# Surveys for Detection and Measurement of Subsidence—Why, What & How

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## ABSTRACT

*Subsidence is a change in elevation of the land surface—usually involving a large area and grading from zero at the periphery to a maximum, measured in inches or feet, in the central area. Subsidences do not necessarily culminate in sinkholes; the relationship between subsidence and sinkhole formation is still being investigated.*

*WHY Survey results (and associated maps and data plots) provide the first indication of involvement of the environment; negative results document absence of involvement. Results provide input into decisions to continue, limit, allocate or terminate production from an area and to the efficacy of Solution Mining Plan concepts. In the event of inquiry or litigation by regulatory agencies or neighbors claiming damage, a set of data with adequate background can provide needed documentation.*

*WHAT Subsidence data can be obtained by technicians using access or non-access methods. Non-access methods are reserved for broken ground or other areas where entry is prohibited. Data is obtained by triangulation from safe sites or by airborne methods. All non-access methods are costly. Access methods include triangulation, slope distance or tiltmeter measurements or precise level surveys of a network of monuments. Precise level surveys have many merits—they have proven least costly and most generally applicable.*

*HOW In the precise level method, periodic surveys are run to redetermine the elevation of monuments located in and around the brinefield. Change of elevation for a given monument is interpreted to be subsidence, involving an area half the distance to the surrounding monuments. Monuments and surveys are inexpensive. A plot of settlement (elevation) vs. time for each monument makes the presence or absence of settlement readily visible. A contour map of settlement data for a selected time interval clearly indicates area of involvement.*


## INTRODUCTION

Subsidence is change of elevation observed at the earth's surface usually resulting from removal of subsurface support. Subsidence related to solution mining is thought to be caused by dissolving of salt—usually from bedded deposits and especially by brine fields employing classical methods where cavities joined at the roof and thus undermined large areas. This undermining in turn required the roof rock layers to perform as rim-supported plates—their response was to sag or downwarp as tensile capability allowed. This downwarp, as transmitted to the surface through the underlying section is expressed as subsidence, ranging to zero at the periphery of the involved area.

The correlation between subsidence and sinkhole formation has not been established. Subsidence is downwarping of the earth's surface in response to removal of support, usually non-destructive; a sinkhole is a localized collapse of the surface, usually quite destructive, the culmination of a sequence of events requiring removal of considerable material.

Subsidence related to solution mining activities usually terminates with operation of the cavity since cavity brine saturates and further dissolving, the contributor to roof undermining, terminates. This is in contrast to other extractive technologies (e.g., coal) where pillar deterioration goes on, or even commences, long after operations are discontinued.

## WHY DETECT OR MEASURE SUBSIDENCE

Subsidence surveys of an area dedicated to solution mining operations serve several purposes, as follows:

- They provide real (if delayed by the time lapse between cavity roof downwarp and surface involvement) evidence of the results of Mining Plan, cavity design and rock mechanics calculations. Evidence of presence or absence of subsidence provides an input into production plans and cavity design concepts for future operations.
- Results can be used as input into decisions to continue, limit, allocate or terminate production from

the area involved. Subsequent surveys verify the efficacy of these decisions by responding to changes.

- In the event of inquiry or litigation by regulatory agencies or neighbors, subsidence surveys can delineate areas of activity (or inactivity), can delineate the time of commencement (and termination) and can establish the magnitude of displacements. If measurements are taken by independent outside technicians, only the interpretation of the data is open to question. Background data is a valuable source of defense from nuisance suits related to production activities.

## WHAT TO DO TO DETECT AND MEASURE SUBSIDENCE

Since subsidence is change in elevation of an area, detection and measurement can be accomplished by any of several techniques that will show these changes and allow summaries to be prepared. Techniques now utilized serve to identify areas of involvement and permit topographic maps and sections to be constructed. Comparison of these maps and sections can show change; downward movement is interpreted as subsidence. Techniques for obtaining the necessary data can be classified as access or non-access methods. Non-access methods are reserved for areas where technicians cannot occupy the survey points, usually for reasons of safety. Broken ground is an example. In this case monuments can be dropped on the site from the air or monuments selected from a remote vantage. Surveys are made by triangulation from good ground or by aerial photo techniques. All are expensive and reserved for special applications.

Access methods include slope-distance measurements, tiltmeter measurements showing change in inclination of casings installed for this purpose, and elevation measurements of a network of monuments designated or constructed for this purpose. Elevation measurements are usually taken by the precise level technique. Periodic resurveys provide data indicating change of elevation and the network system can be altered or extended as indications warrant. By virtue of this flexibility and minimum cost of monuments and resurveys, the precise level method has achieved the widest degree of application and employment; it will be discussed further. Other methods are reserved for special applications where their merits warrant.

## HOW TO DETECT AND MEASURE SUBSIDENCE BY THE PRECISE LEVEL METHOD

The precise level method consists of a network of monuments established over the area of interest consisting of designated points on competent structures or monuments constructed for the purpose. Surveys are run to determine elevation of these monuments relative to a base monument located sufficient distance away to be considered to be free of influences from the source under study. Note that elevations relative to sea level are not required nor are they meaningful. Periodic resurveys are run from the base monument to all or selected parts of the reference point network: it is change in elevation of an area represented by the reference point that is an influence of subsidence. The monument can only represent its area of influence (usually one half the distance to surrounding monuments), and its time value is relative to the last previous survey. Thus, each monument is a sample point for elevation and time in an area of study which includes many points; it is the summarization of changes in elevations of these points that delineates areas of interest.

## MONUMENT LAYOUT—GENERAL CONCEPTS

Monuments are laid out to accommodate the needs of the surveyors—usually a circle of 200 feet radius can be encompassed from an instrument station. Surveys originate at a monument known as a Permanent Bench Mark, located several depth-to-salt distances away on ground considered to be free of salt cavity influences and constructed to be free of frost heave, etc. Precise level surveys are run as a continuous chain of readings (backsights and foresights) from each instrument station in closed loops usually 6000 feet in length. Thus a suitable monument must be provided every 400 feet (diameter of the circle discussed above) in this circuit. Other monuments are designated to provide the needed density ("fabric") coverage in the area of interest. It is changes in elevation in the area covered by the monuments that report subsidence. As a rule of thumb, one monument is required per acre; others may be added or deleted as interest varies.

Internal monuments are designated as Reference Points. Reference Points serve as witnesses to changes in their area of influence (one half the distance to neighbors, as discussed above) and should be constructed in a manner to free them of frost heave and other such influences. Since unconsolidated overburden by definition acts as a plastic layer to transmit change in state of the upper bedrock surface without loss, monuments can be constructed in surface layers at nominal cost with expectation of valid indication of change in bedrock configuration.

In monumenting for subsidence monitoring it is important to recognize that subsidence related to solution mining is currently thought to result from removal of support of roof rocks by dissolving of the salt deposit which then causes the roof rocks to sag. It is the vertical component of this sag or downwarp expressed at the surface that is measured and reported as subsidence. The dissolving mechanism which results in removal of salt is controlled by many variables, such as the type of injection, flow paths between wells, the structure of the beds, impurity layers and the roof rocks themselves. The impact of this concept is that although well casings may be utilized as subsidence monuments, they only serve to witness their area of influence, and that they are not necessarily the locus of subsidence. Other surface monuments may be located to complete the fabric overlying the area of extraction; subsequent readings will verify these decisions. Additional monuments may be installed as indications warrant.

## MONUMENT DESIGN AND CONSTRUCTION

Summarizing general concepts of monument layout as discussed above, monuments may be constructed in any area of interest either by converting an existing well or other suitable structure or constructing a shallow monument in the interval between, observing the need to provide suitably monumented backsights and foresights for the surveyor on 400-foot centers.

Monuments may be left projecting two or three feet for ease of location or may be completed flush with grade. Generally it is better to install a flush monument than spend money on defenses, only to subsequently damage expensive mowing, grading or snowplow equipment and create additional obstacles and hazards.

Another design concept is that while access conduits serve to protect the actual measuring point from external forces such as frost heave, climatic effects or mechanical damage, every effort should be made to preclude introduction of granular material in the annular space between conduit and inner rod, since a small amount of granular material in this annulus is as good as cement, and thus bonded, the protection function of the conduit is lost. Similarly, the urge to pour a slab or collar of cement around the conduit is to be resisted, since this serves to provide a rigid bonded area for frost or climatic changes to work on the conduit.

General concepts of reference point construction—both flush and projecting—are presented in the attached sketches. For estimating purposes, total costs should be on the order of $40 to $50 each, since standard pipe and fittings are utilized and installation by a soil boring crew in average brine field terrain should accomplish the installation of 8 to 10 per day.

Each monument should be documented with a sketch showing appearance and location dimensions. A 5″ × 7″ card may be used for this purpose. Copies of these cards may be made for field use. Elevations and dates may be recorded on the back, along with a conversion factor for monuments to be utilized as bench marks for construction activities. Only the front is copied for field use.

## SURVEY PROCEDURES AND RECORD KEEPING

Initial and repeat surveys may be contracted outside. This is good practice because the outside surveyor is usually a registered professional, whose data are free from the stigma of results generated "in house". Similarly, he has the personnel to do this work. Specialized equipment for precise level work might be beyond his custom, but a level and rods might better be owned by the operating company and reserved for this activity. The surveyor makes his report on the form of an easily filed transmittal. No effort at transferring to a master sheet is warranted, since the transmittals may be copied if required and a source of errors and "busy-work" is eliminated.

A typical report sheet is reproduced herewith.

## DATA PRESENTATION

Two types of summaries have proved effective for data presentation to accomplish the purposes outlined above. They are the Time vs. Settlement Plot and the Contour Map. Examples are reproduced herewith.

**Time vs. Settlement Plot.** A plot is made of survey elevation data on the appropriate time line of a separate sheet for each monument. This should be done immediately after the survey results are in. A smooth line is made connecting the points on these plots for several reasons:

- The monuments are no more than data points randomly located on a surface being defined—it is change in shape of this surface that is interpreted as subsidence. A smooth line conveys the concept that the monument represents its *area*, not its site.
- The time of the survey is selected at the convenience of the operators and coincidence with a change in elevation of a monument is random. A smooth line through data points will show the onset or absence of subsidence—whereas a "knee" at a particular point infers that the event took place at that specific time.
- The data points themselves are approximations of true elevations, never exact and only as precise as survey cost allows. Considering that settlement amounts to many inches or feet and that many years are involved, cost-benefit considerations should be carefully elevated in designating survey precision limits.

**Settlement Contour Map.** Taking data (elevation change over a given time span) from the Time vs. Settlement Plot described above and entering these at their respective locations on a base map, lines (contours) can be drawn through points of equal settlement. The base map does not need to be precise. An 8 1/2 × 11 inch size will serve. Thus there is no need for precise location of the wells or monuments depicted. Settlement Contour Maps serve to delineate active and static areas and provide the basis and input into the decisions discussed in the opening section above on "Why Detect or Measure Subsidence". An example of a contour map is included herewith.

## SUMMARY—OTHER REFERENCES

This paper is a condensation of a report prepared in 1981 for the Solution Mining Research Institute with the title "Surveys for Detection and Measurement of Subsidence". The reader is directed to this publication for enlargement on the matters covered above. A concurrent SMRI publication, "A Manual on Ground Surveys for the Detection and Measurement of Subsidence Related to Solution Mining" by Kam W. Wong also treats this subject and expands on the matter of survey precision and methods to improve accuracy.

The distinction between subsidence related to salt production and that resulting from other extractive technologies was discussed above. Procedures described herein are directed to detection and measurement of subsidence resulting from salt extraction to achieve the objective ("Why" above) while maximizing cost-benefits.

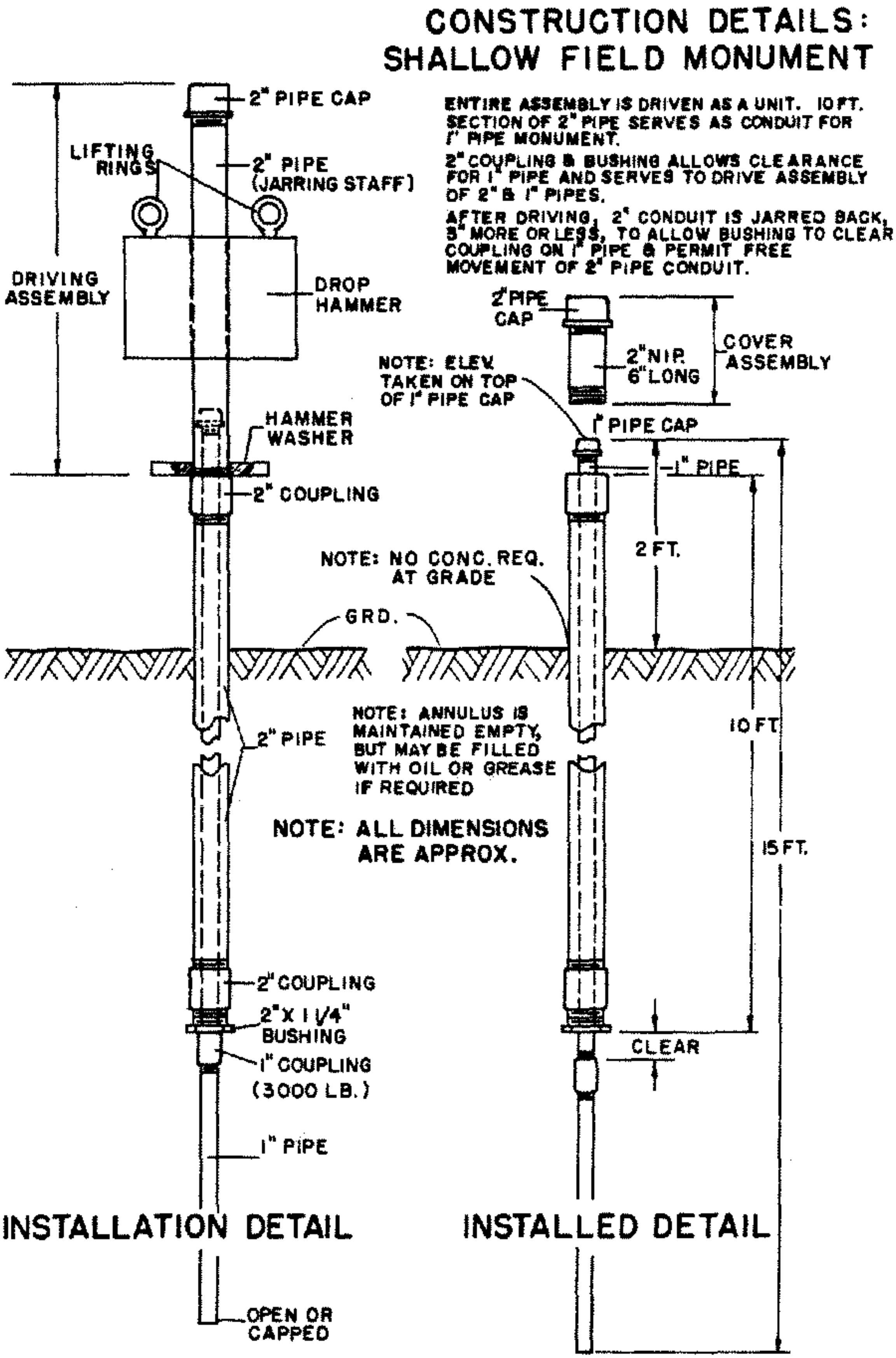

CONSTRUCTION DETAILS:
SHALLOW FIELD MONUMENT
ENTIRE ASSEMBLY IS DRIVEN AS A UNIT. 10 FT. SECTION OF 2" PIPE SERVES AS CONDUIT FOR 1" PIPE MONUMENT.
2" COUPLING & BUSHING ALLOWS CLEARANCE FOR 1" PIPE AND SERVES TO DRIVE ASSEMBLY OF 2" & 1" PIPES.
AFTER DRIVING, 2" CONDUIT IS JARRED BACK, 3" MORE OR LESS, TO ALLOW BUSHING TO CLEAR COUPLING ON 1" PIPE & PERMIT FREE MOVEMENT OF 2" PIPE CONDUIT.
2" PIPE CAP
LIFTING RINGS
2" PIPE (JARRING STAFF)
DRIVING ASSEMBLY
DROP HAMMER
HAMMER WASHER
2" COUPLING
NOTE: NO CONC. REQ. AT GRADE
GRD.
2" PIPE
NOTE: ANNULUS IS MAINTAINED EMPTY, BUT MAY BE FILLED WITH OIL OR GREASE IF REQUIRED
NOTE: ALL DIMENSIONS ARE APPROX.
2" COUPLING
2" X 1 1/4" BUSHING
1" COUPLING (3000 LB.)
1" PIPE
OPEN OR CAPPED
INSTALLATION DETAIL
2" PIPE CAP
2" NIP. 6" LONG
COVER ASSEMBLY
NOTE: ELEV. TAKEN ON TOP OF 1" PIPE CAP
1" PIPE CAP
1" PIPE
2 FT.
10 FT.
15 FT.
CLEAR
INSTALLED DETAIL

Figure 1.

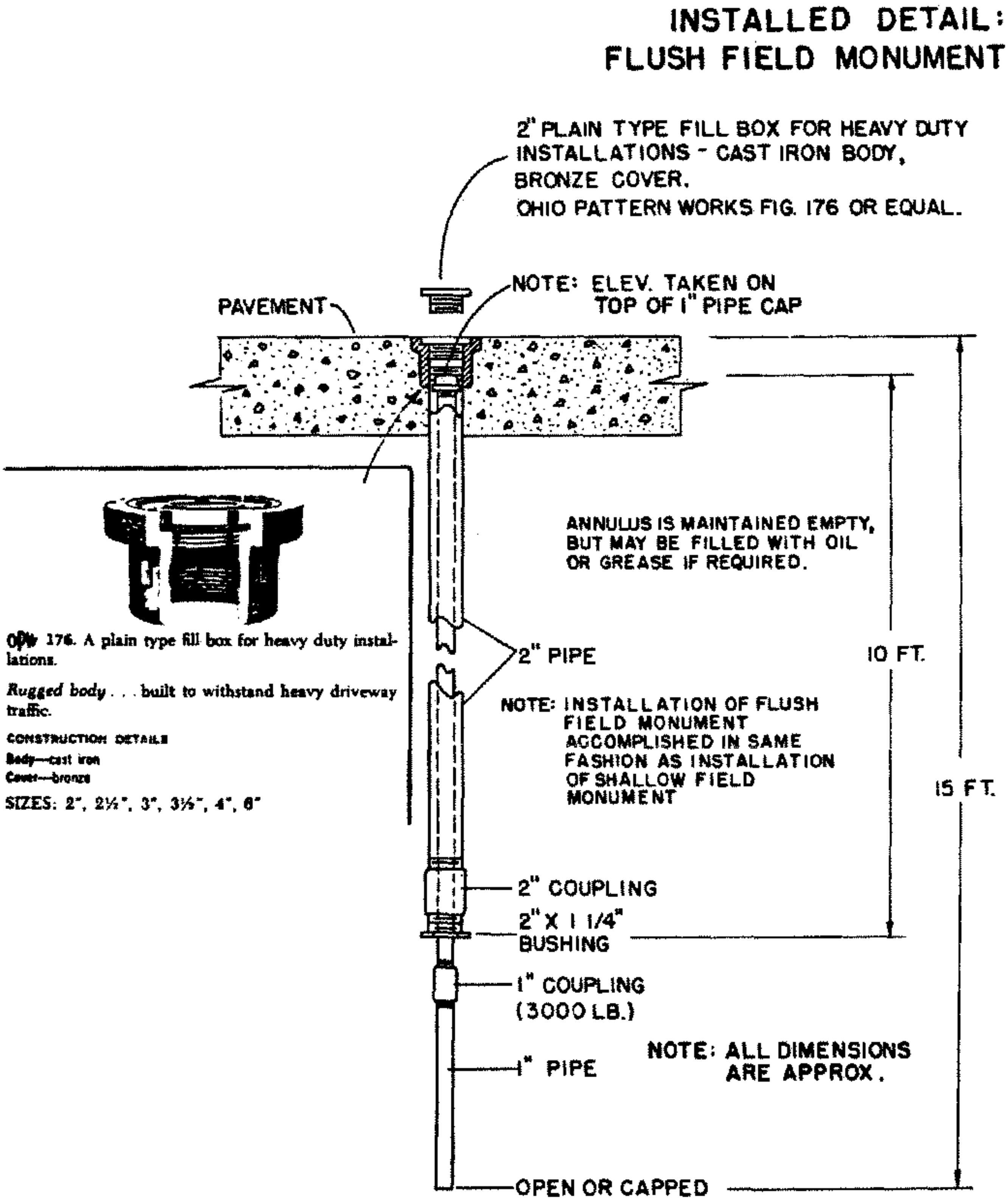

INSTALLED DETAIL:
FLUSH FIELD MONUMENT
2" PLAIN TYPE FILL BOX FOR HEAVY DUTY INSTALLATIONS - CAST IRON BODY, BRONZE COVER.
OHIO PATTERN WORKS FIG. 176 OR EQUAL.
NOTE: ELEV. TAKEN ON TOP OF 1" PIPE CAP
PAVEMENT
OPW 176. A plain type fill box for heavy duty installations.
Rugged body . . . built to withstand heavy driveway traffic.
CONSTRUCTION DETAILS
Body—cast iron
Cover—bronze
SIZES: 2", 2½", 3", 3½", 4", 6"
ANNULUS IS MAINTAINED EMPTY, BUT MAY BE FILLED WITH OIL OR GREASE IF REQUIRED.
2" PIPE
10 FT.
NOTE: INSTALLATION OF FLUSH FIELD MONUMENT ACCOMPLISHED IN SAME FASHION AS INSTALLATION OF SHALLOW FIELD MONUMENT
15 FT.
2" COUPLING
2" X 1 1/4" BUSHING
1" COUPLING (3000 LB.)
1" PIPE
NOTE: ALL DIMENSIONS ARE APPROX.
OPEN OR CAPPED

Figure 2.

**Figure 3.** Typical survey party. Instrument man sets up instrument, reads intercepts of instrument wires through telescope focused on rod. Rodman holds rod erect on monument or turning point, verifies rod is vertical by observing rod level. Field Recorder makes entries in book, calculates foresights and backsights from three readings, verifies all are correct. Usually recorder is field engineer in charge of party—his duties also include route planning and selection of instrument sites so that foresights and backsights are approximately equidistant and provide optimum view of all monuments available to instrument man at this location.

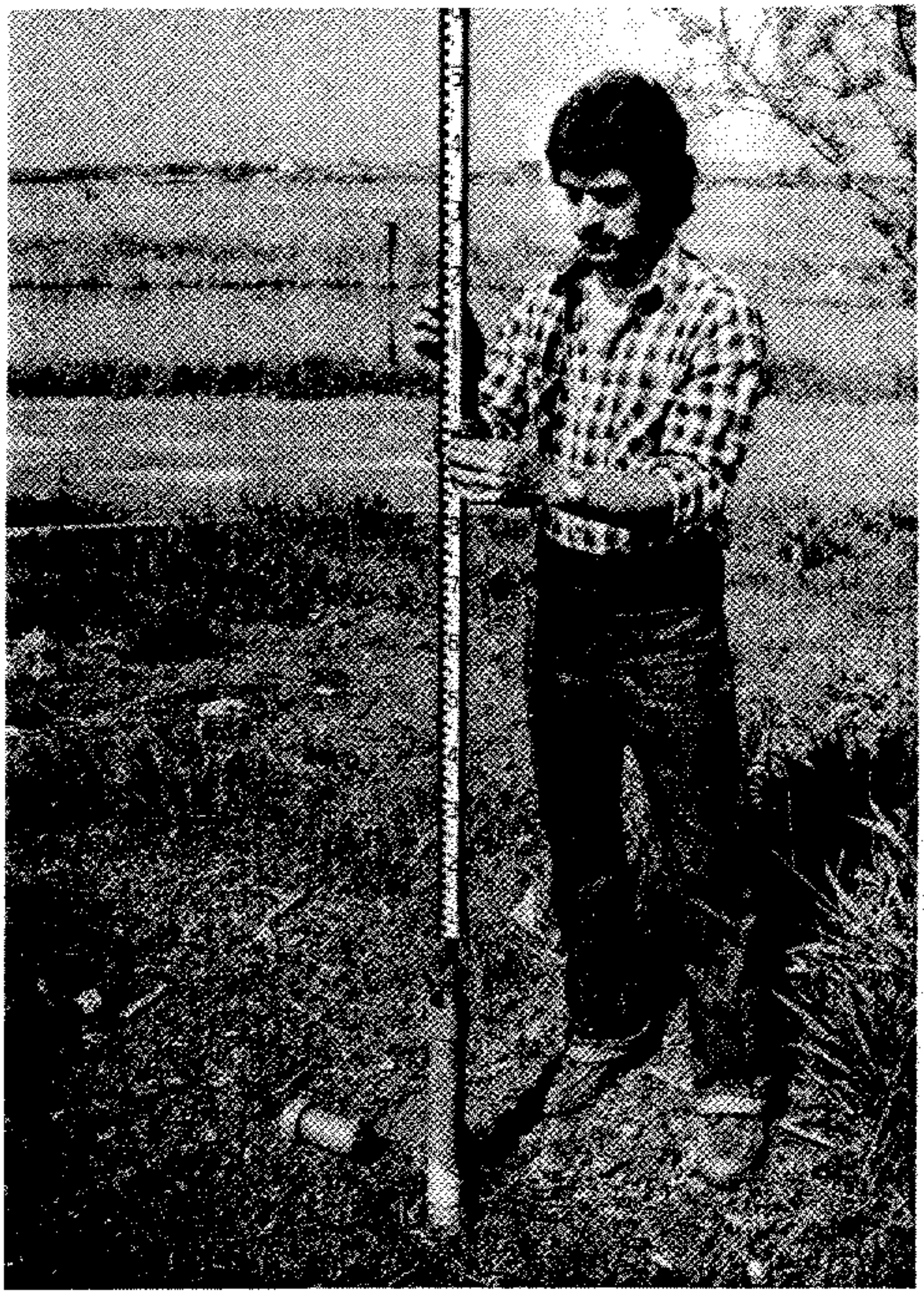
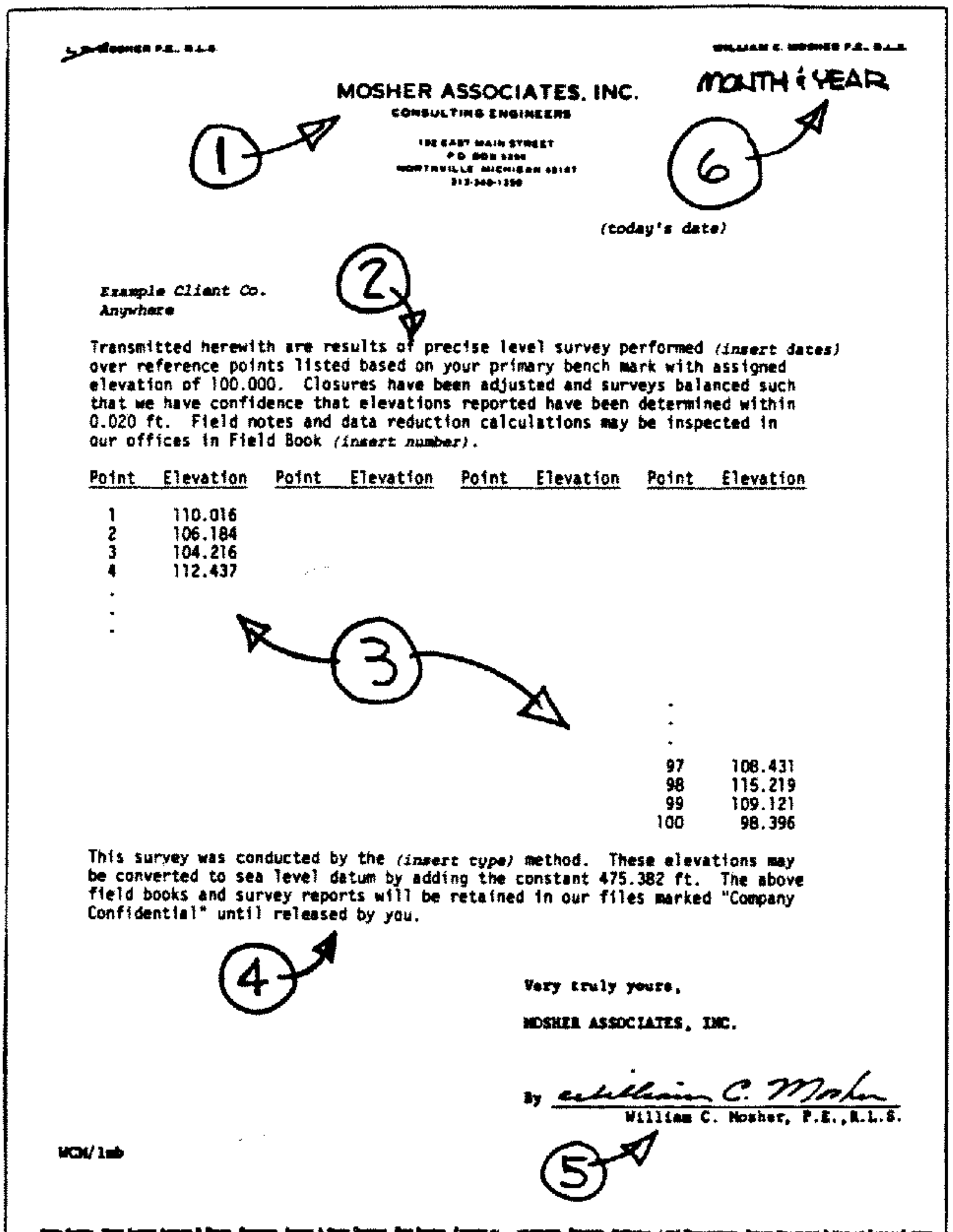


**Figure 4.** Rodman, rod and survey monument. Rod is placed on inner pipe cap or crown, may be rotated so numbered side faces instrument man at new station as instrument advances. Note rod level used to verify rod is vertical. Monument cover removed. Note that numbering of rod does not go to zero. Length of shoe is not critical so long as same rod is used for transferring elevation of previous monument (backsight) and determining elevation of next monument (foresight).



MOSHER ASSOCIATES, INC.

CONSULTING ENGINEERS

MONTH & YEAR

(today's date)

*Example Client Co.*
*Anywhere*

Transmitted herewith are results of precise level survey performed *(insert dates)* over reference points listed based on your primary bench mark with assigned elevation of 100.000. Closures have been adjusted and surveys balanced such that we have confidence that elevations reported have been determined within 0.020 ft. Field notes and data reduction calculations may be inspected in our offices in Field Book *(insert number)*.

| Point | Elevation | Point | Elevation | Point | Elevation | Point | Elevation |
|---|---|---|---|---|---|---|---|
| 1 | 110.016 | | | | | | |
| 2 | 106.184 | | | | | | |
| 3 | 104.216 | | | | | | |
| 4 | 112.437 | | | | | | |
| . | | | | | | | |
| . | | | | | | | |
| . | | | | | | | |
| | | | | | | . | |
| | | | | | | . | |
| | | | | | | . | |
| | | | | | | 97 | 108.431 |
| | | | | | | 98 | 115.219 |
| | | | | | | 99 | 109.121 |
| | | | | | | 100 | 98.396 |

This survey was conducted by the *(insert type)* method. These elevations may be converted to sea level datum by adding the constant 475.382 ft. The above field books and survey reports will be retained in our files marked "Company Confidential" until released by you.

Very truly yours,

MOSHER ASSOCIATES, INC.

By William C. Mosher
William C. Mosher, P.E.,R.L.S.

WCM/lmb

**Figure 5.** Sample survey report. Transmittal letter has these characteristics: (1) on letterhead of professional surveyor, (2) opening paragraph giving dates of survey and quality of closures, (3) tabulation of results in compact form to minimize filing volume, (4) closing statement giving location of primary data and "company confidential" classification, (5) signature by Professional Engineer or Registered Land Surveyor. The data are plotted on individual Time vs. Settlement sheets and the letter is filed by the month (6) plotted. No master elevation data sheet need be maintained.

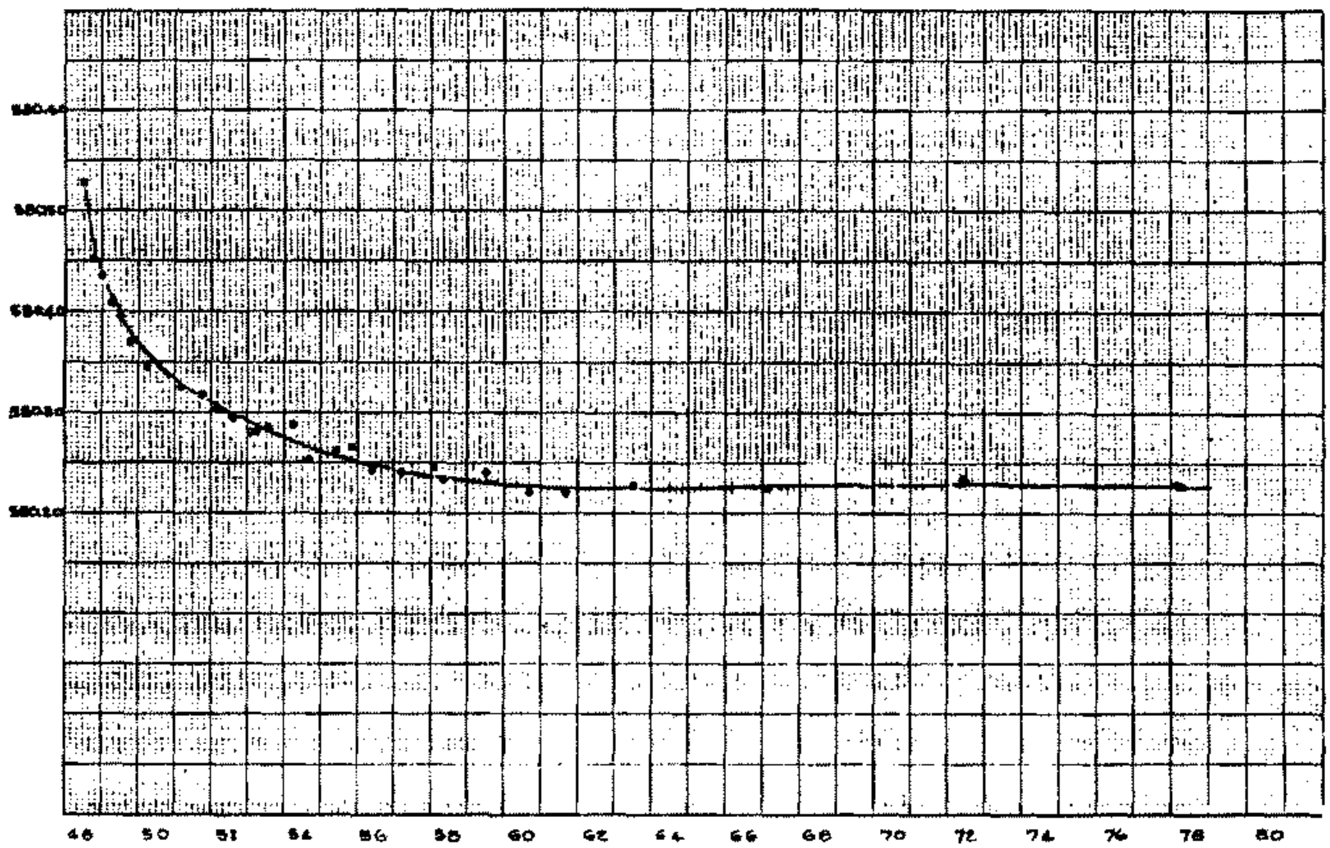


**Figure 6.** Time vs. Settlement. Plot of surveys for typical monument, size reduced for inclusion in this report. Indicates result of termination of brine production (1950–56), and documents steady-state (1956–present) subsequently.

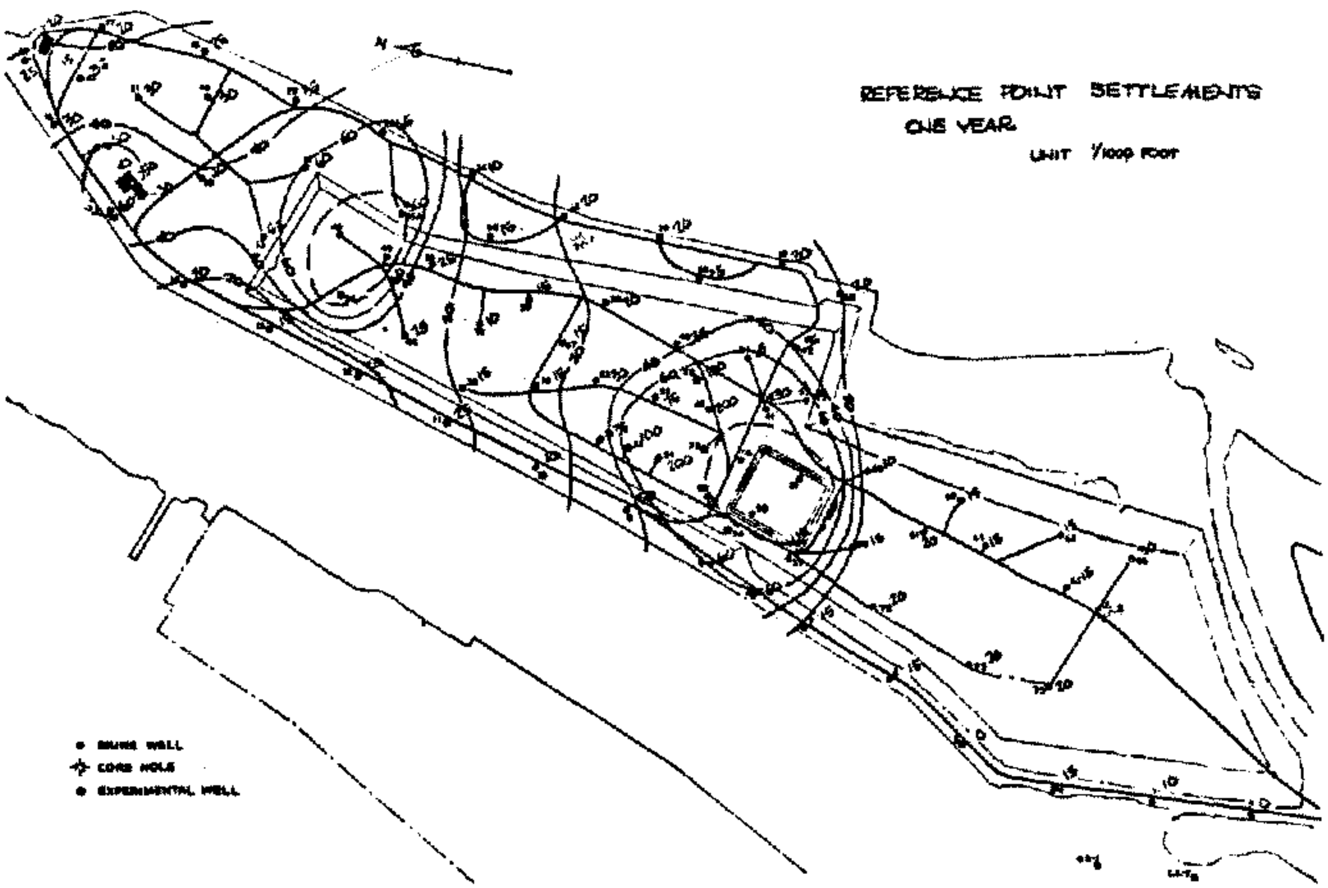



**Figure 7.** Subsidence contour map. Data points for contours taken from segments of Time vs. Settlement Plots for individual monuments for time interval to be depicted. Contour interval of 20/1000 ft. depicts areas of interest.

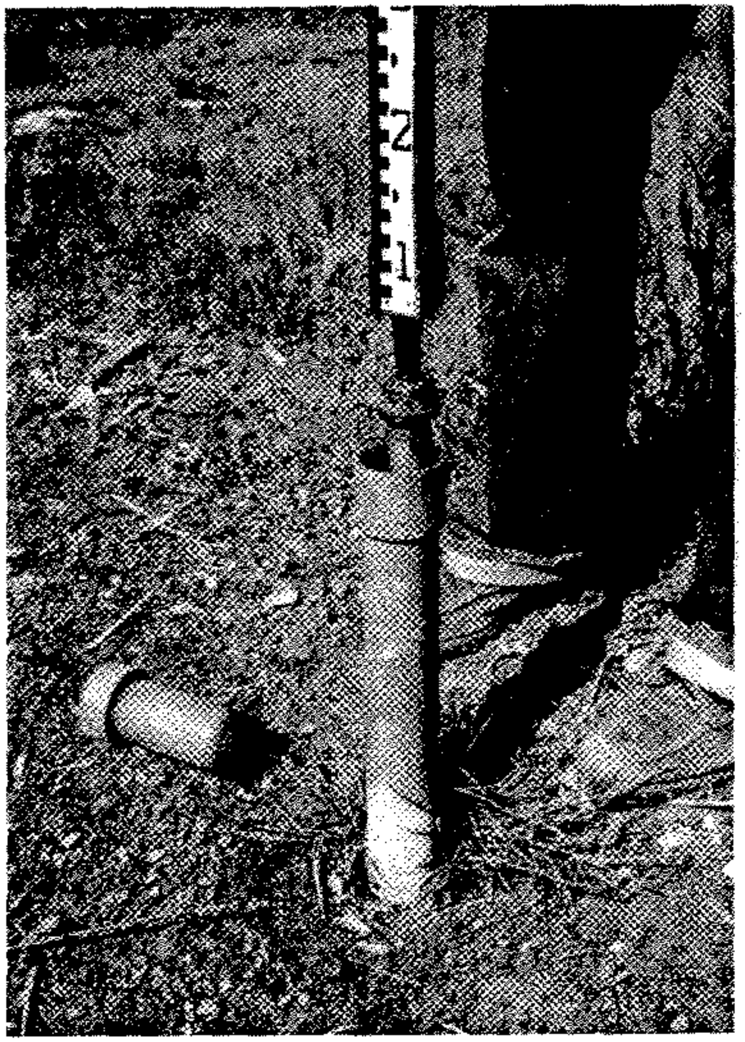


**Figure 8.** Typical monument, cover removed, rod in place. Note rod projects above protective sleeve when cover is removed. Rod "shoe" is placed on crown-shaped cap which automatically provides a high point for repeat surveys. "Shoe" does not figure into elevation obtained for monument since it is a constant—added in and subtracted out. Similarly, rods may be interchanged so long as same rod is used for backsight and foresight. Note absence of cement pad around protective sleeve, minimizing area presented for frost "heave".

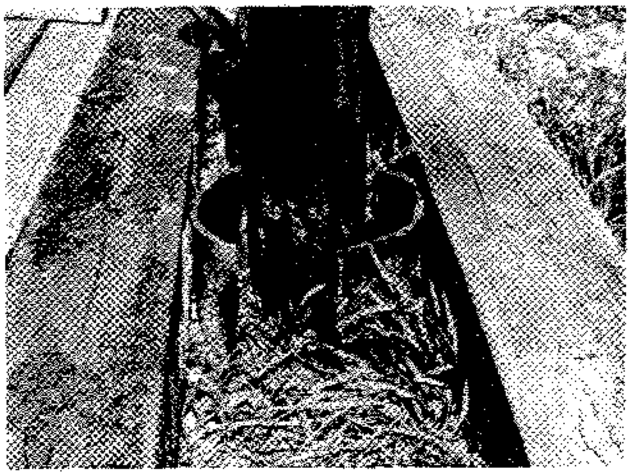


**Figure 9.** Monument or turning point. Note high spot on conductor casing (8 o'clock position in this photo). Serves as a reference point monument or turning point. Usually painted for ready identification.

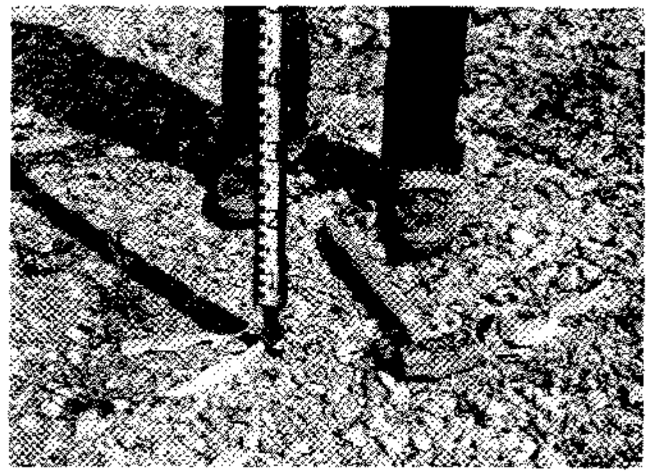


**Figure 11.** Turning point. Spike or other temporary device used to provide a stable site for rod while instrument makes transition from one station to next—immediately removed, not reoccupied. Layout of survey route calling for turning points usually indicates need for a monument in this area.

**Figure 10.** Well casing monument. Rod welded to casing provides a "deep" monument (to depth of cement bond) for the cost of a field weld. Rod is long enough to clear wellhead or wellhead piping. Note upward slope eliminates need for decision or possible inaccuracy in selecting location on a rod set level or near level.

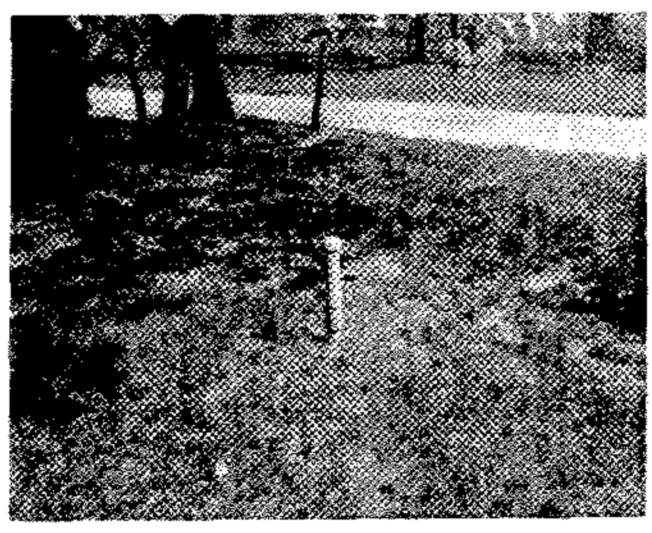


**Figure 12.** External Reference Point. Reference points in buffer zone surrounding area of interest provide data to be used in the event of inquiry as to the extent of activity related to mineral production. Points may also be established on route from external Bench Mark thus formalizing turning points.

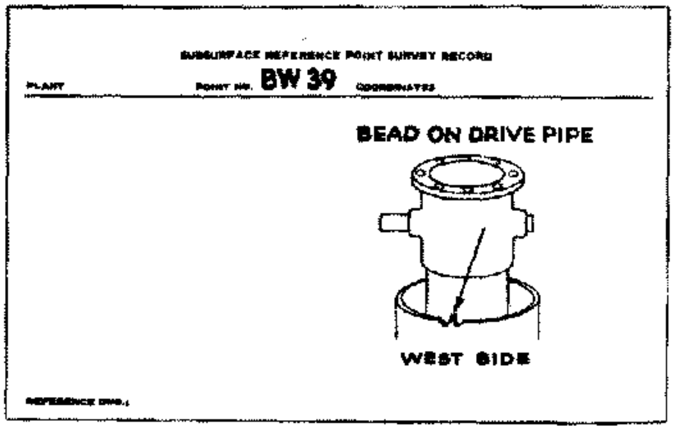



**Figure 13.** Monument Identification Card. Provides a detail sketch of each monument showing precise site of data point. Copies of cards may be made and utilized by surveyor to assure that each point is properly located. Elevations derived for this point may be recorded on the reverse side.

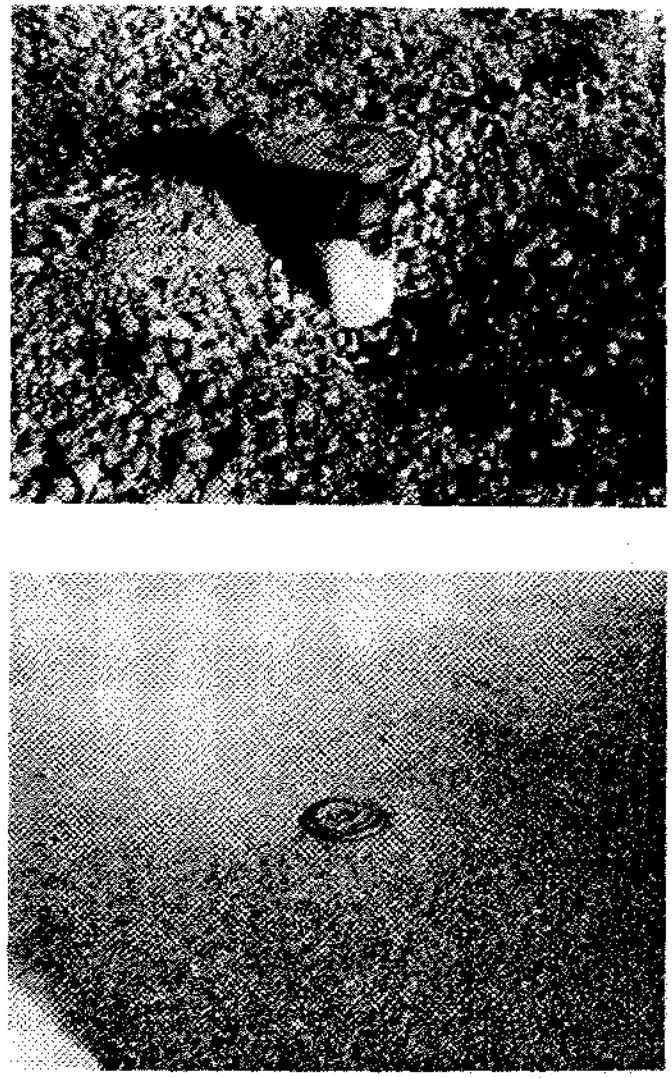


**Figure 14.** Flush reference point monument in pavement. Flush fill cap (upper photo) assembled and installed on protective casing set to finish grade. Pavement reinstalled (lower photo) results in monument which presents no obstacle to traffic. Slight slope for drainage should be away from installation.

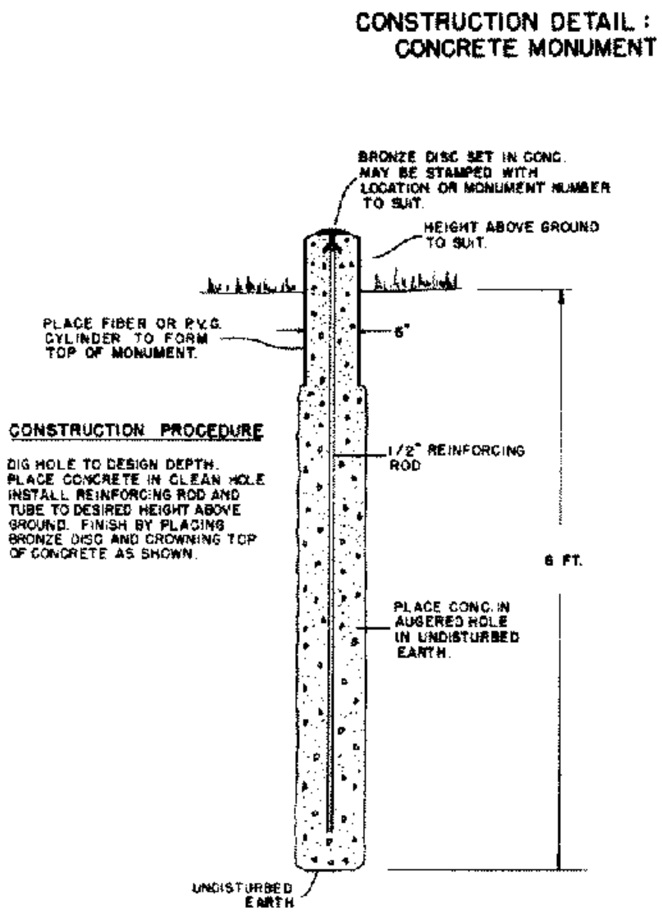



Figure 15.

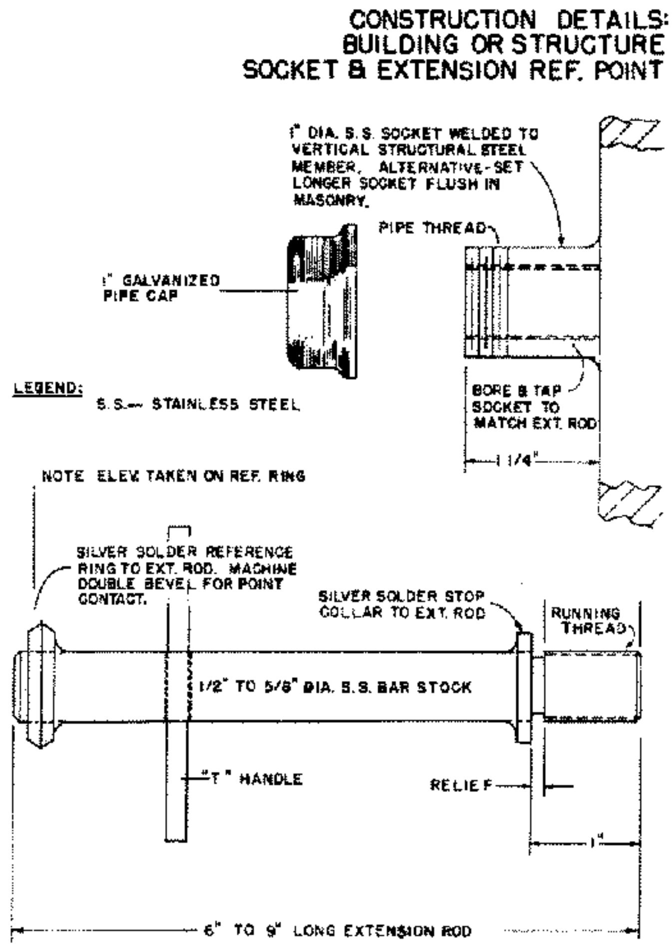



Figure 16.

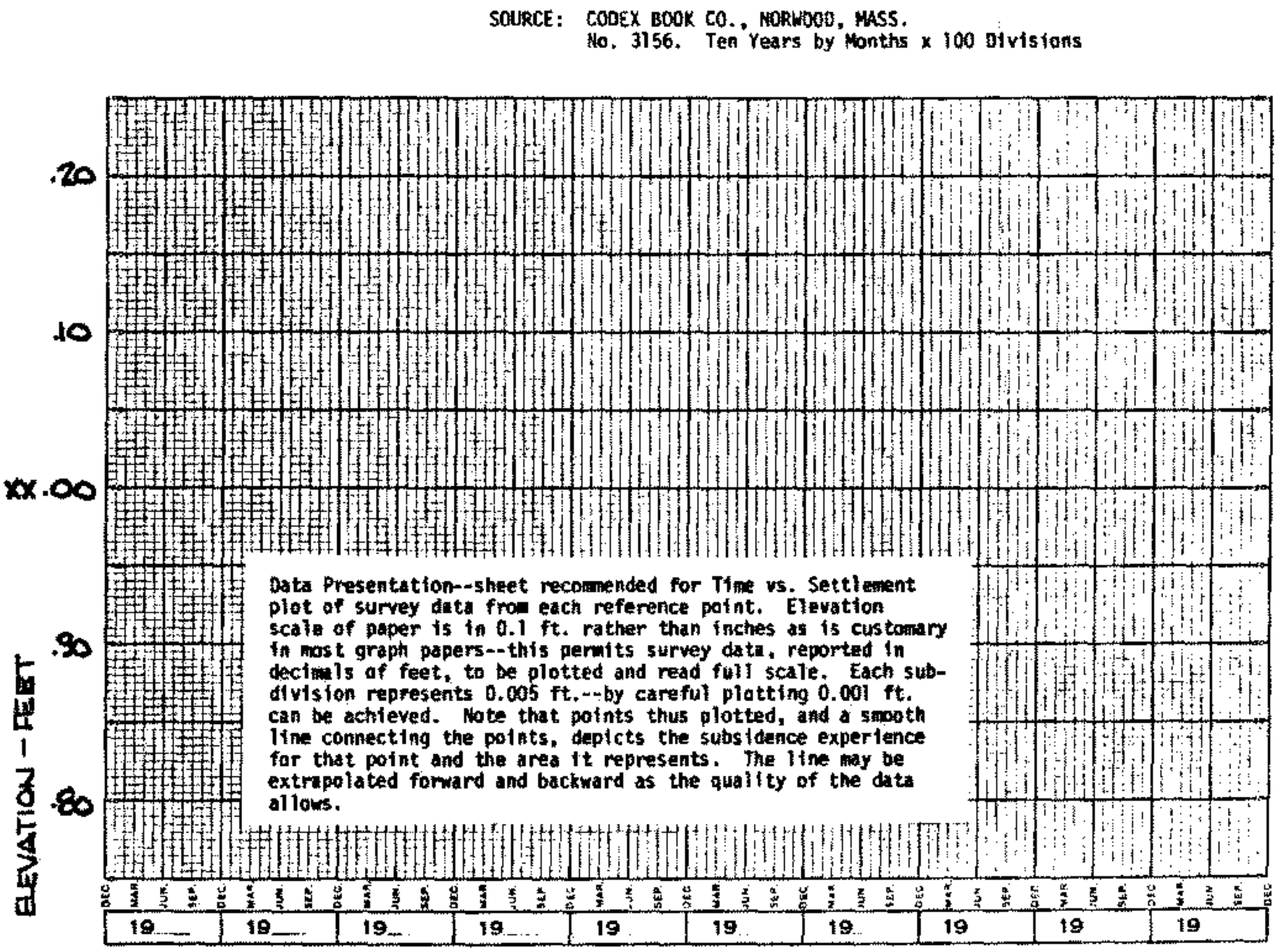



**Figure 17.** Data Presentation—sheet recommended for Time vs. Settlement plot of survey data from each reference point. Elevation scale of paper is in 0.1 ft. rather than inches as is customary in most graph papers—this permits survey data, reported in decimals of feet, to be plotted and read full scale. Each subdivision represents 0.005 ft.—by careful plotting 0.001 ft. can be achieved. Note that points thus plotted, and a smooth line connecting the points, depicts the subsidence experience for that point and the area it represents. The line may be extrapolated forward and backward as the quality of the data allows.

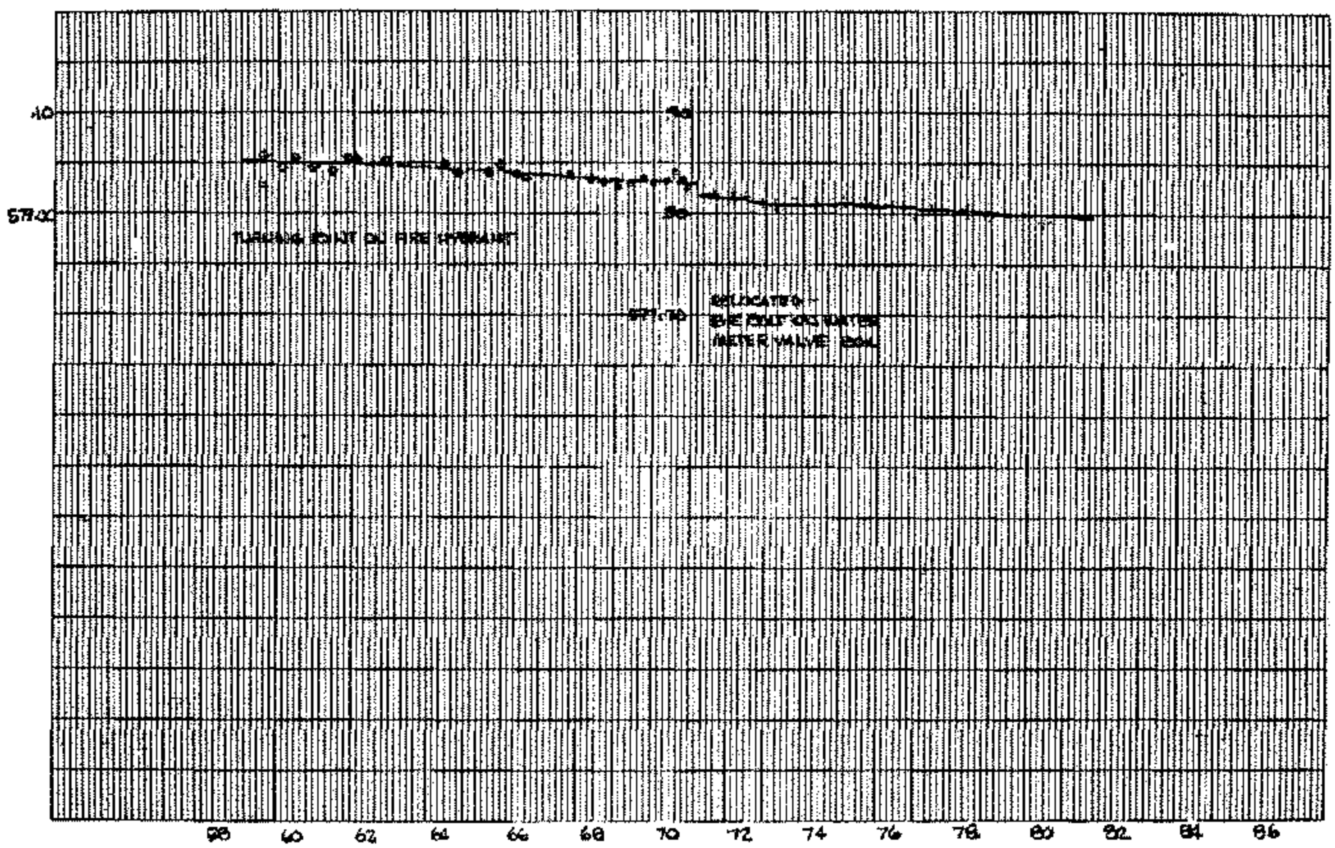


**Figure 18.** Plot of surveys for one monument. Size reduced for inclusion in this report; sheet made by joining two sheets described previously. Plot shows essentially "zero" settlement for the period 1959–1980, also shows method of accommodating abandonment and relocation of monument. Symbols identify surveyor. "Scatter" and average line show acceptable closure and trend of plots.