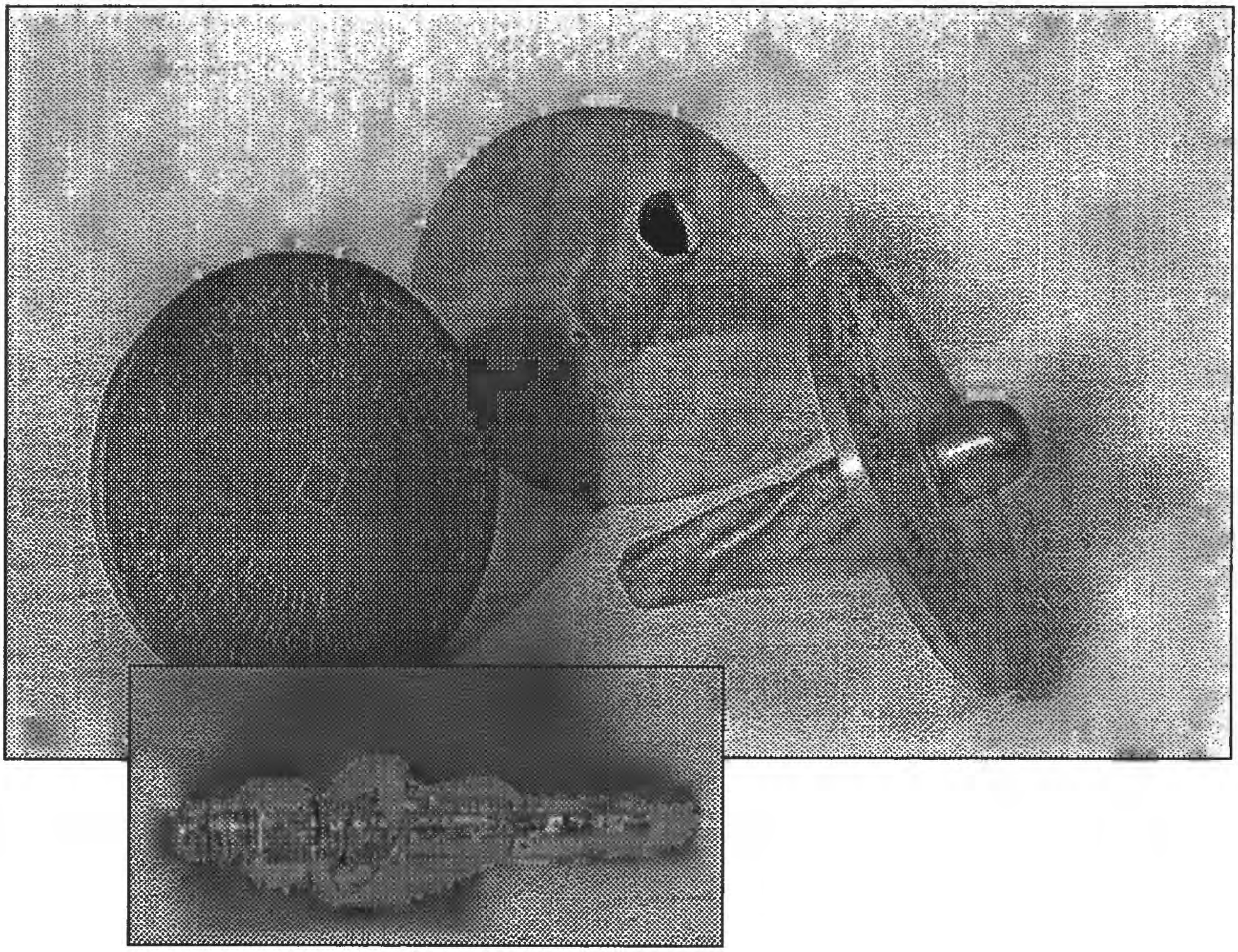

U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

A MANUAL FOR THE INSTALLATION OF BENCH MARKS ON ACTIVE VOLCANOES

by

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Open-File Report 93-176B

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A MANUAL FOR THE INSTALLATION OF BENCH MARKS ON ACTIVE VOLCANOES

by Michael P. Doukas

INTRODUCTION

The Use of Bench Marks in Volcano Monitoring

A variety of physical phenomena can occur and be measured before the eruption of a volcano. Principle eruption precursors include seismic activity, ground deformation, changes in the chemistry and exhalation rates of fumarolic gases, changes in crater lake water chemistry and temperature, and changes in magnetic or gravitational fields (Banks and others, 1989a). Each is monitored separately, but all types of measurements must be compared in order to interpret changes in physical parameters as possible precursors to volcanic eruptions (fig. 1).

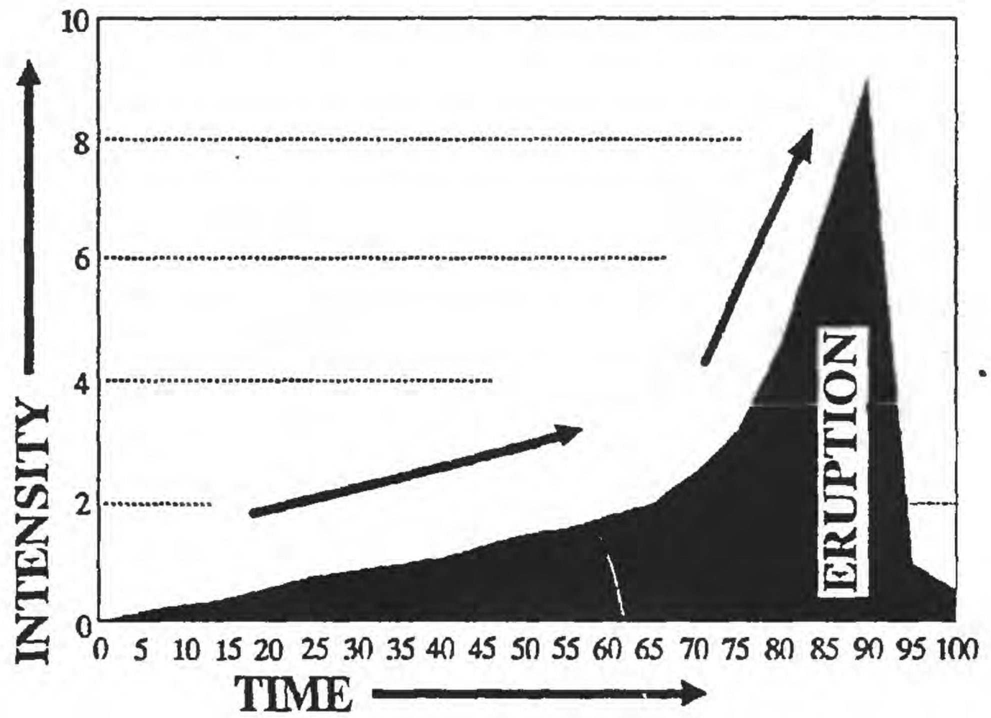


Figure 1. Graph showing relation between measured changes in physical phenomena plotted against time before an eruption. Time axis can be hours, days, weeks, or months; Intensity units may represent changes in seismic amplitude, distance, or temperature.

One important phenomenon that often occurs as an eruption precursor is ground deformation. Ground deformation that precedes an eruption can be due to movements of molten magma below or within a volcano. This deformation commonly begins as barely discernible changes in the total volume of the volcano as the magma rises up into the volcano. As the volume of magma increases within the volcano, changes can be measured in the slope (tilt) of the surface or as horizontal and vertical movements.

Conducting repeated geodetic surveys to monitor the vertical or horizontal changes that occur on active volcanoes has proven to be a useful tool in detecting the early warnings of an approaching eruption (fig. 2).

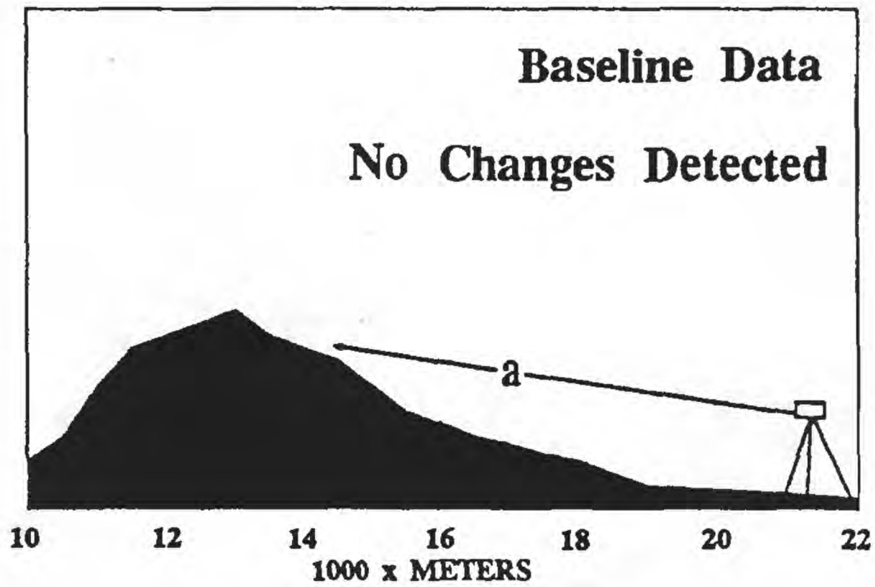


Figure 2a.

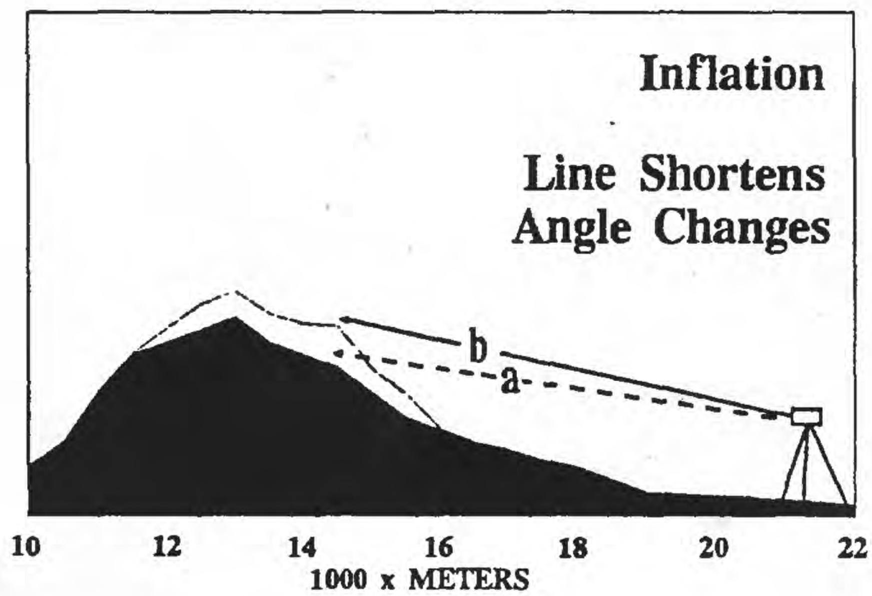


Figure 2b.

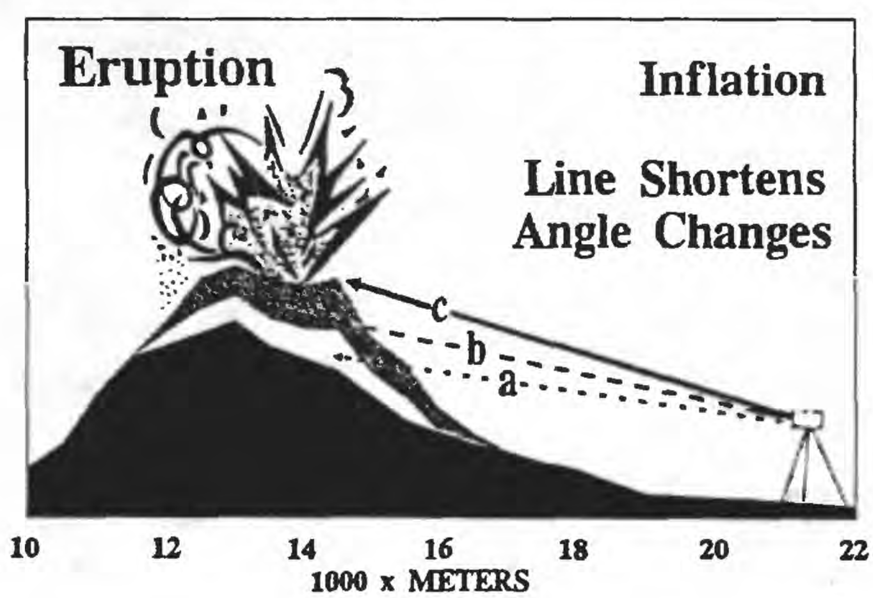


Figure 2c.

Figure 2. Schematic representation of changes in line length and vertical angle measured at an active volcano (a through c). Dashed and dotted lines indicate previous surveys.

The two common geodetic methods used are *precise leveling*, which can measure the tilt or the vertical component of strain, and *electronic distance measuring* (EDM), which when combined with accurate measurement of angles to targets, can measure the vertical as well as the horizontal components of strain (Kinoshita and others, 1974; Lipman and others, 1981; Swanson and others, 1981, 1983; Chadwick and others, 1983, 1985; Banks and others, 1989b).

As an example, inflation that occurred on the north flank of Mount St. Helens, Washington prior to the May 18, 1980 eruption was monitored using geodetic techniques. The results of repeated measurements were interpreted to mean that new magma was rising into the mountain causing it to deform at an easily measured rate. This conclusion contributed to assessments by US Geological Survey personnel that, despite the seemingly mild small-scale phreatic eruptions that were then the most conspicuous activity, Mount St. Helens remained highly dangerous (Lipman and others, 1981).

Each of the two deformation monitors (leveling and EDM) require permanent ground installation of bench marks on the volcano because of the need to have fixed, dependable points of reference (Doukas and Ewert, 1992). To measure the small changes that occur on the slopes of a volcano at the target, requires absolute stability at the instrument-station bench mark. Instability of the bench mark may be interpreted as movement on the volcano as a result of premonitory activity and cause undue worry.

Descriptions of the methodology for setting up *precise leveling* deformation monitoring networks are given in other papers (Ewert, 1992; Dzurisin, 1992). This report describes in detail, a versatile, fast, inexpensive installation system for deformation bench marks developed for deployment by the U.S. Geological Survey's Volcano Crisis Assistance Team (VCAT). It is the companion to a video tape that is part of a training program on the establishment of volcanic monitoring systems on active and dangerous volcanoes. The main purpose of this report is to introduce and review the steps for locating and installing permanent and temporary reference bench marks shown in the video tape program.

SUMMARY OF THE BENCH MARK INSTALLATION SYSTEM

General Techniques of Geodetic Monitoring

There are four requirements and several cautions that need to be followed during the installation of a deformation network. These include: setting up the shortest measurement line possible to increase precision, while still maintaining a safe distance; establishing monitoring networks on the volcano to take advantage of geologic structure; monitoring all flanks of the volcano; locating instrument stations with clear line-of-sight to targets and good access.

The first step in any geodetic monitoring program is locating and installing fixed reference points. A leg of an EDM survey consists of a laser distance meter, set up over a stable bench mark (assumed to be free or little afected by volcanic deformation) located near the subject volcano and one or more reflector-target prisms at established points on the volcano (Swanson and others, 1983) (fig. 3).

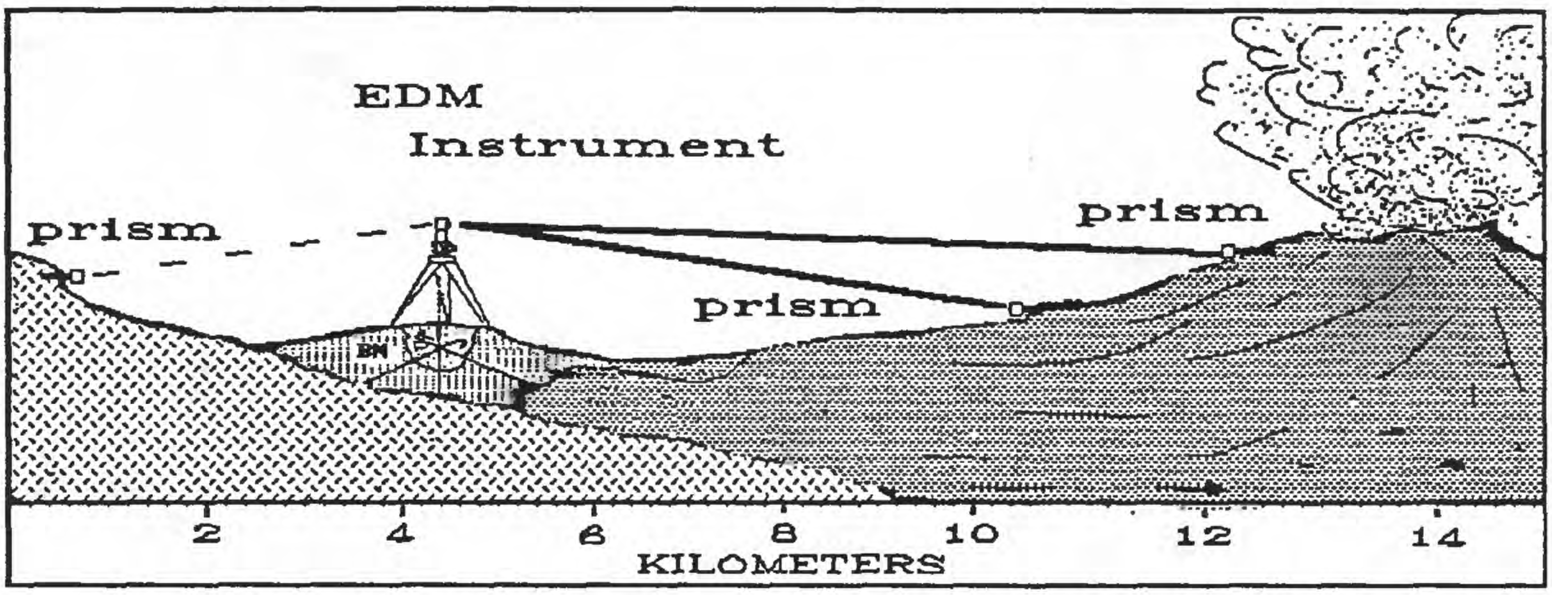


Figure 3. Schematic drawing of a leg of a EDM network at an active volcano. Prisms may be 1-10 kilometers distance from instrument. Note bench mark underneath EDM instrument.

The chosen distance from instrument to the prisms on the volcano depends on the precision and power of the laser instrument used (manufacturer's technical data) (fig.4).

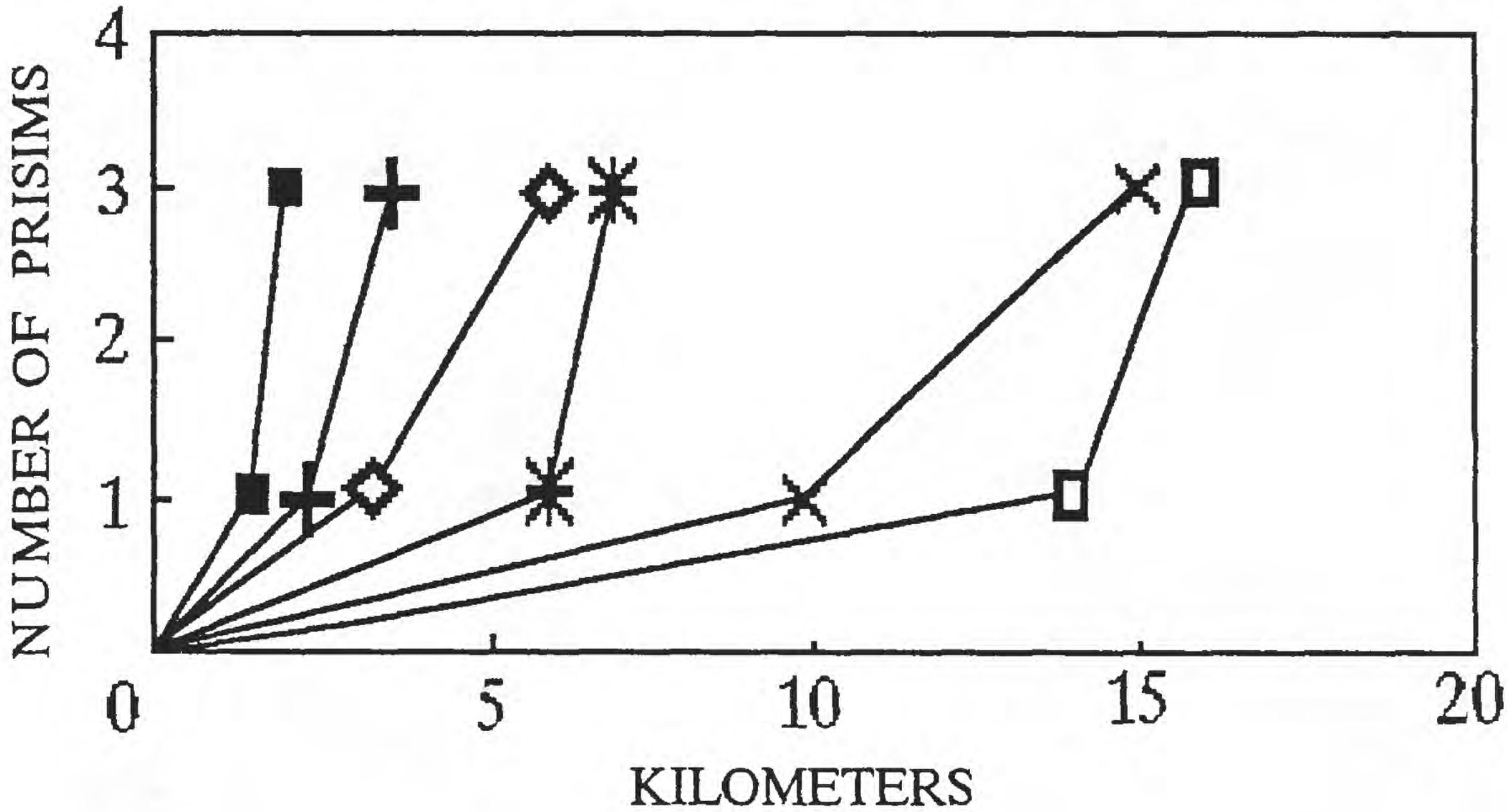


Figure 4. Graph showing power relation between EDM models, average range and number of target-prisms required. Filled square: Lietz, model RED2A; plus, WILD model DI5; star: WILD model DI3000; cross, CUBIC PRECISION model Ranger Va; open rectangle, GEODIMETER model 6000 (data from McDonnell, 1987).

Short EDM lines also result in better and more precise measurements. When the volcano becomes active it is even more important to be able to measure deformation from bench marks located so as to minimize risk to field crews. Therefore, EDM instrument stations should be located, for safety, on the crest of a ridge or other high ground and where practical, close enough to give the most precise measurement.

Single setup leveling sites (dry tilt) need to be located in areas where a triangle can have 40-meter sides and no more than 3 meters (2 meters of elevation if using 2 meter long rods) of elevation separating all three bench marks (Yamashita, 1992) (fig. 5).

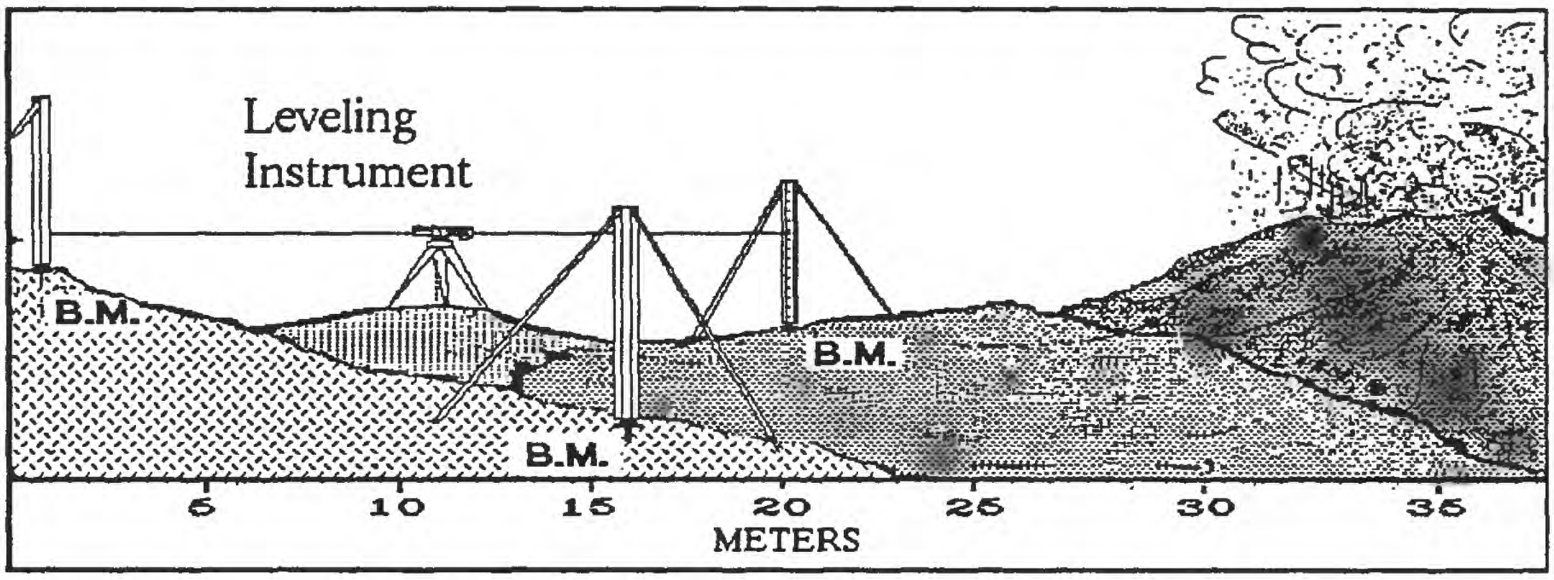


Figure 5. Schematic drawing of a single-site tilt-leveling setup (dry tilt). Bench marks may be 30 to 40 meters apart and with 3 meters difference in elevation. Note: no bench mark needed under instrument.

On the steep slopes of a volcano these sites can be difficult to find. Dry-tilt arrays should be spaced along radial lines on the slopes of the volcano to better evaluate the magnitude of deformation occurring (fig.6).

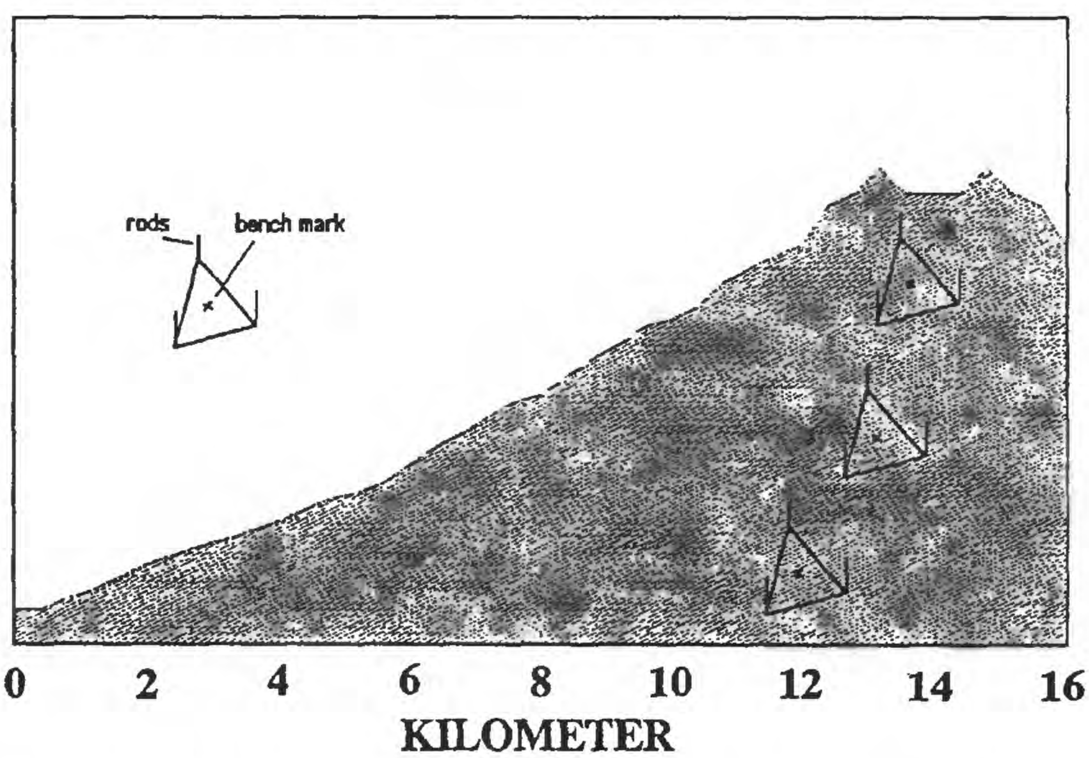


Figure 6. Schematic drawing of a radial single-site tilt-leveling setup (dry tilt) array on the flanks of an active volcano. Individual dry-tilt triangles may be several kilometers apart.

A trigonometric leveling setup can tolerate more elevation difference between triangle bench marks and more distance along triangle sides (Ewert, 1992) (fig. 7).

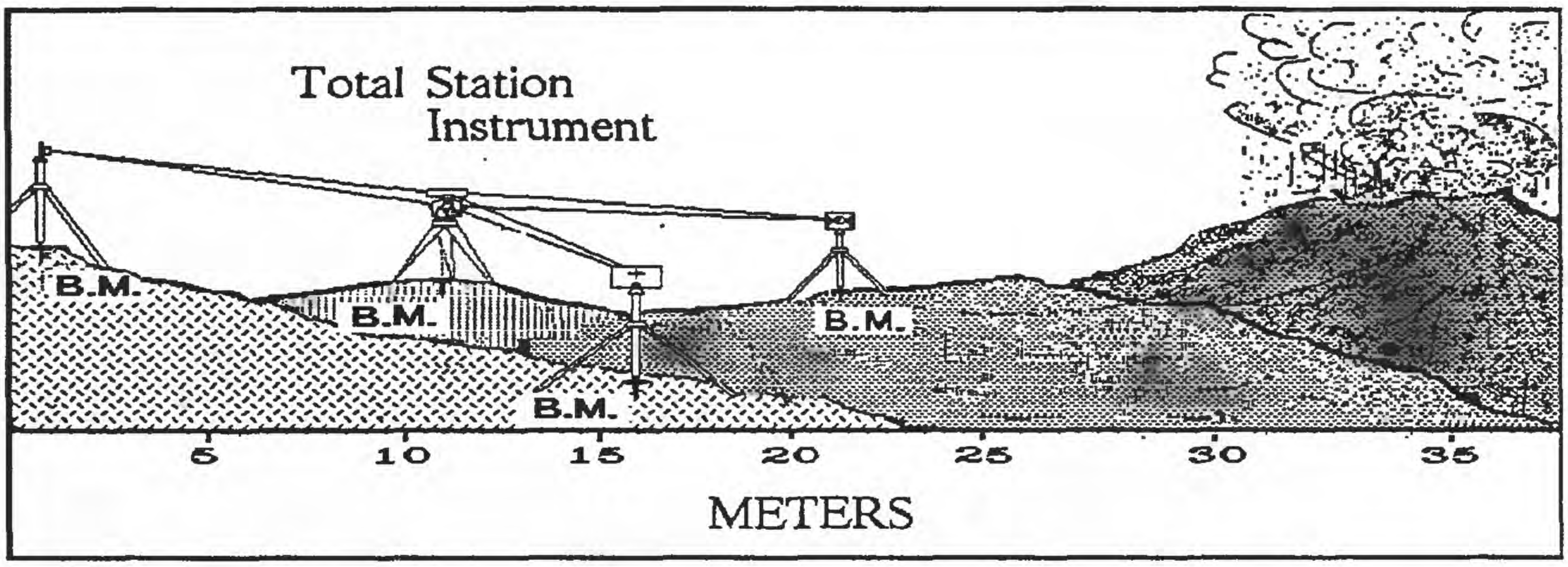


Figure 7. Schematic drawing of a trigonometric single-site tilt-leveling setup. Bench marks may be 50 to 100 meters apart and 10 to 20 meters apart in elevation. Note: bench mark under instrument.

Precise leveling traverses of radial lines at volcanoes need permanent bench marks at both ends and with temporary bench marks in between (Dzurisin, 1992) (fig. 8). These bench marks might be separated by 0.5-1.0 kilometers distance.

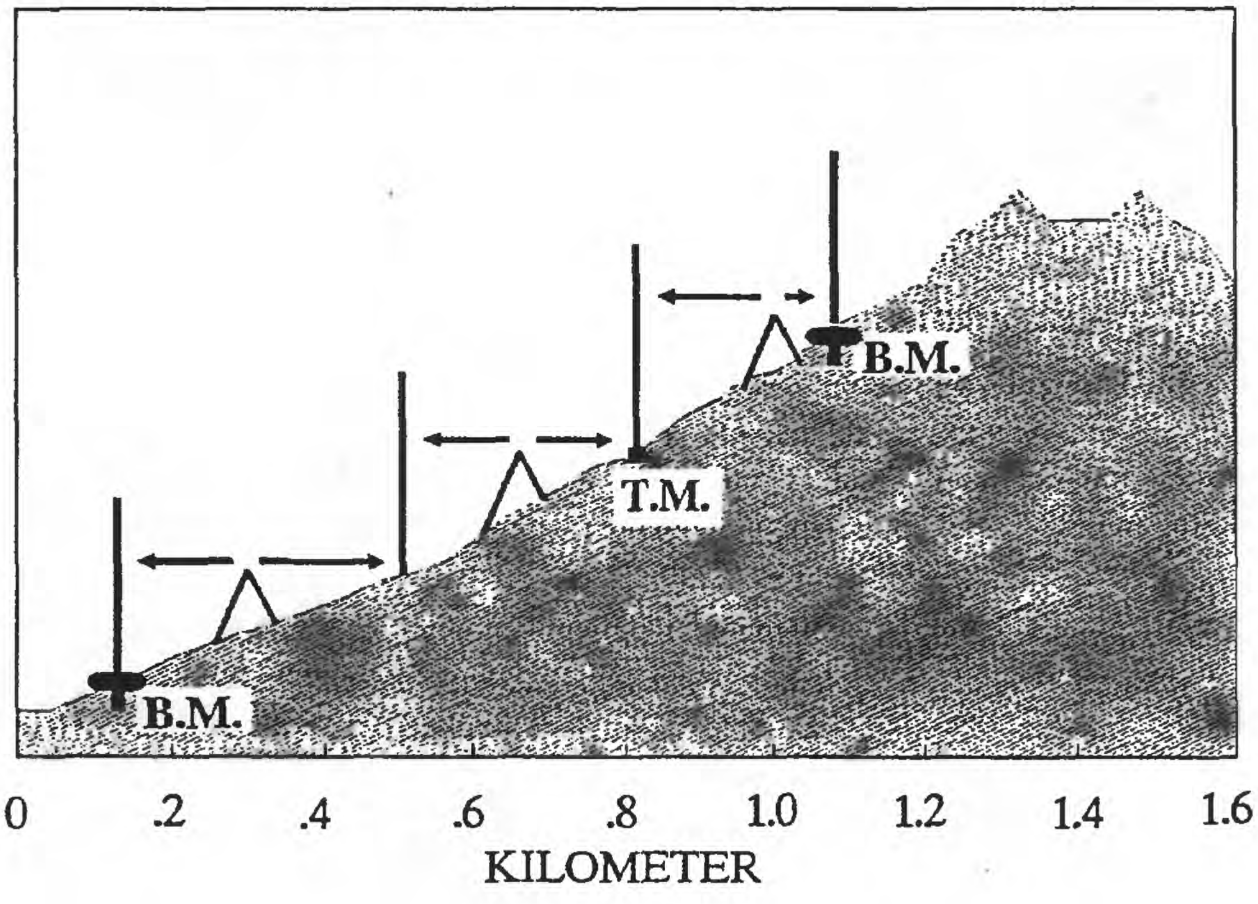


Figure 8. Schematic drawing of a radial precise tilt-leveling traverse on the flanks of a volcano. Bench marks (permanent [B.M.]) may range from several decameters to several kilometers apart. Note: temporary bench mark; T.M.

Knowledge of the geologic structure at the volcano (location of rift zones, fault trends etc.) is also important in deciding where to place bench marks. To measure the maximum horizontal strain during dike intrusion into a cone, EDM instrument station bench marks should be located at the end of lines perpendicular to the suspected trend of the dike (fig. 9).

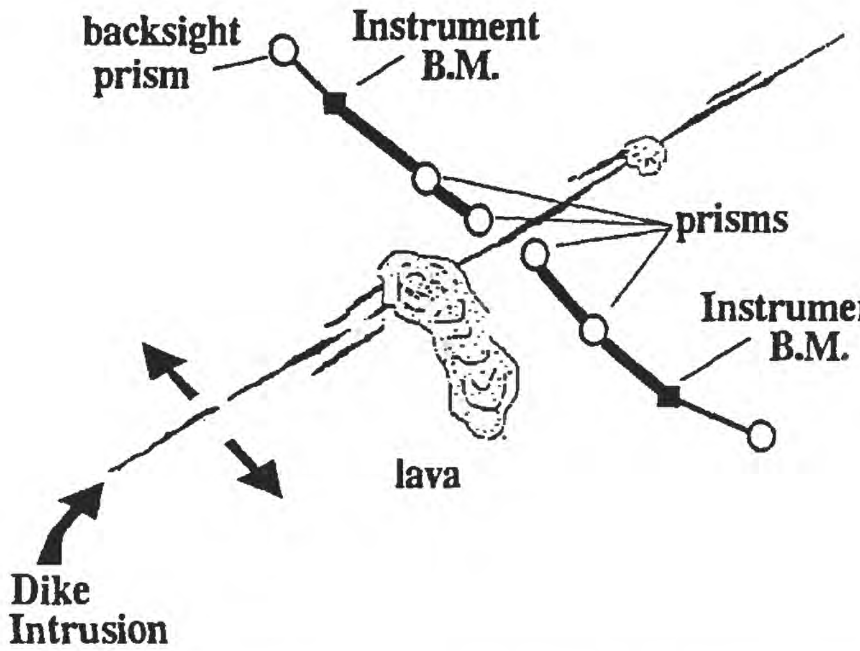


Figure 9. Schematic drawing of an EDM deformation network, perpendicular to a suspected dike emplacement. Maximum horizontal strain in direction of opposed paired arrows. Bench marks, filled squares; reflector prisms, open circles.

Whenever possible, leveling survey traverses should also cross perpendicular to the dike trend (fig. 10).

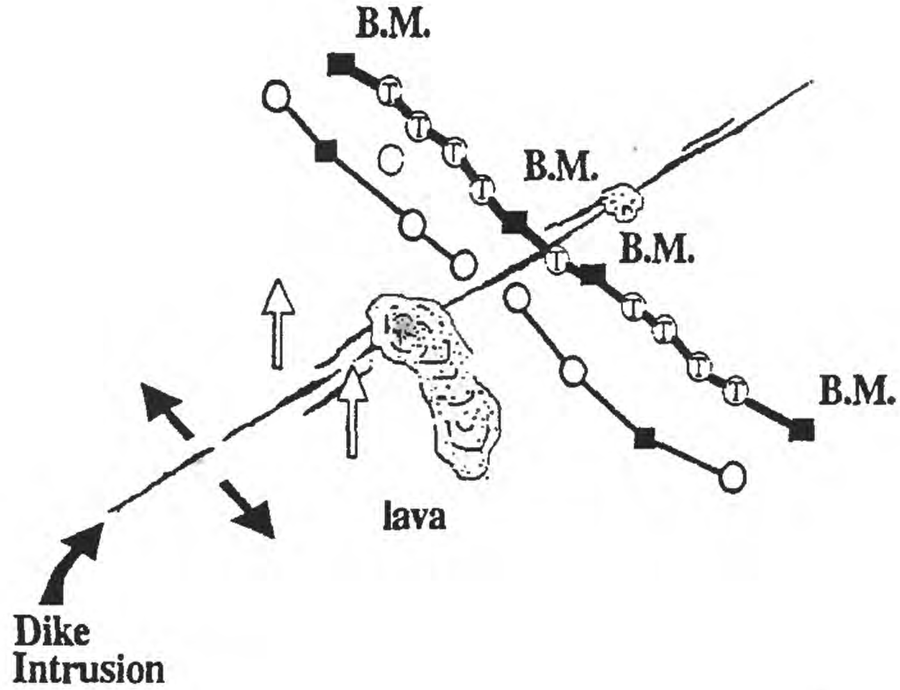


Figure 10. Schematic drawing of a leveling traverse perpendicular to a suspected dike emplacement. Maximum vertical strain in direction of open arrows (vertical and perpendicular to filled arrows). Bench marks, filled squares; temporary marks, circles with enclosed T; Reflector prisms, open circles.

When monitoring a stratovolcano, all flanks should be monitored. Based on the 1980 Mount St. Helens eruption, each 60 degree arc of the volcano's circumference should be monitored (Chadwick and others, 1985). Ideally, a minimum of six radial EDM lines and instrument bench marks should be installed equally spaced around the volcano (fig. 11).

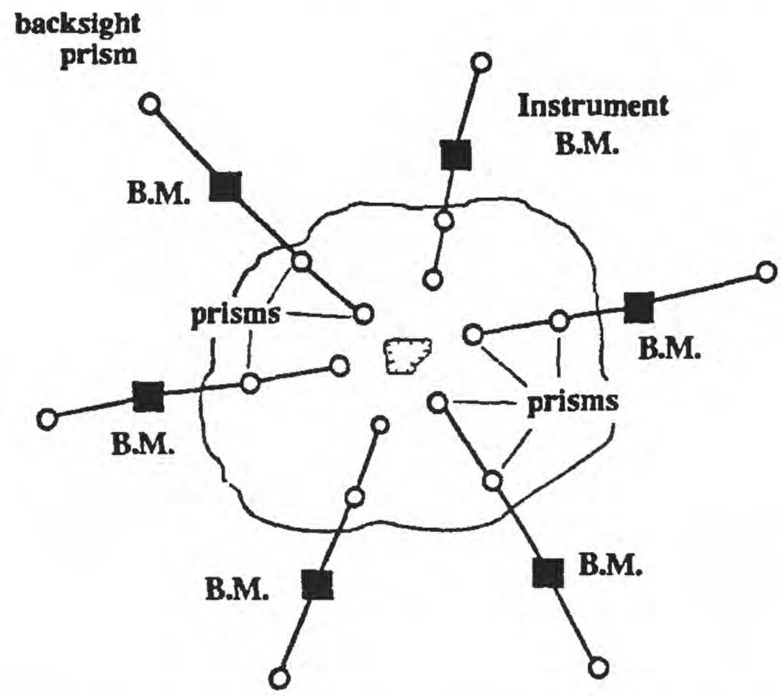


Figure 11. Schematic drawing of an EDM deformation network, radial to an active volcano. Bench marks, filled squares; reflector prisms, open circles.

This placement of radial lines is used to detect inflation from intrusion of magma or the possible onset of deformation which may lead towards the collapse of a section of the volcano (fig. 12).

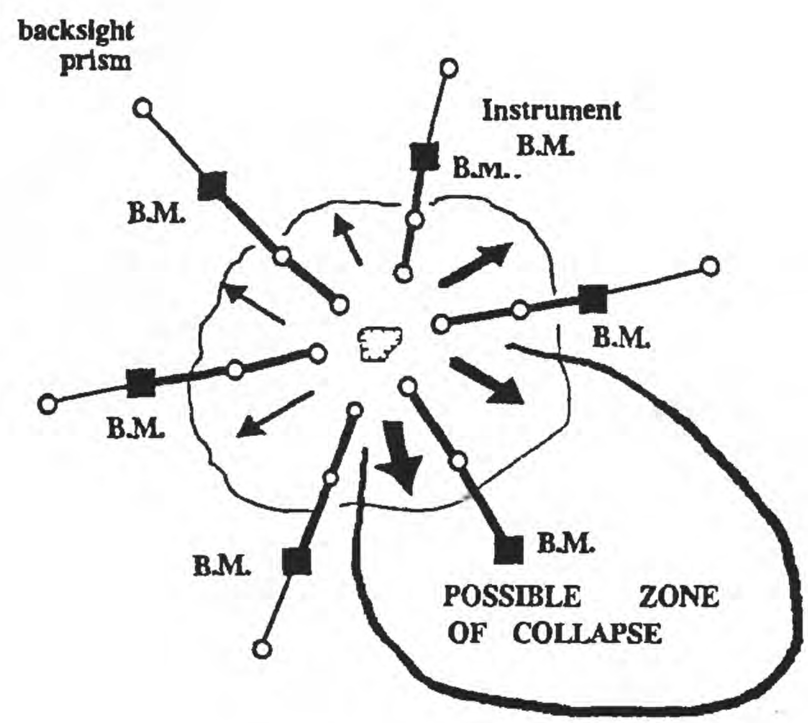


Figure 12. Schematic drawing of an EDM deformation network, radial to an active volcano. Radially spaced arrows indicate magnitude of measured displacements, possibly leading to collapse of a section of the volcano. Bench marks, filled squares; reflector prisms, open circles.

Placement of dry-tilt arrays and leveling traverses radial to the cone complement the existing EDM network (fig. 13).

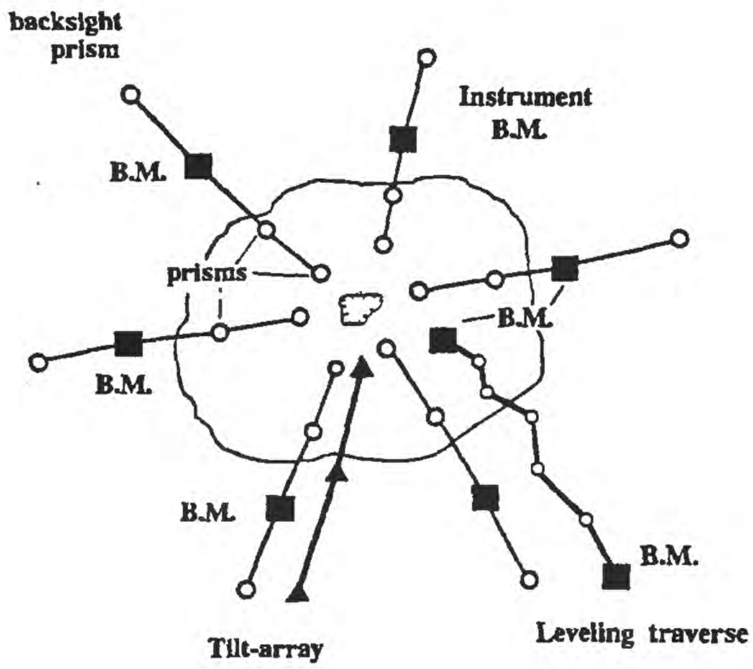


Figure 13. Schematic drawing of a leveling traverse and single-site tilt-leveling array radial to a volcano. EDM and leveling bench marks, filled squares; reflector prisms, medium open circles; single setup leveling array, filled triangles connected by thick line; leveling traverse, filled squares connected by dark line and small open circles (small circles represent temporary bench marks).

For EDM monitoring, a clear line-of-sight between the target and the instrument station is absolutely necessary. Before going into the field, preliminary sites can be selected and tested for line-of-sight to the proposed reflector-target by using a topographic map as shown in the following figures.

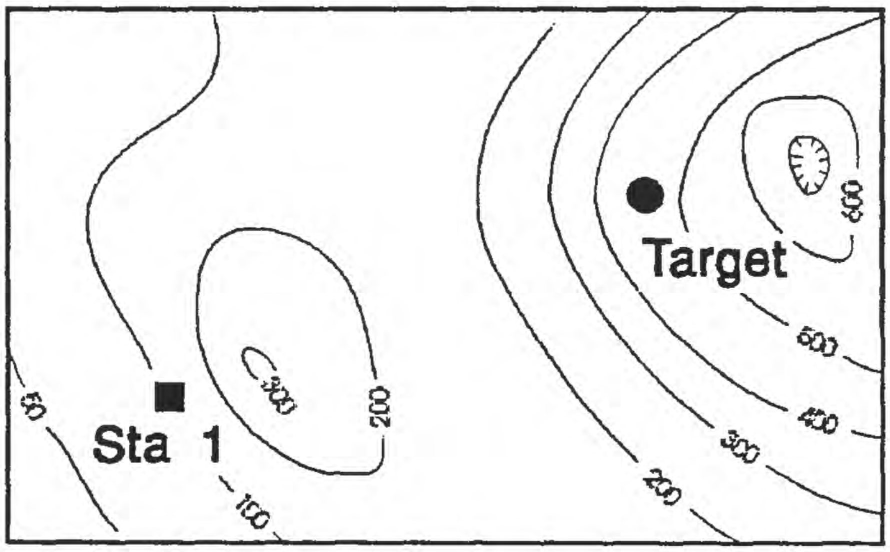


Figure 14a. On a topographic map locate the prism-target site and the proposed bench mark location (Sta. 1).

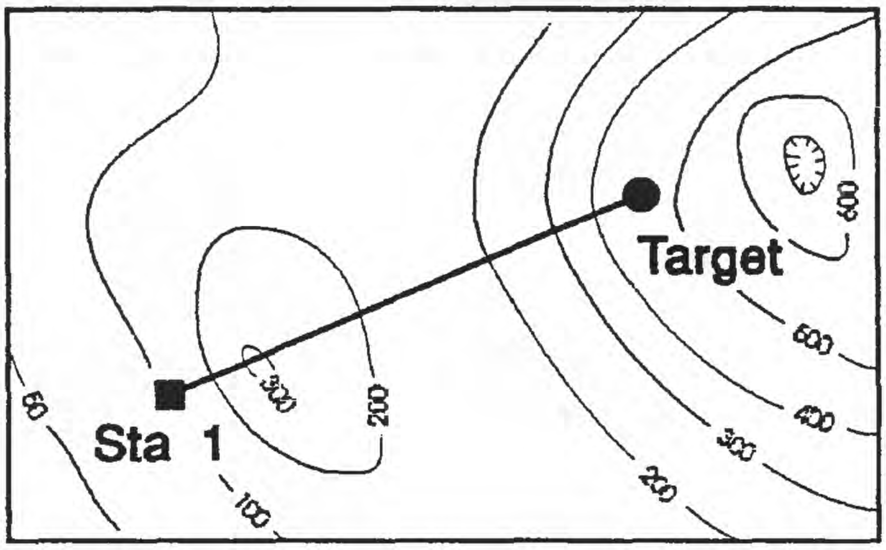


Figure 14b. Draw a line between the proposed bench mark location and the prism-target site.

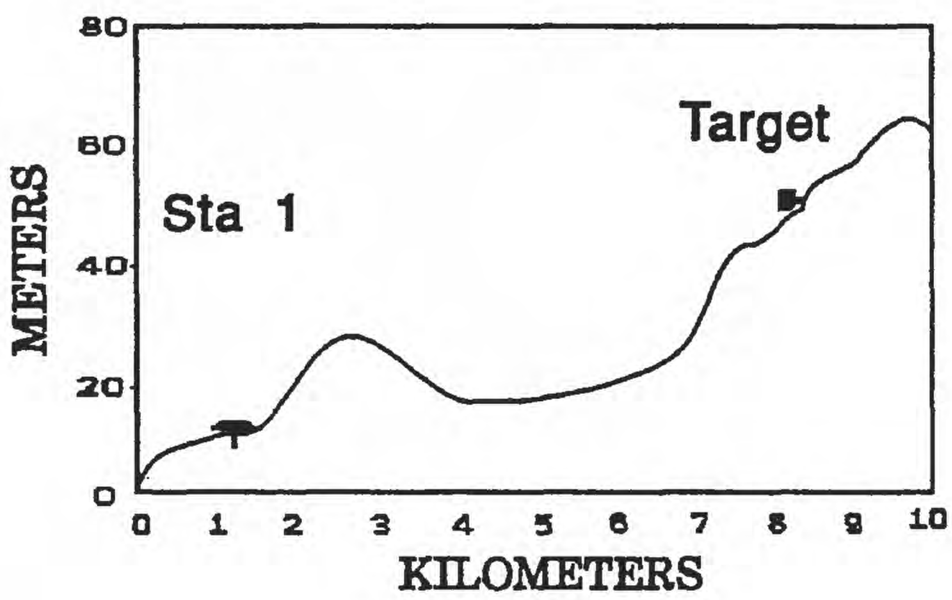


Figure 14c. Plot the altitude of the ground along the line against the distance between the two points.

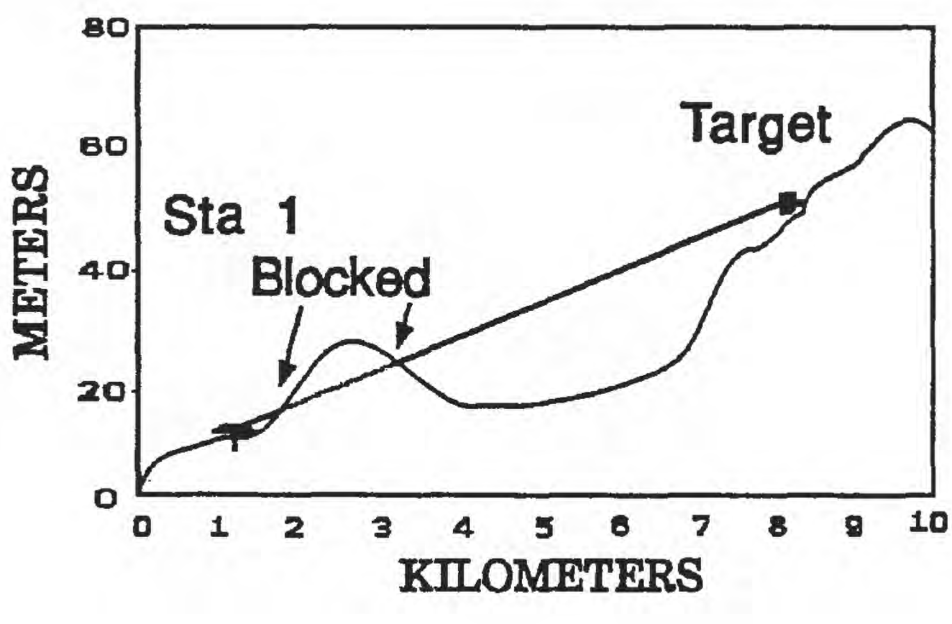


Figure 14d. Draw a straight line on the graph between the station and the target. If the resulting figure shows that the straight line intersects the plotted elevations, then the line-of-sight is blocked and the bench mark location is not a good site.

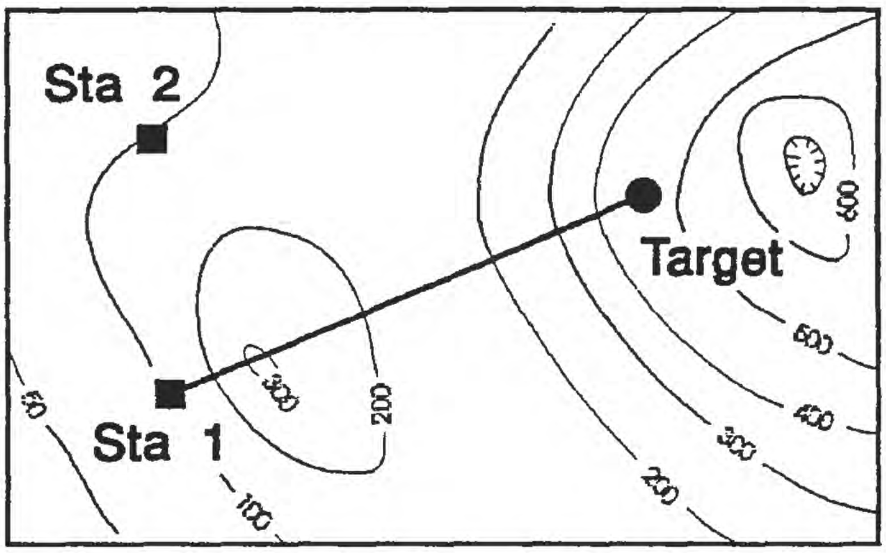


Figure 14e. Select another location (Sta 2).

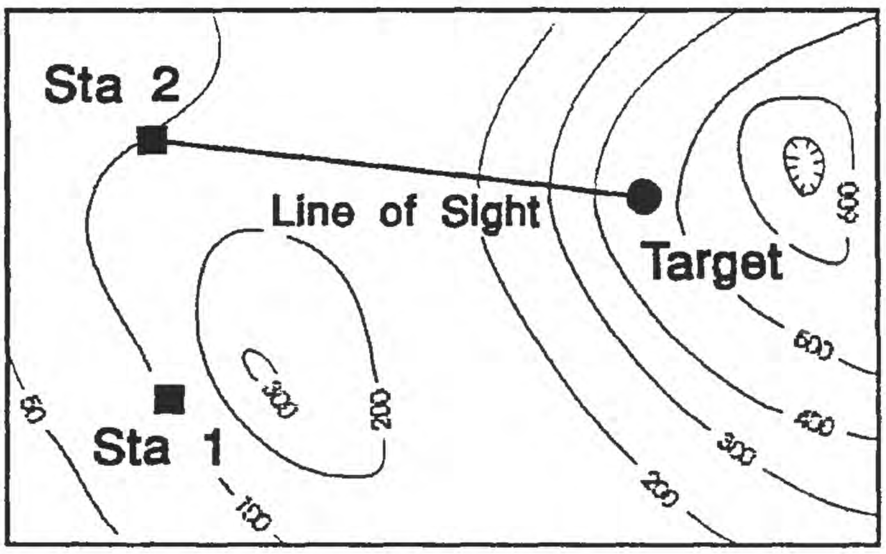


Figure 14f. Draw a line between the new bench mark location and the target.

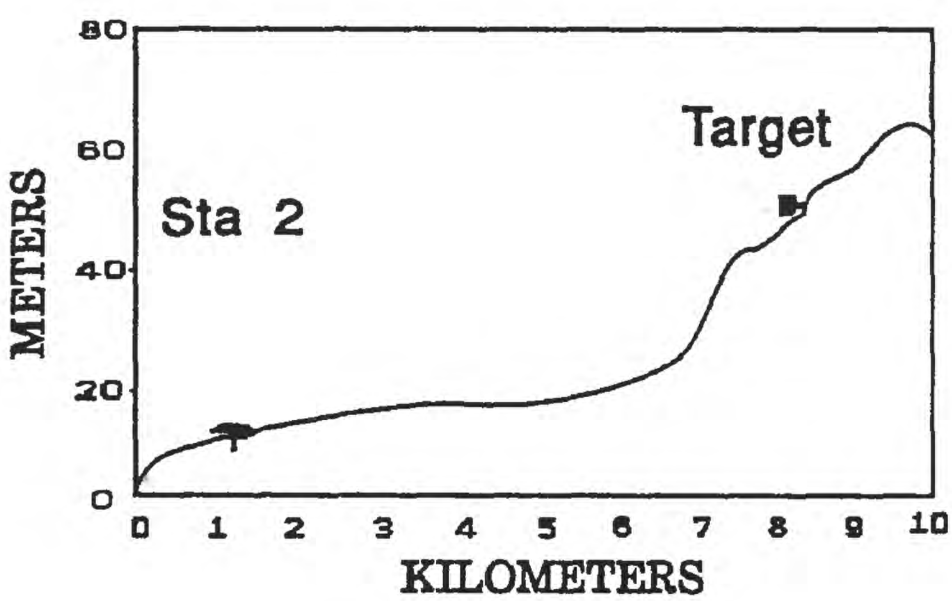


Figure 14g. Plot the elevation against the distance between the points.

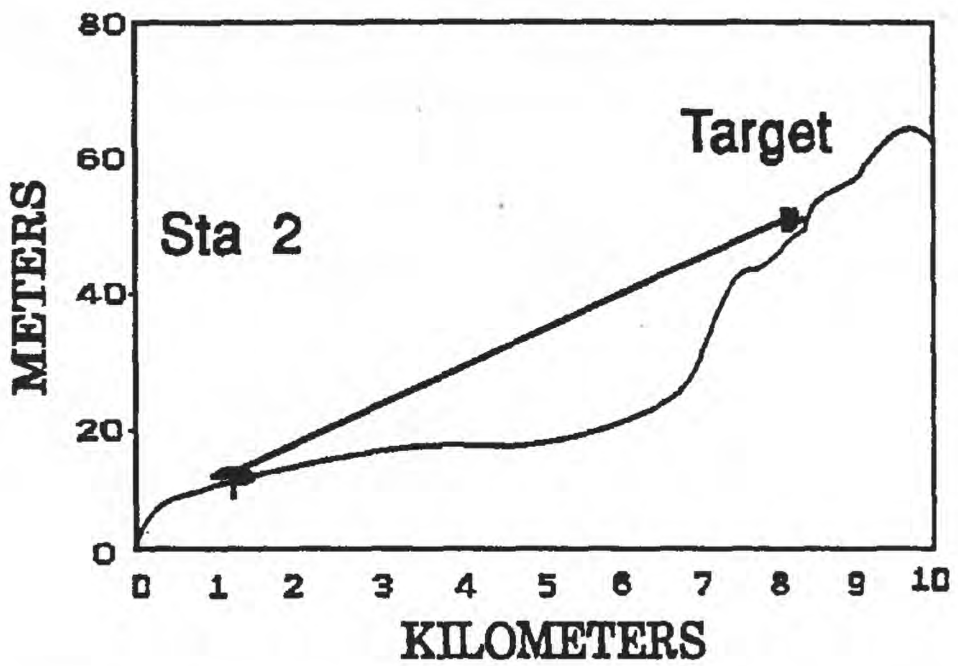


Figure 14h. Draw a connecting line between the station and the target. If resulting figure shows that the straight line does not intersect the plotted elevations, then the bench mark location may be a good one. ** Remember that vegetation around the bench mark location may grow and may block the line-of-sight **

Consider the effects on landscape by the products of volcanic activity when choosing the final location site for the bench mark. Mudflows can erode and bury the site if it is located in a valley bottom. Ash falls can also bury the site so good location notes are important to find the buried bench mark. Placement of the bench mark out of any drainage is a good idea. If possible, place the bench mark on the crest of a ridge rather than on side slopes (fig. 15).

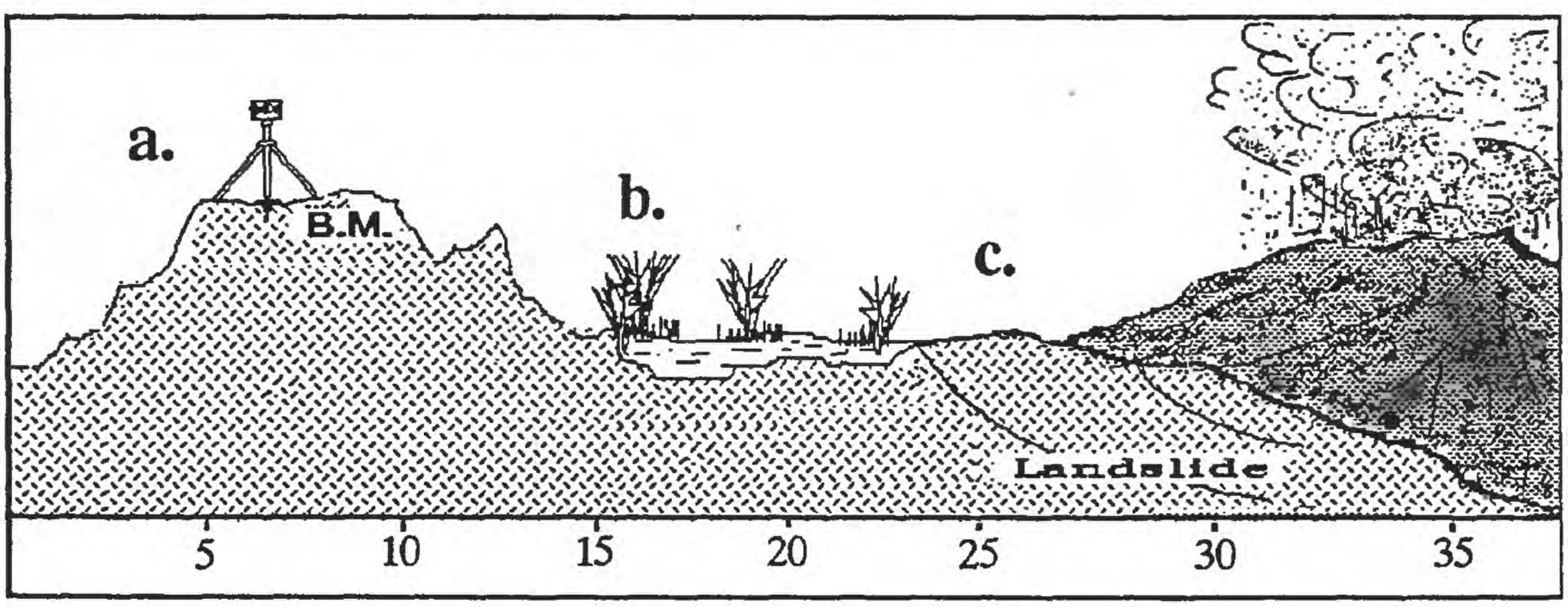


Figure 15. Schematic drawing indicating best placement of a bench mark near an active volcano. Safe high ground (a) avoiding swampy (b) or unstable ground (c).

This placement also helps minimize the effects of slope creep. Be aware of local ground conditions while looking for good sites. Avoid swampy areas where the ground is wet and not stable, or sloping ground where downhill movement of the surface could move the mark (b). If bedrock is present the bench mark should be placed in as flat a spot as possible with room to set up the instrument tripod. Bedrock substrate helps eliminate seasonal effects caused by frost heave or other surficial movements at the site. Unconsolidated substrate requires more hardware to support the bench mark in the ground and a concrete foundation is needed for stability. Avoid mixing substrate in the single setup leveling arrays, place bench marks on the same type of ground so that any disturbance will effect all the marks in the same manner. Leveling traverses commonly follow roads due to their good accessibility. Location of the bench marks need to be off the road bed away from traffic. Because of traffic, souvenir hunters, and vandals, the bench marks should be located out of sight in high-traffic areas. Do not place bench marks in the middle of cultivated fields where plowing will disturb the site.

Even after the installation of the bench mark, the stability of the mark should still be evaluated while collecting data. Seasonal movement of the ground around the mark may give false measurements, so the results of the deformation measurements need to be continually compared with fixed points called backsights (fig 16).

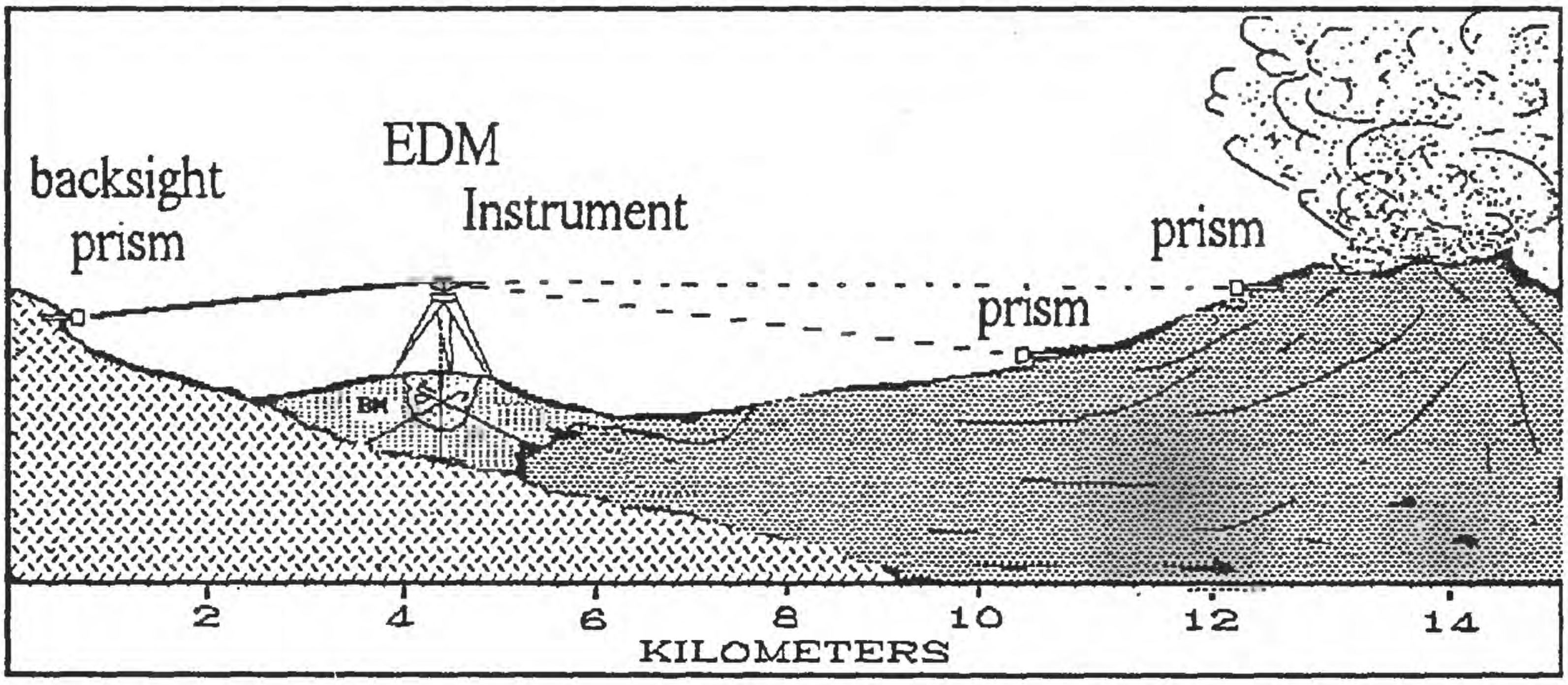


Figure 16. Schematic drawing showing position of a backsight prism used to test reliability of an installed instrument bench mark of a EDM deformation network. Note bench mark underneath the EDM instrument.

Backsight lines are measured away from the volcano to areas of presumed stability and are illustrated here as perpendicular lines pointing away from a dike in figure 17a or radial lines pointing away from the volcano as in figure 18.

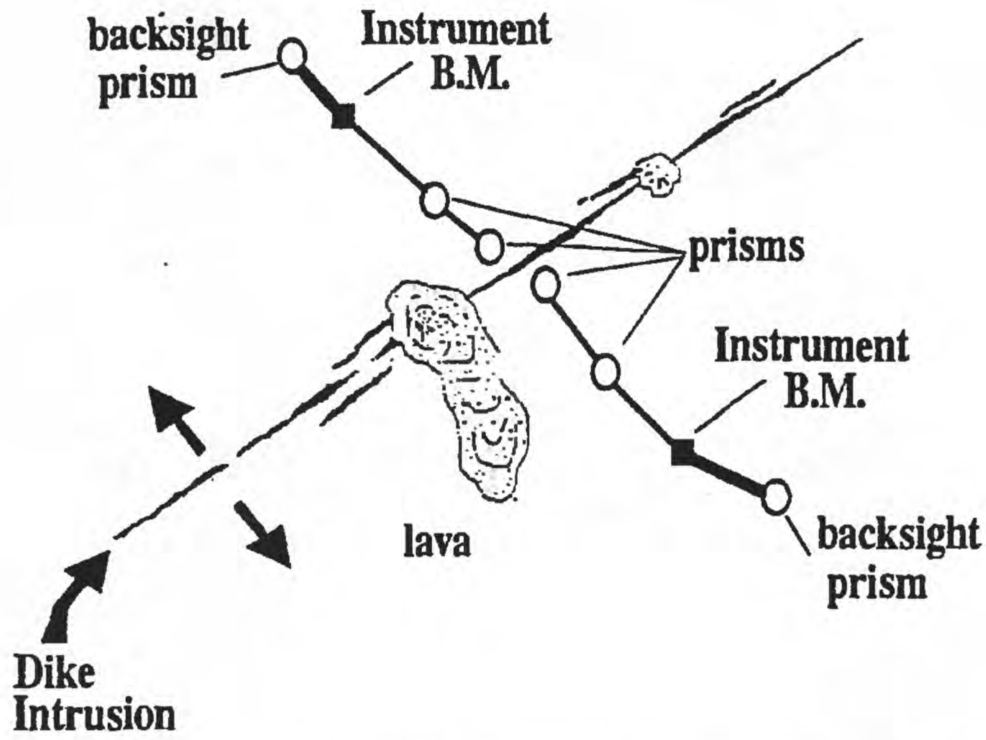


Figure 17. Schematic drawing of an EDM deformation network, perpendicular to a suspected dike emplacement with location of a backsight prism. Bench marks, filled squares; reflector prisms, open circles.

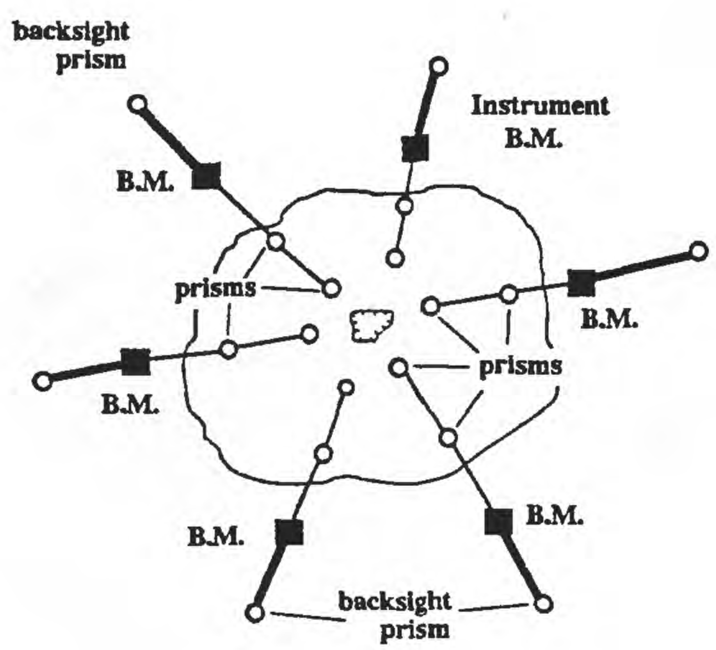


Figure 18. Schematic drawing of an EDM deformation network, radial to an active volcano with location of a backsight prism. Bench marks, filled squares; Reflector prisms, open circles.

Bench Mark Types

The permanent bench mark installation can require a one-time visit and can be set up by one person. The nature of the substrate at a proposed bench mark site is usually unknown prior to arrival on the volcano. The installation might require attachment to hard rock which is most desirable or ash-sand or altered-rock substrate. The situation may call for a permanent or temporary reference point (fig. 19).

		BOLT
	PERMANENT	BENCH MARK
BEDROCK		
	TEMPORARY	PK NAIL
		BOLT
	PERMANENT	BENCH MARK
UNCONSOLIDATED SUBSTRATE		
	TEMPORARY	REENFORCEMENT-BAR

Figure 19. Flow chart showing relation between possible bench mark site conditions, substrate, situation requirements and bench mark types.

With these conditions in mind, four types of bench marks are used. Each one is for a specific condition that may be encountered in the field. All permanent type bench marks must be resistant to corrosion. The benchmarks we use are made of brass or aluminum, and the bolts are made of stainless steel. The stainless steel bolt is used as a permanent bench mark in hard rock outcrops (fig. 20).

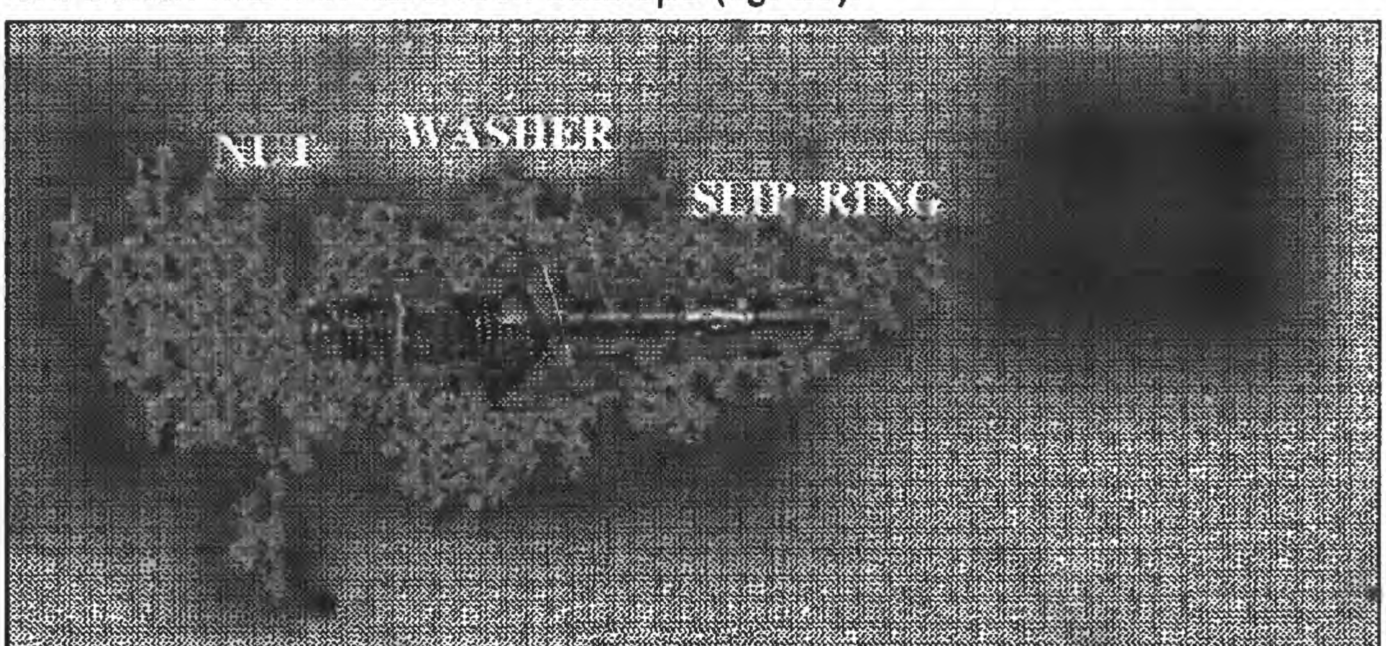


Figure 20. Photograph of a stainless steel bolt. Approximately 4 inches in length, includes nut, washer, and locking slip ring.

The Brass Bench mark (fig. 21) can be used as a permanent bench mark in both hardrock and unconsolidated substrate locations.

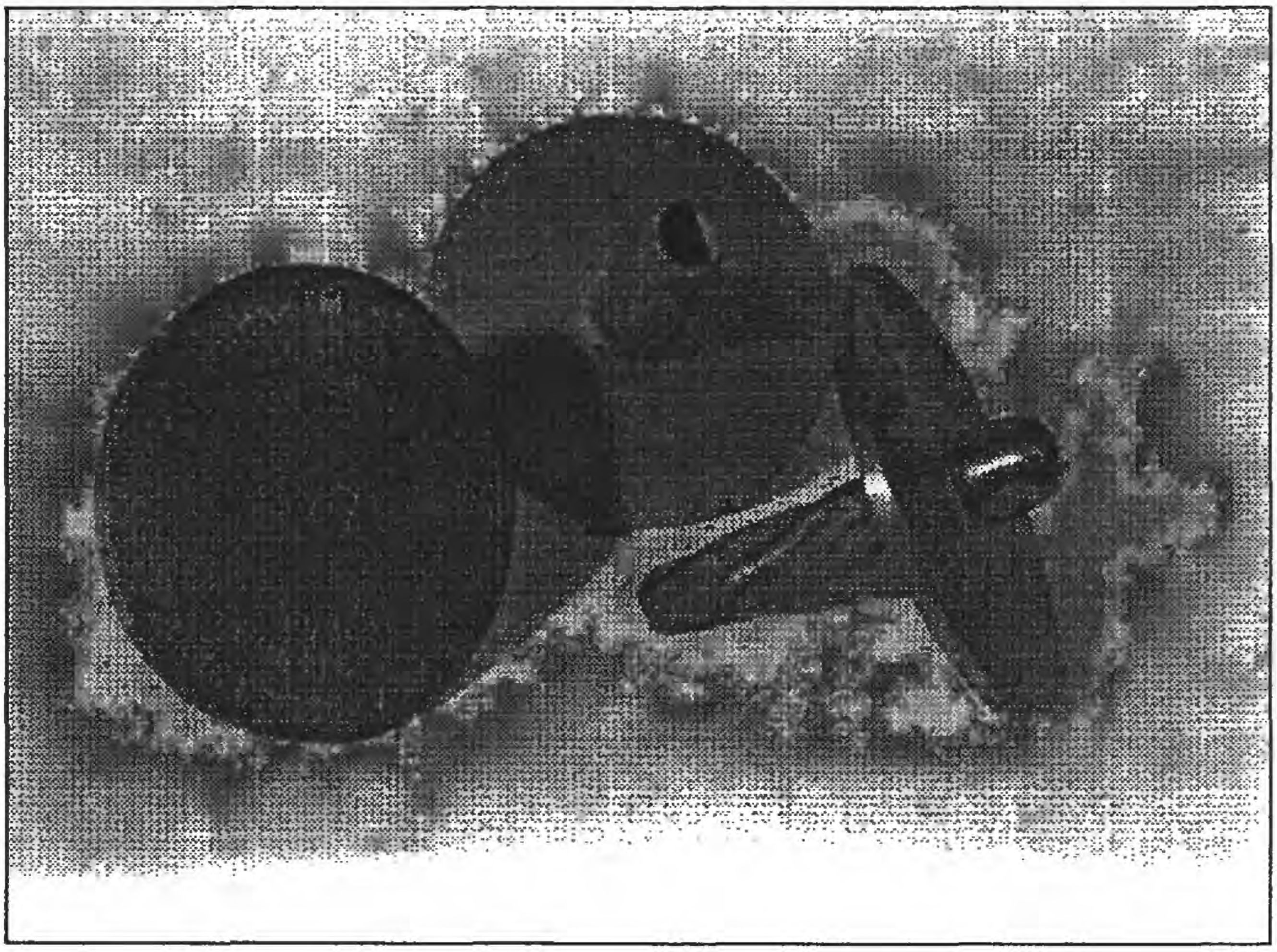


Figure 21. Photograph showing brass bench mark types. Classic mushroom shape, with smooth head form EDM networks, nippled head for leveling surveys (fluted stem for holding strength in concrete and hollow stem for connection to rod during unconsolidated substrate emplacement).

During leveling surveys, the PK nail is used as a temporary point in bedrock or paved road surfaces and a reenforcement rod can used as the temporary point in soft ground.

Tools Required

Depending on the nature of the substrate and whether permanent or temporary bench marks are needed, a variety of hardware and tools is required. A complete list of tools required is shown in Table 1 (further discussion in Doukas and Ewert, 1992). Tool sizes and dimensions used in this report are typical for vendors in the United States, metric conversions are used where appropriate.

Table 1. Tools required for installation of bench marks on active volcanoes.

TOOLS	STEEL BOLT	BENCH MARK	PK NAIL	REENFORCEMENT ROD
1/2 inch diameter steel anchor bolt	X			
brass bench mark, 3/4 inch stem		X		
PK nail, various lengths			X	
2-m reenforcement rods, 3/8-1/2 inch (9-13 mm) diameter		X		X
Hammer, 1/2 to 1 kg	X		X	
Sledge hammer, 2-4 kg		X		X
Star drill, 1/2 inch	X			
Star drill, 3/4 inch		X		
Portable hammer/drill (battery operated) with spare batteries	X	X		
Bit, 1/2 inch	X			
Bit, 3/4 inch		X		
Wrench, 3/4 inch	X			
Plastic tubing, trowel, water, plastic sheet, portland cement, plastic bags,	X	X		
Shovel, trowel, water, plastic sheet, mortar (1 part cement, 3 parts clean sand, 2 parts water), plastic bags, gravel, and stones			X	X

BENCH MARK INSTALLATION

Permanent Installation of a Stainless Steel Bolt into Hard Rock

The stainless steel bolt, is used for quick and permanent installation in hard rock locations (fig. 20). The bolt consists of a four inch shaft; it is threaded at one end, with a nut and washer and has a locking ring located at its base. The nut is turned up to protect the threads when the bolt is hammered into a drilled hole. A wrench is then used to tighten the nut which pulls the shaft up, which then slides the locking ring down the shaft and locks the bolt into the hole. This bolt can be used immediately after installation. The tools required for installation of the bolt are listed in table 2.

Table 2. Tools required for installation of anchor bolts into hard rock.

Hammer
Star drill, 1/2 inch
or
Portable hammer/drill (battery operated)
Spare batteries
Bit, 1/2 inch
Wrench, 3/4 inch
Plastic tubing, trowel, water, plastic sheet, portland cement, plastic bags

To make the installation as fast as possible at hard rock outcrops, a battery operated hammer/drill can replace the hand held star drill (fig. 22). It uses 1/2 or 3/4 inch hardened drill bits. The drill shortens drilling time from 20-30 minutes or more to several

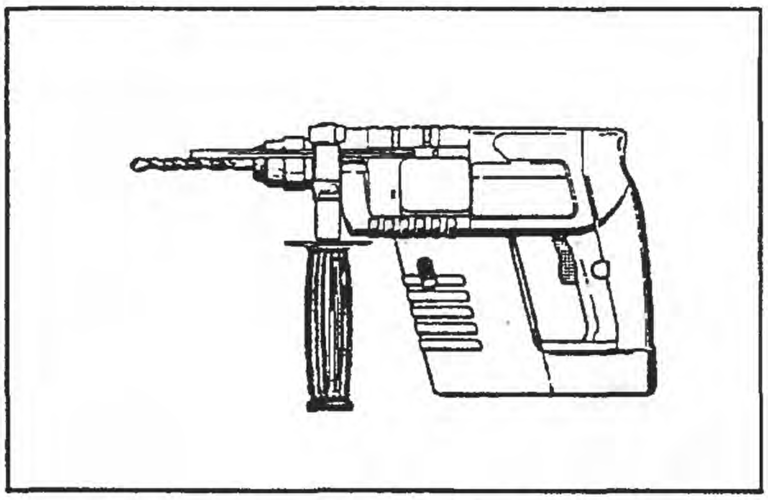


Figure 22. Schematic drawing of a battery powered hammer/drill. Drill can be obtained in a gasoline powered version.

minutes, increasing the number of stations installed per day and decreasing the exposure time to volcanic hazards.

If it is required to hike or helicopter to the bench mark site carry pre-measured cement in plastic bags. Fill each plastic bag with about a liter of dry portland cement (NOTE: Latest recommendation from the Geodetic survey = no sand or gravel). This should be more than enough for one bolt installation. In the field, add approximately 1/3 to 1/2 liter of water to the dry mixture. Mix this mixture well in the plastic bag for two or three minutes to produce a smooth, homogeneous mixture, that can be easily worked with a trowel. You may want to practice mixing a bag at the office before going out into the field. Using a plastic bag to mix the cement produces a clean cement uncontaminated with leaves or soil that may be found on the ground near the site.

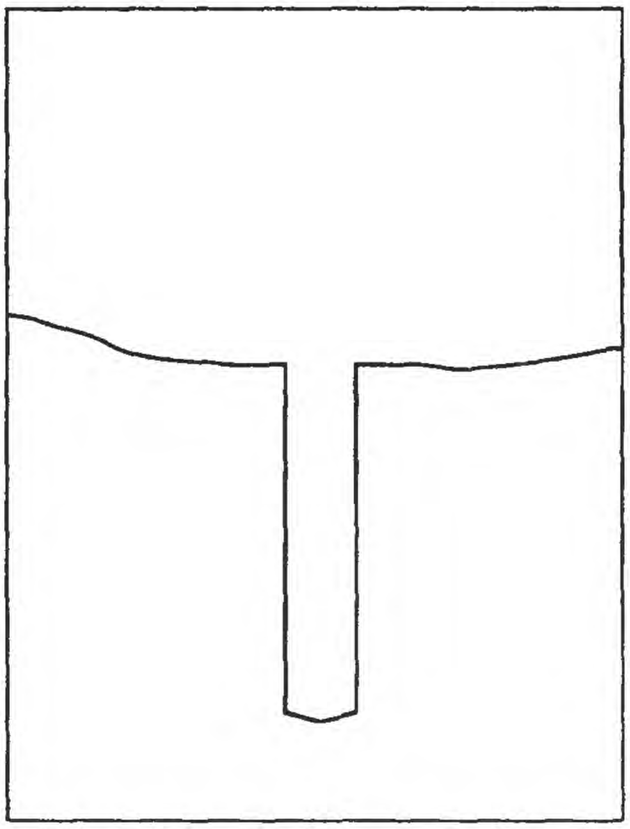


Figure 23a.

When installing the stainless steel bolt, a 1/2" dia., 4" deep hole is drilled, using a star drill or the battery operated hammer/drill (fig. 23a). Then a plastic tube is used to blow out rock fragments from the hole. Any plant fragments or soil is removed from around the hole.

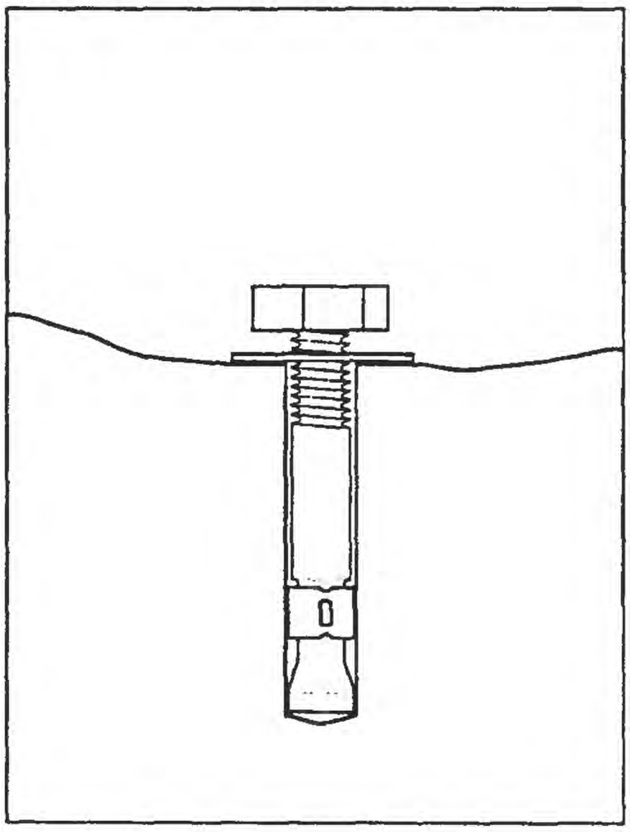
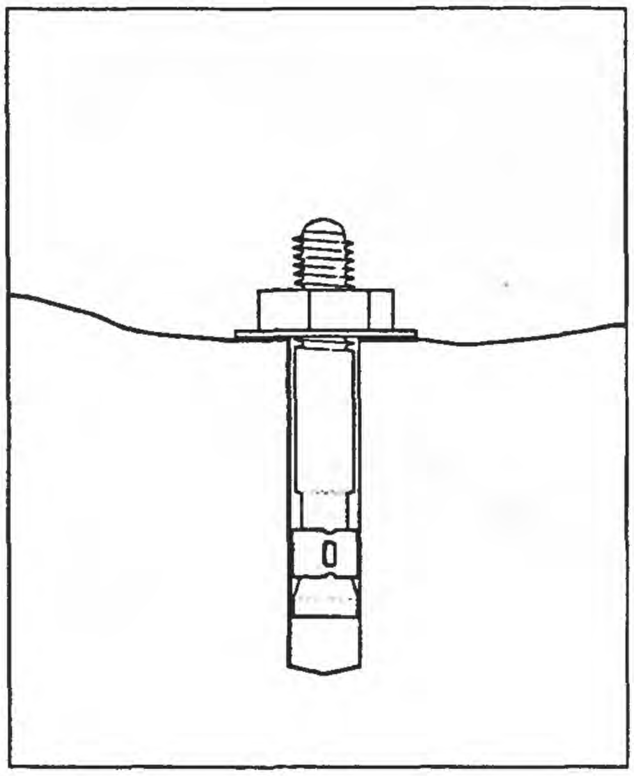


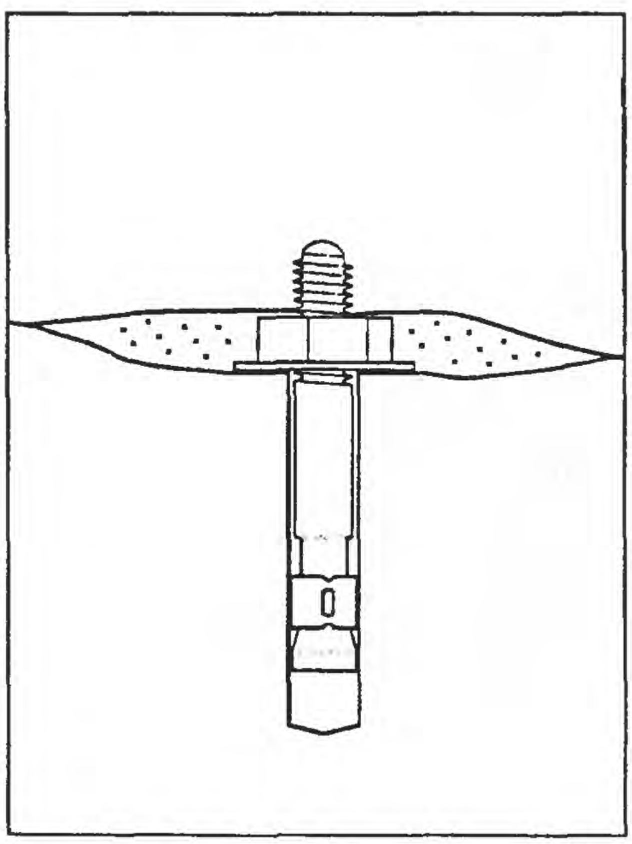
Figure 23b.

With the threads protected by turning the nut to the end of the bolt, the anchor bolt is hammered into the hole until firmly seated (fig 23b).



The nut is then tightened, drawing the bolt upward, this slides the rear locking ring on the bolt into a tight and locking position (fig. 23c).

Figure 23c.



A mortar patch is then placed around the nut and head of the bolt for further protection (fig. 23d).

Figure 23d.

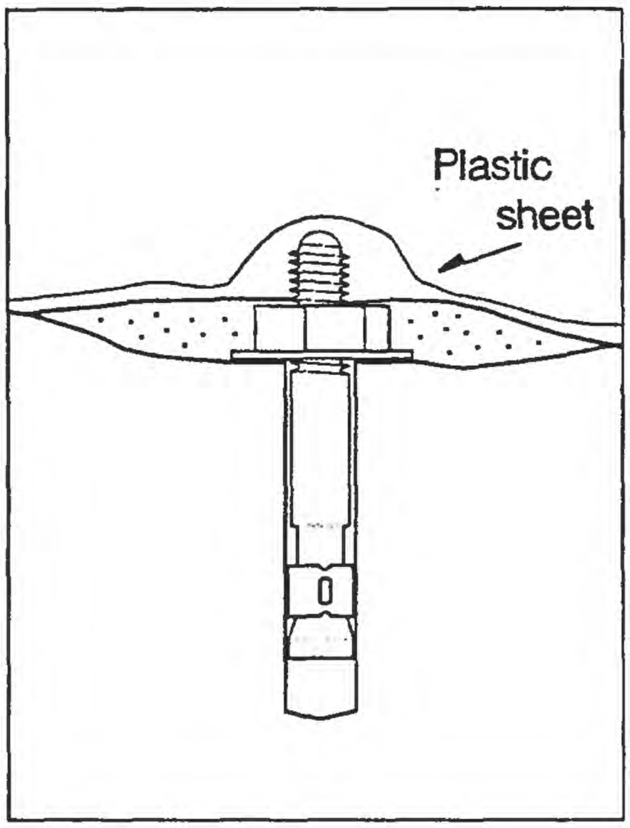


Figure 23e.

The last step when working with mortar is to cover the patch with a piece of plastic to help the patch cure properly (fig. 23e).

Permanent Installation of a Brass Bench Mark into Hard Rock

The brass bench mark can be installed permanently into hard rock and soft ground locations. It is typically constructed of cast brass, mushroom shaped, with a 4 in diameter head and three inch stem. Usually there are identifying labels and numbers on the upper surface (fig. 21). To give the bench mark better grip in concrete, the stem has a twisted, fluted shape. Another style of bench mark has a hollow stem. A small air hole should be drilled through the cap to let air out from under the cap when the bench mark is being placed into wet mortar.

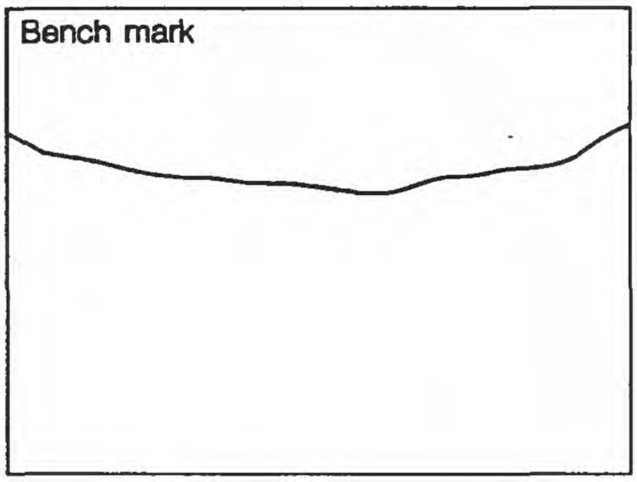
There are two models of the brass bench mark. A flat-headed bench mark for use in EDM networks and a nippled bench mark for use in precision leveling surveys. Set into concrete, the site is not permanent until the concrete has properly cured.

The tools required for installation of the brass bench mark into hard rock are listed in table 3. Use of the battery-operated hammer drill with a 3/4 inch bit will shorten rock

Table 3. Tools required for installation of a brass bench mark into hard rock.

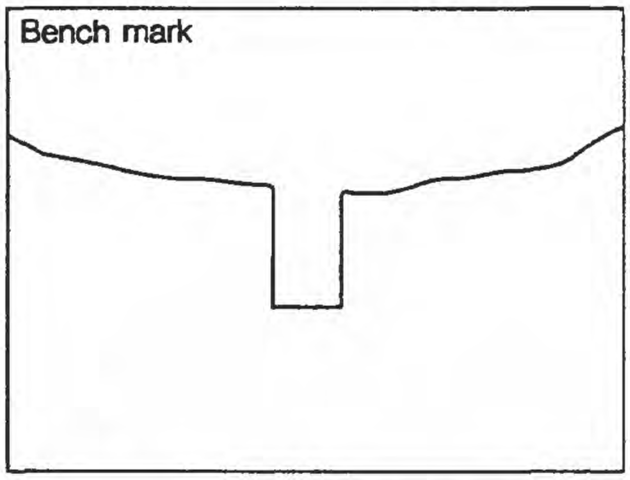
Hammer
Star drill, 3/4 inch
or
Portable hammer/drill (battery operated)
Spare batteries
Bit, 3/4 inch
Plastic tubing, trowel, water, plastic sheet, portland cement, plastic bags

preparation time. Carry plastic bags with portland cement into the field. One bag should be sufficient for a bench mark in hard rock (don't forget water).



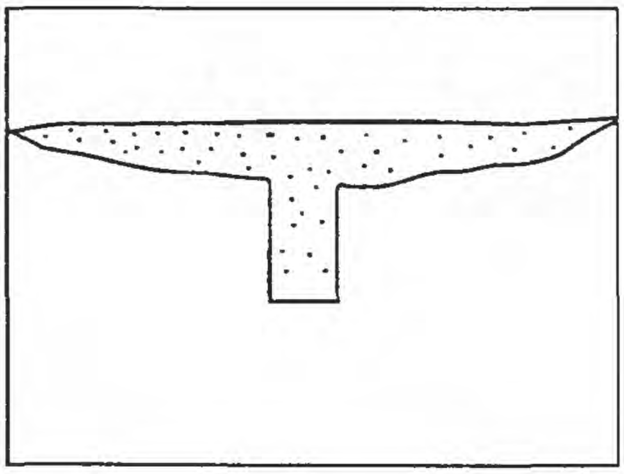
For the installation of the brass bench mark in a hard rock site, try to select a small slightly concave surface to hold a mortar patch (fig. 24a).

Figure 24a.



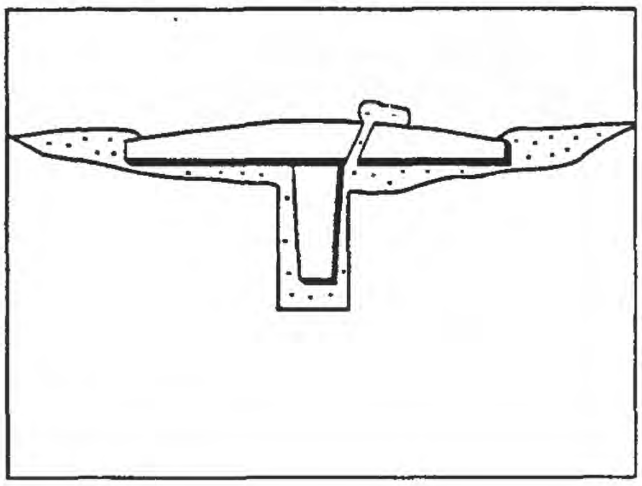
Drill a 3/4 inch diameter hole about 4 inches deep near the center of the low spot (fig. 24b). The next step, is to take the plastic tube and blow away the rock dust caused by the drilling. Clear away any soil or plant material nearby. To improve the holding power of the mortar, wet down the surface around and in the hole.

Figure 24b.



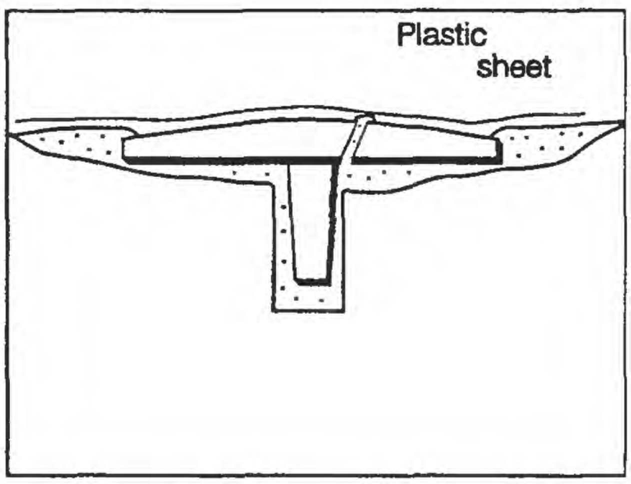
Mix up a batch of mortar and place it in and around the hole (fig. 24c).

Figure 24c.



Place the bench mark into the hole, seating it firmly into the mortar (fig. 24d). Check to see if mortar comes out of the airhole, indicating a good seal. More mortar may be added around the rim of the mark to slightly cover the top edges.

Figure 24d.



The last step when working with mortar is to cover the patch with a piece of plastic to help the patch cure properly (fig. 24e). This bench mark can be used imediately as a stable reference point (EDM monitoring, using an optical plummet) as long as you do not touch the mark (do not set a level rod on the mark until the cement has cured).

Figure 24e.

Permanent Installation of a brass bench mark into unconsolidated substrate

If unable to find a hard rock outcrop it will be necessary to construct a foundation for the bench mark. In areas where the ground freezes concrete foundations are required that must reach below the frost line to prevent the effects of frost heave. The preferred method of installing a vertically stable bench mark in unconsolidated substrate is to attach the bench mark to a single length of rod that has been driven as far as possible (to refusal) through the bottom of a shallow hole (fig. 25).

This installation is not good for horizontal control work unless the bench mark can be prevented from sideways sway by backfilling around the mark. Two-meter-long stainless steel or copper-clad steel rods are driven with a gasoline-powered hammer/drill or sledge hammer. Total refusal is 25 to 30 seconds of operation of the hammer without movement. If total refusal is not met in the first 2 meters, a second rod is coupled to the first with a threaded and crimped coupling, and driving is resumed. This procedure is repeated until total refusal. If the supply of rods is exhausted or total refusal not achieved, the bench mark should be identified as potentially unstable. In areas with deep tephra, the total rod length may approach 15-20 m. Once at refusal, the exposed portion of the rod is trimmed to the desired length and a hollow-stemmed bench mark is attached with a hydraulic crimper. The weight and bulk of the tools needed make this sort of installation better suited to truck- or helicopter-supported operations. Floyd (1978) gives more detailed descriptions of the method.

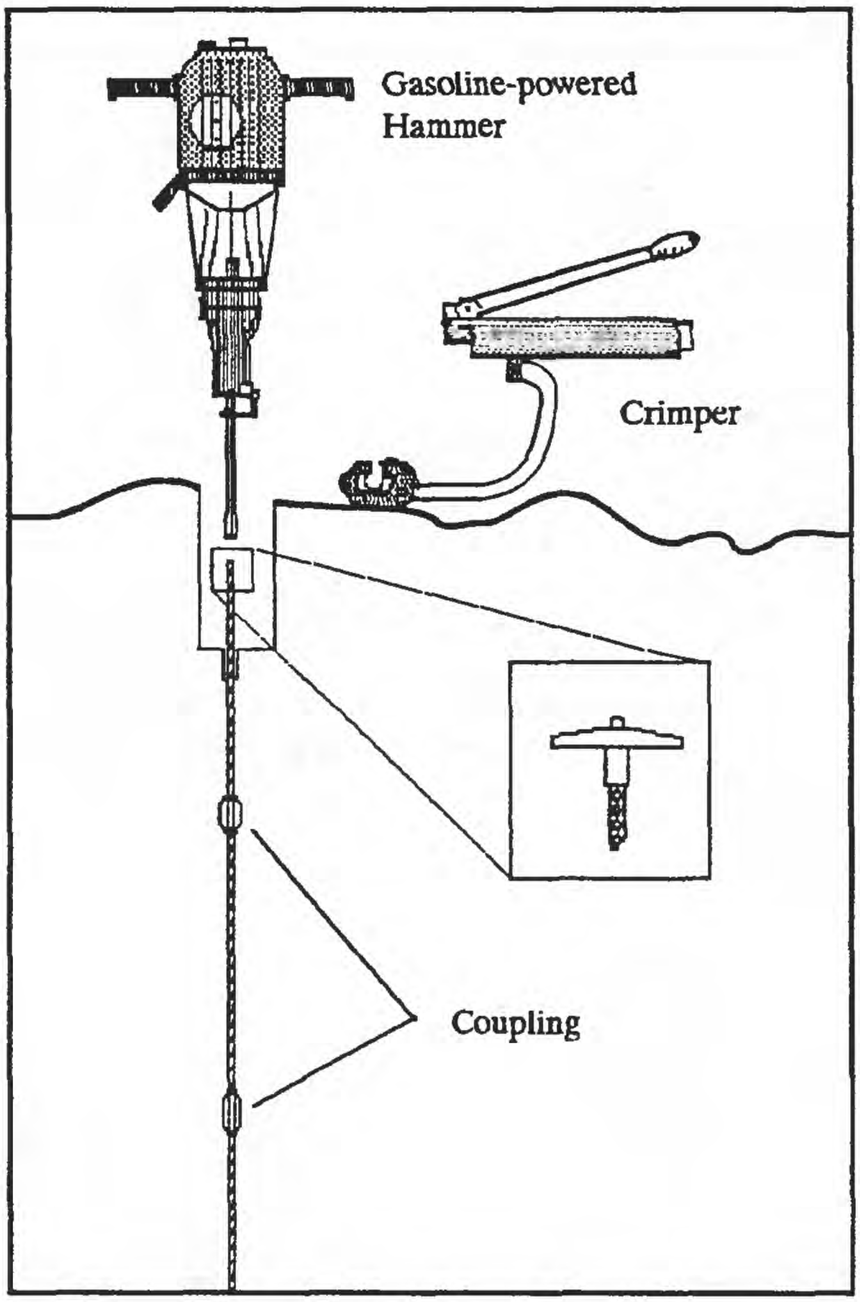


Figure 25. Illustration showing the use of a large-gasoline powered hammer-drill for driving steel weld rod into soft ground during installation of a bench mark. A gasoline-powered hammer drives weld rod to refusal. Weld rod is coupled together using a hydraulic crimper. A hollow stemmed bench mark is crimped onto the rod after refusal has been reached and the rod cut to length.

The method described here, follows the same technique but is more laborious. Instead of weld rod, half inch or greater diameter reenforcement rod is used and hammered into the ground by hand. The tools required for an installation of the brass bench mark into unconsolidated substrate are listed in table 4. This method requires

Table 4. Tools required for bench mark installation in unconsolidated substrate

Sledge hammer
Three 2-m reenforcement rods, 9-13 mm diameter
Shovel, trowel, water, mortar (1 part cement, 3 parts clean sand, 2 parts water) stones, gravel and stones, plastic sheet

more mortar, gravel and stones than the installation of a bench mark into hard rock method. Normally more than six liter bags are needed (1 part cement to 3 parts clean sand). If a vehicle is available to transport materials, use 100 pounds of mortar. Mix with water in the field.

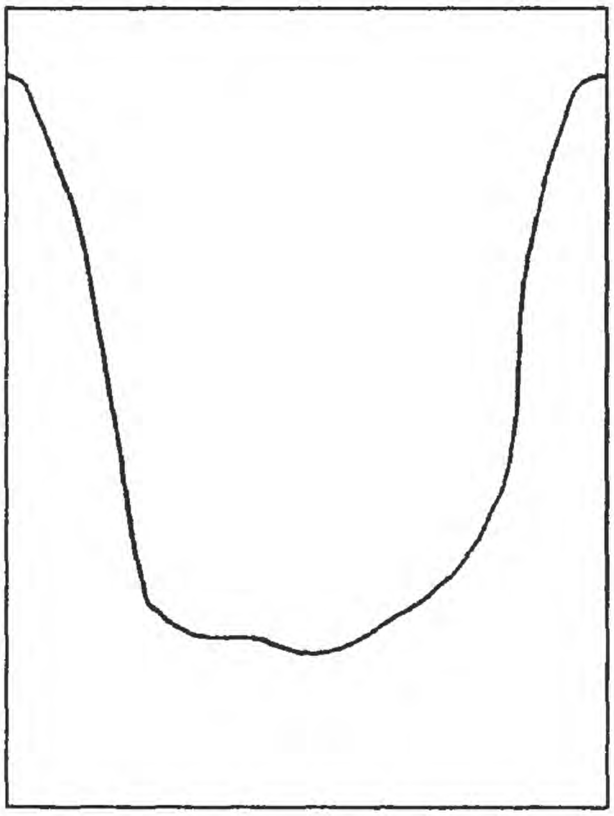


Figure 26a.

To begin construction of the foundation dig a hole about 0.3 m in diameter and about one meter deep (fig. 26a).

Three 3/8 to 1/2 inch reenforcement rods are driven into the ground at a 60 degree angle, at the bottom of the hole. The ends of the rods are bent over, back into the hole (fig. 26b and 26c).

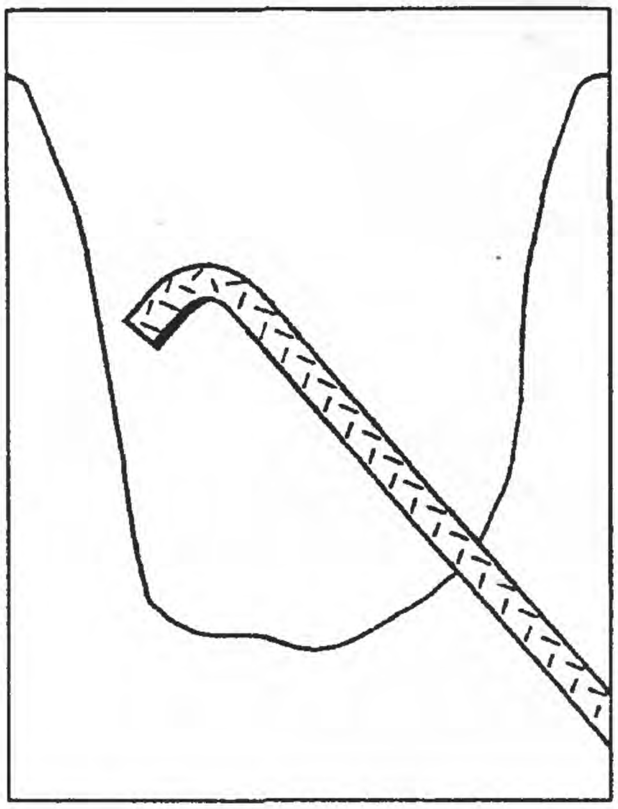


Figure 26b.

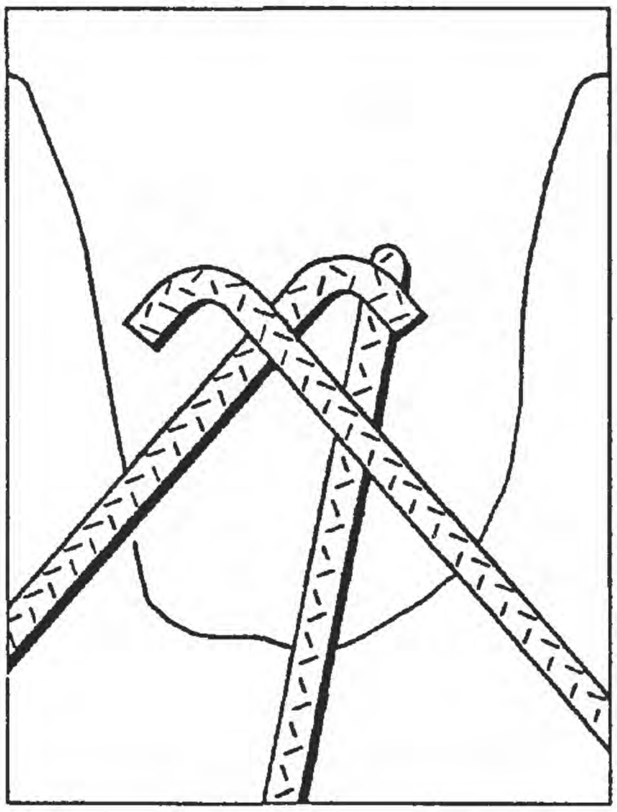
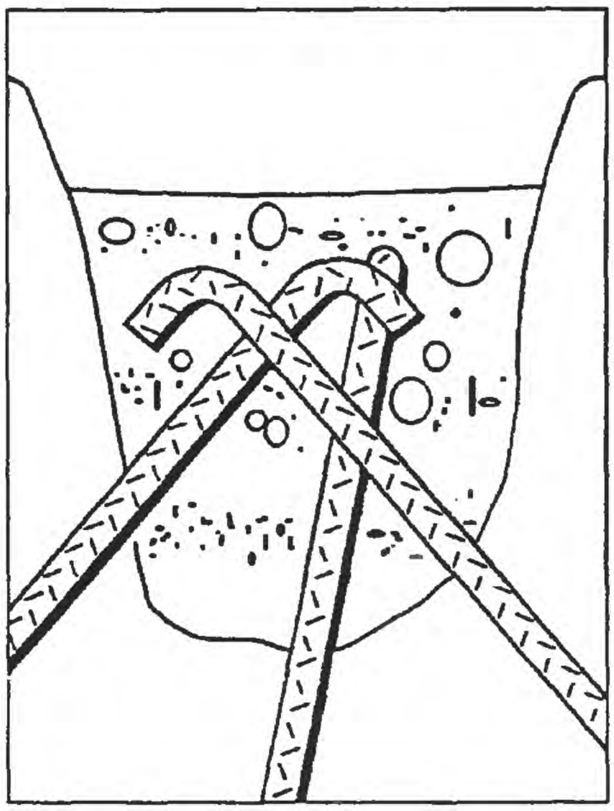
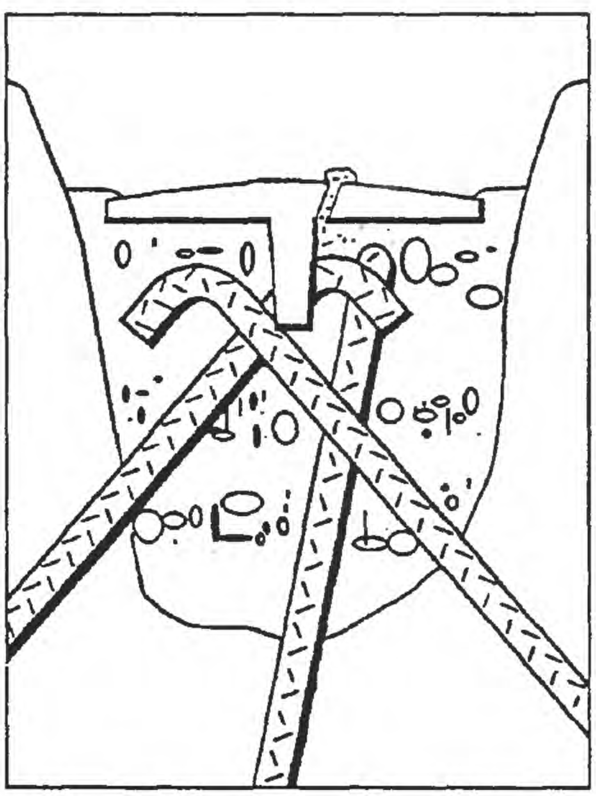


Figure 26c.



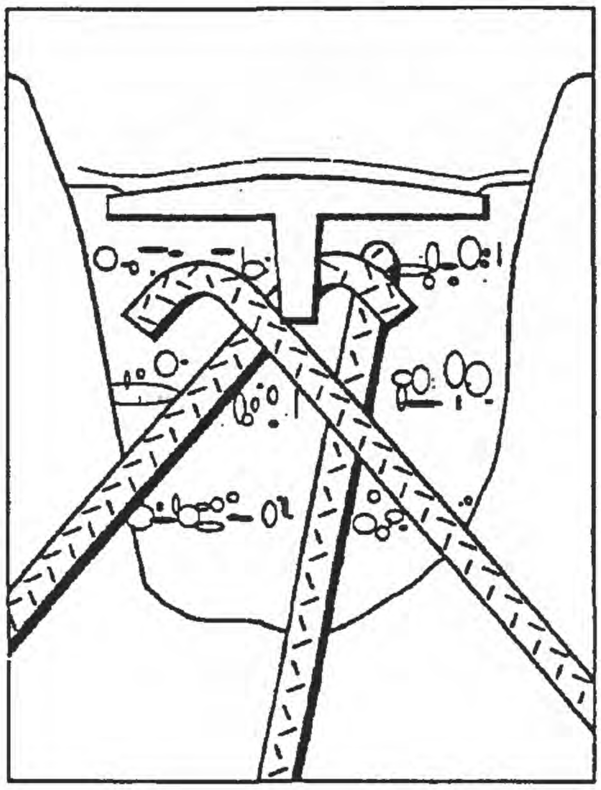
The hole is then filled with layers of rocks, mortared together (fig. 26d). The use of about one bag of premixed concrete (90 pounds [40 kgs]) is sufficient. In the field purchased supplies may be cement and the use of sand and gravel from near the site reduces carry-in weight. Pre-wetting down the rocks will give the mortar better grip. There now is a support structure (rods) that will hold on to the concrete of the foundation and add to the stability of the bench mark.

Figure 26d.



The bench mark is then placed into the wet mortar (fig. 26e). Mortar should squeeze out of the air hole in the top of the cap. This shows that all the air is out from under the cap and a good seal has been made with the mortar underneath. Take a trowel, and work some of the mortar just over the lip, do not cover up any markings on the top. Cover enough of the edge to add to the holding power of the mortar. A good seal is very important for the stability of the bench mark especially in areas where freezing ground occurs, which can loosen the mark by frost wedging. A stainless steel bolt shown in figure 19 can replace the brass bench mark in the mortar. Place the bolt with nut, threaded end down into the mortar.

Figure 26e.



The last step when working with mortar is to cover the patch with a piece of plastic to help the patch cure properly (fig. 26f).

Figure 26f.

Temporary Installation of a PK Nail into Hard Rock

During leveling surveys or EDM work temporary marks are needed. For temporary bench marks in hard rock a PK nail is used. The nail is a zinc-plated hardened steel masonry nail that can easily be driven into any crack that is found along a level line (fig. 27). The tools required for installation are the PK nail and a hammer.

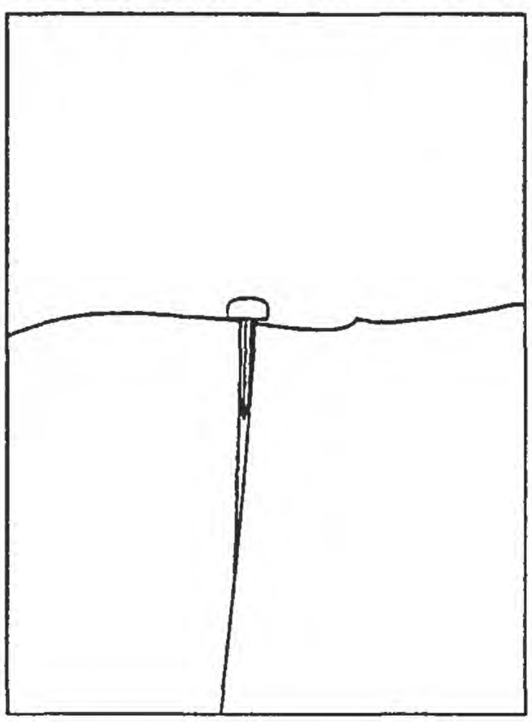


Figure 27. Schematic drawing of an installed PK nail used as a temporary bench mark. The nail can be 20 to 50 millimeters in length.

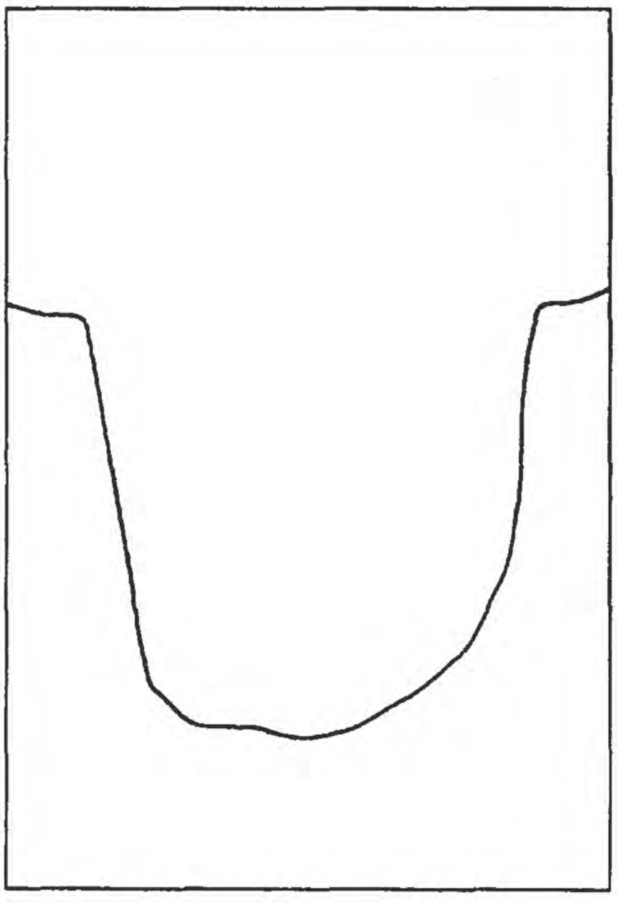
Temporary Installation of a Reenforcement rod into Unconsolidated Substrates

The 1/2 inch reenforcement rod used is approximately 1.5 meters in length and is used as a temporary point in tilt-leveling survey traverses (fig. 8). It is driven into unconsolidated substrates by hand and hardened with a collar of concrete.

The tools required for installation of the reenforcement rod are listed in table 5.

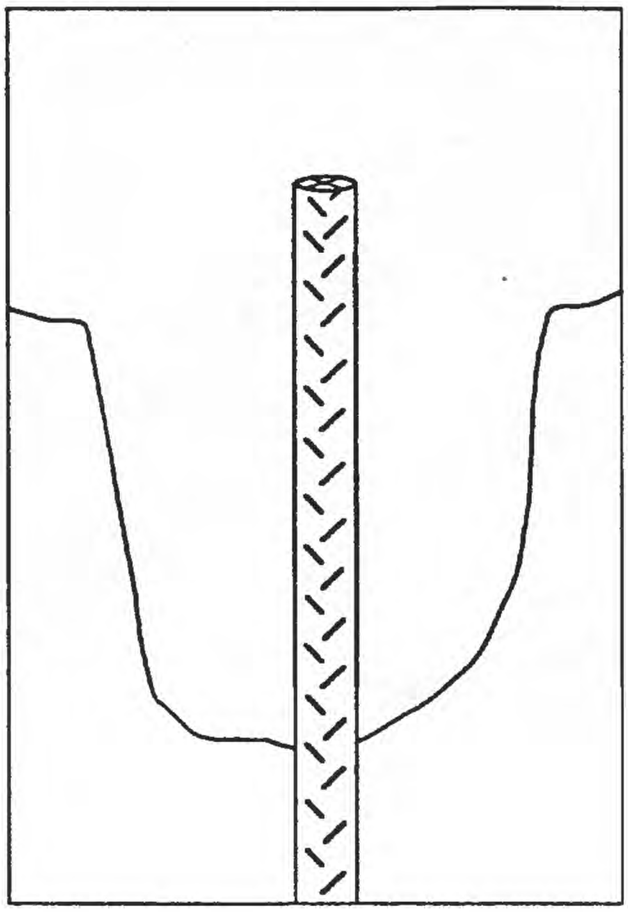
Table 5. Tools required for Reenforcement rod in unconsolidated substrate

Sledge hammer
One 2-m reenforcement rod, 3/8-1/2 inch (9-13 mm) diameter
Shovel, trowel, water, plastic sheet, mortar (1 part cement, 3 parts clean sand, 2 parts water), gravel and stones



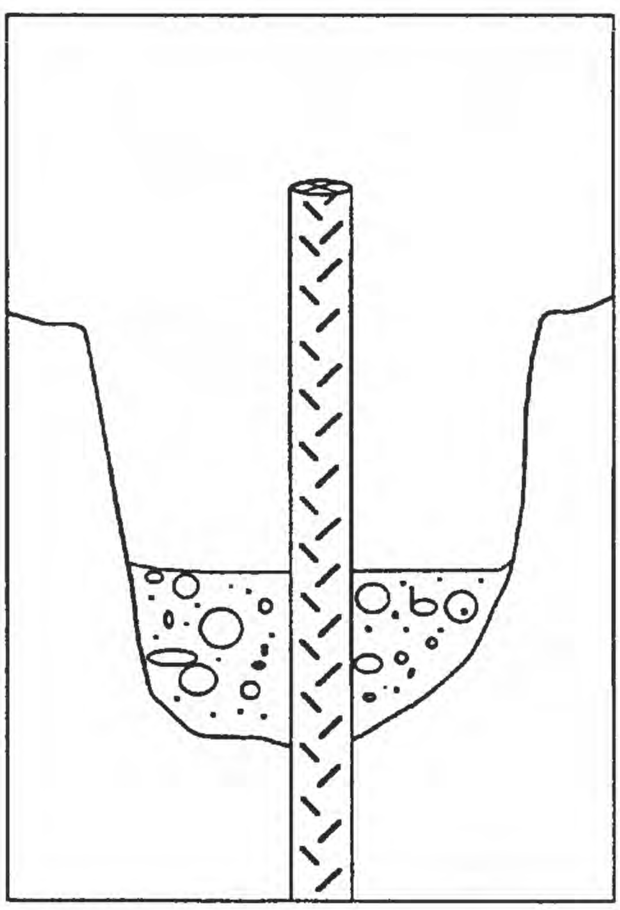
Installation is similar to the construction of the concrete platform for the brass bench mark. A smaller volume hole is used. About 0.3 meter across and 0.5 meter deep (fig. 28a).

Figure 28a.



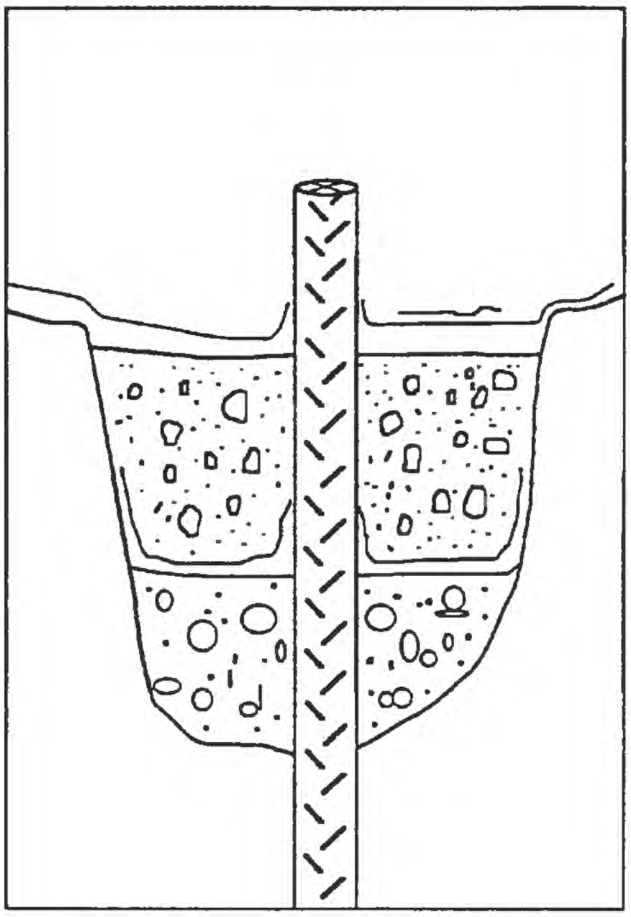
A single rod is driven vertically into the hole leaving the tip at about ground level (fig. 28b).

Figure 28b.



A collar of rocks and two liter bags of wet mortar is formed around the rod leaving several centimeters of rod exposed (fig. 28c).

Figure 28c.



A plastic sheet is placed over the collar to help the mortar cure properly. Back fill the hole with excavated material. Figure 28d shows a side view of an installed bench mark in soft substrate.

Figure 28d.

If the temporary point is to be used in trigonometric leveling cut a cross in the end of the rod with a metal file. This cross provides a target for an optical plummet, plumb-bob or seat for the center of a tripod leg. The reenforcement rod is not corrosion resistant. To protect it from the elements apply grease or vaseline all around the exposed end. This will allow instruments to be set up on the rod and still water proof it.

SUMMARY

The instrument-target leg of a deformation net requires an established bench mark at the instrument station. For reliable measurements, the stability of the instrument bench mark is of prime importance. Two possible conditions exist at possible bench mark sites, hard rock or soft sediment substrate. At hard rock sites, a stainless-steel anchor bolt is driven into a drilled hole, or a brass bench mark is cemented in place. At soft ground locations, reenforcement rods are driven into the ground and the site is then hardened with a foundation of concrete and a brass bench mark rod is set into the concrete.

The proper installation of a stable bench mark becomes the first and important step in preparing monitoring networks at volcanoes. A well placed and monitored geodetic network can help to assess possible hazards to both lives and property and allow for minimizing the effects of volcanic eruptions.

REFERENCES CITED

Banks, N.G., Tilling, R.I., Harlow, D.H., and Ewert, J.W., 1989a, Volcano monitoring and short-term forecasts, in Tilling, R.I., ed., Volcano Hazard, Short Course in Geology, Volume 1: American Geophysical Union, Washington D.C., p. 26-80.

Banks, N.G., Carvajal, C., Mora, H., and Tryggvason, E., 1989b, Deformation monitoring at Nevado del Ruiz, Colombia-October 1985-March 1988: Journal of Volcanology and Geothermal Research, v. 41, p. 269-295, Elsevier Scientific Publishing Co., Amsterdam, The Netherlands, p.87-115.

Chadwick, W.W., Jr., Swanson, D.A., Iwatsubo, E.Y., Heliker, C.C., and Leighley, T.A., 1983, Deformation monitoring at Mount St. Helens in 1981 and 1982: Science, September 30, 1983, v. 221, no. 4618, p.1378-1380.

Chadwick, W.W., Jr., Iwatsubo, E.Y., Swanson, D.A., and Ewert, J.W., 1985, Measurement of slope distances and vertical angles at Mount Baker and Mount Rainier, Washington, Mount Hood and Crater Lake, Oregon, and Lassen Peak, California, 1980-1984: U.S. Geological Survey Open-File Report 85-205, 96 p.

Doukas, M.P. and Ewert J.W., 1992, Installation of Bench Marks and Permanent Reflectors for Geodetic Deformation Networks, in Ewert, J.W. and Swanson, D.A., eds., Monitoring Volcanoes: Techniques and strategies used by the staff of the Cascades Volcano Observatory, 1980-90: U.S. Geological Survey Bulletin 1966, p.115-124.

Dzurisin, Daniel, 1992, Geodetic leveling as a tool for studying restless volcanoes and their surroundings, in Ewert, J.W. and Swanson, D.A., eds., Monitoring Volcanoes: Techniques and strategies used by the staff of the Cascades Volcano Observatory, 1980-90: U.S. Geological Survey Bulletin 1966, p. 125-134.

Ewert, J.W., 1992, A single-setup trigonometric leveling method for monitoring ground-tilt changes: in Ewert, J.W. and Swanson, D.A., eds., Monitoring Volcanoes: Techniques and strategies used by the staff of the Cascades Volcano Observatory, 1980-90: U.S. Geological Survey Bulletin 1966, p. 151-158.

Floyd, R.P., 1978, Geodetic Bench Marks: National Geodetic Survey, National Ocean Survey, National Oceanic and Atmospheric Administration Manual, no. 1, Washington D.C., 52 p.

Kinoshita, W.T., Swanson, D.A., and Jackson, D.B., 1974, The measurement of crustal deformation related to volcanic activity at Kilauea Volcano, Hawaii, in Civetta, L., Gasparini,P., Luongo, G., and Rapolla, A, eds., Physical Volcanology: Elsevier Scientific Publishing Co., Amsterdam, The Netherlands, p.87-115.

Lipman, P.W., Moore, J.G., and Swanson, D.A, 1981, The bulging of the north flank before the May 18 eruption--geodetic data, in Lipman, P.W. and Mullineaux, D.R., eds., The 1980 eruptions of Mount St. Helens, Washington: U.S. Geological Survey Professional Paper 1250, p. 143-155.

McDonnell, P.W., 1987, EDM Survey: Point of Beginning, P.O.B. Publishing Company, Canton, Michigan, v. 13, no. 1, p. 22-32.

Swanson, D.A., Lipman, P.W., Moore, J.G., Heliker, C.C., and Yamashita, K.M., 1981, Geodetic monitoring after the May 18 eruption, in Lipman, P.W. and Mullineaux, D.R., eds., The 1980 eruptions of Mount St. Helens, Washington: U.S. Geological Survey Professional Paper 1250, p. 157-168.

Swanson, D.A., Casadevall, T.J., Dzurisin, Daniel, Malone, S.D., Newhall, C.G., and Weaver, C.S., 1983, Predicting eruptions at Mount St. Helens, June 1980 through December 1982: Science, September 30, 1983, v. 221, no. 4618, p.1369-1376.

Yamashita, K.M., 1992, Single-setup leveling used to monitor vertical displacement (tilt) on Cascades Volcanoes, in Ewert, J.W. and Swanson, D.A., eds., Monitoring Volcanoes: Techniques and strategies used by the staff of the Cascades Volcano Observatory, 1980-90: U.S. Geological Survey Bulletin 1966, p. 143-158.