Chapter 7
Alignment, Deflection, and Crack Measurement Surveys --Micrometer Observations

7-1. Scope

This chapter describes micrometer observation methods for accurately measuring small relative deflections or absolute deformations in hydraulic structures.

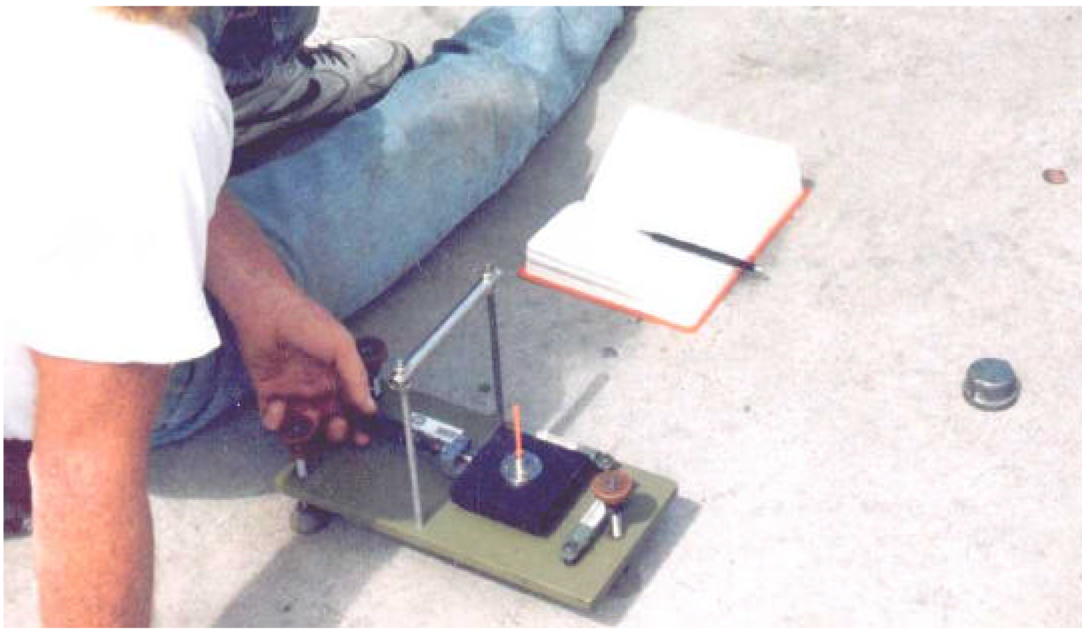


Figure 7-1. Alignment micrometer measurements relative to fixed baseline

7-2. Relative Alignment Deflections from Fixed Baseline

Deflections of points along structural sections can be monitored by observing their offset from an alignment established by two baseline control points. The deflection of a point relative to a fixed baseline is observed either by micrometer target methods (translation stage--Figure 7-1) or by directly observing the deflection angle to the alignment pin with a theodolite. The lateral movement is computed relative to the alignment using trigonometric identities. Alignment requirements for each structure will be listed in tabular form on project instructions, identifying the baseline reference points used (instrument/target stands), the deflection points to be observed, and structure loading requirements (e.g., lock fill elevations). Requirements for establishing new alignment points, and constructing reference baseline instrument/target stands will be detailed as required. Additional background on relative deflection techniques is described in EM 1110-2-4300, Instrumentation for Concrete Structures.

a. General. Relative deflections on structures are monitored by measuring the position of a series of alignment pins set at regular intervals along an alignment section--e.g., the reference baseline "A" shown in Figure 7-2. Baselines typically range from 100 to 1000 feet in length, depending on the structure. The baseline is established perpendicular to the direction in which deflection observations are required--e.g., along the axis of a dam. Alignment control points located on the structure form a sub-network where each pair of structure control points acts as a separate alignment section for making deflection measurements. The alignment control point (CP) positions are tied directly to the reference network pillars using the established project coordinate system. Separate or adjacent alignment sections should be tied together using conventional measurements from at least two other nearby control points and from at least two reference network stations. Precision distance ties between alignment section control points should be made to strengthen positioning of the alignment control points.

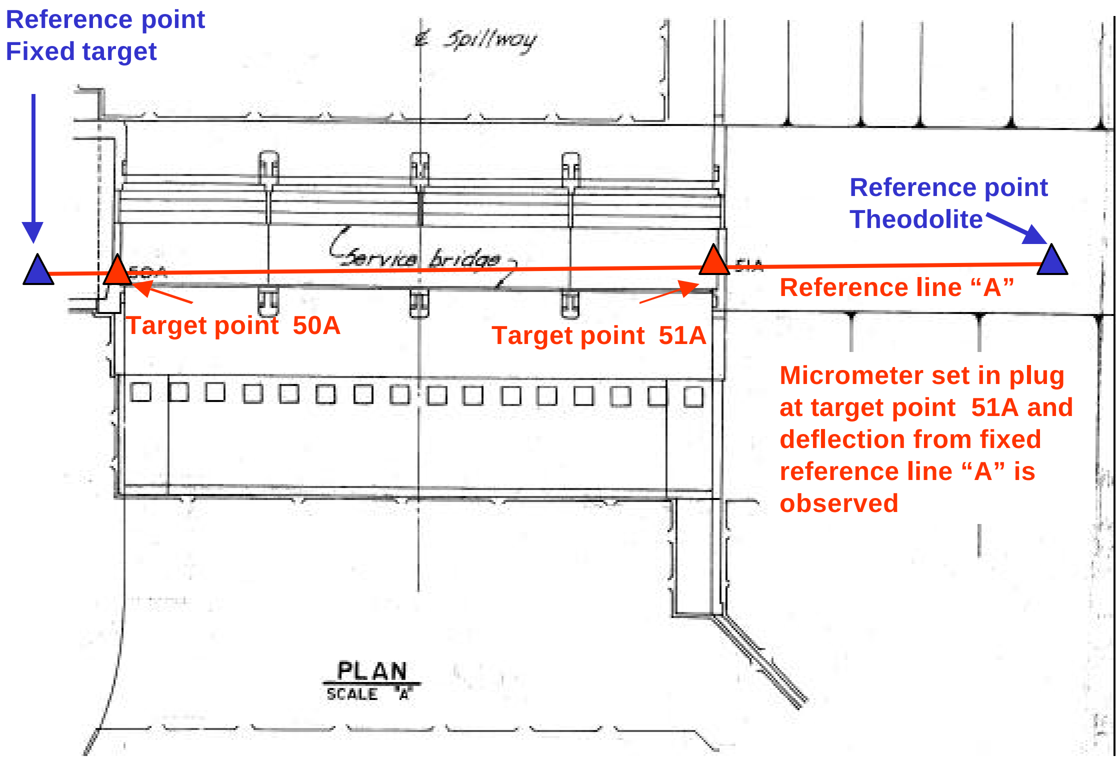


Figure 7-2. Typical relative alignment deflection measurements of concrete structures relative to fixed baseline. Micrometer deflections relative to line between theodolite and target set on external points. Port Mayaca Spillway (S-308C), Central and Southern Florida Flood Control Project, Jacksonville District

b. Instrumentation specifications. Guidance on recommended alignment survey equipment and procedures are presented as follows.

(1) Instruments. Optical or electronic theodolites such as the Wild T-2 or T-3 theodolite or other similar instruments such as electronic total stations may be used.

(2) Targets. An inverted "V" or conic plug inserts, prism tribrach combinations with target housings, or other specialized metrology type targets are acceptable.

(3) Monuments. Permanent alignment pins or other permanent disk type monuments are acceptable. Structure monitoring target points (or plugs) are normally set (grouted) within ± 0.5 inch

from the reference baseline. Established control point monuments on the structure should be used instead of temporary point-on-line reference marks.

(4) Alignment micrometer. A translation stage type mechanism with forced centering plug insert with a tribrach or an inverted "V" or conic target mount on the micrometer is acceptable. See EM 1110-2-4300, Instrumentation for Concrete Structures, for details on forced-centering monument construction and monolith alignment marker design.

c. Observing procedures. These guidelines are provided for determining offsets using theodolite-based methods for measurements of deflection angles or with a micrometer-based translation stage.

(1) Equipment set-up. The theodolite and reference target(s) must be set up on concrete instrument stands or stable tripods using forced centering devices. After force centering the theodolite, accurately level theodolite to its reversing point and re-level to the reversing point before each observation--this leveling/re-leveling procedure is critical. Next, remove parallax from the theodolite's cross-hairs. The reference target on the opposite end of the reference line is aligned by forced-centering, ensuring the target is aligned vertically over the plug center. For each alignment pin, the orientation of the stage axis to the alignment should be perpendicular to within 5 degrees to the alignment. This alignment tolerance is easily achieved in the field.

(2) Establishing alignment. Both the theodolite and target are force-center mounted at each end the reference baseline to establish the alignment and measure a reference line distance tie. When using two instruments, each respectively is centered over a monumented control point that establishes the alignment section, and each instrument backsights the center circular element within the other theodolite objective lens.

(3) Deflection angle method. A series of small deflection angles can be measured between the initial position of the micrometer target when centered over the alignment pin and the reference line. For the deflection angle method, the instrument is set up at either end of the alignment section, and the prism or micrometer assembly is centered over the alignment pin closest to one end of the alignment. The theodolite's vertical cross-hair is centered on the reference target and four (4) alignment deflection sets are observed with the theodolite in both direct and reverse positions. Redundancy can be increased by combining both the micrometer offset measurement method with the small deflection angle method by also sighting the translated position of the target when it is collimated with the alignment section reference line and recording the micrometer offset measurement and in-line distance. The procedure for the combined method would be as follows. For each alignment pin, establish the initial alignment as usual. Turn the instrument onto the prism target centered directly over the alignment pin, read and record the small deflection angle and measure the distance to the alignment pin, then turn the instrument back onto the original alignment and observe the conventional micrometer offset and in-line distance.

(4) Micrometer offset measurements. Sight the alignment reference target and move the alignment micrometer/target into to collimation with theodolite alignment. Radios may be required for communication between the instrumentman and micrometer operator. Five (5) independent offset measurements should be observed with the alignment micrometer in the LEFT position. (i.e., micrometer is to left of baseline as viewed from the theodolite's position). The offset distance from the alignment pin is measured by moving the target on-line, and recording the offset distance with the micrometer scale. Read alignment micrometer to nearest $\pm$ 0.001 (thousandth) inch. Rotate alignment micrometer 180 degrees to its RIGHT position and observe five (5) additional offsets. Always run the micrometer against the spring such that after each offset measurement, the micrometer should be backed off a few hundredths

of an inch. Reversing the micrometer to the LEFT and RIGHT positions eliminates index error in the device.

(5) Alignment pin in-line distances. Extensional (in-line) movement components for each alignment pin are determined by measuring the in-line distance to the prism/target when collimated over the alignment pin and when collimated to the reference baseline. When using two instruments for the alignment, the offset reading and in-line distance is repeated and confirmed by the instrument at the other end of the line when the offset bar is rotated 180 degrees.

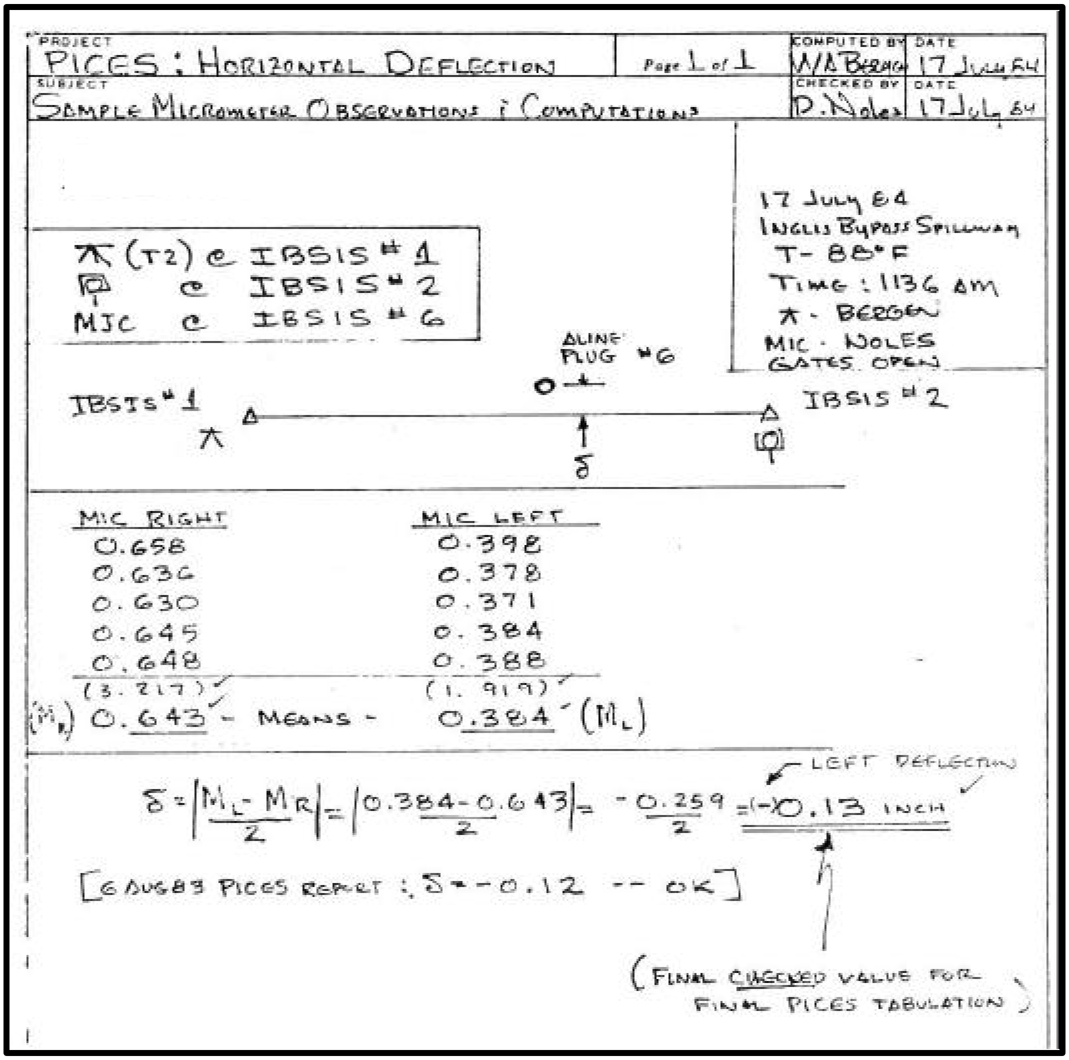


Figure 7-3. Field alignment micrometer alignment observations and reduction--Inglis Bypass Spillway, Cross Florida Barge Canal, Jacksonville District

d. Field computations and tolerances. A mean value for the LEFT and RIGHT micrometer observations (5 each) will be calculated and reported to the nearest 0.001 inch--see sample field notes at Figure 7-3. The difference between the mean of the LEFT set and the mean of the RIGHT should not exceed $\pm$ 0.02 (two-hundredths) inch. If the difference between the two means does exceed this limit then both the LEFT and RIGHT set must be re-observed. Large variations probably indicate poor target centering, instrument parallax not eliminated, or mis-levelment of the theodolite. The final left/right deflection angle will be computed in the field after each alignment observation. All field reductions shall be independently checked in the field.

e. Final micrometer data reductions. From the mean value for the micrometer left/right readings, compute the adjusted deflection as follows:

(1) Deflection Calculation. The deflection (D) will be calculated as:

$$D = (ML - MR) / 2 \qquad \text{(Eq 7-1)}$$

Where

ML = mean value of the five (5) LEFT micrometer readings on baseline
MR = mean value of the five (5) RIGHT micrometer readings on baseline
D = the calculated value for the "+" Right deflection off baseline to structure point as viewed from theodolite position.

(2) Recording. Round adjusted deflection to the nearest 0.01 inch. Additional accuracy and recording requirements for micrometer based measurements are found below.

(3) Check sum. The sum of the micrometer LEFT and RIGHT means will not necessarily total to 1.000 inch, given the micrometer index errors.

(4) Tabulation. Tabulate field computed deflection values for the final report using a standard field survey book or similar recording form for both observations, computations, and adjustments of data. A sample micrometer alignment field record is shown in Figure 7-3.

(5) Summary sheets. Figure 7-4 depicts a typical summary data sheet for sequential alignment observations.

7-3. Micrometer Crack Measurement Observations

a. General. This section describes absolute micrometer joint or crack measurement procedures using micrometers. Crack/joint observations are measured relative to grouted bronze plugs set 12 inches (±) on center across a concrete crack or structural construction joint where periodic monitoring is required. Monitoring points are usually set on each adjacent monolith. Monitoring is performed periodically for long-term trends or during short-term load deformation studies. Often, three plugs are set across each crack or joint in a triangular pattern. In most cases, two opposite plugs set perpendicular to the joint/crack plane will be adequate. Expected short-term accuracy is on the order of ± 0.0005 inch, relative to the fixed calibration reference bar. Errors due to the nonalignment (vertical) of the crack plugs relative to one another could effect observational accuracy (and long-term repeatability) upwards of ±0.01 inch. Given all of the above errors and uncertainties, estimated long-term crack measurement accuracy is at the ± 0.005 to 0.010 inch level; totally independent of short-term movements in the structure due to load or temperature influences. Crack and joint measurement requirements are typically listed in tabular form, including instructions for varying hydraulic head levels against the monoliths, if applicable. Requirements and instructions for setting new monitoring points will be provided as required. Structure loading requirements will also be provided for each new observation point.

REFERENCE POINT WITH INSTRUMENT AT IS4	INITIAL DISTANCE **APR 1990**	5TH READING **APR 1994**	CHANGE INCHES	CUM. CHANGE INCHES	6TH READING	CHANGE INCHES	CUM. CHANGE INCHES	7TH READING	CHANGE INCHES	CUM. CHANGE INCHES
L 2 MIC RIGHT	0.292	NOT VISIBLE								
L 1 MIC RIGHT	0.690	NOT VISIBLE								
L 2 MIC LEFT	0.729	NOT VISIBLE								
L 1 MIC LEFT	0.278	NOT VISIBLE								

6TH READING **MAR 1995**	REFERENCE POINT WITH INSTRUMENT AT IS	INITIAL DISTANCE **APR 1990**	7TH READING **SEPT 1996**	CHANGE INCHES	CUM. CHANGE INCHES	8TH READING	CHANGE INCHES	CUM. CHANGE INCHES	9TH READING	CHANGE INCHES	CUM. CHANGE INCHES
0.6290	L 1 MIC RIGHT	0.4915	0.6990	0.0700	0.2075						
0.8588	L 2 MIC RIGHT	0.6560	0.9060	0.0472	0.2500						
0.3350	L 1 MIC LEFT	0.5094	0.3500	0.0150	-0.1594						
0.0460	L 2 MIC LEFT	0.3570	0.0960	0.0500	-0.2610						

NOTES :
1. All distances are in hundredths of an inch and changes in hundredths of an inch.
2. Location of the points is shown in the Pre-Inspection Brochure on Plates 38 and 39.
3. Readings from IS-4 rejected due to guardrail built on line.
4. Continued readings on L2 MIC RIGHT from 5 th reading of April 1994.

S-352 SPILLWAY (HGS 5)
(SPILLWAY)
ALIGNMENT MONITORING POINT READINGS
(Continued from Plate 73 in 1995 report)

PLATE 78

Figure 7-4. Data summary sheet for alignment observations between 1990 and 1996. Only the first (1990) and last (seventh) observations are recorded. The change is measured relative to the previous observation in 1995 (shown in left margin). The cumulative change is relative to the original (1990) measurement. Hurricane Gate Structure 5, Jacksonville District.

Figure 7-5. Starrett vernier caliper crack measurements between monoliths. Central & Southern Florida Flood Control Project (Jacksonville District and Arc Surveying & Mapping, Inc)

b. Equipment specifications. The following equipment and instruments are used for crack and joint extension measurements.

(1) Inside micrometer. Any standard machine tooling inside micrometer may be used for crack measurements. Precision calipers may also be employed in lieu of an inside micrometer (Figure 7-5).

(2) Inside micrometer calibration bar. 12 inch c/c standard reference for all micrometer observations. An independent re-calibration of this bar is necessary to monitor long term stability.

(3) Plug inserts. Stainless steel threaded half-inch inserts are used and inserted into the dual or triad points across monolith joints or cracks--Figure 7-6. Inserts are stamped to insure consistent use on periodic measurements. The 0.500-inch O/D inserts should be precision machined to an accuracy of ±0.001 inch, and verified by micrometer measurement.

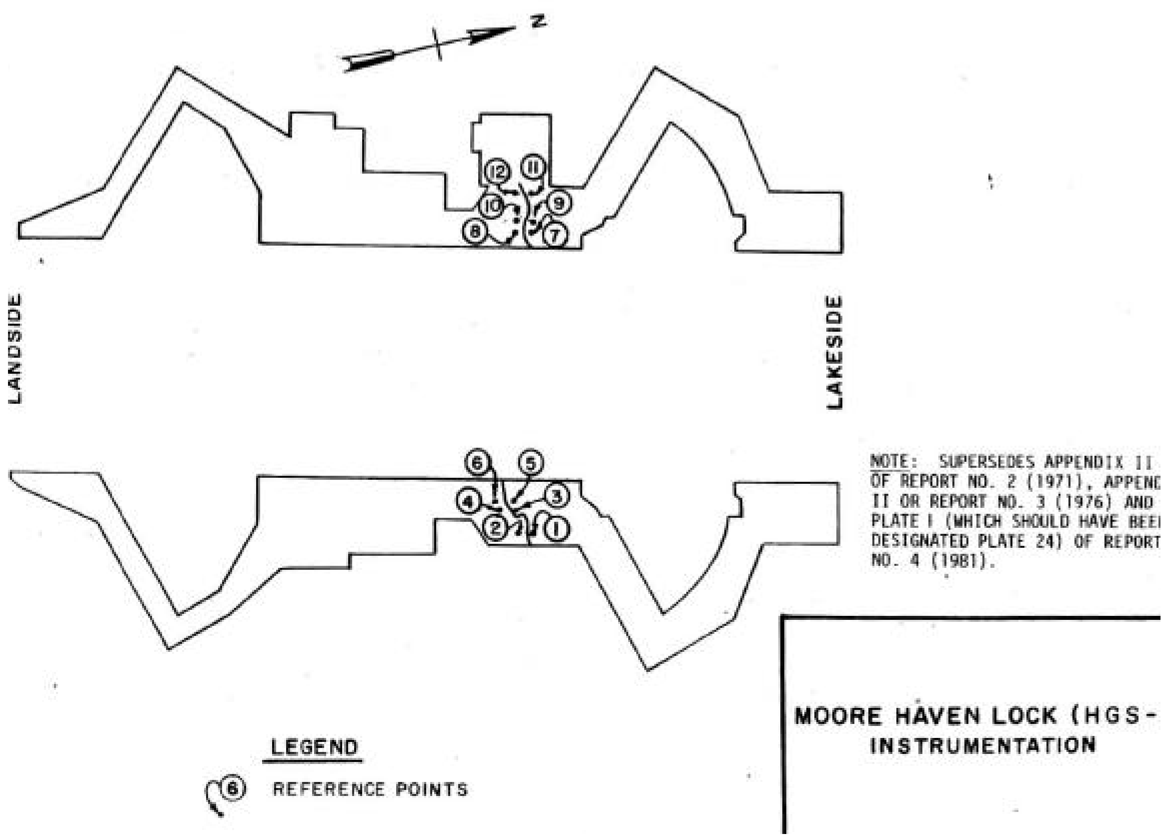


Figure 7-6. Typical monitoring point scheme across existing cracks on a concrete structure--HGS-1, Central and Southern Florida Flood Control Project (Jacksonville District)

c. Crack measurement techniques. The following procedures are used for crack and joint extension measurements.

(1) Micrometer measurement. Insert plug pins and measure crack or joint distance using an inside micrometer or caliper. Hold micrometer ends as low as possible on each plug pin. Gently rotate each end for minimum distance observation.

(2) Reading procedures. Read micrometer/caliper values to nearest 0.001 (thousandth) inch. Read in both directions (i.e., reverse micrometer ends) between crack plugs and mean result to nearest 0.001 (thousandth) inch. Do not attempt to interpolate between 0.001-inch values. Record a single minimum reading for each direction and mean as required.

(3) Tolerances. Readings in each direction should not vary by more than ±0.001 inch unless it can be verified that the crack plugs are grossly misaligned vertically. This can be verified by raising the micrometer at both ends to confirm non-verticality of the grouted plugs.

(4) Dial micrometer. The following applies to a inside micrometer with dial. Lock micrometer to nearest 0.025 inch division and use dial indicator to obtain minimum distance. (Maximum reading on scale which is subtracted from the preset micrometer value). Ensure dial range is within 0.025-inch micrometer setting range to avoid misreadings and insure relatively constant spring tension. The following example illustrates crack measurement data.

Micrometer set at:	11.475 inches
Maximum dial scale reading (minimum distance):	-0.021 inch
Observed uncorrected micrometer length:	11.454 inches

(5) Triad crack/plug configurations. Three marked pins shall be used in the same plug upon each inspection, per the following convention:

"L" Lowest numbered crack plug
"H" Highest numbered crack plug
"b" "Blank" -- in medium numbered crack plug

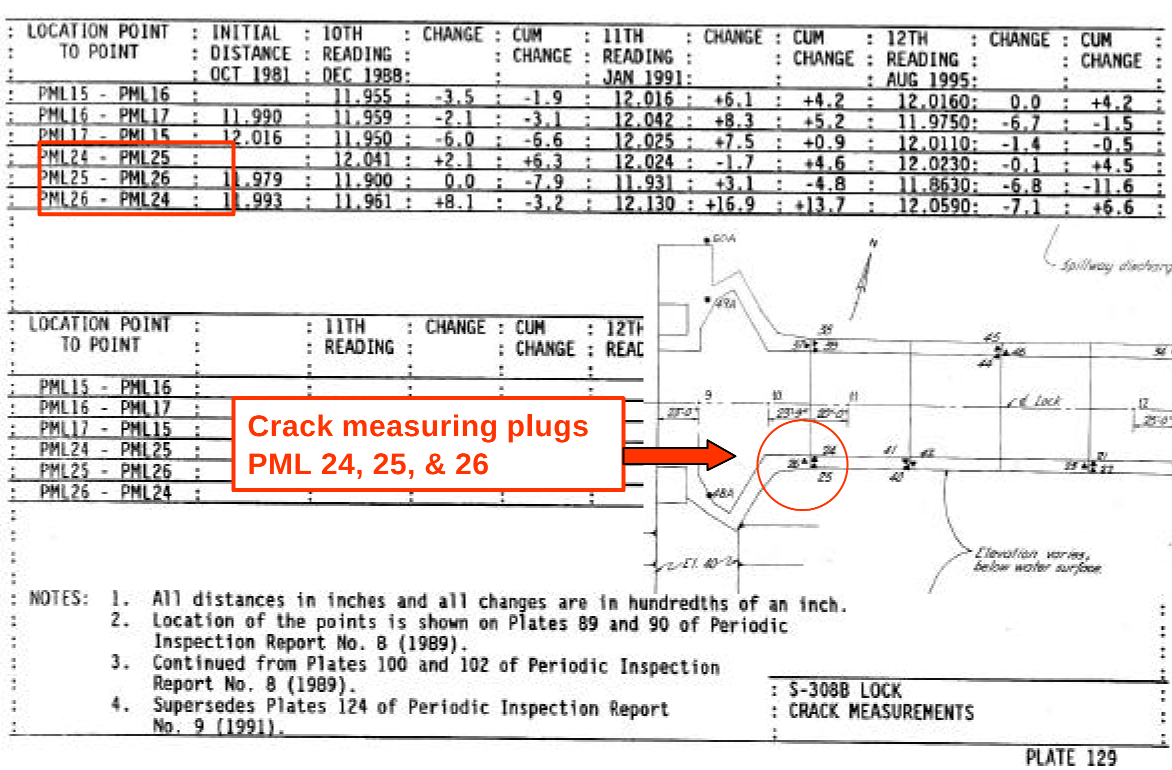
For example, at "Inglis Lock" the following naming convention might be used:

PLUG	PLUG
IL19N4	"L"
IL19N5	Blank
IL19N6	"H"

Normally, only one forward/reverse observation will be required for each pair of plugs -- approximately a 1 to 2 minute procedure. Additional observations under different structural loading conditions or temperature conditions will not be performed unless specifically requested in the project instructions. In cases where observations are taken over varying points in time or condition, they will not be meaned; given the external structural variability on the measurements.

(6) Tolerance specifications. The measurement rejection criteria are ±0.001 inch between each direction reversal and ±0.001 inch from nominal calibration bar constant. Failure to obtain agreement in each direction may be due to non-verticality of the plugs; in which case, no re-observations are necessary.

(7) Recording formats and reductions. Standard field survey books for both observations and corrected/adjusted lengths are normally used. All observations and reductions shall be computed and verified in the field--and recorded directly into the field survey book. Micrometer data are corrected for calibration constants as shown above. Quick comparisons should be made with previous observations to preclude against blunders. Tabulate field reduced distance into final reports and compute changes from past readings, as shown in the example at Figure 7-7. Standard forms for periodic crack measurements are also found in EM 1110-2-4300.



LOCATION POINT TO POINT	INITIAL DISTANCE OCT 1981	10TH READING DEC 1988	CHANGE	CUM CHANGE	11TH READING JAN 1991	CHANGE	CUM CHANGE	12TH READING AUG 1995	CHANGE	CUM CHANGE
PML15 - PML16		11.955	-3.5	-1.9	12.016	+6.1	+4.2	12.0160	0.0	+4.2
PML16 - PML17	11.990	11.959	-2.1	-3.1	12.042	+8.3	+5.2	11.9750	-6.7	-1.5
PML17 - PML15	12.016	11.950	-6.0	-6.6	12.025	+7.5	+0.9	12.0110	-1.4	-0.5
PML24 - PML25		12.041	+2.1	+6.3	12.024	-1.7	+4.6	12.0230	-0.1	+4.5
PML25 - PML26	11.979	11.900	0.0	-7.9	11.931	+3.1	-4.8	11.8630	-6.8	-11.6
PML26 - PML24	11.993	11.961	+8.1	-3.2	12.130	+16.9	+13.7	12.0590	-7.1	+6.6

LOCATION POINT TO POINT		11TH READING	CHANGE	CUM CHANGE	12TH READ
PML15 - PML16					
PML16 - PML17					
PML17 - PML15					
PML24 - PML25					
PML25 - PML26					
PML26 - PML24					

NOTES:
1. All distances in inches and all changes are in hundredths of an inch.
2. Location of the points is shown on Plates 89 and 90 of Periodic Inspection Report No. 8 (1989).
3. Continued from Plates 100 and 102 of Periodic Inspection Report No. 8 (1989).
4. Supersedes Plates 124 of Periodic Inspection Report No. 9 (1991).

S-308B LOCK
CRACK MEASUREMENTS

PLATE 129

Figure 7-7. Port Mayaca Lock (St. Lucie Canal) crack measurements--1981 to 1995. Distance changes are tabulated for successive readings. Cumulative changes are recorded relative to the initial observation in October 1981.

d. Micrometer calibration bars. The calibration bar is used to insure the micrometer is accurate by verifying a 12.000-inch center to center distance. The calibration bar should be kept shaded to prevent dimensional changes. Calibrate caliper/micrometer prior to structure observation using an independent reference. The single, meaned, forward/backward micrometer positions on the calibration bar should be observed/recorded to the nearest 0.001 inch.

(1) Calibration example. The following example illustrates calibration of a Starrett Micrometer. The resulting micrometer and caliper calibration correction is then applied to all subsequent crack readings.

	FORWARD	BACKWARD
Micrometer	11.475	11.475
Dial	-0.021	-0.020
Reading	11.454	11.455

Meaned Calibration Reading = 11.454 inches

CALIBRATION CORRECTION

(Nominal Calibration Bar Length)	12.000
- (Calibration Reading)	-11.454
Calibration Correction	00.546 inches

(2) Observation record example. The following is a typicle example of a field book entry for a crack observation using a Starrett Inside Micrometer:

Cross Florida Barge Canal, Inglis Lock & Spillway
Points: IL19N4 to IL19N5
19 July 1984 0845
Mic-Bergen, Notes-Noles, Bergen
T - 86^{o} F, Rain
Lock Full @ 36.0' elev.

FWD		BACK
11.475	Mic	11.475
-0.019	Dial	-0.020
11.456		11.455
Mean =		11.456 in
Calibration Correction =		+ 0.546 inch
Corrected Plug Reading = (IL19N4 to IL19N5)		12.002 inches

The corrected plug-to-plug reading (12.002 inches) may be directly inserted on tabulation report with no further adjustments required.

e. Periodic micrometer calibration. Independent annual calibrations should be performed on the following components:

- Inside Micrometer or Calipers
- Reference Calibration Bar
- Threaded ½ inch Plug Inserts

(1) Temperature effects. Calibrations should be checked over the normal temperature range that these devices are subject to in order to determine if expansion (temperature dependent) corrections become significant.

(2) Non-verticality of plugs. There is no method for eliminating the error due to non-verticality of the plugs other than using identical inserts on each visit. Use of inside/outside precision calipers will eliminate most independent calibration requirements other than the calipers themselves and insure true roundness and alignment of the threaded plug inserts. The need for a reference calibration bar may also be eliminated.

7-4. Mandatory Requirements

Micrometer observation and calibration procedures outlined in this chapter are considered mandatory.