLAGE, 27.22 M (89.3 FT) SW FROM THE CENTER OF BRACED SECTION OF RIGHT OF WAY FENCE, 9.81 M (32.2 FT) SE FROM THE CENTER OF FRONTAGE ROAD, AND 4.78 M (15.7 FT) NW FROM THE RIGHT OF WAY FENCE.

THIS BASE LINE WAS ESTABLISHED IN CONJUNCTION WITH THE STATE OF NORTH CAROLINA. FOR FURTHER INFORMATION CONTACT MR. LARRY W. AKERS, CHIEF GEODETIC SURVEY SECTION, NORTH CAROLINA DEPARTMENT OF NATURAL RESOURCES AND COMMUNITY DEVELOPMENT, BOX 27687, RALEIGH, NORTH CAROLINA 27611. TELEPHONE (919) 733-3836.

Figure 3.--Sample of a description for a calibration base line.

APPENDIX C. 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 field party which does not possess one.

2. Instruments will be allowed to warm up for a minimum of 30 minutes before measurements are taken. Check the monitor to ensure 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 balance the two light returns. In no case shall the external light return exceed the internal light return.

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 must not exceed 5 mm.

7. Reflectors placed at other stations along the line must be turned 90° off-line while measuring to another reflector in the same direction to avoid multiple reflections.

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