LA-UR-94-2581

TITLE: STRING-SURVEY RESULTS FROM THE CHECKPRO EXERCISE

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String-Survey Results from the CHECKPRO Exercise

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Summary

Exercise CHECKPRO was conducted by the Arms Control and Nonproliferation Division at DOE/NVOO to evaluate procedures related to verification of the Threshold Test Ban Treaty. It took place at the Edgar Mine, operated by the Colorado School of Mines, from June 1 through June 19, 1994. One of the procedures being considered was a method for determining the coordinates of installed hydrodynamic sensor cables without the use of conventional surveying equipment. A test of this method was made for a cable installation similar to the one proposed for the Russian PRILIV event. Though the accuracy obtained, about 4 mm, was more than adequate for verification purposes, the man-hour requirements of the method make its use questionable for likely fielding scenarios.

Background

The goal of CHECKPRO was principally to exercise and evaluate the surveying, logging and coring elements of the TTBT verification cadre. But the occasion was also used to try out some procedures associated with hydrodynamic measurements. These activities included sensor cable installation and repair, fiber-optic closed-circuit TV installation and repair, and sensor cable as-built documentation using a string-survey technique. CHECKPRO planning was based on "snapshots" taken from the Coordinated Schedule of the Russian PRILIV event originally planned for the fall of 1993 at the Novaya Zemlya test site. Because the hydro-team part of CHECKPRO was outside the framework of the Coordinated Schedule, it was not conducted under the formal TTBT rules adopted for the rest of the exercise. Indeed, hydro-team activities were conducted for the most part during off hours so as not to interfere with the geologic work.

This report deals with the string-survey activity. An essential component of the hydrodynamic data taken for TTBT verification is the as-built locations of the CORTEX sensor cables relative to the emplacement configuration. This requirement entails a "final survey" of the cable installation just prior to the departure of the geodetic team. The string-survey method was being considered as an alternate, low-technology, method which the hydro team could use to do the final survey by itself. In principle, the method could serve as a backup if unforeseen events caused problems with personnel, schedules, or equipment. It could also serve as a cross-check of the conventional survey data.

The goal of the final survey is to locate identified points on the sensor cables with respect to the coordinate system defined by the initial survey of the tunnel complex. The string-survey method described below does this by means of meter-stick and tape measurements that link the cable points to a limited number of *pre-surveyed* reference points. Prior to CHECKPRO, a proof-of-principle test of the method was performed in P Tunnel at the NTS.

String Survey Method

In the string-survey method, the location of each unknown point on a sensor cable is based on measurements of two types: *longitudinal* measurements giving the distances between adjacent points on the cable, and *transverse* measurements giving the distances from cable points to a string running roughly parallel to the cable. At least two separate sets of transverse measurements are needed to determine the cable locations uniquely. In addition, auxiliary measurements are needed (1) to establish the location and orientation of the string with respect to the survey coordinate system, and (2) to determine points of reference for the longitudinal measurements. To accomplish this task, the horizontal run of sensor cabling is divided

into *sections* of typically 20 m in length. These sections define corresponding *segments* of the individual cables. At the ends of each section, 3 reference points are established and pre-surveyed before sensing-cable installation. All subsequent measurements are related to the known coordinates of this collection of reference points and, in principle, no further surveying is required. Fig. 1 illustrates how direct measurements to the 3 reference points are used to establish the coordinates of a longitudinal reference point at one end of a cable segment (3 parameters determine a point). This procedure is applied at both ends of each cable segment to provide a reference frame for longitudinal, point-to-point data. Fig. 2 illustrates how measurements from 2 reference points at each end of the section define the string coordinates (4 parameters determine a line), assuming the string extends somewhat beyond the ends of the section.

Fig. 1 A point near the end of a cable segment is located by measurements to 3 reference points

Fig. 2 The location of a string is determined by measurements to 4 reference points.

Figs. 3 and 4 illustrate how a pair of strings (actually the same string in two locations) are first referenced to the known, surveyed points and then used to determine transverse coordinates for points on two separate cable segments.

Fig. 3 Reference points are used to locate strings.

Fig. 4 Strings are used to locate cable points.

The following features of this method are worth noting:

- Though the method is to be applied to a “horizontal” sensing cable, there is no requirement that the cable be particularly level or straight. Its as-built geometry is defined by the locations of specific points on it that have been identified and labelled.
- Accuracy is required only in distance measurements. There are no stringent requirements on the location or alignment of the reference points or the strings.
- The analysis is exact. No assumptions are made, and exact measurements will produce exact results. Any uncertainties in the results are due to uncertainties in measurement.
- Redundant measurements (more than 4 reference points per string, more than 2 strings per cable point) can be accommodated by least-squares fitting to reduce dependency on individual measurements.
- All point-to-string measurements are to be taken perpendicular to the string line (minimum distance) where sensitivity to the measuring-stick orientation is minimal.
- The method includes calibration and correction of offsets due to the sag of the string. [These offsets are minuscule. At CHECKPRO, the *maximum* correction applied was 0.15 mm--about a tenth of the string diameter.]

The step-by-step procedure used to implement the string-survey method at CHECKPRO is indicated in Appendix A. Here we reproduce the instructions that accompanied the data sheets used in the exercise. Note that one of the steps (Step 3) involves point-to-point measurements between pairs of pre-surveyed reference points. This step gives a direct cross-check of the pre-survey data.

P-Tunnel Test

A proof-of-principle test of the string-survey method was conducted on February 7-8, 1994 in P Tunnel at the NTS. This test was done in conjunction with the Field Survey Procedures Training session sponsored by the ACND. A description of the test and its results has been provided in a separate report.

The “sensing element” used in P Tunnel was a single 19-m segment of Kevlar rope with 16 points indicated on it with a marking pen. It was strung at a convenient elevation in the U12P.06 bypass drift with no attempt to replicate actual TTBT deployment conditions. Transverse distances were measured using 4 different string locations. The method used differed slightly from the CHECKPRO case in that 2 of the 6 surveyed reference points were on the ends of the cable itself. The procedure illustrated in Fig. 1 was therefore not required. [That procedure was subsequently added so that only survey data taken *prior* to sensing cable installation would be used in the analysis.]

The P-Tunnel report concludes that the overall accuracy of the string-survey method was about 3 mm. Of this uncertainty, about 1 mm was due to the accuracy of the reference survey data and about 2 mm was due to errors introduced from the method itself.

There was one hitch encountered during the P-Tunnel test. Direct measurements between the surveyed reference points, and systematic errors noticed during data analysis both indicated that the location of one of the surveyed points was in error by about 0.11 m. When this problem was detected, auxiliary measurements that had been taken during the exercise were used to reconstruct the coordinates of the bad point. When this correction was made, the 3-mm accuracy quoted above was obtained. Without this correction, the string-survey results would have been off by as much as 0.14 m. The test therefore emphasized the desirability of (1) cross-checking the survey data with direct measurements and (2) including redundant and auxiliary measurements in the string-survey method.

CHECKPRO Installation

The sensor cable configuration used at CHECKPRO was derived from the setup proposed for the PRILIV event. Requirements for pre-grouting the cable run at PRILIV led to a proposed installation close to the invert of the satellite drift. In particular, pairs of anchor bolt were to be installed along the right rib every 5 meters at heights of 0.2 m and 0.4 m above the invert in a manner that would allow straight cable runs at

roughly the 0.3 m level. Vertical cross pieces bolted to the horizontal anchor-bolt pairs were to provide support for the cables.

The designated "satellite drift" at CHECKPRO was more irregular than that intended for PRILIV, so it was impractical to attempt an identical installation. Instead, 4 pairs of anchor bolts were installed at roughly 16-m intervals at locations that allowed an open line-of-sight path for cable runs between adjacent pairs of bolts. Cable support at 5-m intervals was achieved by installing vertical "shower curtain" rods between the anchor bolts. These rods were equipped with pointed, threaded extensions at each end and could be seated firmly between the invert and the back of the drift.

The two sensor cables brought to CHECKPRO were each only 30 m long, so only 3 of the 4 pairs of anchor bolts were used. The installation is illustrated schematically in Fig. 5.

The two cables (designated K-1 and K-2) were installed with the following steps:

- Short vertical cross pieces were wired to the 3 anchor-bolt pairs.
- Two Kevlar-rope messengers were installed with a 0.10 m vertical separation and tightened with turnbuckles attached to the cross pieces.
- Four vertical support rods (designated A, B, C, and D) were installed at intermediate locations along the messengers and the messengers were fixed to them.
- Sensor cables K-1 (upper) and K-2 (lower) were fixed to the messengers and tightened with additional turnbuckles at the cross pieces.

Both of the 30-m sensor cables were pre-labeled at 1-meter intervals. In addition, as shown in the figure, each sensor cable had two 2-m signature loops. Thus the final cable lengths were about 26 m. As shown in Fig. 5, the cables extended just outside the CHECKPRO hydro-zone at the north end and just beyond rod D at the south.

Fig. 5 Installation of cables K-1 and K-2. The dashed sections are Kevlar messenger only.

Setup and Measurements

Nine reference surveyed points (designated P1 through P9) were located in triplets at the north, middle, and south pairs of anchor bolts. Their configuration relative to the bolts and sensor cables is shown in Figs. 6 through 11. All points except P1 and P4 were indicated with PK nails anchored in solid rock. Point P1 was marked on the head of a long spike driven into the sandy material forming the invert. Point P4 was an "X" scribed onto the track running through the drift. The arrangement of points P7, P8, and P9 (Figs. 6 and 7) is not ideal. To obtain a reliable longitudinal reference (Fig. 1) it is important that the triplet of known points used in the process depart significantly from being co-linear. This rule was hard to satisfy at the north end of the drift, but the results appear not to have been affected.

Fig. 6 Configuration at the north end, looking toward the south.

Fig. 7 Configuration at the north end, looking toward the east.

Fig. 8 Configuration in the middle, looking toward the south.

Fig. 9 Configuration in the middle, looking toward the east.

Fig. 10 Configuration at the south end, looking toward the south.

Fig. 11 Configuration at the south end, looking toward the east.

On June 10, after the 9 reference points were identified, their coordinates were determined by CHECK-PRO Team 1 surveyors using the coordinate system established during the first week of the exercise. The results of that survey are shown in Appendix B.

Following cable installation on June 11, stickers with cross-hairs (like this) were used to indicate 16 points on the cables whose locations were to be determined by the two survey methods. They were numbered sequentially from 101 to 116 (on cable K-1) and from 201 to 216 (on cable K-2) starting at the north end. The relation of these points to the meter-mark labels on the cables is indicated below.

point index	location on K-1	point index	location on K-2
101	on Kevlar rope	201	on Kevlar rope
102	1-m mark	202	1-m mark
103	3-m mark	203	3-m mark
104	6-m mark	204	6-8 meter loop
105	8-m mark	205	10-m mark
106	11-13 meter loop	206	13-m mark
107	just north of middle anchor bolts	207	just north of middle anchor bolts
108	just south of middle anchor bolts	208	just south of middle anchor bolts
109	18-m mark	209	18-20 meter loop
110	20	210	22-m mark
111	22-m mark	211	24-m mark
112	23-25 meter loop	212	25-m mark
113	27-m mark	213	27-m mark
114	29-m mark	214	29-m mark
115	cable connector	215	cable connector
116	on Kevlar rope	216	on Kevlar rope

For purposes of the string survey, cables K-1 and K-2 were divided into two sections--north and south of the middle anchor bolts. This resulted in 4 cable segments altogether:

Segment 1: points 101 - 107 (K-1 north)

Segment 2: points 201 - 207 (K-2 north)

Segment 3: points 107 - 116 (K-1 south)

Segment 4: points 207 - 216 (K-2 south)

Two teams (3 persons each) were designated to conduct the string surveys. The string used was the standard 3-strand nylon twine used by the hydro team for many other purposes. It was installed under tension (10 - 40 lbf) with rigid support at each end being supplied by suitable anchors (rods in boreholes, etc.) and spreaders (3/4-inch dowels). The configuration of the 4 strings, as they crossed the planes of the anchor bolts, is indicated in Figs. 6 through 11.

Team A surveyed segments 1 and 2 using string locations 1 (upper) and 2 (lower).

Team B surveyed segments 3 and 4 using string locations 3 (upper) and 4 (lower).

On the same day as the string survey was done (June 12), surveyors from CHECKPRO Team 2 surveyed the 32 points on the cables using the same control points and coordinate system that was used on June 10. They also re-surveyed 6 of the 9 reference points (P1, P3, P4, P6, P7, and P9). The results of that survey are shown in Appendix C.

The Locations of Points on Cables K-1 and K-2

Figs. 12 and 13 show the installed cable coordinates as determined by conventional survey of the 32 points (data of Appendix C). The coordinate axes chosen for these plots are not the survey axes (northing, easting, and elevation) but instead are aligned along a line joining the two ends of cable K-2. This alignment allows plotting the transverse components to a scale 100 times larger than that of the longitudinal component. Also indicated in the figures are the locations of the supporting anchor bolts and vertical rods.

Fig. 12 Side view of the as-built sensor cable configuration.

Fig. 12 (side view) shows indications of a general, primary sagging of the installation between the anchor bolts, and also indications of secondary sagging between the vertical rods. The primary sagging is that of the Kevlar messenger ropes, which were tensioned between the anchor bolts and then (in their sagged state) taped to the rods. The secondary sagging (particularly noticeable on the lower cable, K-2) is presumably due to the additional weight of the cables (also under tension) that were added later. A calibration weight of 130 gm was hung from the midpoint of each of the 4 Kevlar sections before they were taped to the rods. From the measured deflections (~ 0.008 m) and lengths of the sections (~ 16.2 m) we estimate a tension in the rope of 670 newtons (150 lbf). Combining this result with the measured mass per unit length of the Kevlar (0.0272 kg/m), we compute the midpoint sag of the Kevlar sections, under their own weight, to be 13 mm. As seen in Fig. 12, this estimate is consistent with the observations.

Fig. 13 Top view of the as-built sensor cable configuration.

Comparison Between the Two Conventional Surveys

Six of the reference points (P1, P3, P4, P6, P7, and P9) were surveyed twice by conventional means. If we don't count the point P1 (which was "in the dirt"), a comparison of these two surveys (Appendices B and C) show differences as large as 6 mm. A closer look shows that these differences are systematic rather than random in character. A slight shift and rotation (about the tripod axis) of the first set of data brings them into much better agreement with the second set:

$$\text{NORTHING}(\text{adjusted}) = \text{NORTHING} + 0.0050\text{m}$$

$$\text{EASTING}(\text{adjusted}) = \text{EASTING} - 0.0005 \text{ m} - 0.00016 (\text{NORTHING} - 1996.34 \text{ m})$$

$$\text{ELEVATION}(\text{adjusted}) = \text{ELEVATION} + 0.0055 \text{ m}$$

When this adjustment is applied to the data of the first survey, then the differences are minor:

First survey (adjusted) minus second survey in millimeters

point	northing	easting	elevation
P1	1.2	0.0	-8.4
P3	-1.2	3.2	-0.3
P4	0.0	0.5	0.6
P6	-0.1	-0.1	0.3
P7	-0.3	0.0	-0.9
P9	-0.2	-0.2	0.3

In the case of point P1, it was found that coordinates from the first survey agreed better with the point-to-point distance measurements made during the string survey. Therefore the adjusted first survey data for points P1 through P9 were used as reference points for the string survey. [Note that, for purposes of comparison, we could as easily have applied the adjustment to the second set of data instead. We chose the first set because it had fewer points to deal with.]

A Problem with Point P5

Both of the string survey teams made point-to-point measurements of the distances between triplets of reference points. With one exception, these all agreed well (within 2 mm) with the distances computed from the survey data. The exception was the distance between points P5 and P6. As computed from the data in Appendix B, it is 0.592 m, whereas the measured distances were 0.621 m (Team A) and 0.624 m (Team B). When this discrepancy was discovered, the point-to-point measurement was re-checked, and it was agreed that 0.62 m is correct. Point P6 was surveyed twice with good repeatability (see above table), but point P5 was not. Looking at all the evidence, we conclude that the coordinates of point P5 given by the first survey are in error. As was done for the P-Tunnel case, the coordinates for P5 could be reconstructed by making an appeal to other measurements. In particular, distance measurements from P5 to neighboring reference points (P4 and P6) and cable points (107, 108, 207, and 208) were used to show that the elevation given for P5 was too high by 32 mm. This correction was made before the string-survey data were analyzed.

String Survey Comparisons

The string-survey data can be analyzed in a variety of ways, depending on which reference points are used to determine the string locations. As a base case, an analysis was done in which all 3 reference points at each end of a given string (6 points total) were used to determine the string parameters in least-squares fashion (See Fig. 14a). The results of this analysis for the 32 unknown points on the 2 cables are displayed in Appendix D. Here we show the difference between the point coordinates as determined by the string survey and the coordinates listed in Appendix C. Also shown are the arithmetical and root-mean-square averages of these differences. In the column on the right, under "magnitude" we show the direct distance implied by the coordinate differences. The data show some signs of systematic errors (arithmetic averages not small), but no strong differences between the three coordinates.

Fig. 14 Illustrating different methods by which 2 strings can be located with respect to the reference points.

As a measure of the discrepancy between the two survey approaches, consider the root-mean-square magnitude averaged over all 32 points. For the case at hand (method a in Fig. 14), this value was 4.0 mm. Thus we can conclude that the over-all accuracy of the string-survey method as applied at CHECKPRO was 4 mm. Of this uncertainty, we can attribute about 1 mm to the accuracy of the reference survey data and about 3 mm to errors introduced from the method itself. The slight increase in uncertainty relative to the P-Tunnel test (3 mm total) is consistent with the less favorable installation at CHECKPRO.

If other options are chosen for determining the string locations, the over-all results are changed very little. For example, Figs. 14b, c, and d depict three ways in which the 2 string locations can be determined using

only 2 reference points at each end. For method **b**, the 32-point rms discrepancy was 3.9 mm. For method **c**, it was 4.1 mm. Even the worst case, method **d**, was not off that much: 5.0 mm.

These results depend on the accuracy of the original survey of the 9 reference points P1 - P9. As noted above, a problem was encountered in the case of point P5. If the original survey is taken literally and P5 is not corrected, then the 32-point rms discrepancy becomes 13.4 mm for method **a**, with points in the vicinity of P5 off by ~20 mm.

When we compare methods **b**, **c**, and **d** against method **a** (instead of against the conventional survey), we find 32-point rms discrepancies of 1.6 mm, 2.2 mm, and 5.0 mm. In the last case, it seems that difficulties in locating the string are dominant. Otherwise, it appears from such comparisons that uncertainties in string location are at about the 2 mm level (compared with a string diameter of 1.6 mm).

Conclusions and Recommendations

Two considerations are involved in evaluating the string-survey method: accuracy and practicality.

Regarding accuracy, once the uncertainties in measurement get below about 0.1 m, the location of the sensor cables is no longer a significant factor in the determination of yield by the hydrodynamic method. Uncertainties in the properties of the rock (the logging and coring part of the exercise) then become dominant. Thus it is a mistake to dwell at length about discrepancies of a few millimeters. The string-survey method, because it depends on pre-surveyed reference points, will always be less accurate than the direct results of conventional surveying. In the case of CHECKPRO, we have seen that the additional loss of accuracy is of the order of 3 mm. This value is consistent with our experience in making meter-stick and tape measurements in tunnel environments, and is not a result of installation problems, measurement mistakes or defects in the analysis. As far as conventional surveying goes, accuracies in the 1-2 mm range appear to be commonly achieved. The systematic differences of ~5 mm seen between the two separate surveys of 6 of our reference points are no cause for concern. Such differences could presumably be reduced with more effort, but such effort does not appear justified.

Of more concern is the possibility that a surveyed point can be just plain wrong. Bad points were a problem both in the P-tunnel test (11 cm error) and at CHECKPRO (3 cm error). Such discrepancies, of unknown origin, are reaching the threshold of significance, and, as we have seen, they introduce errors in the string-survey method that propagate through the analysis. In both cases, we were able to "reconstruct" the bad points using auxiliary data. In the CHECKPRO case, this reconstruction was "illegal" in the sense that it depended on data from a second survey.

Regarding practicality, the string survey method has notable drawbacks:

- If we consider a scenario in which the reference points are to be pre-surveyed during logging and coring operations, then we require that decisions about the placement of these points be made by someone not involved in cable installation.
- For PRILIV style installations, the string-survey method requires reference points near or in the tunnel invert. Such points are needed only for longitudinal orientation (Fig. 1), not for string location (Fig. 14b). Nonetheless, they're a nuisance. At CHECKPRO we ended up with a poor installation (point P1), an acceptable but unconventional approach (point P3), and a less-than-ideal configuration (point P7).
- The string survey requires effort. At CHECKPRO, a total of 17 man-hours was used to complete all the steps listed in Appendix A. Of these, about 2 man-hours were devoted to layout documentation that would have to be done by the hydro team under any circumstances. This leaves 15 man-hours devoted to the string survey. Because we were partly in a training mode and had two 3-man teams working simultaneously, efficiency was not at its height. One might reasonably expect a reduction to 12 man-hours, equivalent to the 1 team-hour per string achieved in P-tunnel. A real deployment, with an 80-m-long hydro-zone and 6 cables, could easily require two 6-hour working days at Novaya Zemlya. For comparison, it took two surveyors exactly one hour to "shoot" 32 cable points plus 6 reference points.

In summary, CHECKPRO showed that the accuracy of the string-survey method is adequate for back-up purposes. It also showed a number of inconveniences that would be encountered in a deployment situation. Of these, the most significant appears to be the extra burden that it places on the geodetic team before the sensor cables are installed. Second in importance is the burden on the hydro team itself to make the measurements. Some steps in the process could be improved with practice, but the effort required is not justified. On the other hand, our very limited experience in P-Tunnel and at CHECKPRO indicate the desirability of cross-checking the survey data for possible bad points. Such points are only a problem if they are off by at least a few centimeters. One way to check, of course, is to repeat the survey. This would seem to be the best course since it requires the fewest man-hours. Another option would be for the hydro team to do cross-check measurements that, while sufficient to detect survey problems, would not constitute a separate survey. An example of an intermediate level of effort in a PRILIV geometry would be for the survey team to record the location of the tip of the top anchor bolt at each 5-m interval. This would provide sufficient information for the hydro team to manually determine the cable layout to within a couple of centimeters if no final survey were available. If a future deployment for TTBT verification does occur, such an option could be considered at the time.

Acknowledgments

This work was conducted under the auspices of the DOE Office of Nonproliferation and National Security, project number TT001.

We are indebted to G.L. Bates, S.A. Boroski, R.S. Remington, and S.P. Woolsey of RSN for taking extra time at CHECKPRO to provide the survey data of Appendices B and C. EG&G hydro-team personnel who installed the sensor cables and performed the string surveys were T.E. Graves, E.E. Hunt, G.A. Mize, R.X. O'Connor, L.G. Reynolds, T.D. Sandoval, and F.S. Tibbits.

We are especially grateful to Bill Strickland of the Colorado School of Mines and his crew for their hospitality and for preparing the satellite drift for this exercise.

Appendix A: Instructions for the String-Survey Method

Step 1

Make diagrams showing the general layout and details as required. Features to be included are:

- The location of cables relative to the drift, landmark features, hydro-zone boundaries, etc.
- The location and type of cable support fixtures
- The location and numbering (in sequence starting with 1) of all surveyed points that are not on the cables
- The numbering and scope of separate cable segments
- The location and numbering of strings (actually the same string in different locations). Note that the strings extend beyond the ends of the segments to which they apply.

Step 2

List the points to be surveyed (PK nails, etc.) that are not on the cable using the numbering scheme defined in Step 1. On this data sheet, enter brief descriptors (to back up the numbers). The four remaining columns to the right are filled in later with information provided by the surveyors.

Step 3

Measure point-to-point distances between pairs of surveyed points for as many cases as is practical. In particular, record the 3 inter-point distances between the 3 points at the end of each cable segment. This step serves as a check on the survey values and can help to reconstruct any erroneous points. To help keep track of the sequence of events, record the time at which this data sheet is completed. Ditto for all sheets that follow.

Step 4a

For each cable segment separately, make a diagram showing the cable segment and identifying by number (in sequence, left to right, starting with 1) all the points on the cable to be string-surveyed. Indicate landmarks and fixtures as appropriate.

Step 4b

Record distances between these points and the surveyed points to meet the following minimum requirement:

- At each end of the segment there is a group of 3 surveyed points that define a plane. Identify points on the segment that are reasonably close, but not too close, to this plane (say from 0.2 to 2.0 m). For each such point on the segment (recorded as cable pt. #), record the distances to the 3 survey points nearby.

Complete Step 5 before doing Steps 4a and 4b for the next segment.

Step 5

For each segment, beginning at the left (point 1) measure the distances between the points on the cable designated in Step 4. During the first pass, measure the distances between adjacent points separately. During the second pass, take a cumulative measurement along the tape with zero corresponding to point 1. In either case, the first non-zero entries in columns 2 and 3 are for cable pt. #2. If the data in column 2 are immediately converted to a calculated cumulative distance (column 4) then the measured cumulative data of column 3 can be cross-checked while they are being taken.

Note:

There is only one string. For each string location, Steps 6, 7, and 8 are done before the string is moved.

Step 6a

Describe the location of the string relative to the cable segment(s) to which it applies. Locate (approximately) the center of the string. Measure the unloaded vertical distance of the string from the invert. Measure the loaded distance when the calibration mass is hung. The difference is the mid-point deflection. This step is to be performed at least twice: when the string is first installed, and after all measurements involving the string are taken. Record the times when these measurements are done. A mass/length ratio is required to convert this calibration to a sag estimate. It is measured later and recorded at the bottom of the sheet.

Step 6b

Locate the ends of the string approximately (to within ~ 0.1 m). At each end of the string: Pick the surveyed point that is closest to each end of the string, and record its number and descriptor (from Step 2). Record how much the string end is displaced upward (negative if downward), outward (away from the rib), and left/right-ward (away from the string center) with respect to the chosen point.

Step 7

Record the minimum (perpendicular) distance from the string to the surveyed points within its range. A minimum of 2 survey points are required at each end to locate the string. More are better. Record the survey point descriptor as well.

Step 8

Record the minimum (perpendicular) distance from the string to the points on the cable segment designated in Step 4a. Descriptors for these points can be entered as appropriate. Don't forget to repeat the sag calibration (Step 6a).

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

Appendix B: Survey of 9 Reference Points

Date: 06-12-94

Time: 12:27:10

Page: 1

Coordinate File: CABLEABS.CRD

List of Coordinate Points

* Denotes Contouring Masspoint

Point ID	NORTH	EAST	ELEV	Descriptor
14	1997.5960	3999.9690	999.4960	CENTER OF CANISTER
203	1976.6971	3979.8838	999.5315	PT. # 1 FOR CABLE A/B
204	1976.5727	3980.3023	999.5367	PT. # 2 FOR CABLE A/B
205	1976.4046	3980.3096	1000.1051	PT. # 3 FOR CABLE A/B
206	1993.4189	3982.3586	999.9206	PT. # 4 FOR CABLE A/B
207	1993.4631	3983.0293	999.9944	PT. # 5 FOR CABLE A/B
208	1993.2971	3983.0898	1000.5595	PT. # 6 FOR CABLE A/B
209	2008.9055	3985.2778	1000.2762	PT. # 7 FOR CABLE A/B
210	2008.9112	3985.5825	1000.5140	PT. # 8 FOR CABLE A/B
211	2008.7141	3985.7401	1000.8344	PT. # 9 FOR CABLE A/B

Appendix C: Survey of 32 Cable Points and 6 Reference Points

Date: 06-12-94
Time: 11:03:03
Page: 1

Coordinate File: CORRTEX.CRD
List of Coordinate Points
" Denotes Contouring Masspoint

Point ID	NORTH	EAST	ELEV	Descriptor
1.	1976.7009	3979.8864	999.5454	REF. PT. #1
3	1976.4108	3980.3091	1000.1109	REF. PT. #3
4	1957.0960	3977.3690	0.0000	TRAV. PT. #4
5	1996.3400	3982.1480	1001.4559	TRAV. PT. #5 ← TRIPOD
6	1993.3022	3983.0899	1000.5647	REF. PT. #6
7	2008.9108	3985.2753	1000.2826	REF. PT. #7
9	2008.7193	3985.7378	1000.8396	REF. PT. #9
10	1979.8180	3980.1360	1001.1137	TRAV. PT. #10
11	0.0000	0.0000	1002.0890	TBM#4
12	0.0000	0.0000	1001.4740	TBM#3
14	1997.5960	3999.9690	999.4960	CENTER OF CANISTER
101	2008.3143	3985.3467	1000.5258	ALL PTS ON CORRTEX
102	2005.9043	3984.9488	1000.4664	↓
103	2003.9302	3984.6247	1000.4275	
104	2000.9719	3984.1375	1000.3733	
105	1998.9969	3983.8106	1000.3369	
106	1996.0309	3983.3228	1000.2883	
107	1993.7328	3982.9521	1000.2476	
108	1992.9295	3982.8196	1000.2297	
109	1991.0981	3982.5291	1000.2075	
110	1989.1200	3982.2143	1000.1750	
111	1987.1435	3981.9011	1000.1434	
112	1986.1556	3981.7472	1000.1234	
113	1984.1866	3981.4334	1000.0968	
114	1982.2093	3981.1299	1000.0699	
115	1981.1965	3980.9716	1000.0560	
116	1977.0783	3980.3205	1000.0122	
201	2008.3339	3985.3453	1000.4192	
202	2005.8739	3984.9457	1000.3614	
203	2003.9029	3984.6219	1000.3266	
204	2000.9391	3984.1352	1000.2592	
205	1998.9715	3983.8120	1000.2359	
206	1996.0103	3983.3247	1000.1879	
207	1993.7294	3982.9572	1000.1526	
208	1992.9294	3982.8265	1000.1375	
209	1991.0786	3982.5293	1000.0947	
210	1989.1067	3982.2132	1000.0706	
211	1987.1337	3981.9037	1000.0449	
212	1986.1443	3981.7511	1000.0270	
213	1984.1701	3981.4388	999.9930	
214	1982.1924	3981.1319	999.9671	
215	1981.1889	3980.9743	999.9552	
216	1977.0755	3980.3244	999.9129	
316 = 116 ✓	1977.0803	3980.3177	1000.0110	
404	1993.4239	3982.3581	999.9255	REF. PT. #4

Appendix D:

Differences Between String-Survey and Conventional-Survey Results

CABLE SEGMENT NUMBER 1

differences (mm) between string survey and conventional survey

pt.	northing	easting	elevation	magnitude
101	5.8	0.9	-2.1	6.2
102	3.8	0.0	0.1	3.8
103	-0.1	2.7	-0.2	2.7
104	1.2	1.9	0.3	2.3
105	0.0	2.5	-0.4	2.5
106	0.2	-0.1	-1.5	1.5
107	-1.7	4.2	1.6	4.8
average	1.3	1.7	-0.3	3.4
rms	2.7	2.2	1.2	3.7

CABLE SEGMENT NUMBER 2

differences (mm) between string survey and conventional survey

pt.	northing	easting	elevation	magnitude
201	1.2	0.6	-2.2	2.6
202	0.9	-1.0	-0.1	1.3
203	-0.9	-1.1	0.8	1.7
204	4.1	4.9	-1.8	6.6
205	-0.7	0.2	0.9	1.1
206	0.2	1.6	-1.1	2.0
207	-0.5	6.3	3.2	7.1
average	0.6	1.6	-0.0	3.2
rms	1.7	3.1	1.7	4.0

DATE

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END