NOAA Technical Memorandum NOS NGS 8

Establishment of Calibration Base Lines

By:

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Revised:

Paul R. Spofford (1982)
Dennis Wegenast (1983)
Kendall L. Fancher (2014)
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National Geodetic Survey

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Silver Spring, MD 20910
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National Ocean Service
National Geodetic Survey

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The National Geodetic Survey (NGS), an office of the National Oceanic and Atmospheric Administration's (NOAA) National Ocean Service (NOS), establishes and maintains the National Spatial Reference System and provides government-wide leadership in the improvement of geodetic surveying instruments and methodologies. The NGS also coordinates operations to ensure the development of an accurate and reliable geodetic network and provides guidelines, specifications and criteria for survey operations by federal, state, and other agencies.

Additionally, the NGS engages in research and development to improve our understanding of Earth's size, shape and gravity field, processes geodetic data and makes these data generally available to users via a central database. NOAA geodetic publications and relevant geodetic publications of the former U.S. Coast and Geodetic Survey are available online at
http://www.ngs.noaa.gov/PUBS_LIB/pub_index.shtml

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Abstract

The calibration of electronic distance measuring instrumentation (EDMI) involves the determination or verification of instrument constant and scale error and the assurance that the measured distances meet accuracy specifications. To assure that the measuring accuracy, as well as the operating precision capabilities of an instrument, has not diminished, 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 in-line monuments spaced at specific intervals will meet the needs of users. Specifications and recommended procedures herein satisfy requirements for establishing calibration base lines (CBLs) that are suitable for sharing at the NGS's CBL website. This revision of procedures enables the user community to establish base lines where they are needed and rectify issues with existent ones.

Introduction

The revision of this publication supports changes discussed in the NGS's 2017 release of EDMI CBL Program Policy and EDMI CBL Program Participation Procedures. It addresses the installation and establishment of new CBLs and the re-measurement of an existent CBL with a reported discrepancy. For guidance on using a CBL to check the performance of an EDMI against the manufacturer's specifications, go to the CBL website for NOAA Technical Memorandum NOS NGS-10: Use of Calibration Base Lines.

This publication supports the NGS's revised policy encouraging the surveying community to maintain existent CBLs, establish new ones for convenience, and then share that information through a NGS-maintained website. Data submitted for sharing must be validated by testing EDMI for performance and accuracy over an appropriate CBL before and after the measurements are made at the subject CBL. The NGS will provide technical support and quality assurance to the extent possible for the benefit of both the submitter and the community before releasing. Guidelines for Federal CBLs (FCBL) and Cooperative CBLs (CCBL) are found herein. FCBL establishment is closely monitored by the NGS, while CCBLs simply must pass NGS review.

History

Standards of length have existed in the United States since before the establishment of the Survey of the Coast in 1807, predecessor to the U.S. Coast and Geodetic Survey (USC&GS) and currently the NGS. In the Mendenhall Order of 1893, the USC&GS officially adopted the meter as the most stable standard of length for use in geodetic surveys in the United States. The same order tied the U.S Customary System *foot*, favored by land surveyors and engineers, to the meter. Whether working in meters or feet, everyone was now using the same length standard, as long as their measuring device was properly calibrated to the standard.

For many years, the standardization or comparison of measuring devices with known values was rudimentary, even after the National Bureau of Standards (now the National Institute of Standards and Technology) developed methods for accurately determining the length of a tape or wire. Eventually, however, most surveyors had access to some means of ascertaining the length of their tapes to an acceptable degree of accuracy. With the introduction of electronic distance measuring instrumentation (EDMI) in the United States in 1952, a new dimension was added to the surveying profession. With these instruments came the capability of performing measurements with speed and a degree of precision not previously possible. However, the standardization problem was compounded because EDMI measurements are affected by meteorological conditions other than temperature and by several instrument uncertainties that require frequent periodic reevaluations. Although the need for calibration base lines was evident, a test range specifically designed for EDMI reevaluations was not available for more than a decade.

In 1963, the USC&GS measured a 1.8-km, multi-mark line in Beltsville, Maryland, using high-precision taping techniques (Poling 1965). Later, a 9.05-km CBL 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 these facilities to calibrate their equipment.

By 1970, a number of EDMI were commercially available. As more surveyors acquired EDMI, the surveying profession became concerned about the accuracy of their measurements. It has been shown that whereas accuracies attributed by the manufacturers to the instruments are reliable, 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 to verify the instrument constant and evaluate the measuring accuracy at more frequent intervals. Since then various manufacturers have produced many more models of which most are short-range instruments. Because the equipment was being used for nearly all conceivable surveying problems, it was critical that observations meet project accuracies.

To resolve the accuracy issue, the NGS held in-house discussions and investigated several methods for establishing a calibration base line. The original concept was to tape the distances between a number of monuments using several Invar-type tapes and high-precision measuring techniques. Four calibration base lines were measured in this manner before discontinuing this time-consuming operation.

In 1977, NGS established a new base line at its Corbin, Virginia facility, now the NGS Testing and Training Center (NTTC), but mostly on property owned by the U.S. Army (Fort A.P. Hill). The base line was measured using high-precision taping methods. This base line replaced the Beltsville base line for calibrating NGS equipment. Realizing the need for all EDMI users to have local access to base lines, the NGS launched a national CBL Program, complete with dedicated field parties. By the early 1990s, the NGS shared over 400 base lines at its public website. The demand for new base lines dwindled. The NGS disbanded base line parties and began responding to requests on a case-by-case basis, often through its State Advisor Program.

After 2001, base line marks on Fort A.P. Hill became less accessible. In 2011, the NGS transferred length standardization from the 1977 base line to a modern base line located entirely on the Testing and Training Center property. The new base line consists of five forced-centering piers measured using a combination of legacy EDMI and modern total station theodolites with integrated, high-precision EDMI.

Changes within the NGS and new technology prompted changes in base line policy and procedures. The NGS began reassessing its CBL Program in 2013, and by 2017 had released new policies and procedures documents. NGS site visits are now limited to maintaining one FCBL per state. However, the revised documents also provide the community with a pipeline to a NGS-managed, publicly shared database for individuals or groups who value the program and choose to help keep it viable.

Responsibility for Base Lines and Costs

Rights and responsibilities of the NGS, contributing partners and users are described in the NGS's online publication Electronic Distance Measuring Instrumentation Calibration Base Line [EDMI CBL] Program Participation Procedures. Refer to sections entitled "Contributing Partner Rights and Responsibilities" (page 4) and "NGS Rights and Responsibilities" (page 5).

Calibration Range

CBL Classification

Every CBL has a set of distances that reflects a best estimate of length between marks. Distance sets are subject to change over time, occasionally due to local disturbances that predicate the measurement of a new, updated distance set. In any case, distances between marks may be superseded with better estimates at any time, i.e. measurements made using EDMI of equal or higher specifications while adhering to recommended procedures. The latest best-estimate distance sets are always posted in a prominent location at the NGS CBL webpage.

The term "mark" refers to a stamped, non-ferrous metal disk or forced-centering adapter embedded into a substantial setting that firmly embeds a disk into the earth's lithosphere. A poured-in-place concrete post, pier or drill hole in rock outcropping can make good CBL marks. See the section on Base Line Marks.

CBL classes are derived primarily on the precision of the EDMI (sometimes called "accuracy" or standard deviation in the manufacturer's specifications) used to determine the best estimate of lengths. This is important because a CBL that is established using a 5-millimeter (mm) + 5-parts-per-million (ppm) EDMI may be fine to test a similar EDMI, but the final distances may be too far from the "truth" to apply to a 2mm+2ppm EDMI. Working the other way, a 1mm+1ppm EDMI can be used to measure distances closer to "truth" and any EDMI of lower precision should have no trouble matching those distances within their looser tolerances. This assumes that recommended procedures are followed and all systematic errors have been addressed.

Based on high-quality instrumentation and stringent practices at the time of establishment, a FCBL's class is always assumed to be 1mm + 1ppm (1+1). If one or more of a FCBL's marks experiences gradual movement over time or a sudden physical disturbance, it may be re-measured as a FCBL and assigned a new, updated distance set. Note that the NGS Primary CBL* is the only CBL that can be used to validate new or updated FCBL measurements.

A contributor may decide to re-measure a problem FCBL as a CCBL. The CBL would then assume a classification based on the contributor's EDMI's specifications. Any FCBL may be use to validate a new or re-measured CCBL, provided its distances are verified during the validation process. Contributors wanting to share a new CBL, or supersede an old one are expected to follow recommended procedures. Table 1 summarizes the subsequent classification of a new or re-measured CBL base on the contributor's EDMI of choice.

Contributor's EDMI spec (mfr)	Validation before and after at:	New measurements classifies CBL as:
1mm+1ppm	the NGS Primary CBL	FCBL
1mm+1ppm	a FCBL	CCBL 1+1
1mm+2ppm	a FCBL	CCBL 1+2
2mm+2ppm	a FCBL	CCBL 2+2
5mm+5ppm	a FCBL	CCBL 5+5

Table 1. Example of how CBLs arrive at their classifications

> ***Note:*** *FCBLs can only be established or updated after EDMI validation at the NGS Primary CBL located at the NTTC near Corbin, VA.*

Design

The typical base line configuration consists of four strategically spaced marks set in a straight line. To be considered a straight line, the center points of the intermediate marks must not be off-line by more than two arc minutes. The range should not be less than 900 meters; a shorter overall length will not adequately determine scale error. When spaced properly, a four-mark design provides six distinct distances and a total of 12 forward and backward distances when a complete calibration is performed.

The mark stamping includes the nominal distance from the 0 mark and the year the mark is set. A mark set at a distance of 120.01 meters from the 0 mark in 2018 includes *120 M* and *2018* in the stamping. Likewise, the mark set at a distance of 389.98 meters from the 0 mark includes *390 M* and *2018* in the stamping. For simplicity's sake, it is highly desirable to set the marks so that the center points are within a few centimeters of the design distances. In all cases, the mark designation and stamping will reflect the nominal distance from the 0 mark. Table 2 is an example of the recommended conventions for a four-mark base line set in 2018.

Staked-out Dist	Stamping	Mark designation	Working ID (for recording or note keeping)
0.00 m	0 M 2018	JUNIPER CBL 0	1 or 0
120.02 m	120 M 2018	JUNIPER CBL 120	2 or 120
390.01 m	390 M 2018	JUNIPER CBL 390	3 or 390
1199.99 m	200 M 2018	JUNIPER CBL 1200	4 or 1200

Table 2. Example of CBL nomenclature

To ensure six distinct distances, spacing of the marks cannot repeat segment lengths. Keeping within the recommended spacing from Figure 1 will avert, for example, a 0 to 150 segment and a 150 to 300 segment. Both of these segments would be essentially the same length and would add very little to the final analysis. Marks placed at 90 meters to 150 meters, 360 meters to 420 meters, and 900 meters to 1,410 meters from the initial or "0" mark (figure 1) would satisfy spacing requirements.

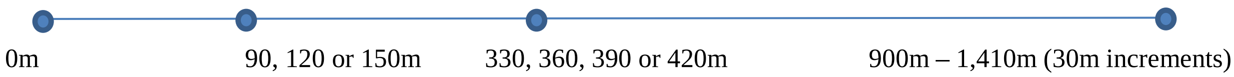


Figure 1. Example of a calibration base line configuration

Additionally, mark spacing should follow the "multiple of 30 meters" rule, where all nominal distances from the 0 mark are a multiple of 30.

Multiple of 30 meters

The NGS requires using the "multiple of 30 meters" rule for new FCBLs and highly recommends it for CCBLs. Most EDMI are designed with the basic instrument "yard stick" (wavelength) of 1, 2, 3, 5, or 10 meters. 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 +/- 30 mm.) To avoid contaminating sub-centimeter 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 the least common factor of wavelengths (30 meters) will enforce this requirement. Any resolver error included in the computation then becomes nearly a constant for all measurements. The error can be disregarded when determining the instrument constant, but it must be compensated for if a sub-centimeter length measurement or calibration is desired. The test for resolver error has been described in professional journals (Couchman 1974, Rueger 1978).

Because the CBL is designed for length calibration only, connecting the marks to the National Spatial Reference System (NSRS) is desirable, but not required. At a minimum, elevations from double-run differential leveling observations between the marks must accompany any new or re-measured CBL data before the NGS can review and share them (see Appendix B for further details).

Site Selection

Numerous considerations enter into the selection of a calibration base line site. These considerations are as follows:

Manufactured and natural obstacles. The location should be in an area removed from potential disturbance (construction, excavation, farm machinery, etc.), easy to reach with minimal restrictions and in a reasonably safe working environment. The adjusted base line distances will be a matter of public record; the site should be reasonably accessible to fellow surveyors.

Terrain. As a first consideration, it is important that the site be geologically stable. Abrupt changes in terrain or other features might indicate undesirable geological breaks. With the reality of crustal motion, marks set in the same geological formation tend to move in unison, making the base line distances more reliable over time.

Avoid areas of fill; the soil may take decades to stabilize. Fill is often found along low-lying stretches of roadway and airport runways in hilly terrain. Fill found along old, abandoned railroads, is generally suitable because almost all settlement has already occurred; these sites offer other rather obvious advantages. Avoid areas where water pools or drains.

Mark layout guidelines:

- Marks at an ideal site allow for EDMI platforms (tripods, concrete piers) to be set at a comfortable observing height while offering unobstructed lines-of-sight between them.
- Lines-of-sight should maintain at least a 1 meter (3 ft.) ground clearance along their entire length.
- Elevation differences from the 0 mark should not exceed one percent.

  Examples: D.E. from 0 to 120, < +/- 1.2 meters.

  D.E. from 0 to 390, < +/- 3.9 meters.

  D.E. from 0 to 1200, < +/- 12 meters.

- No lines-of-sight should slope more than +/- 3 percent (+/- 1° 45' vertical angle).
- Instrument platforms at the intermediate marks *should* fall below the line-of-sight of the platforms at the end marks.

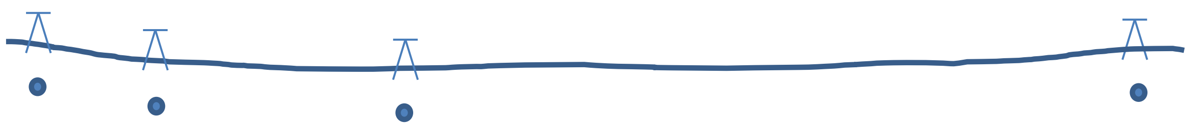


Figure 2. Ideal topography for intervisibility and ground clearance

Old abandoned railroad beds, often repurposed for recreational use, are generally suitable for CBLs. They feature long, straight, gradual grades and a safe working environment. Instrument platforms for intermediate marks along a flat grade, though, would need to be set relatively low to facilitate intervisibility. Airports across the country have been utilized for CBLs with mixed results. Aside from uncertainties such as future accessibility and renovations that would endanger a CBL, field reconnaissance may reveal that terrain severely limits longer sight distances.

In many cases, the ideal sites cannot be found, and compromises may be necessary. The essential considerations are that all instrument platforms should be intervisible and that grade tolerances are followed as closely as possible.

Expansive soil and frost heave. To mitigate upheaval, marks at sites affected by these conditions should be set deeper than the standard 1.2-meter (4 ft.) depth. Soils, most notably clay, expand considerably when wetted and contract as much when dried. In many areas of the country, freezing and thawing of the soil have a similar impact. Marks set under these conditions should be set to a depth that passes ***through*** the affected soil. This could be 3 meters (10 ft.) or more. The bulk of the mark should maintain a diameter-to-depth ratio of about 1:4. The diameter of the top 15 cm (6 in) of the post may be reduced to 30 cm (12 in) for ease of troweling to attain a more aesthetically pleasing finish. To further counter these less stable soil conditions, dig the mark hole at least 15 cm (6 in) larger than the engineered diameter of the mark.

When ready, fill the hole with concrete ***below*** the frost line or the expansive soil (whichever runs deeper). Measure down and then cut a circular cardboard form (tube) to length. Carefully insert the tube, resting it on the concrete. ***Clean out any soil that may have collected on the concrete inside the tube!*** Fill the tube with concrete and then backfill with sand. The bottom of the mark will cleave to the sides of the hole. The smooth formed sides will prevent upheaval as soil expands and contracts.

Manufactured and natural obstacles. For best results, the air density along an EDMI's entire light wave path should be stable and consistent. Because air density is primarily affected by air temperature, the ground surface that warms the air should be consistent along the entire length. The path should not cross (but can run parallel to) pavement or waterways, nor should it pass closer than 6 meters (20 feet) from trees, telephone poles, or other structures that could refract or bend the signal. The path should not pass through fences, particularly metal mesh fences. As an added precaution, no part of the CBL should be within 0.4 km (0.25 mi) of high-voltage (greater than 4,000 volts) transmission lines, microwave towers, radio masts, or radar facilities.

> ***Tip:*** *Planning to share your data at the NGS CBL website? When establishing a new base line or verifying an existent one, start by submitting a* Project Proposal Form*. For a new base line, submit it after initial field reconnaissance, but before setting marks.*

Base Line Marks

Typical CBL

The key to the usefulness of a CBL lies with long-term mark stability. Installation of FCBL marks must comply with these guidelines; any deviations must be approved by the NGS. For best results, CCBL installations should also comply with the guidelines. Generally, marks with significant mass placed in relatively undisturbed soil have the best chance for long-term stability. Refer to the previous section on Site Selection for more information. Table 2 provides an example of the minimum stamping of a disk or forced-centering adapter.

A poured-in-place concrete post topped with a survey disk is sturdy and economical. To aid in preservation, the post should be recessed below grade to a reasonable depth, perhaps about 5 cm (2"). For ease of recovery, a substantial magnet should be buried with the recessed mark or an iron rod driven beside it. In well-protected areas, the post may be set flush with the ground. The disks must have a small, well-defined center point, preferably a drilled hole with a diameter of 1 mm (1/32"). A center punch should not be used because it can result in irregular shapes of varying sizes. For concrete post setting instructions refer to Appendix C.

A poured-in-place concrete pier topped with a forced-centering adapter is a sturdy, convenient, permanent instrument platform and is recommended for sites where high use is anticipated. See Appendix D for additional guidance.

Before including either type of concrete monument in base line measurements, it should undergo a complete seasonal freeze/thaw cycle or have been in the ground for at least six months. This allows time for any settlement to occur, as well as ensuring the concrete has cured sufficiently.

Rock outcropping and bedrock in shallow soil are ideal settings as long as the location of the rock features meet guidelines for spacing and alignment. Cement a disk into a drill hole, making sure to countersink it into the rock for protection. Disks must have a well-defined center point, preferably a 1 mm (1/32”) in diameter drill hole. A center punch should not be used.

Base Line Layout and Installation

Once site selection considerations have been met, the following procedures are recommended for mark or pier installation:

Staking-out Marks

1. Drive a temporary hub for the 0 mark and plumb a total station theodolite over it.
2. Stake out the end mark between 900 meters and 1410 meters. End mark hub should be within a couple of centimeters of an even 30-meter interval and not exceed a slope of one percent.
3. Stake out intermediate hubs at appropriate “multiple of 30” intervals. To help ensure the alignment of the final marks falls inside 2 arc minutes, the hubs should be staked out at 20 arc-seconds of the terminal mark (observed from the 0 mark).
4. The interval distances and alignment for all hubs should then be verified with the instrument centered over the 0 hub. Any adjustments to the stakes should now be made.
5. Set out two reference stakes (RS) at each mark site hub (MSH). Each pair of reference stakes are set out at right angles to one another in an area where they will not be disturbed during mark setting. Distances between the stakes should be carefully measured and recorded.

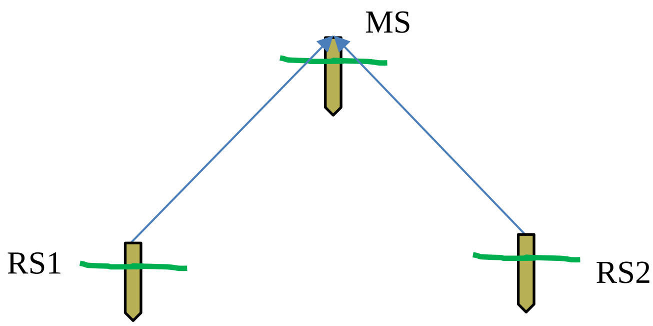


Figure 3. Typical layout of two reference stakes (RS) locating a mark site hub (MSH)

6. Remove the hub and dig the hole. Before filling with cement, check that the hole is still centered around the point-of-intersection (POI) measured from the reference stakes.
7. After troweling the top of the post, pull the distances once again and lightly mark the POI. Push the disk into the cement, starting with the shank positioned at the POI, and then tap the disk with the trowel handle until it is countersunk into the cement and the disk is level. Tapping helps to remove air trapped under the disk.

Staking out and Aligning Forced Centering Piers

Figure 5: Using a plumb bob to position bench (10 ft. 2x4). Alignment tripod (center) with reflector removed. Bench supports (tall tripods) on both sides. Tops of support tripods and ends of 2x4 bench are well-marked so it can be removed and repositioned precisely.

Lay out and dig the holes following steps for Staking-out Concrete Posts and referring to Attachment D, Guidelines for Setting a Type II CBL Monument for dimensions and other details. Set the zero pier first, the end mark pier next and intermediate piers last.

Figure 4: Yellow tribrach with black tribrach adapter inserted. Reflector and target pole attached.

1. Set up a plumb bench at the 0 pier site:

   a. Place a board with a tack across the open hole. Pull measurements from the reference stakes and adjust the board so the tack is at the original location of the staked-out hub.

   b. Set up a tripod and plumb a tribrach and target over the tack. Once properly placed, the top center of the tribrach adapter represents the top of the finished pier's forced-centering adapter. Adjust tripod height as necessary to ensure a reflector set on any pier can be seen from any other pier. It is critical that intermediate reflectors fall below the line-of-sight between the 0 and the end mark pier.

   c. Set up a bench support (tall tripods work well) on both sides of the alignment tripod, raised a few decimeters (about a foot) higher. The edge of a bench (2x4 board or similar) placed across the supports should align directly over the center of the tribrach adapter. The tops of the bench supports should be fairly level and set far enough apart to allow ample working room between them. Expect to use a bench with a length of 3 to 4 m (10 to 12 ft.). The bench supports must not be disturbed during pier installation.

   d. Place the bench on the supports and hang a plumb bob directly over the center of the tribrach adapter. Clearly mark the position of the bench on the supports. The bench and center tripod will be removed during pier installation, but the bench must be replaced in this exact position later.

Figure 6: Determining the bench's height from the top of tribrach adapter.

e. Measure and record the height of the bench above the top of the tribrach adapter.

2. Set the bench aside, remove the center tripod and refer to Appendix C for pouring cement.

    a. When ready to position the PVC pipe, stand it up in the hole and then align the plumb bench in its original position using the markings on the supports.

    b. Alternating between a carpenter's level, a plumb bob and a measuring tape, rough-in the PVC close to its final position.

    c. Attach the braces to the PVC as described in Appendix C and begin filling with cement.

    d. As it is being filled, use the carpenter's level to maintain the verticalness of the PVC, the plumb bob to maintain the alignment of the top, and the tape measure to maintain the pier height (measured down from the bench).

3. While filling, continue making slight adjustments as necessary to the PVC to simplify the final step of precisely aligning the forced-centering adapter. Tip: Use a concrete vibrator or similar device to remove voids that would compromise the integrity of the pier.

4. Set the forced-centering adapter into the top of the PVC, use the bench and plumb bob to position it. Fine-center the adapter by tweaking the PVC's braces (not shown).

Figure 7: Plumbing the forced-centering adapter. Brace boards not shown.

Figure 8: Assuring the adapter is neither too high nor too low (before the concrete sets).

5. Measuring down from the bench, ensure the top of the adapter is no higher than the tribrach adapter was in Step 1e and no lower than 3 cm (0.1 ft.). This assures the original intervisibility between marks is maintained and the slope between marks stays within limits.

Procedures

Electronic Distance Observations

When a CBL is established (or re-measured), the EDMI's compliance to the manufacturer's specifications must be demonstrated over an appropriate existent CBL twice; once before once after. When establishing a FCBL, the NGS Primary CBL in Virginia must be used. When establishing or re-measuring a CCBL, any existent FCBL may be used. In either case, two occasions will be observed and must compare favorably. Each occasion consists of measuring all possible segments, both forward and backward. This is explained late in this section.

To help determine if atmospheric corrections are being read and applied correctly, observe the two occasions under differing conditions. If measured on the same day, follow instructions for Day One in the morning and then Day Two in the afternoon. Ideally, a single occasion should be completed all in one day. Occasions do not have to fall on consecutive days.

Occasion Measurements

Day One: Beginning on the 0 mark, measure to all other marks. Move to the next mark and measure between all marks, including back to the 0 mark. Continue to the next mark and repeat until all marks have been occupied and each mark has a set of measurements to every other mark. The number of sets depends on the number of marks, *n*, using the formula:

$$\text{Measurement sets} = n(n\text{-}1)$$

Where n = number of marks

Formula 1

For example, a typical four-mark base line will generate 4*(4 - 1) sets or 12 measurement sets. Six sets are in a forward direction and six are backward.

Use the program CALIBRATE to compare forward and backward measurements for any discrepancy. Any segment can be re-measured and saved to the data file at any time. Adding a note to a measurement set is good practice when re-observing a segment.

If multiple EDMI are used, use CALIBRATE to compare all measurement sets for each base line segment according to the formula. CALIBRATE will warn if the spread between the mean of the observations of the two instruments for each line segment, after corrections, exceeds:

$$\delta = [0.0017^2 + (D * 10^{-6})^2]^{½}$$

Where D = segment length in meters.

Formula 2

Day Two: Start at the opposite end of the base line. Beginning on the end mark, measure to all other marks. Move to the next mark and measure between all marks, including back to the last mark. Continue to the next mark and repeat until all marks have been occupied and each mark has a set of measurements to every other mark for a total of $n(n\text{-}1)$ measurement sets.

CALIBRATE allows the user to compare the results of all measurement sets (Day One plus forward and backward measurements completed on Day Two) over a given segment. Any suspect measurement set can be re-measured in either direction.

The spread between each occasion's mean for each line segment, after corrections, should not exceed:

$$\delta = [0.0015^2 + (D * 10^{-6})^2]^{½}$$

Where D = segment length in meters.

Formula 3

CALIBRATE generates both horizontal and mark-to-mark adjusted distances. When making comparisons, use either type of distance, do not to mix the two.

> ***Tip:*** *For any given segment, the horizontal distance ≤ the mark-to-mark distance.*

When verifying an existent base line, you must use an instrument of equal or greater precision to the base line's classification (see Table 1). Use Formula 3 to compute the allowable error for each measured segment against the current distances recognized by the NGS.

Useful information regarding general observing procedures applicable to most EDMI can be found in NOAA Technical Memorandum NOS NGS-10: Use of Calibration Base Lines (Geoghegan 2018).

Appendix A - Equipment for Establishing a Calibration Base Line

List of instrumentation:

	FCBL, required	CCBL, recommended
Total station theodolite, mfr. spec.	≤ +/-(1mm + 1ppm)	≤ +/-(2mm + 2ppm)
Tripods, one per mark (typically four)*	Leica Professional 5000 series, equivalent or better	Leica GST05, equivalent or better
Retro-reflector (corner cube), one (1)**	Centering accuracy: ≤ +/-0.03mm	Centering accuracy: ≤ +/-1.0mm
Reversible optical plummet w/spirit bubble, one (1)	Centering accuracy: ≤ +/-0.3mm Plummet accuracy: ≤ +/-1.5mm	Centering accuracy: ≤ +/-1.0mm Plummet accuracy: ≤ +/-1.5mm
Aspirated thermometer, two (2)	Accuracy: ≤ +/-0.5^{o} C	Accuracy: ≤ +/-1.0^{o} C
Barometer, two (2)	Accuracy: ≤ +/-2.0 millibars	Accuracy: ≤ +/-5.0 millibars
Hygrometer, two (2) (or psychrometer kit with means to compute relative humidity)	Accuracy: ≤ +/-2.0%	Accuracy: ≤ +/-5.0%

Table A1.

*Not required for forced-centering piers

If one reflector does not return enough light, the glass probably needs cleaning. Follow manufacturer's instructions. Two or three reflectors can be used for the longest segment **if absolutely necessary. Extra care must be taken with multiple reflector heights and offset constants.

> ***Tip:*** *Dirty reflector glass will reduce measuring distance. Closely follow manufacturer's recommendations for cleaning.*

Total station theodolite usage notes:

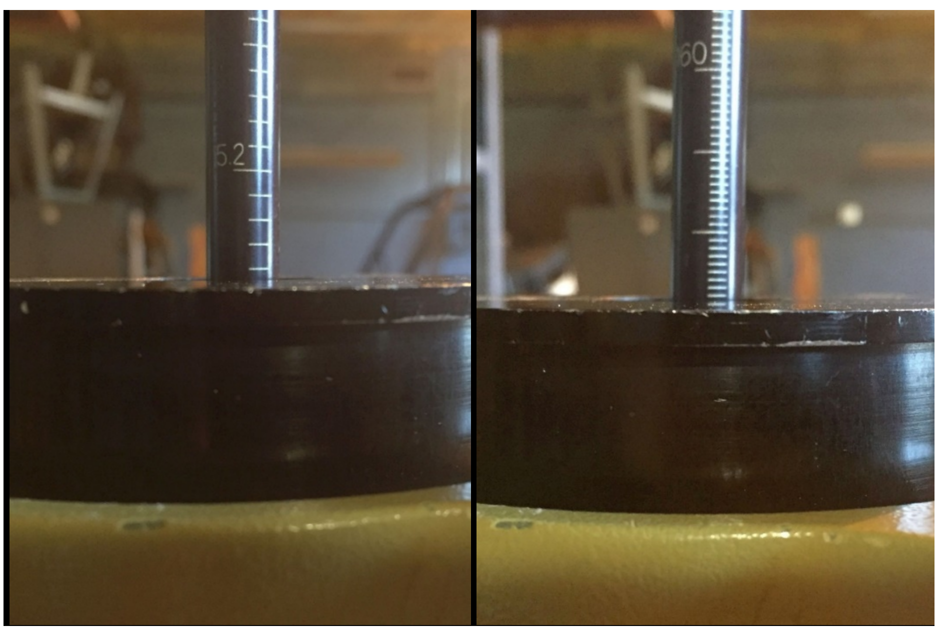
- For CCBLs, use the highest precision EDMI available. Instrument precision will define a CCBL's class. A base line established or re-measured with a lower precision instrument would not be suitable for later checking an instrument of higher precision. When re-measuring a CBL, an instrument of higher precision may be used to override any previously shared distances (following the same guidelines for establishing or re-measuring).
- Instrument must have an integrated optical plummet. Re-center the tribrach at each setup to ensure any centering error will not be carried forward.
- Edit CALIBRATE's inst.par file with the EDMI light wave parameters used by the manufacturer. See section on Editing the INST.PAR File.
- CALIBRATE computes atmospheric corrections. Set parameters in EDMI so that it computes

0ppm. Enter temperature, barometric pressure and relative humidity into CALIBRATE.

List of Equipment

- Tribrachs, four (4), one for each mark
- 1 tribrach adapter with removable gitney (Figure A1)

Figure A1. Tribrach and adapter with gitney (not shown) removed.



Figures A2 & A3. A measuring stick graduated in meters and feet provides a quick blunder check. Read 1.571 m. Read 5.155 ft. Convert feet to meters (x 0.3048): 1.5712 m. Check!

  - Use adapter to determine tripod height. After leveling the tribrach, attach adapter, use a measuring rod down through the center hole.
  - At the office, determine the vertical offset constant between the top of the adapter and the

electronic phase center of the EDMI; on a total station theodolite, usually the telescope's horizontal axis of rotation.

  - This value will be entered in CALIBRATE as INS HT under INSTRUMENT.
  - Similarly, determine the vertical offset constant of the reflector and enter as INS HT under the REFLECTOR side.

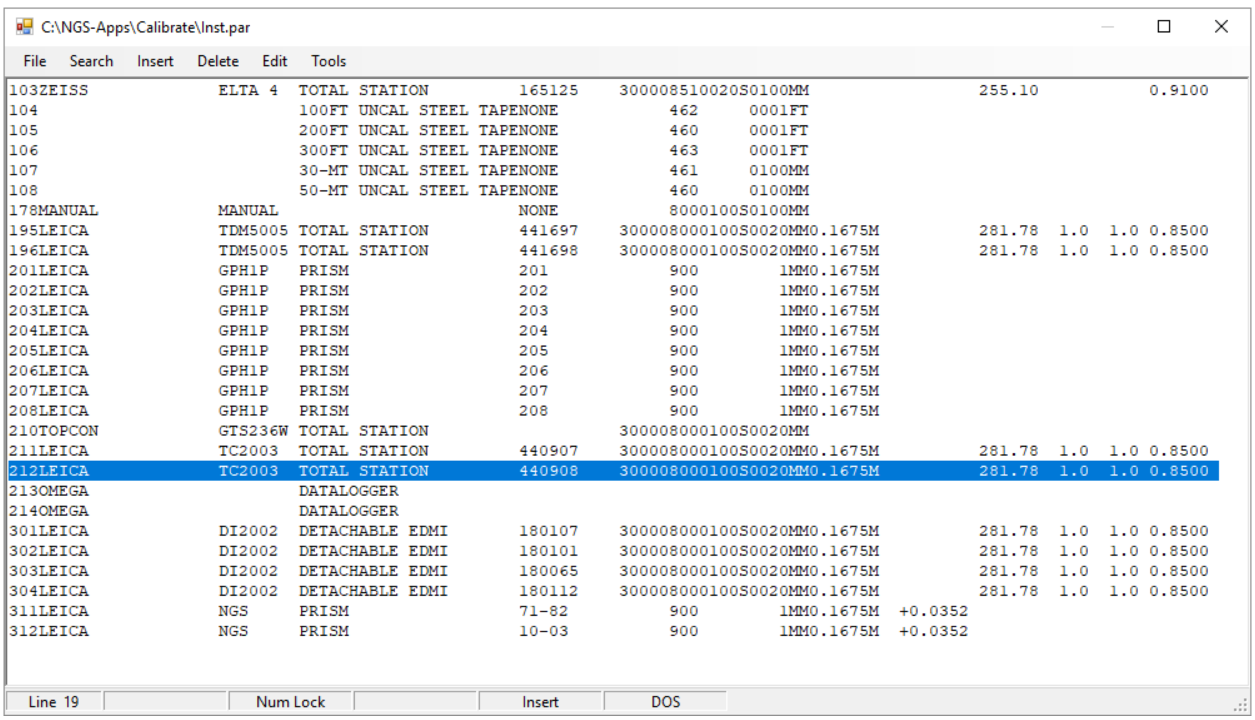
- Windows 7 or 10 device with CALIBRATE installed (NGS home page > Tools>Download PC Software).
- Two-way radios (or cell phones, but be sure CBL has cell coverage)
- Umbrella to shade the EDMI
- Slender measuring stick. For best results use a stick graduated in both feet and meters (Figures A2 and A3) and slender enough to fit through the tripod's 5/8-11 bell for a true vertical measurement.

Editing the INST.PAR File

Before measuring, the INST.PAR file must be updated to include specific instrumentation to be used on the base line. Calibrate has a helpful built-in text editor. The INST.PAR file typically may be found at C:\NGS-Apps\Calibrate.

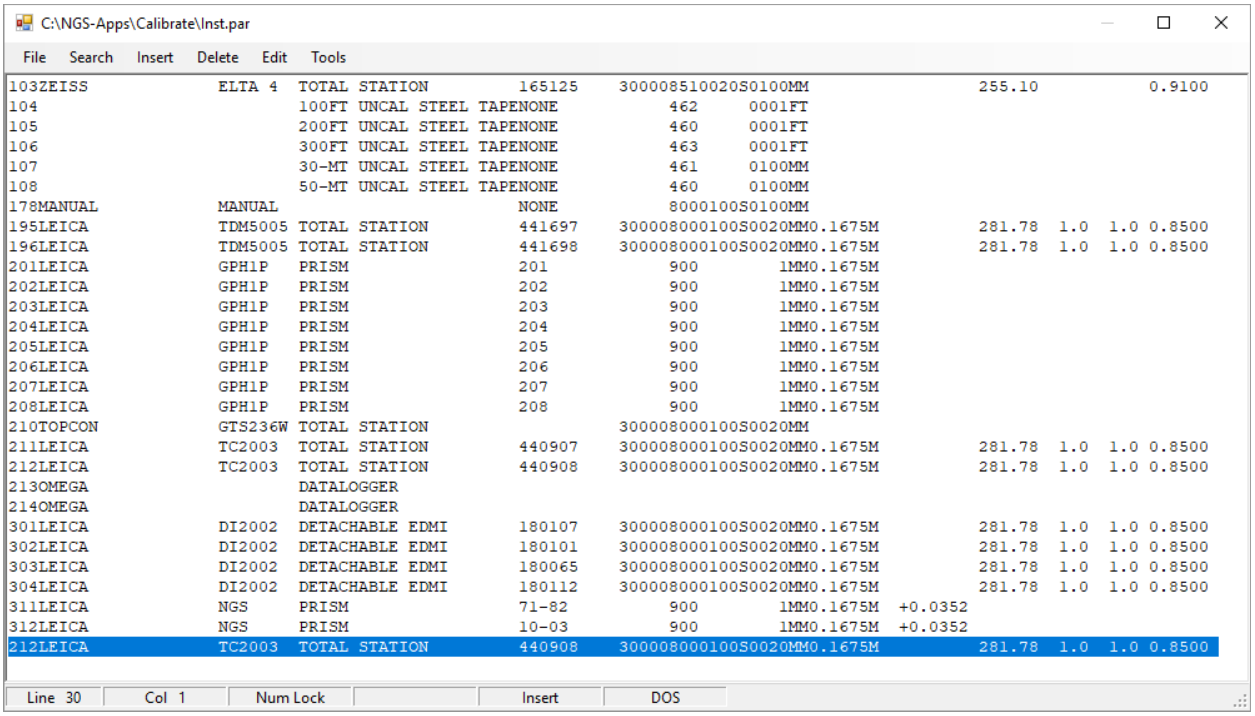
1. Open with the text editor

Selecting Edit > Inst.par File opens the built-in editor.



```
C:\NGS-Apps\Calibrate\Inst.par
File  Search  Insert  Delete  Edit  Tools
103ZEISS            ELTA 4  TOTAL STATION       165125    300008510020S0100MM              255.10          0.9100
104                         100FT UNCAL STEEL TAPENONE       462      0001FT
105                         200FT UNCAL STEEL TAPENONE       460      0001FT
106                         300FT UNCAL STEEL TAPENONE       463      0001FT
107                         30-MT UNCAL STEEL TAPENONE       461      0100MM
108                         50-MT UNCAL STEEL TAPENONE       460      0100MM
178MANUAL           MANUAL                      NONE          8000100S0100MM
195LEICA            TDM5005 TOTAL STATION       441697    300008000100S0020MM0.1675M       281.78  1.0  1.0 0.8500
196LEICA            TDM5005 TOTAL STATION       441698    300008000100S0020MM0.1675M       281.78  1.0  1.0 0.8500
201LEICA            GPH1P   PRISM               201            900         1MM0.1675M
202LEICA            GPH1P   PRISM               202            900         1MM0.1675M
203LEICA            GPH1P   PRISM               203            900         1MM0.1675M
204LEICA            GPH1P   PRISM               204            900         1MM0.1675M
205LEICA            GPH1P   PRISM               205            900         1MM0.1675M
206LEICA            GPH1P   PRISM               206            900         1MM0.1675M
207LEICA            GPH1P   PRISM               207            900         1MM0.1675M
208LEICA            GPH1P   PRISM               208            900         1MM0.1675M
210TOPCON           GTS236W TOTAL STATION                 300008000100S0020MM
211LEICA            TC2003  TOTAL STATION       440907    300008000100S0020MM0.1675M       281.78  1.0  1.0 0.8500
212LEICA            TC2003  TOTAL STATION       440908    300008000100S0020MM0.1675M       281.78  1.0  1.0 0.8500
213OMEGA                    DATALOGGER
214OMEGA                    DATALOGGER
301LEICA            DI2002  DETACHABLE EDMI     180107    300008000100S0020MM0.1675M       281.78  1.0  1.0 0.8500
302LEICA            DI2002  DETACHABLE EDMI     180101    300008000100S0020MM0.1675M       281.78  1.0  1.0 0.8500
303LEICA            DI2002  DETACHABLE EDMI     180065    300008000100S0020MM0.1675M       281.78  1.0  1.0 0.8500
304LEICA            DI2002  DETACHABLE EDMI     180112    300008000100S0020MM0.1675M       281.78  1.0  1.0 0.8500
311LEICA            NGS     PRISM               71-82          900         1MM0.1675M +0.0352
312LEICA            NGS     PRISM               10-03          900         1MM0.1675M +0.0352
Line 19    Num Lock    Insert    DOS
```

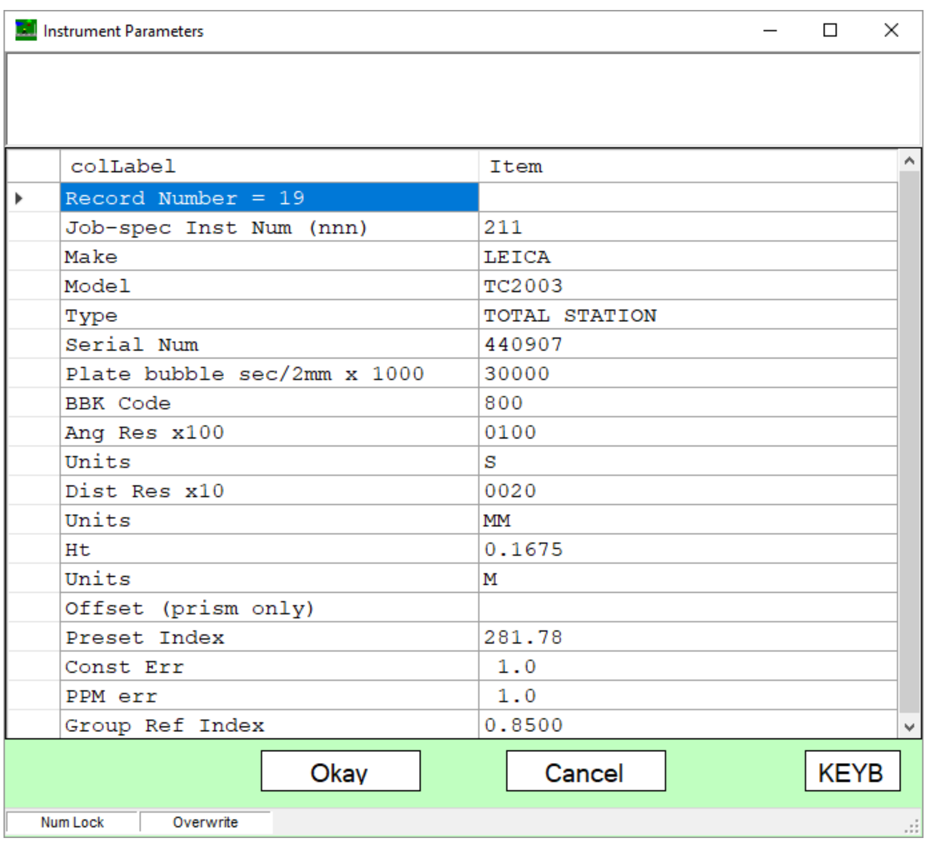
Find the line most similar to the EDMI being used and highlight it.



Copy and paste it to the end of the file.

Repeat this step for the reflector (prism) being used.

Click on the new instrument line to select it. Right-click on it and select Edit Line.



Edit each line to match the EDMI to be tested.

This information does not impact the mathematical reduction of distances. It is primarily for record keeping purposes.

Job-spec Inst Num:	Assign a unique 3-digit number
Make:	Instrument manufacturer
Model:	Name and/or number
Type:	TOTAL STATION (EDMI is integrated)
	MODULAR EDMI (EDMI is removable)
	EDMI (stand-alone unit)
Serial Num:	Instrument serial number
Plate bubble sec/2mm x 1000:	Consult spec sheet or tech support
BBK Code:	See FGCS Blue Book, Annex F; default: 800
Ang Res x100:	Consult spec sheet or tech support
Units:	S, seconds
Dist Res x100:	Consult spec sheet or tech support
Units:	Millimeter (MM), feet (FT) or inches (IN)

This information DOES impact the reduction of distances and must be accurate.

Ht:	Constant height above some point on tribrach*
Units:	M, meters, F, feet
Offset (prism only):	<leave blank>
Preset Index:	Mfr.'s reference refractive index (aka VC1)
Const Err:	Mfr.'s mm component of stated accuracy**
PPM err:	Mfr.'s ppm component of stated accuracy**
Group Ref Index:	Mfr.'s wavelength in micrometers (µm)

***** *the NGS measures the height difference between the top of a tribrach adapter and electronic phase center of the EDMI (usually the telescope axis). Subsequent tripod height is measured from the mark to the top of the tribrach adapter.*

****** *example: If manufacturer's stated accuracy is 1mm+2ppm, Const Err is 1 and PPM err is 2.*

Click on the new prism/reflector line to select it. Right-click on it and select Edit Line, substituting values for the reflector being used.

Appendix B - Measurement Standards, Specifications and Procedures

Elevation Differences

Leveling should be completed in advance and "field" elevations entered into the NGS mark description app, WinDesc (see Descriptions). The height differences between all marks are determined and recorded using double-run, third-order (or better) procedures. Maximum allowable closures at any of the individual marks will conform to third order standards and specifications, as stated in *Standards and Specifications for Geodetic Control Networks* (Federal Geodetic Control Committee 1984), available at: http://www.ngs.noaa.gov/FGCS/tech_pub/1984-stds-specs-geodetic-control-networks.htm.

For digital barcode leveling, see *FGCS Specifications and Procedures to Incorporate Electronic Digital/Bar-Code Leveling Systems*, available at: http://www.ngs.noaa.gov/FGCS/tech_pub/Fgcsvert.v41.specs.pdf

Descriptions

Use WinDesc to compile a description file (required when submitting CBL data to the NGS). The WinDesc file provides convenient information to the CALIBRATE software allowing auto-fill of mark designations, but also elevations that are necessary to reduce EDMI measurements. CALIBRATE also uses positions from the description to error-trap a misidentified mark during the measuring process. WinDesc software is available for download from https://www.ngs.noaa.gov/PC_PROD/pc_prod.shtml#WinDesc and has an excellent "Help" guide.

General Distance Observations

To meet the desired calibration base line accuracy, great care must be taken during all phases of the operation. It is critical the following metadata entries (as prompted by the software) are complete and accurate (always include units of measure where applicable):

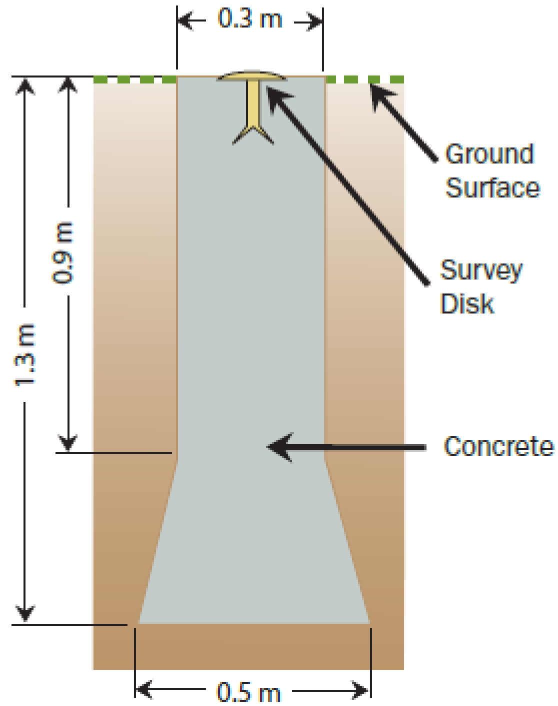
1. Occasion: usually 1 or 2, but could be up to 4 if problems are encountered.
2. Instrument station serial number (SSN from description file)
3. Instrument job specific instrument number (JSI – user controlled in inst.par file)
4. Reflector station serial number (SSN from description file)
5. Reflector job specific instrument number (JSI – user controlled in inst.par file)
6. Instrument mark designation (auto-fill from description file)
7. Reflector mark designation (auto-fill from description file)
8. Instrument mark elevation (auto-fill from description file)
9. Reflector mark elevation (auto-fill from description file)
10. Instrument tripod height (from mark up to top of tribrach adapter)

11. Reflector tripod height (from mark up to top of tribrach adapter)
12. Instrument INS HT (top of adapter up to EDMI electronic phase center)
13. Reflector INS HT (top of adapter up to center of reflector(s))
14. Meteorological observations (temperature/barometric pressure/relative humidity)

Appendix C - Standard Concrete Mark Setting Guide

Survey Disk Set in the Top of a Concrete Post

1. **Monument Design.** A concrete monument should be poured-in-place in a hole, dug in the ground; cylindrical or squared in appearance; and slightly "bell-shaped," or wider at the bottom. The monument must extend well below the frost line; typically 1.2 meters (4 feet) deep and 30 cm (12 in) in diameter. Local ground conditions, such as hard soil types with subsurface rock, may prohibit desired monument depth; whereas, softer, sandy soil types may require slightly deeper monuments to assure stability. Avoid setting concrete monuments in areas affected by sliding or other potential movement, such as in slopes and all earth-fill situations.



2. **Stamping.** Stamp the station designation and setting year on the top surface of the disk prior to setting (see example of stamping convention in Table 2).

3. **Digging the Hole.** The hole is generally dug with an auger or post-hole digger, then backfilled with concrete mix. The bottom of the hole is enlarged about 10 cm (4 in) in radius, tapering upward for 0.4 meters (1.4 feet), in order to make the bottom of the monument bell-shaped (to help keep the monument stable). Care should be taken to avoid widening or "mushrooming" near the top of the monument, which might afford opportunity for frost heave or surface soil action to move the monument. Place a cylinder such as a 30 cm (12 in) cardboard form, at the top of the hole and extend just below the frost line. This makes for a round mark with smooth sides, which further reduces the likelihood of frost heave.

4. **Concrete Ingredients.** The quality of the ingredients and their proportions help determine how dense and impervious the cured concrete will be. The ingredients include aggregate, cement, and water. Aggregate should be clean (free from silt and clay, harmful chemicals, and organic

matter) and well graded, i.e., contain proportionate amounts of many particle sizes. In specifying mix proportions, the aggregate is usually divided into two parts: sand (particle size less than 4 mm (5/32 in) and gravel (particle size greater than 4 mm (5/32 in). Both parts should be well graded.

Aggregates that are porous, split easily, or are otherwise weak or permeable, result in poor concrete. Examples of poor aggregate include shale, claystone, sandstone, and micaceous rocks.

Varying sized bags of pre-mix concrete are readily available, and work well for setting concrete monuments. When using pre-mix concrete, ensure that the aggregate is well graded. Additional Portland cement or Portland cement and sand mix can be added to improve consistency and quality of the finished monument (typically a half shovelful per each 60-pound bag of concrete mix). A typical concrete monument setting requires 480 lbs. to 600 lbs. of bagged concrete mix, depending on the size of the hole. The water used in concrete mix should be relatively free of impurities such as acids, alkalis, salts, oil, organic matter, and silt. Impurities can decrease the strength and durability of cured concrete. As a rule, do not use water that you would not drink.

5. **Mixing and Placing.** Suitable proportions (by bulk volume) of cement, to sand, to gravel are 1:2:3. If the gravel is made up of fragmented or angular particles, use a little less gravel and, proportionately, more sand. Add only enough water to make the mix workable. About half the water added to the mix is used in the chemical reaction (hydration) that causes the paste to harden into binder. If too little water is used, however, the mix will not compact properly and spaces will be left in the mass. A good indication of the right amount of water is that the mix neither runs nor falls off the shovel, but sluggishly slides off and flattens upon hitting the ground.

   Fresh concrete must be well mixed before placed, otherwise the minute particles of cement will not be sufficiently wet, and the aggregate will not be completely coated with paste. Before placement, the hole should be damp, so the moisture will not be drawn from the fresh concrete into the surrounding soil. In no case should it be so wet as to be muddy. Segregation of the various sizes of aggregate should not be much of a problem when pouring concrete survey monuments. However, be aware that segregation can occur, and is undesirable when it does. Continuously tamp the mix into a compact mass, while filling the hole, so it becomes less pervious and, consequently, more durable. Some bleeding (water gain at the surface) is to be expected when finishing the mark. Excessive bleeding indicates too much water in the mix or poor gradation of aggregate.

Note: *Pour the entire concrete monument in a single setting to ensure a solid stable monument. Allowing a pour surface to partially dry, or cure, between consecutive pours creates a weakness in the concrete.*

6. **Finishing Monument and Setting the Disk.** After pouring concrete and tamping to settle and remove voids, the top of the monument is smoothed off and slightly beveled with a trowel. The top of the finished monument should be flush with the ground, or slightly recessed for protection from mowers, etc. Wet and clean the disk by rubbing all surfaces with cement, to remove unwanted dirt and oils; rinse well. Fill underside of disk with cement, using a trowel. Hold disk loosely upside-down by end of the shank then gently tap domed surface of disk from below, with

the handle of the trowel, several times, to allow cement to settle and trapped air to escape. This process is very important, because it will minimize the existence of highly undesirable voids under the disk once in place. Carefully turn the disk over so as not to dislodge the under-disk cement and press the disk stem into the top center of the monument until the rim of the disk touches the concrete. The disk is typically oriented to read with the observer facing north. This is useful for GNSS and gravity observations, which orient to north. Lightly press and tap the disk into the top of the concrete monument until the concrete slightly overlaps the edges of the disk which helps protect the disk. Once the disk is in place, finish the top of the monument by smoothing with the trowel.

7. **Clean Up.** Excess concrete is cleaned from the surface of the disk after installing. Excess dirt and trash are removed, and the site is returned to its "as-found" condition. The mark is the only evidence left to represent the quality of work performed, and therefore the cleanliness of the site should reflect similar quality.

Caution: *Lime and/or cement in concrete can cause burns on skin and destroy clothing. Water used to rinse tools, concrete/cement mixing containers, etc., can kill vegetation if dumped on the ground.*

8. **Curing Concrete**. Concrete should be covered for several days after it is placed. This prevents rain from making the mix too wet, and ruining the finished surface. It also prevents the surface from drying too rapidly, leaving too little water for complete hydration, as well as concealing the disk from people who might tamper with it at this vulnerable stage. A piece of wood, cardboard, heavy paper, or similar item should suffice for covering the mark, and should be removed after cement has cured.

9. **Cold Weather Precautions.** Freezing of uncured concrete has a damaging effect, because the expansion of water as it freezes separates solid particles in the mix. This reduces the strength of the bond and makes the concrete more porous and less durable. Three protective measures should be taken in cold weather; either singly or in combination.

    a. Use warm ingredients; the first 24 hours after a mix has been placed, it develops little heat of its own to prevent freezing. After 24 hours some heat is developed, as a product of the chemical reactions occurring in the mix. The use of warm ingredients is especially beneficial during the first 24 hours. To keep the aggregate and cement warm, store them indoors and keep them in a heated vehicle until they are mixed.

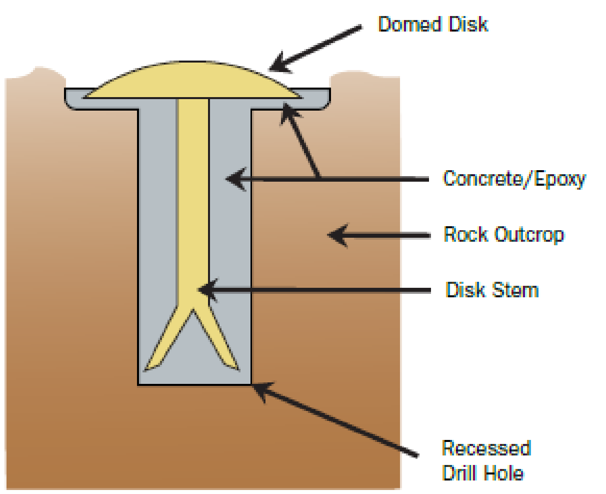
    b. Use Type III (high-early-strength) cement or special additives, such as calcium chloride, which speeds curing. The calcium chloride should be dissolved in the mixing water, instead of mixing it with other ingredients. If a large number of concrete marks are being installed, by mass production, using a "ready-mix" contractor, fast-curing additives should not be added until the concrete is delivered on site.

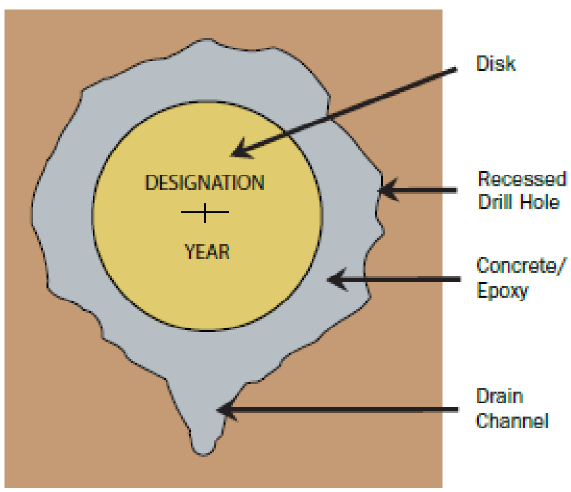
    c. Insulate the finished mark for a week after the concrete is poured. One method is to cover the mark with boards, resting on supports. Cover with paper or plastic, then add a layer of straw, Styrofoam, or similar insulating material, about 15 cm (6 in) thick, and finally a 20 cm (8 in) layer of soil. Pile snow loosely on top, if available.

Survey Disk Set in Bedrock

Sound bedrock is the most desirable setting for marks. Besides the ease and cost effectiveness with which a disk can be installed, bedrock provides the most stable setting in terms of both crustal motion and disturbances inflicted by people. Always use bedrock when a suitable outcrop exists. As a rule of thumb, bedrock is considered potentially good, if the distance between natural joints and fissures is greater than 1 meter (3 feet).

1. **Station Designation.** Stamp the station designation and setting year on the top surface of the disk, prior to setting (see example of stamping convention in Table 2).
2. **Site Selection.** Pick a fairly level and accessible spot on the outcrop, that appears intact with the bulk of the rock. A simple test can be performed to help determine the condition and integrity of the rock by placing one's hand near the area the disk will be set, then striking the outcrop with a moderately heavy hammer, and feeling for vibration. Sound outcrop will force the hammer to rebound with each impact and vibration through the rock should be minimal. Avoid rock that sounds hollow from this test.





3. **Drilling the Hole.** Drill a hole sufficient for the size and shape of the disk shank into the bedrock. Chisel a flat, level recessed area around the top of the hole, to a diameter slightly larger than the disk. Test the hole with the disk to see if it is deep enough, and the disk sits flush in the chiseled area. When installation is completed, the top surface of the disk should sit level and slightly below the surface of surrounding rock, to help protect the disk. Chisel a drain channel through the low edge of the chiseled recess, to allow water to drain away from finished mark.

***Caution:** Protective eye-wear should be worn when drilling into bedrock or masonry.*

4. **Mixing Cement/Epoxy.** Remove all rock powder and debris from the hole and recessed area.
    a. **Cement -** Flush and fill the hole with clean water; then pour dry cement into it. Mix ingredients right in the hole with a thin stick or other implement such as a screw-driver. Add water and cement to make enough mortar/cement to fill hole, with a little

extra available to place on the underside of the disk. When the mortar is completely mixed, it should be thick, but still workable, like heavy mashed potatoes.

b. **Epoxy –** Use canned air with a straw and remove debris from down inside the hole. Follow label instructions.

5. **Preparing the Disk.** Wet and clean the disk by rubbing all surfaces with cement, to remove unwanted dirt and oils; rinse well. Fill underside of disk with mortar, using a trowel. Hold disk loosely upside-down by end of the shank then gently tap domed surface of disk from below, with the handle of the trowel, several times, to allow mortar to settle and trapped air to escape. This process is very important, because it will minimize the existence of highly undesirable voids under the disk once in place.

6. **Setting the Disk.** Place the shank of the disk into the cement-filled hole and press the mark firmly into place. The disk is typically oriented to read with the observer facing north. This is useful for GNSS and gravity observations, which orient to north. Slightly twist the disk back-and-forth and gently tap it with the end of the trowel handle, to help settle the disk, completely and evenly, into the recess in the bedrock. The disk is considered set when the slight back-and-forth movement stops and the disk settles firmly in place. Work excess mortar around the outer edge of the disk, making sure that it is smooth, and slightly overlaps the top, edges of the disk. An exposed disk edge could provide a weak spot that can be used by someone, or the elements, to dislodge the mark.

7. **Cleaning and Finishing.** Sprinkle a little dry cement on the exposed surface of the disk, and then rub it with a clean rag or short bristled brush, using circular strokes. This cleans the disk and removes excess mortar from its surface and recessed letters. Rubbing the wet mortar around the edge of the disk in the same manner is done intentionally to finish its surface and help prevent cracking. Brush away loose cement and make sure the finished product has a neat appearance.

8. **Curing Cement.** Cover the newly set disk while the cement is still wet, to prevent heavy rains or other debris from ruining its surface; and to conceal the disk from people who might tamper with it at this vulnerable stage. A piece of wood, cardboard, heavy paper, or similar item should suffice for covering the mark, and should be removed after cement has cured.

9. **Clean Up.** The area is cleaned; excess dirt and trash removed; and returned to its "as-found" condition. The mark is the only evidence left to represent the quality of work performed, and therefore the cleanliness of the site should reflect similar quality.

10. **Caution:** Lime and/or cement in concrete can cause burns on skin and destroy clothing. Water used to rinse tools, concrete/cement mixing containers, etc., can kill vegetation, if dumped on the ground.

Appendix D - Forced-Centering Pier Setting Guide

Guidelines for Setting a Type II Calibration Base Line Pier Introduction

The Type II CBL pier (Figure D1) is a mark that functions as an instrument platform. It is equipped with a forced-centering adapter (Figure D1a). The adapter allows a standard survey tribrach to be precisely centered on the pier simply by threading it onto the 5/8-11 stud. An instrument or reflector clamped into the tribrach is forced-centered over the "mark."

Figure D1. Type II pier with forced-centering adapter   *Figure D1a. Close up of installed adapter*

The pier's horizontal point-of-reference is the stud's vertical center-of-rotation. The vertical point-of-reference (VPR) is the horizontal surface of the adapter near one edge, for example, "near the north edge." To allow for accurate, repeated and consistent elevation differences and EDMI height measurements, a pointer should be stamped into the side of the adapter (Figure D1b) indicating the edge where the rod or staff is to be place during leveling operations. This is the point above which the EDMI height will be measured. Tribrach height, and therefore the EDMI height changes whenever the tribrach foot screws are turned.

Figure D1b. VPR pointer stamped into adapter to indicate where the VPR is on the top surface

The pier can be described as having two parts, but structurally speaking, it is a single-pour, concrete monolith. The visible portion is a concrete-filled PVC pipe that will hereafter be called “the pier.” The below-grade portion will be called the pier “foundation.”

The foundation is at least 3 meters (10 ft) deep by ½ meter (1½ ft) in diameter. The PVC pipe form for the pier varies in length according to the desired finished height above grade, but it must extend down into the foundation at least ¾ meters (2½ ft). The lower portion is perforated to allow the concrete inside of the pipe to bond with the foundation (Figure D2).

Construction of the monument involves purchasing materials, assembling components, and scheduling services. Most of the materials are commercially available. Services may be required to fabricate the forced-centering adapter, locate and mark any underground utilities, drill the foundation hole, and deliver concrete to the construction site. A concrete vibrator must be available and used throughout the pour to completely eliminate voids (air bubbles) in the concrete.

Concrete strength throughout is at least 250 kg/cm^2 (3,500 psi), mixed with 0.9 kg/m^3 (1½ lbs/yd^3) synthetic fiber reinforcement. Ready-mix concrete is prepared to exact specifications at the plant. Adding water onsite weakens it.

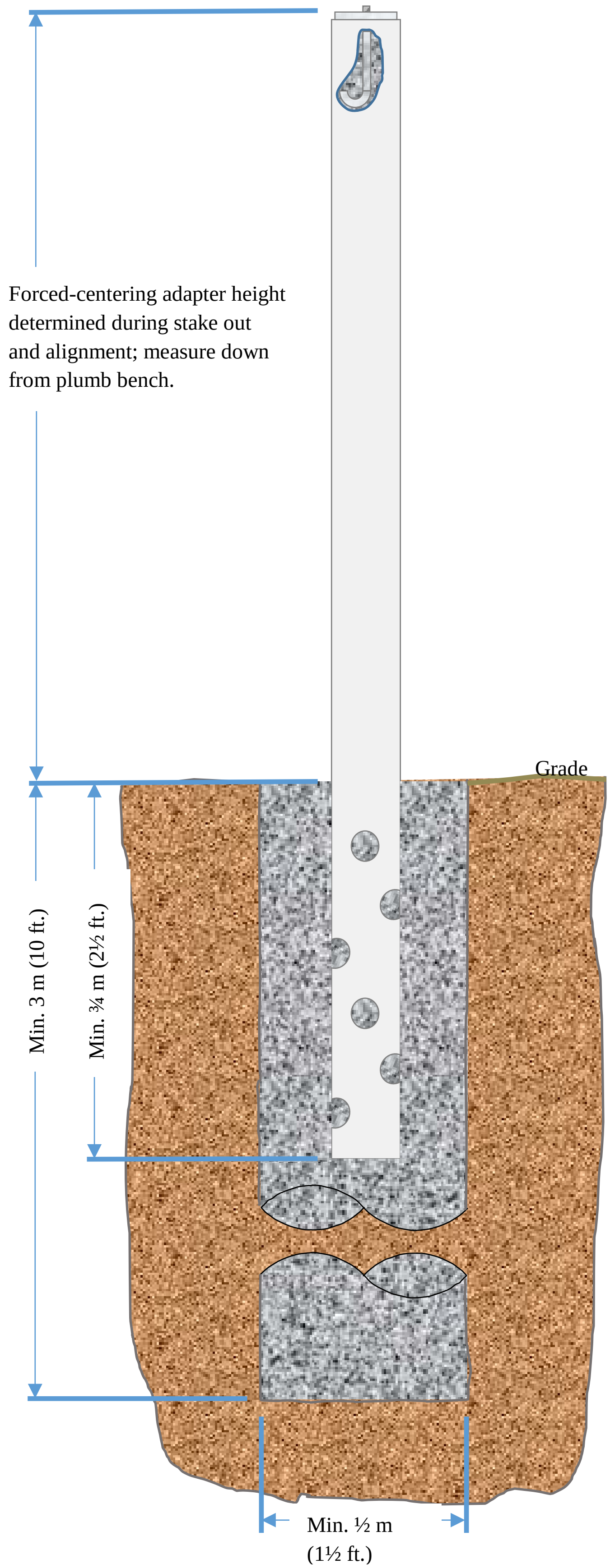


Figure D2. Type II pier

Forced Centering Adapter

The forced-centering adapter is a stainless steel disk with a J-bolt passing through the center. Use a minimum 12 mm (½ in) thick disk. A machine shop can turn the disk, if necessary, to ensure its diameter is small enough to fit just inside the pier's PVC pipe form. The shop can also tap a $^{5}/_{8}$-11 thread in the center of the disk. Screw the J-bolt up through the bottom until about 12 mm (½ in) of the bolt is protruding. Tightening a nut onto the protruding thread takes out any play and squares up the bolt with the disk. Weld the bolt to the disk on the underside.

Figure D3. Forced centering adapter.

Foundation

Have the construction site inspected for any underground utilities. Augering equipment will greatly simplify digging the foundation, but will wreak havoc on buried cables. Ensure it can handle a hole at least 3 meters (10 ft) deep by ½ meter (1½ ft) in diameter. After digging, tamp any loose soil remaining in the bottom of the hole to avoid settling.

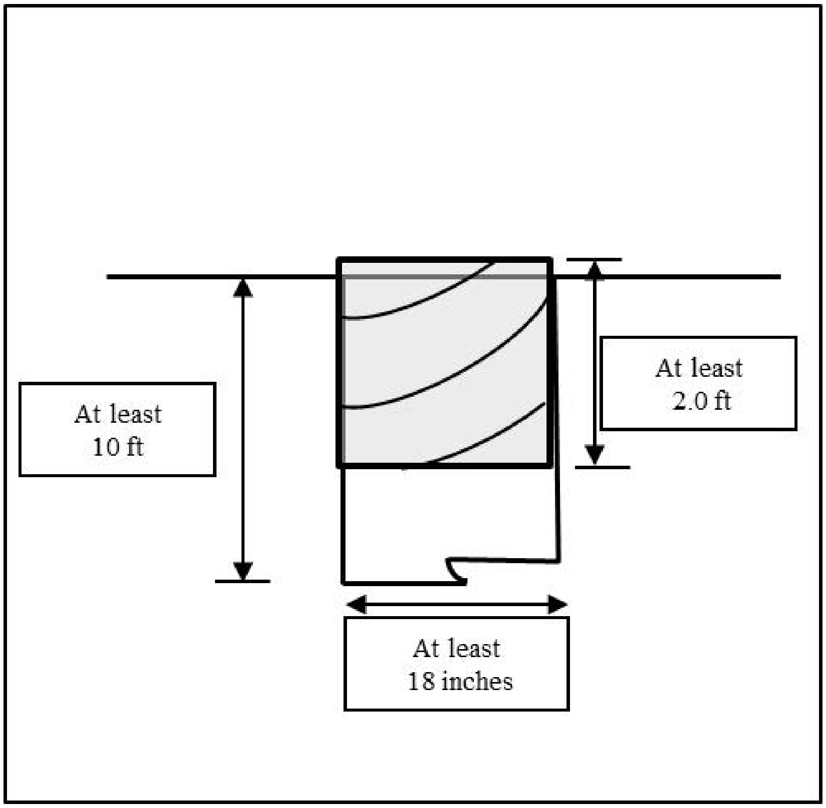


Figure D4. Foundation of Type II Monument

Plan on using at least 0.5 cubic meter (0.7 cubic yards) of reinforced concrete. A tubular cardboard form may be used at ground level for appearance sake (Figure 4), but must not extend deeper than about 0.5 meter (2 ft) into the hole. Excess forming material interferes with the foundation's ability to cleave to the walls of the hole. Vibrate the concrete as the hole is filled to work out trapped air. Stop filling at about ½ meter (2 ft) from the top of the hole and ready the PVC pier form.

Pier

The finished pier consists of the forced-centering adapter set into the top of the PCV pipe filled with concrete. The PVC pipe extends into and bonds with the foundation (Figure 6).

Materials for the pier consist of a thick-walled 6-inch PCV pipe (schedule 40 or better). Use white, foam-core PVC, if available. It helps insulate the pier and mitigate uneven expansion/contraction of the concrete when the pier is in use, especially on sunny days. Use a section of PVC pipe long enough to allow for the desired height of the finished pier, plus about ¾ meters (2 ½ ft) below the ground. The top end of the pipe should be squared off and nicely finished. Bore multiple holes (5 cm/2½ in) into the lower section to promote bonding between the pier and foundation.

Figure 5. Above-ground Section of Type II Monument.

Setting the Monument

Figure D6. Filling the hole with concrete.

After having drilled the 18-inch diameter hole to a depth of 10 feet and tamping any loose soil in the bottom, fill to within 1½ feet of the top of the hole with 3,500 PSI synthetic fiber reinforced concrete. Use a vibrator to consolidate the concrete. Insert the 1½ foot-long section of 18 inch diameter cardboard form into the hole.

Figure D7.

Position the PVC pipe at the desired location in the drill hole. Mark the PVC pipe at 2 ½ feet from the bottom. Insert the PVC pipe into the hole until the mark on the PVC pipe is at the same level as the top of the form.

Figure D8.

Level the top and brace the PVC pipe. With the PVC pipe positioned at the desired location in the hole, attach one end of a 2- by 4-inch board to the top of the PVC pipe using 2-inch drywall screws. Attach the other end of the board to a wooden stake driven securely into the ground using 3-inch drywall screws. Repeat this process using a second board at a 90 degree angle. Double-check the position and level of the PVC pipe in the hole to be sure it is securely braced.

Figure D9.

Fill the PVC pipe and form with remaining concrete. With the PVC pipe braced, fill the PVC pipe to the top with concrete. While adding the concrete into the PVC pipe, tap the sides of the pipe with a hammer to consolidate the concrete. Finish filling the form at ground level to the top with concrete, consolidate with existing concrete, and finish off the top surface.

Figure D10.

Install the forced centering adapter. Insert the forced centering adapter into the top of the PVC pipe tapping sides of the pipe with a hammer until the top of the adapter is fully seated. Ensure there is no air gap between the bottom of the adapter and the concrete inside the pipe. (Plumb bench not shown)

Figure D11.

Fine leveling of the adapter. Using a precision bubble level, fine level the top of the forced centering adapter by gently tapping on the top sides. Leave the braces in place for at least two days before removing them. (Plumb bench not shown)

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