Saskatchewan Precise Calibration

Base Lines

for Calibration of Electronic Distance Measuring Systems

Prepared by

Information Services Corporation of Saskatchewan

Available Through: **Geomatics Distribution Centre**
1301 1st Avenue
Regina, Saskatchewan
S4R 8H2
Or at www.geosask.ca

October 2008

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Foreword

While land surveyors are not the only professionals using Electronic Distance Measuring (EDM) systems, the need for some means of standardization is alluded to in the Land Surveys Act which states:

> **12 The measure of length used in surveys made pursuant to this act must be determined on the basis of the International System of Units and the Canadian units of measure in accordance with the Weights and Measures Act (Canada) 2000, c.L-4.1,s.12.**

It is hoped that the two Saskatchewan base lines; Saskatoon and Regina-Davin, will be instrumental in setting the standard for EDM calibration.

Geodetic surveys integrated into the North American Datums, NAD27 and NAD83 use the same measure of length, being the meter defined by Appendix A of the CSA Standard CAN3-Z2341 as follows:

> **The meter is the length equal to 1,650,763.73 wavelengths in vacuum of the radiation corresponding to the transition between the levels 2P10 and 5D5 of the krypton-86 atom.**

Users need locally accessible standard distances to test and calibrate EDM systems to ensure measurements conform to the standards required by law.

In Saskatchewan the provincial government through the Information Services Corp is responsible for the establishment and maintenance of physical base lines. The federal government through Geomatics Canada, is responsible for calibration of the base lines against the national standard.

A calibration base line is a standard length. Several points on a straight line are finely marked on stable permanent piers and the inter-point distances are very accurately measured against the national standard of length. The primary purpose of these base lines is to provide precisely known distances on suitable platforms to calibrate EDM instruments, which typically measure in the range from 20 to 2,000 meters. Some special purpose instruments can measure longer distances.

The precise calibration base lines established in the province can be used by land surveyors and others wishing to calibrate EDM systems.

Information Services Corp is the controlling agency for precise calibration base lines in Saskatchewan. For further information please contact:

Information Services Corporation of Saskatchewan
Surveys Branch
1301 1st Avenue
Regina, Saskatchewan
S4R 8H2

1-866-275-4721

Acknowledgments

SaskGeomatics Division wishes to thank the following organizations and people for their assistance, without which, implementation of the Regina-Davin and Saskatoon Calibration Base Lines would not have been possible.

Geodetic Survey of Canada for providing expertise and assistance in pier configuration, pier design and plate design. As well as, determining pier to pier lengths for both base lines and third order spirit levels for the Regina-Davin Base Line.

Tim Flaman of Eagle Surveys Limited for most of the reconnaissance, pier installation and horizontal determination for the Regina-Davin Base Line.

The **Rural Municipality of Lajord** for allowing the Regina-Davin Base Line to be constructed in their jurisdiction.

George, Nicholson, Franko and Associates Ltd. for reconnaissance, pier installation, horizontal and vertical determination for the Saskatoon Base Line.

The **Rural Municipality of Corman** for allowing the Saskatoon Base Line to be constructed in their jurisdiction.

1.0 Background

1.1 Introduction

Since technology developed during World War II led to the manufacture of affordable electronic distance measuring (EDM) systems, government and private survey organizations have realized the need to precisely calibrate these systems to detect systematic errors.

Prior to the availability of precise EDM systems (sub-millimeter range) the only way of establishing a precise baseline was by the use of calibrated invar taping. This method, by its very nature, was very costly and very time-consuming.

In 1972, the Federal-Provincial Conference on Control Surveys recommended that EDM calibration baselines be constructed across Canada to ensure that a consistence uniform scale be applied to all measurements.

It was further agreed that provincial governments would construct their own precise calibration base lines and the federal government provide precise measurements for them.

Resulting from this, the province of Saskatchewan constructed the first Saskatchewan precise calibration baseline in 1976, north of Regina on Highway 11. This baseline consisted of traditional survey type monuments set flush with the ground.

In 1987, a precise calibration base line was constructed south east of the city of Saskatoon. The base line consists of six concrete piers protruding 1.5 meters above the surface, crowned with stainless steel forced centering plates, as per EM&R specifications, as detailed in Appendix A. These plates allow EDM instruments to be placed directly on the piers, as opposed to being centered on a tripod over the monuments, as was the case with the original Regina base line.

Due to the nature of the monuments and location of the Regina base line, there were several problems associated with stability and consistency of measurements. This coupled with the advent of easily available more accurate EDM systems (sub-centimeter range) being used by most land surveyors in the province, rendered the base line effectively unsuitable for EDM calibration.

As a result, the Regina-Davin calibration baseline was constructed 36 kilometers south east of the city of Regina in 1990.

Piers were constructed in the same fashion as at the Saskatoon location (see Appendix A).

1.2 Why are Precise Calibration Base Lines Needed?

Crystal frequency and instrument-reflectors combinations change from project to project. These changes may not be immediately obvious to EDM users. Each manufacturer has their own way of dealing with instrument-reflector corrections. Inter-changing instruments and reflectors without calibration may introduce undetected errors into measurements.

A precise calibration base line is the cheapest and easiest way of determining and monitoring the performance of EDM systems. By measuring different combinations of lengths of lines on a base line and comparing these values to the adopted values, a user can determine the scale of correction to be applied to all measurements for that instrument-reflector combination.

If a regular program of instrument calibration is adopted, users will be able to identify frequency changes, malfunctions or operators errors before unreliable measurements are made. Therefore, reducing the need for costly field re-measurements.

1.3 Features of a Precise Calibration Base Line

A precise calibration base line must meet several requirements, the most important of these being:

1. Provide a consistently high standard of scale control.

2. Provide a systematic way of determining total system corrections.

3. Provide the ability to monitor the performance of EDM systems.

4. Provide a way of assessing the accuracy and capabilities of new EDM systems.

1.4 Properties of a Precise Calibration Base Line

In order for a precise calibration base line to meet the requirements set out in the previous section the following conditions must be met:

1. It must be physically stable.

2. The adopted values for distances between piers must be determined to an accuracy greater than that of the instruments to be calibrated.

3. It must be located in a place where the piers are unlikely to be disturbed.

4. The base line must be easily accessible.

5. It must not pose a hazard to users or the general public.

1.5 How to Use the Base Line

Marker to marker distances between all piers are provided in Appendices B and C. The advantage to using marker to marker distances is that the lengths can be compared right at the base line.

A conclusive calibration should yield consistent differences with the adopted values on lines of different lengths.

1. Make measurements using the same instrument reflector combination that is usually used.

2. Compare lines of different lengths covering the full range of the instrument.

3. Make measurements under normal weather conditions.

4. Calibrate after instrument maintenance and repair.

5. Calibrate when instrument-reflector combinations change.

6. Document each calibration and maintain a history so that changes over time can be detected.

7. Implement a regular calibration program; typically at the beginning and end of projects.

A detailed consideration of EDM calibration techniques is attached in Appendix D.

1.6 Conclusion

The vast majority of distances measured today are made with EDM equipment. The market is loaded with many types of EDM equipment of varying capabilities and accuracy. This underscores the need for uniform scale control against a high quality standard.

Just as the standard tape is used to calibrate survey chains, so does the precise calibration base line provide a standard by which to calibrate EDM systems.

2.0 The Regina-Davin Precise Calibration Base Line

2.1 Introduction

The Regina-Davin calibration base line was constructed in 1990 by SaskGeomatics Division; then a part of Sask Property Management Corp. It is located 36 kilometers south east of Regina. Geodetic Surveys of Canada (GSC) performed the first calibration in 1991 and processed the measurements using the EDM program in 1992. A preliminary assessment of a second set of calibration measurements made in 1992 June, indicates that the piers had remained stable within one millimeter.

The base line consists of six concrete piers protruding 1.5 meters above the ground in a north-south line. Pier 1, the most northerly, is 5 kilometers south west of the hamlet of Davin. Each pier is 20 meters east of the centerline of provincial grid road 621.

All piers are inter-visible, forming 15 calibrated lengths. Pier 1 is 3,327 meters from pier 6. Piers 5 and 6 are the closest together and are 100 meters apart.

Reconnaissance for the base line was done by Tim Flaman of Eagle Surveys Ltd. and SaskGeomatics Division staff members. The location for the base line was chosen because it is situated on a spur of the Moose Mountain Uplands protruding into the Regina Basin. This terrain is slowly undulating, and the soil materials consist mainly of till in undulating ground moraine, and till with stratified drift inclusions. This geological formation provides a good stable base for construction. The combination of gently rolling hills, stable soil and its proximity to Regina made the Davin area the ideal choice for this base line site.

The piers are 12 inches in diameter by about 5.5 meters in length, set a minimum of 4 meters below grade. They are constructed of type 5 concrete and are reinforced with four “size 10” rebar placed vertically in each pier from bottom to about three inches below the top of each pier. Re-bars are cross-tied by three circular “size 10” rebar set near the top, middle and bottom of the vertical rebar.

Each pier is capped with a nine inch diameter stainless steel plate custom manufactured to allow forced centering of a WILD tribrach.

2.2 Accuracy

Two factors contribute to the reliability of the adopted values of the pier to pier lengths; quality of the length determinations and the stability of the piers.

Geodetic Survey of Canada performed the first determination (or epoch) in 1991 and the second epoch was recorded in the summer of 1992. All measurements were made with a Mekometer ME 5000. Length determination consisted of four double measurements (both forward and backward) on all lines.

The first epoch observations were processed using the least squares adjustment program EDM. A standard deviation of (0.2 mm + 0.5 ppm) was assigned to each of the ME 5000 length observations, and a scale parameter of (-1.0 +/-0.3 ppm) determined by linear interpolation of time was applied to the observations.

The variance after adjustment of 1.187, with 114 degrees of freedom, passed the Chi-square test on the variance factor at the 95% level. The Chi-square test for the normal distribution of the residuals passed at the 95% level.

The 2003 measurements of this baseline were made by Hennessey/Whalley from July 25-27, using the Mekometer ME5000 (serial number 357061). In 1997 and 2003, the 5 sensors of the automated meteorological measuring system were raised to a variety of heights to better model the conditions along the lines of sight as were noted in the Baseline Site section. See Table 1 for the measurement history of this baseline.

Each baseline measurement for a year consists of at least three double (forward and backward) distance measurements between all intervisible piers using either the Geomensor CR204 or Mekometer ME5000 EDM instruments.

Table 1: Measurement history

Date	Observer	Instrument	Serial Number
August 8-13/1991	Lafrance	Mekometer ME5000	357061
July 2-4/1992	Hennessey	Mekometer ME5000	357061
July 2-4/1997	Hennessey	Mekometer ME5000	357061
July 25-27/2003	Hennessey	Mekometer ME5000	357061

NGBL Calibration

The scale bias for the Mekometer ME5000 was determined from two independent calibration surveys on the National Geodetic Baseline (NGBL). The constant bias from the NGBL was used as a gross check on the value determined from the Regina baseline adjustment. The average scale bias from the two NGBL calibrations was applied to all distance observations. See Table 2 for the 2003 NGBL biases.

Table 2: Mekometer ME5000 biases derived from 1997 NGBL measurements

Date	Measurement Sets	Constant Bias Value ± Std.Dev. (mm)	Scale Bias Value ± Std.Dev. (ppm)
June 10,12,17	3	-0.4 ± 0.1	-0.55 ± 0.14
Aug.16/Sept.7	3	-0.4 ± 0.1	+0.27 ± 0.15
Average		-0.4 ± 0.1	-0.1 ± 0.2

Baseline Adjustment

The 2003 Regina baseline measurements were processed with the baseline adjustment program CALIB (version 1.1, May 95). A minimally constrained adjustment was made with pier 1 fixed. An a priori standard deviation of 0.1 mm + 0.5 ppm was used for all Mekometer distances, and 0.1 mm for the centering errors. The results of the adjustments back to 1991 are summarized in Appendix B.

The constant bias from the CALIB adjustment was -0.4 ± 0.1 mm, which agrees with the estimate obtained from the NGBL calibration (see Table 2). The variance factor for the 2003 adjustment was 0.496, which fails the Chi-square test. The low variance factor indicates an internal consistency that is better than the a priori standard deviations for these measurements. There were no residual outliers in the adjustment using all the observations. All residuals passed the Chi-square goodness-of-fit test for normal distribution. All tests were performed at the 95% confidence level.

Comparison with Previous Epochs

The results of the 1997 and 2003 adjustments were compared to check for any scale differences and pier movements between epochs. The analyses were performed with the baseline comparison program LINCOMP (version 1.3, May 95). The reader is referred to the reports issued prior to 2003 for details of those measurements.

Pier Movement Analysis

The pier movement analysis performed by program LINCOMP uses the "least absolute sum" (L1-norm) solution. Piers that are identified as having statistically significant coordinate differences are removed from the analysis by renaming them. The process is iterated until no "outliers" remain. For the comparisons between the 1997 and 2003 epochs, the pier in Table 3 showed minor movement. This pier movement is statistically significant, but is not considered to be statistically significant since movements of up to a millimeter are possible due to diurnal and/or seasonal factors that may not appear in epoch-to-epoch comparisons. **Therefore, the six piers on the Regina baseline are considered to be stable.**

Scale Difference Analysis

Any scale difference between epochs is estimated with program LINCOMP using the least squares (L2-norm) solution with suspected pier movements removed. The estimated scale differences between the epochs are given in Table 3.

Table 3: Scale difference between epochs

Comparison		Piers Used	Scale Change	
From	To		Value ± Std.Dev. (ppm)	95% Confidence Interval (ppm)
1991	1992	1, 2, 3, 4, 5, 6	+0.83 ± 0.41	+0.03 to + 1.63
1992	1997	1, 2, 3, 4, 5, 6	+0.74 ± 0.25	+0.26 to + 1.22
1997	2003	1,2,3,4,6	-0.66 ± 0.17	-0.99 to –0.33

The estimated scale difference from 1997 to 2003 using five piers is statistically significant at the 95% confidence level.

Adopted Distances

The Adopted Distances for the Regina baseline are given in Appendix B and are based on the 2003 measurements. This appendix gives the adjusted interpier slope distances, estimated standard deviations and elevation differences.

Calib Least Squares Adjustment Summary - Baseline Name: Regina, Saskatchewan

Epoch Dates	Degrees of Freedom	Variance Factor	Statistical Tests		Derived Constant mm ± S.D.	Input Scale ppm ± S.D.	Comments
			V.F.	G.O.F.			
Aug. 8-13 1991	114	1.188	Pass	Pass	-0.1 ± 0.1	-1.0 ± 0.3	No Outliers
July 2-4 1992	84	1.183	Pass	Pass	-0.1 ± 0.1	-0.8 ± 0.2	No Outliers
July 2-4 1997	84	0.346	Fail	Pass	-0.3 ± 0.1	+0.4 ± 0.1	No Outliers
July 25-27 2003	86	0.496	Fail	Pass	-0.4 ± 0.1	-0.1 ± 0.2	No Outliers

Legend: V.F. - Variance Factor Test
G.O.F. - Goodness of Fit Test
NOTE: All statistical and outlier tests performed with a 95% Confidence Level.

2.3 Notice to Users

The Regina-Davin Calibration Base Line is located on public property. Any damage to private or public property which may occur during the use of the base line is the responsibility of the user.

Base line users must obey normal traffic safety laws.

The base line was installed with the cooperation of local residents and common courtesy should be observed during occupations. The adjacent grid road is not paved; please try to keep dust levels at a minimum by driving at a moderate rate of speed.

Users are also asked to assist in the preservation of the base line. Please report any damages to:

Information Services Corporation of Saskatchewan
Surveys Branch
1301 1st Avenue
Regina, Saskatchewan
S4R 8H2

3.0 The Saskatoon Precise Calibration Base Line

3.1 Introduction

The base line was constructed in 1987 along the west boundaries of sections 26 and 35 township 35 range 4 west of the third meridian, about 10 kilometers south east of Saskatoon. Geodetic Survey and Canada (GSC) performed the first measurement in June 1988. The second epoch was measured in May of 1989. A GEOMENSOR CR-204 was used for the measurement of both epochs.

The base line is made up of six concrete piers protruding 1.5 meters above grade in a north south line.

All piers are intervisible, forming 15 calibrated lengths. pier 1 is 3,000 meters from pier 6. Piers 1 and 2 are the closest together and are 100 meters apart.

Reconnaissance for the base line was performed by George, Nicholson, Franko and Associates (1982) Ltd. under CSMA contract ctr17c058.

The piers are 12 inches in diameter by about 5.5 meters in length, set a minimum of 4 meters below grade. They are constructed of type 5 concrete and are reinforced with four “size 10” rebar placed vertically in each pier form bottom to about three inches below the top of each pier. Rebars are cross-tied by three circular “size 10” rebar set near the top, middle and bottom of the vertical rebar.

Each pier is capped with a nine inch diameter stainless steel plate custom manufactured to allow forced centering of a WILD tribach.

3.2 Accuracy

Two factors contribute to the reliability of the adopted values of the pier to pier lengths; quality of the length determinations and the stability of the piers.

Geodetic Survey of Canada performed the first determination (or epoch) in 1988 and the second epoch was recorded in the summer of 1989. All measurements were made with a GEOMENSOR CR-204. Length determination consisted of four double measurements (both forward and backward) on all lines.

Both epoch observations were processed using the least squares adjustment program EDM. A standard deviation of (0.2 mm + 1.0 ppm) was assigned to each of the CR-204 length observations.

The pier movement analysis option of program EDM is used to detect systematic displacements between observing epochs. The 1988 adjustment results were used as input coordinates in the 1989 data adjustment and vice versa. Pier movement analysis of the 1989 data detected statistically significant movement at pier 5, and lesser movement at another pier. The average scale difference for the 1988 data was +0.9 ppm with a standard deviation of 0.3 ppm.

The 1988 and 1989 observation were combined to compute best estimates of the inter-pier distances and their corresponding accuracy. In the 1988 and 1989 sections of the combined adjustment pier 5 was identified as 5(88) and 5(89) respectively. The appropriate instrument parameters for constant and scale for each epoch were used as input in the combined adjustment.

The variance factor after adjustments of 0.967, with 236 degrees of freedom, passed the test on the variance factor based on a prior estimate of 1.0. The Chi-square goodness-of-fit test for the normal distribution of the residuals passed at the 95% level.

The 2001 measurements of this baseline were made by Hennessey and Raymond from July 25-27, using the Mekometer ME5000 (serial number 357061). See Table 1 for the measurement history on this baseline.

Table 1: Measurement history

Date	Observer	Instrument	Serial Number
Jun. 18-22/1988	Lafrance	Geomensor CR204	013
May 20-26/1989	Lafrance	Geomensor CR204	013
Jun. 24-27/1994	Hennessey	Mekometer ME5000	357061
July 8-10/1995	Lafrance	Mekometer ME5000	357061
July 25-27/2001	Hennessey	Mekometer ME5000	357061

Each baseline measurement for a year consists of at least three double (forward and backward) distance measurements between all intervisible piers using either the Geomensor CR204 or Mekometer ME5000 EDM instruments.

NGBL Calibration

The scale bias for the ME5000 was determined from calibration surveys on the National Geodetic Baseline (NGBL). The scale bias for the August calibration was used for this baseline because the TRANSMET units were calibrated on July 7. This change in the meteorological units would affect the scale determination after this date. The constant bias from the NGBL was used as a gross check on the value determined from the Sasktoon baseline adjustment. See Table 2 for the 2001 NGBL biases.

Table 2: Mekometer ME5000 biases derived from 2001 NGBL measurements

Date	Measurement Sets	Constant Bias Value ± Std.Dev. (mm)	Scale Bias Value ± Std.Dev. (ppm)
June 2-9	3	-0.4 ± 0.0	+0.21 ± 0.12
August 5-7	3	-0.4 ± 0.0	+0.35 ± 0.12
Average			+0.28 ± 0.12

Baseline Adjustment

The 2001 Saskatoon baseline measurements were processed with the baseline adjustment program CALIB (version 1.1 May 95). A minimally constrained adjustment was made with pier 1 held fixed. A priori standard deviations of 0.1 mm + 0.5 ppm were used for all ME5000 distances, and 0.1 mm for the centering errors. The results of this and past adjustments are summarized in Appendix B.

The constant bias from the CALIB adjustment was -0.2 ± 0.1 mm, which is consistent with the estimate obtained from the NGBL calibrations (see Table 2). The variance factor for the adjustment was 0.522, which fails the Chi-square test. The variance factor indicates an internal consistency that is better than the a priori standard deviations for these measurements. There were no residual outliers in the adjustment using all the observations. All residuals passed the Chi-square goodness-of-fit tests for normal distribution. All tests were performed at the 95% confidence level.

Comparison with Previous Epochs

The results of the 1995 and 2001 adjustments were compared to check for any scale differences and pier movements between epochs. The analysis was performed with the baseline comparison program LINCOMP (version 1.3 May 95). For the adjustments and analyses of the measurements prior to 2001, the reader is referred to the reports issued for those years.

Pier Movement Analysis

The pier movement analysis performed by program LINCOMP uses the “least absolute sum” (L1-norm) solution. Piers, which are identified as having statistically significant coordinate differences, are removed from the analysis by renaming them. The process is iterated until no outliers remain. For the comparison between the 1995 and 2001 epochs, the piers in Table 3 were found to have moved. The coordinate difference is estimated from a combined CALIB adjustment of the two applicable epochs. A positive sign for the movement implies that the pier has moved away from the first pier (the distance has lengthened over time).

Table 3: Pier movement on the Saskatoon baseline

Comparison			Coordinate Differences	
From	To	Pier	Value ± Std.Dev. (mm)	95% Confidence Interval (mm)
1988	1989	5	-1.0 ± 0.2	-1.5 to -0.5
1989	1994	2	+4.0 ± 0.1	+3.8 to +4.2
1989	1994	4	-2.1 ± 0.2	-2.4 to -1.8
1994	1995	1	+1.3 ± 0.1	+1.0 to +1.6
1995	2001	4	+0.6 ± 0.2	+0.2 to +1.0

Scale Difference Analysis

Any scale difference between epochs is estimated with program LINCOMP using the least squares (L2-norm) solution with suspected pier movements removed. The estimated scale difference between the 1995 and 2001 epochs is given in Table 4.

Table 4: Scale difference between epochs

Comparison			Scale Change	
From	To	Piers Used	Value ± Std.Dev. (ppm)	95% Confidence Interval (ppm)
1988	1989	1,2,3,4,6	+0.83 ± 0.39	+0.07 to +1.59
1989	1994	1,3,5,6	-1.27 ± 0.35	-1.96 to -0.58
1994	1995	2,3,4,5,6	-0.02 ± 0.31	-0.63 to +0.59
1995	2001	1,2,3,5,6	+0.19 ± 0.17	-0.15 to +0.53

The estimated scale difference between the 1995 and 2001 epochs is not statistically significant at the 95% confidence level.

Adopted Distances

The Adopted Distances for this baseline are given in Appendix C and are based on the 2001 measurements. This table gives the adjusted inter-pier slope distances, estimated standard deviations and elevation differences. A cautionary note about the detected movement at pier 4 has been added to the table.

Calib least squares adjustment summary

Baseline Name: Saskatoon, Saskatchewan

Epoch Dates	Degrees of Freedom	Variance Factor	Statistical Tests		Derived Constant	Input Scale	Comments
			V.F.	G.O.F.	mm ± S.D.	ppm ± S.D.	
Jun.18-22 1988	115	0.833	Pass	Pass	+2.1 ± 0.1	-0.1 ± 0.3	No outliers
May 20-26 1989	117	1.060	Pass	Pass	+2.3 ± 0.1	+0.9 ± 0.2	1 outlier kept
Jun.24-27 1994	86	1.384	Fail	Pass	-0.1 ± 0.1	-0.5 ± 0.2	No outliers
Jul. 8-10 1995	85	0.708	Fail	Pass	-0.1 ± 0.1	-0.3 ± 0.2	No outliers
July 25-27 2001	85	0.522	Fail	Pass	-0.2 ± 0.1	+0.3 ± 0.1	No outliers

Legend: V.F. - Variance Factor Test
G.O.F. - Goodness of Fit Test

NOTE: All statistical and outlier tests performed with a 95% Confidence Level.

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S4R 8H2

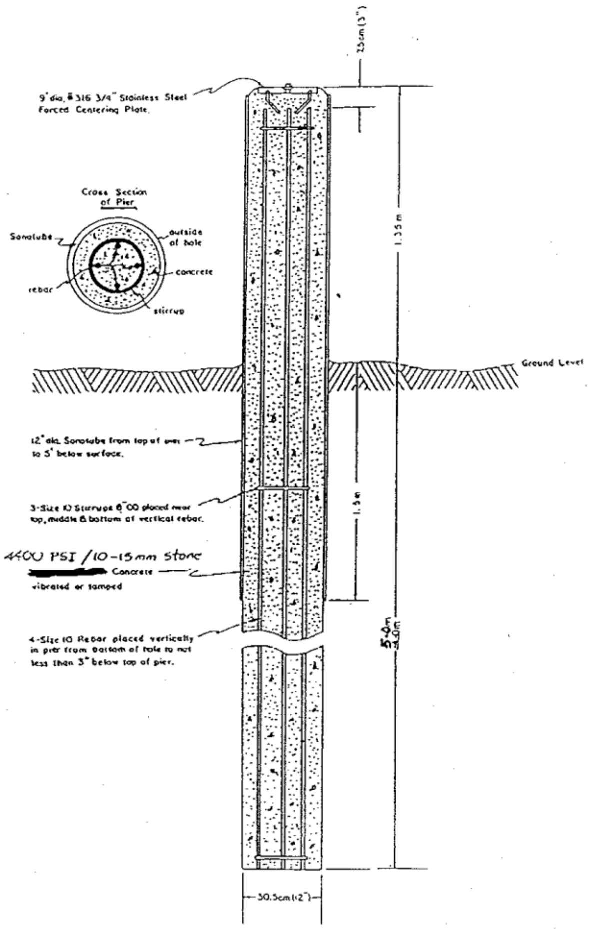
1-866-275-4721

APPENDIX A

Pier Construction Detail

APPENDIX A

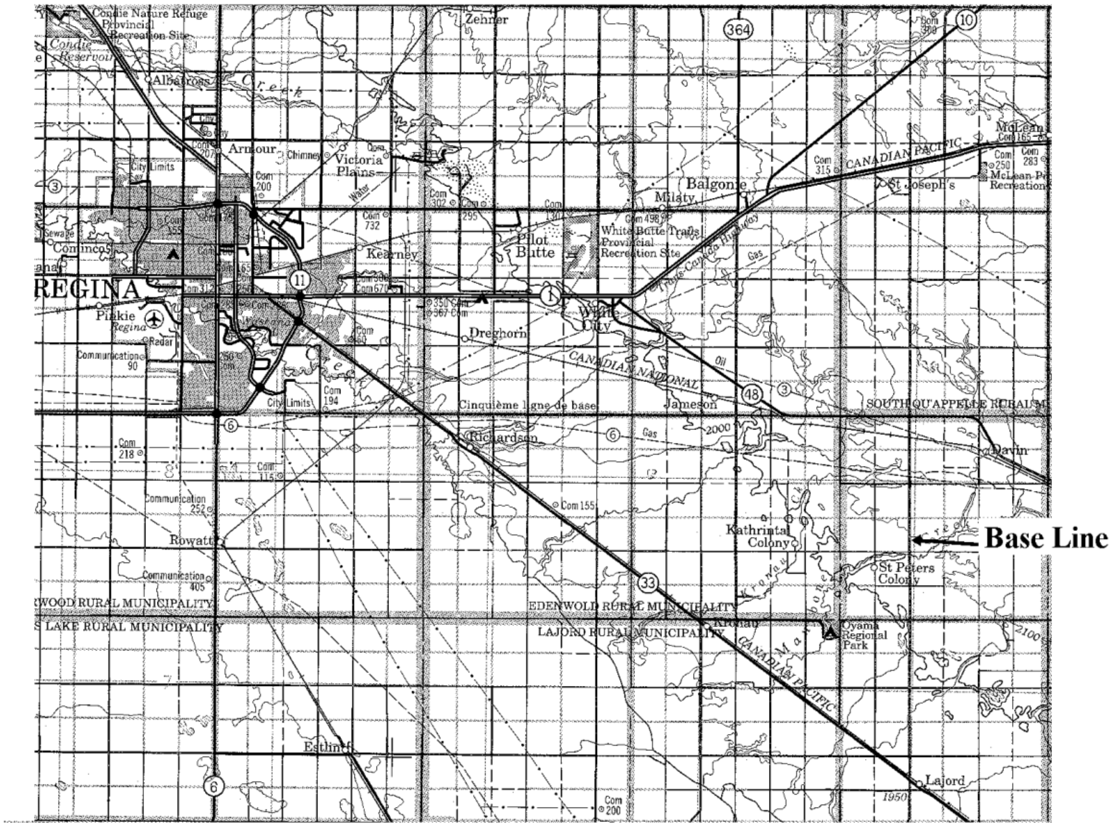
Pier Construction Detail



APPENDIX B

Regina-Davin Base Line Maps, Profile and Lengths

Regina



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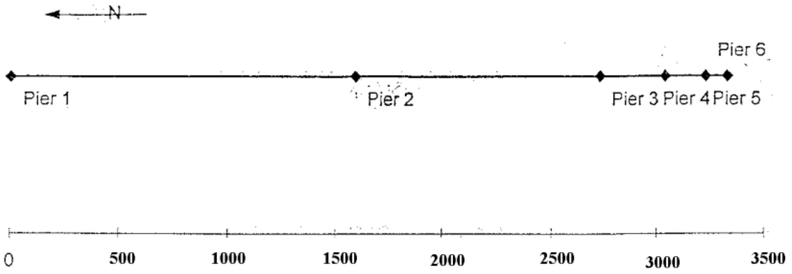
REGINA

PLAN VIEW



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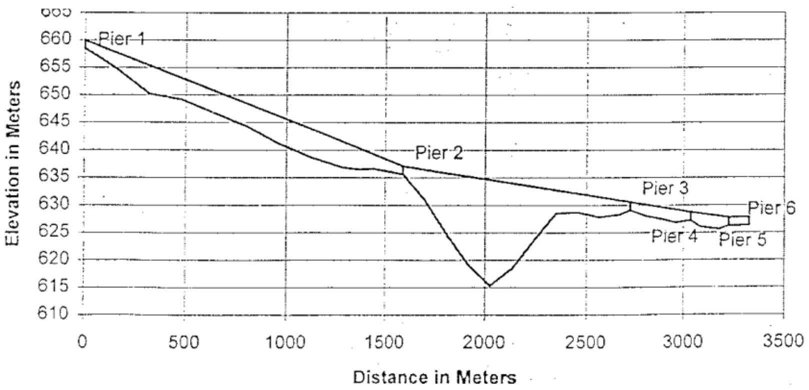


Saskatchewan SaskGeomatics Division
Geodetic Surveys Branch
Regina-Davin Precise Calibration Baseline Inter-pier Lengths
Preliminary Values
Measured 2003

From Pier	To Pier	Elevation Difference Metres (m)	Slope Distance Metres (m)	Std Dev (mm)
90V100	90V101	-22.821	1591.7433	0.3
	90V102	-29.395	2726.3183	0.4
	90V103	-31.248	3036.4977	0.5
	90V104	-32.201	3227.0633	0.5
	90V105	-32.112	3327.2978	0.5
90V101	90V100	22.821	1591.7433	0.3
	90V102	-6.574	1134.5980	0.2
	90V103	-8.427	1444.7803	0.2
	90V104	-9.380	1635.3481	0.3
	90V105	-9.291	1735.5861	0.3
90V102	90V100	29.395	2726.3183	0.4
	90V101	6.574	1134.5980	0.2
	90V103	-1.853	310.1823	0.1
	90V104	-2.806	500.7501	0.1
	90V105	-2.717	600.9884	0.1
90V103	90V100	31.248	3036.4977	0.5
	90V101	8.427	1444.7803	0.2
	90V102	1.853	310.1823	0.1
	90V104	-0.953	190.5678	0.1
	90V105	-0.864	290.8067	0.1
90V104	90V100	32.201	3227.0633	0.5
	90V101	9.380	1635.3481	0.3
	90V102	2.806	500.7501	0.1
	90V103	0.953	190.5678	0.1
	90V105	0.089	100.2400	0.1
90V105	90V100	32.112	3327.2978	0.5
	90V101	9.291	1735.5861	0.3
	90V102	2.717	600.9884	0.1
	90V103	0.864	290.8067	0.1
	90V104	-0.089	100.2400	0.1

APPENDIX C

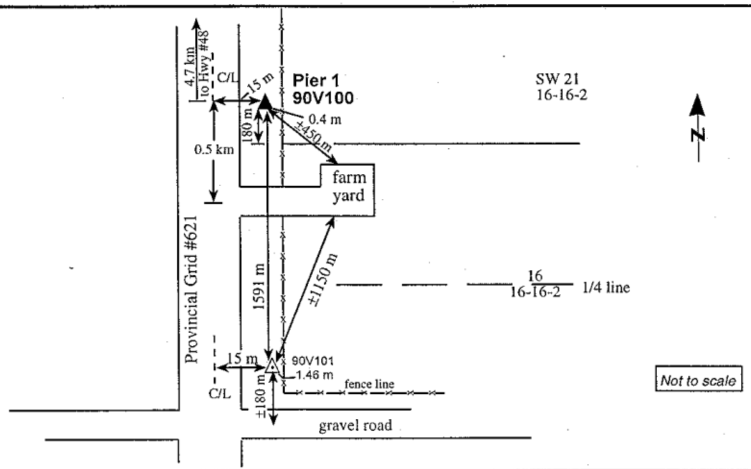
Regina-Davin Base Line
Station Location Descriptions

90V100

REGINA GPS VALIDATION NETWORK

STATION NAME - PIER 1
UNIQUE NO. 90V100

SCALED COORDINATES
LAT: 50°21'18"
LON: 104°09'34"
ELEV: 659 M



DESCRIPTION: Marked by a 10 mm long 5/8" threaded bolt with N.C. 11 thread in a 23 cm diameter stainless steel plate set in top of a 32 cm diameter concrete pier.

ACCESS: ***From Regina via Highway #1***

From Regina proceed easterly on Highway #1 for 15 km to the junction with Highway #48 at White City. Then travel south-easterly on Highway #48 for 16 km to the intersection with grid road #621. Turn south on the grid road for 4.7 km to the top of a prominent hill.

From Regina via Highway #33

From Regina proceed south-easterly on Highway #33 for 24 km to the organized hamlet of Kronau. Then go east on the paved road to Oyama Regional Park, approximately 5 km. Follow the road around Oyama Lake and continue easterly on a gravel road for approximately another 3.2 km to the intersection with grid road #621. Then proceed northerly on grid road #621 for about 5 km to the top of a prominent hill.

Monument is a 12 inch diameter concrete pier protruding 1.5 metres above the ground at the top of the backslope on the east side of the grid road.

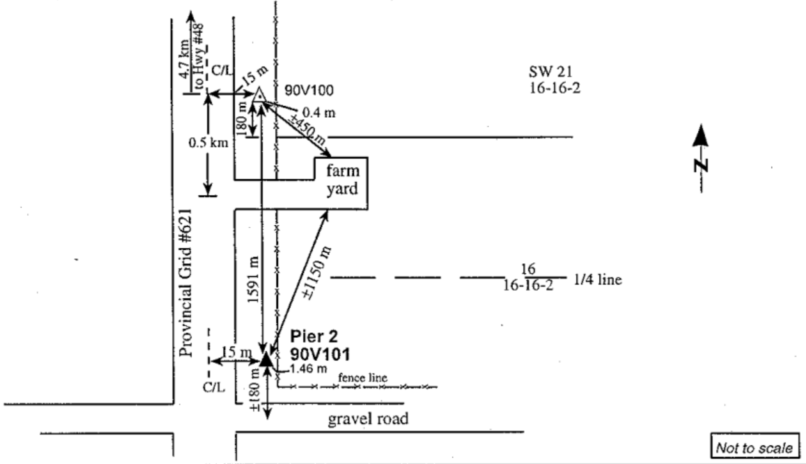
OWNER: Road allowance

90V101

REGINA GPS VALIDATION NETWORK

STATION NAME - PIER 2
UNIQUE NO. 90V101

SCALED COORDINATES
LAT: 50°20'26"
LON: 104°09'33"
ELEV: 636 M



DESCRIPTION: Marked by a 10 mm long 5/8" threaded bolt with N.C. 11 thread in a 23 cm diameter stainless steel plate set in top of a 32 cm diameter concrete pier.

ACCESS: ***From Regina via Highway #1***

From Regina proceed easterly on Highway #1 for 15 km to the junction with Highway #48 at White City. Then travel south-easterly on Highway #48 for 16 km to the intersection with grid road #621. Turn south on the grid road for approximately 6.3 km. Pier is on the east side of grid road.

From Regina via Highway #33

From Regina proceed south-easterly on Highway #33 for 24 km to the organized hamlet of Kronau. Then go east on the paved road to Oyama Regional Park, approximately 5 km. Follow the road around Oyama Lake and continue easterly on a gravel road for approximately another 3.2 km to the intersection with grid road #621. Then proceed northerly on grid road #621 for about 3.4 km.

The monument is a 12-inch diameter concrete pier protruding 1.5 m above the ground on the east side of the grid road.

OWNER: Road allowance

STATION DESCRIPTION Unique Number 90V102

PROJECT Regina Base Net 1990

Project No. ctr10c100 **Station Name.** Regina-Pier 3.

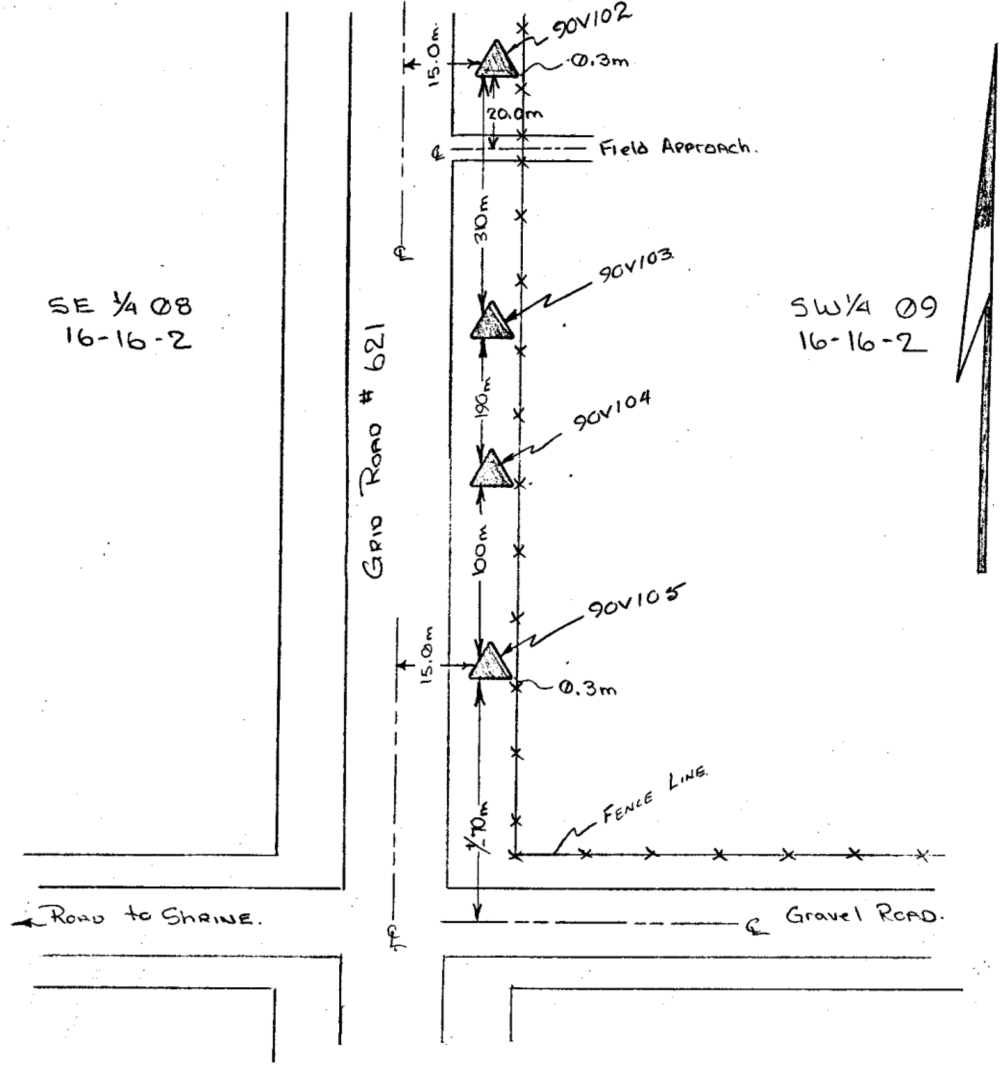
Date 1996102119 **Monument Type** Conc Pier with SS Plate. Old [✓ New]

Prepared By DWS. **Est. Agency** #158 CSMA. **Mon. Cond.** Good.

Map Sheet No. 72I08 **Location** SW¼ Section 09 Twp 16 Rge 16 W2M

Depth Below Grade 1.5m Above Gr. **Target Date** ~ **Target Height** ~

Approx. N ~ **E** ~ **Zone** ~ **Elevation.** ~



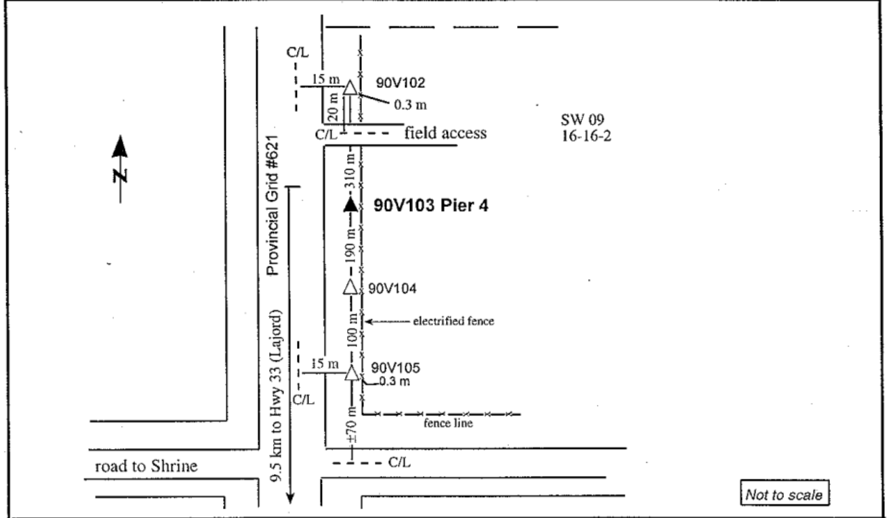
90V103

REGINA GPS VALIDATION NETWORK

STATION NAME - PIER 4
UNIQUE NO. 90V103

SCALED COORDINATES

LAT:	50°19'39"
LON:	104°09'33"
ELEV:	628 M



DESCRIPTION: Marked by a 10 mm long 5/8" threaded bolt with N.C. 11 thread in a 23 cm diameter stainless steel plate set in top of a 32 cm diameter concrete pier.

ACCESS: ***From Regina via Highway #1***

From Regina proceed easterly on Highway #1 for 15 km to the junction with Highway #48 at White City. Then travel south-easterly on Highway #48 for 16 km to the intersection with grid road #621. Turn south on the grid road for 7.7 km.

From Regina via Highway #33

From Regina proceed south-easterly on Highway #33 for 24 km to the organized hamlet of Kronau. Then go east on the paved road to Oyama Regional Park approximately 5 km. Follow the road around Oyama Lake continue easterly on a gravel road for approximately another 3.2 km to the intersection with grid road #621. Then proceed northerly on grid road #621 for about 2.0 km.

Monument is a 12 inch diameter concrete pier protruding 1.5 metres above the ground on the east side of the grid road.

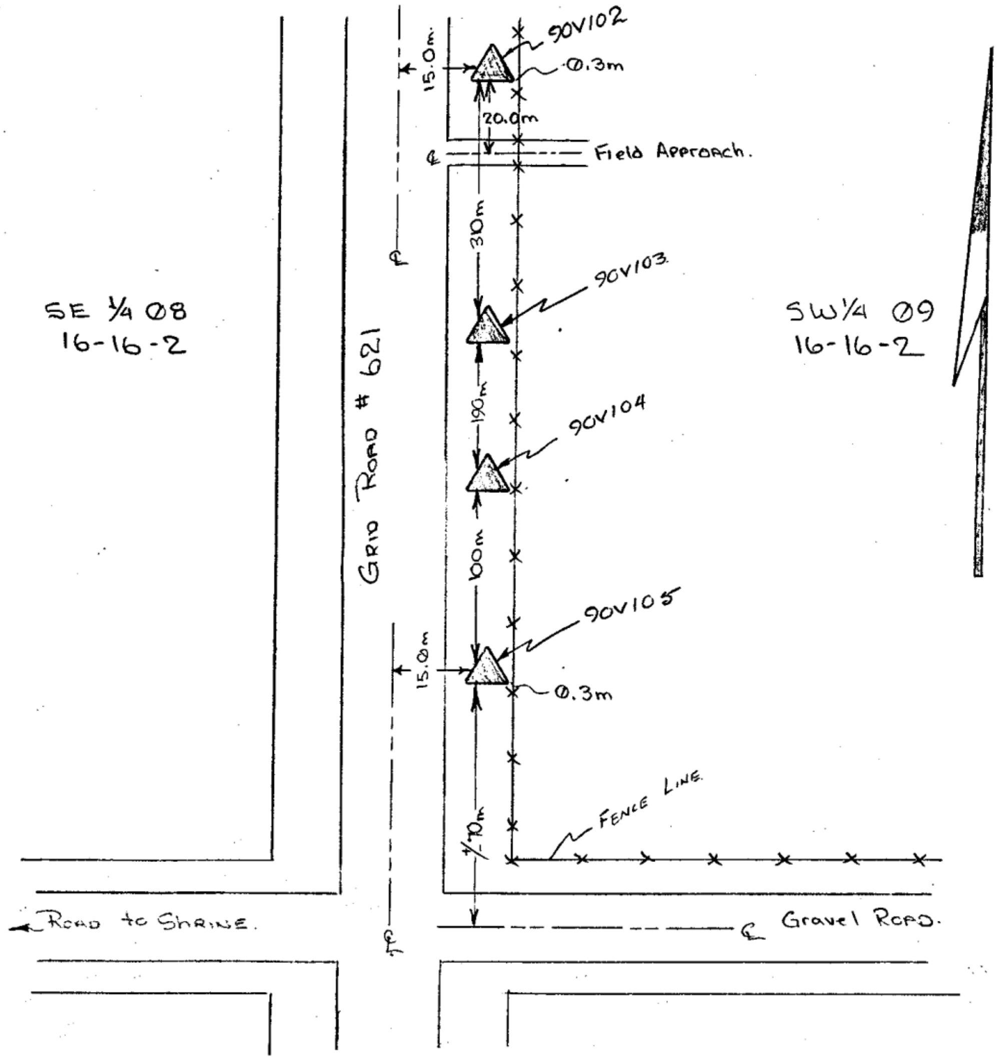
OWNER: Road allowance

STATION DESCRIPTION

Unique Number 90V104

PROJECT Regina Base Net 1990

Project No. ctrl0c100
Station Name. Regina - Pier 5
Date 19900219
Monument Type Conc Pier with SS Plate Old/[✓ New]
Prepared By DWS
Est. Agency #158 CSMA
Mon. Cond Good
Map Sheet No. 72I08
Location SW¼ Section 9 Twp 16 Rge 16 W2M
Depth Below Grade 1.5m Above Grade
Target Date ~
Target Height ~
Approx. N ~
E ~
Zone ~
Elevation. ~



STATION DESCRIPTION

Unique Number 90V105

PROJECT Regina Base Net 1990

Project No. ctrl0c100

Station Name. Regina - Pier #6.

Date 19900719

Monument Type Conc Pier with SS Plate Old [✓ New]

Prepared By DWS

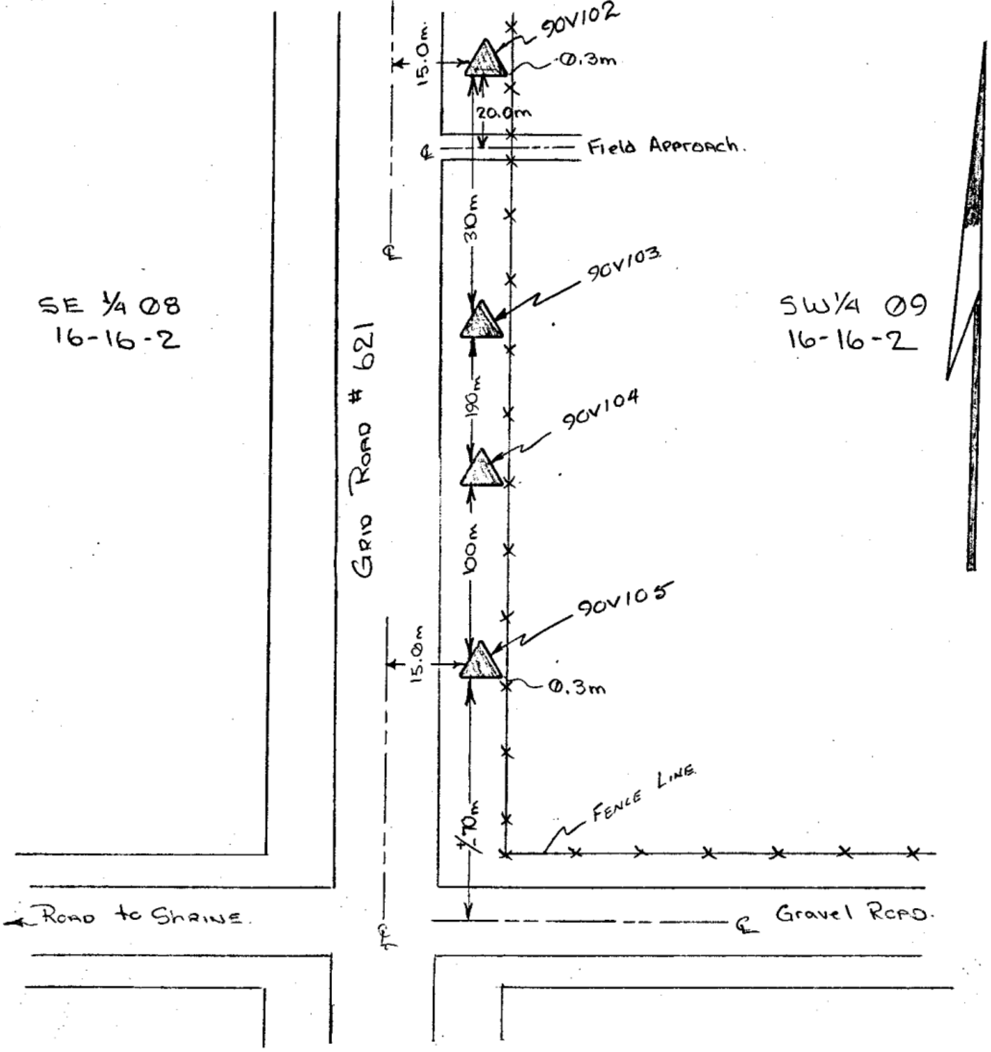
Est. Agency #158 CSMA **Mon. Cond.** Good

Map Sheet No. 72I08

Location SW¼ Sec 09 Twp 16 Rge 16 W2M

Depth Below Grade 1.5 Above Grade **Target Date** ~ **Target Height** ~

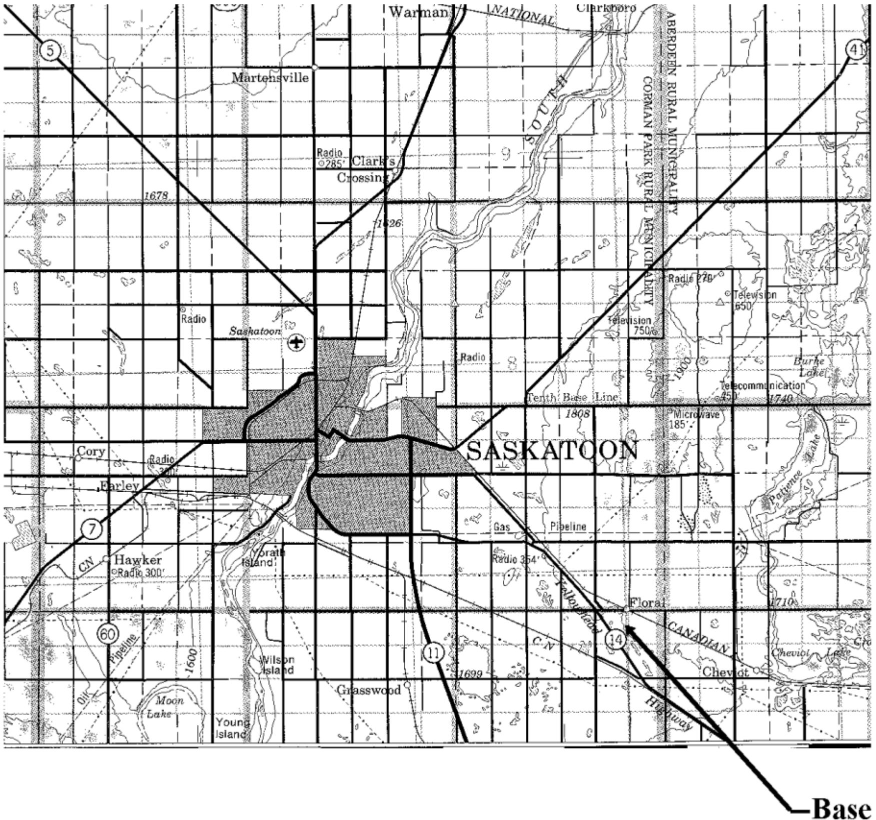
Approx. N ~ **E** ~ **Zone** ~ **Elevation.** ~



APPENDIX D

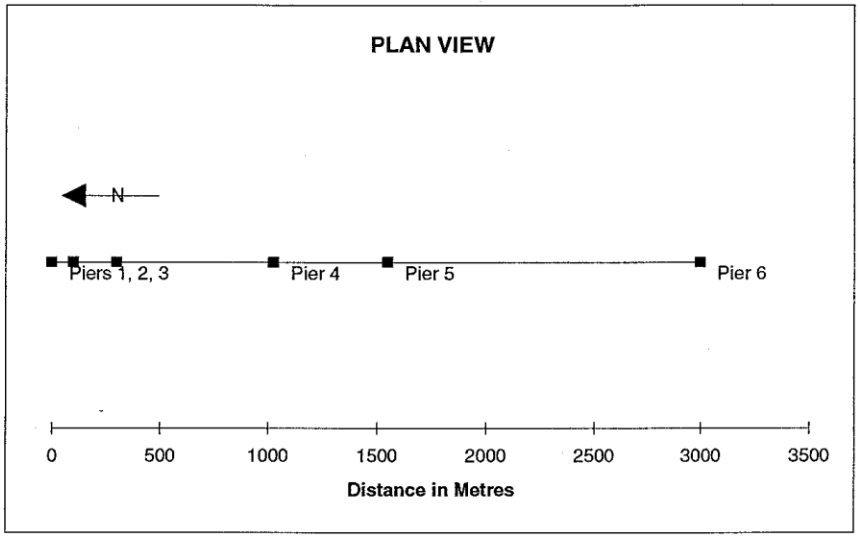
Saskatoon Base Line Map, Profile and Lengths

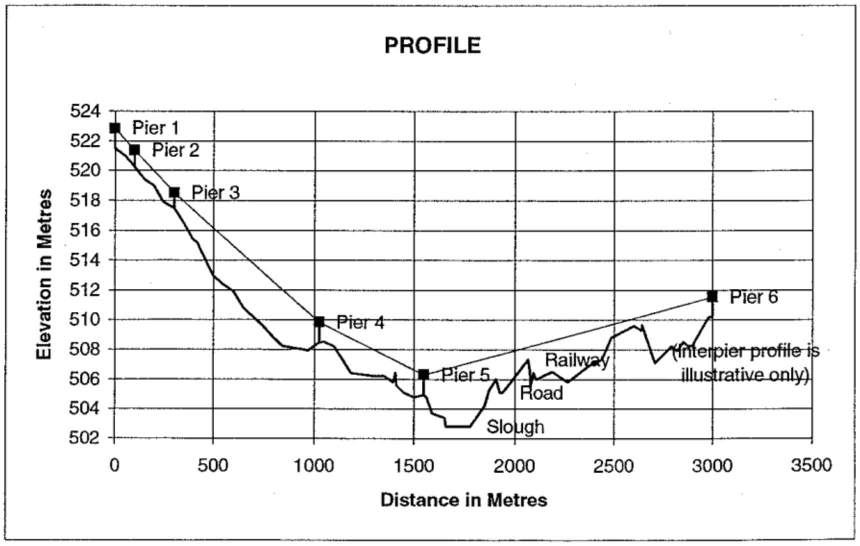
Saskatoon



Base Line

scale 1:250,000


PLAN VIEW
N
Piers 1, 2, 3
Pier 4
Pier 5
Pier 6
0
500
1000
1500
2000
2500
3000
3500
Distance in Metres


PROFILE
524
522
520
518
516
514
512
510
508
506
504
502
Elevation in Metres
Pier 1
Pier 2
Pier 3
Pier 4
Pier 5
Pier 6
Railway
Road
Slough
(interpier profile is illustrative only)
0
500
1000
1500
2000
2500
3000
3500
Distance in Metres

Saskatchewan SaskGeomatics Division
Geodetic Surveys Branch
Saskatoon Precise Calibration Baseline Inter-pier Lengths
Measured 2001

From Pier	To Pier	Elevation Difference Metres (m)	Slope Distance Metres (m)	Std. Dev. (mm)
88V051	88V052	-1.424	99.9108	0.1
	88V053	-4.261	299.9723	0.1
	88V054	-13.073	1024.9265	0.1
	88V055	-16.673	1550.0609	0.2
	88V056	-11.256	3000.0677	0.3
88V052	88V051	1.424	99.9108	0.1
	88V053	-2.837	200.0614	0.1
	88V054	-11.649	925.0158	0.1
	88V055	-15.249	1450.1507	0.2
	88V056	-9.832	2900.1624	0.3
88V053	88V051	4.261	299.9723	0.1
	88V052	2.837	200.0614	0.1
	88V054	-8.812	724.9547	0.1
	88V055	-12.412	1250.0908	0.1
	88V056	-6.995	2700.1130	0.3
88V054	88V051	13.073	1024.9265	0.1
	88V052	11.649	925.0158	0.1
	88V053	8.812	724.9547	0.1
	88V055	-3.600	525.1402	0.1
	88V056	1.817	1975.2022	0.2
88V055	88V051	16.673	1550.0609	0.2
	88V052	15.249	1450.1507	0.2
	88V053	12.412	1250.0908	0.1
	88V054	3.600	525.1402	0.1
	88V056	5.417	1450.0830	0.2
88V056	88V051	11.256	3000.0677	0.3
	88V052	9.832	2900.1624	0.3
	88V053	6.995	2700.1130	0.3
	88V054	-1.817	1975.2022	0.2
	88V055	-5.417	1450.0830	0.2

APPENDIX E

Saskatoon Base Line
Station Location Descriptions

88V051

STATION DESCRIPTION

PROJECT Saskatoon Calibration Base Line

Project No. ____ **Station No.** 88V051

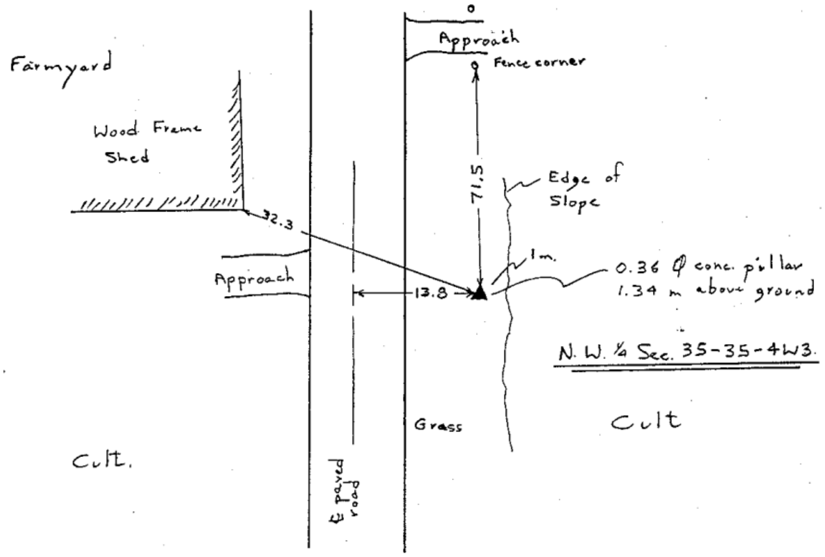
Date ____ Monument Type CONC. PIER: F.C. PLATE [✓ Old]/New

Prepared By GNF Est. Agency #158 CSMA Mon.Cond. GOOD

Map Sheet No. 073B01 Location NW35T35R04W3M

Depth Below Grade +1·2 M Target Date ____ Target Height ____

Approx. UTM Co-ords. N ____ E ____ Zone ____



Document Name ____ Page No. ____

Central Survey and Mapping Agency, Saskatchewan Form No. F203/83

88V052

STATION DESCRIPTION

PROJECT SASKATOON CALIBRATION BASE LINE

Project No. ______ **Station No.** 88V052

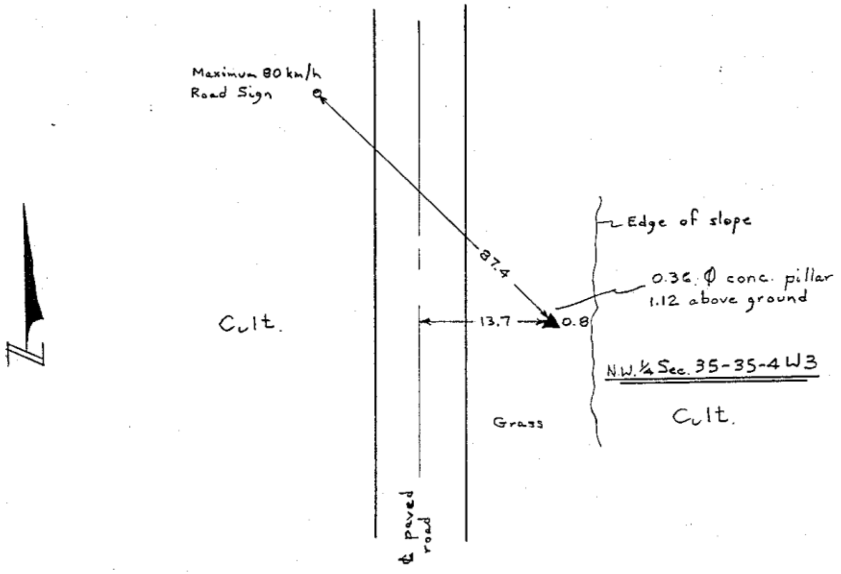
Date ______ Monument Type CONC. PIER & F.C. PLATE [✓ Old]/New

Prepared By GNF Est. Agency #158 CSMA Mon.Cond. GOOD

Map Sheet No. 073B01 Location NW35T35R04W3M

Depth Below Grade +1.2 M Target Date ______ Target Height ______

Approx. UTM Co-ords. N ______ E ______ Zone ______



Document Name ______ Page No. ______

Central Survey and Mapping Agency, Saskatchewan Form No. F203/83

88V053

STATION DESCRIPTION

PROJECT SASKATOON CALIBRATION BASE LINE

Project No.

Station No. 88V053

Date

Monument Type CONC. PIER & F.C. PLATE [✓ Old]/New

Prepared By GNF

Est. Agency #158 CSMA

Mon. Cond. GOOD

Map Sheet No. 073B01

Location NW35T35R04W3M

Depth Below Grade +1.2M

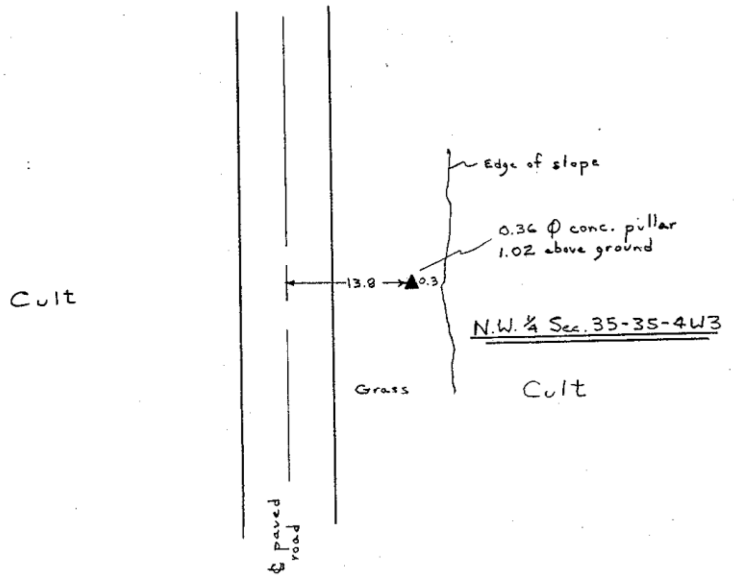
Target Date

Target Height

Approx. UTM Co-ords. N

E

Zone



STATION DESCRIPTION

Unique Number 88V054

PROJECT Canadian Base Network.

Project No. ctr14c301

Station Name. SASKATOON EDM Pier-4

Date 1904 11:206
y y y y m m d d

Monument Type conc Pier & SS PLATE [✓ Old]/New

Prepared By D. SECUUR.

Est. Agency #158 CSMA.

Mon. Cond.

Map Sheet No. 073B

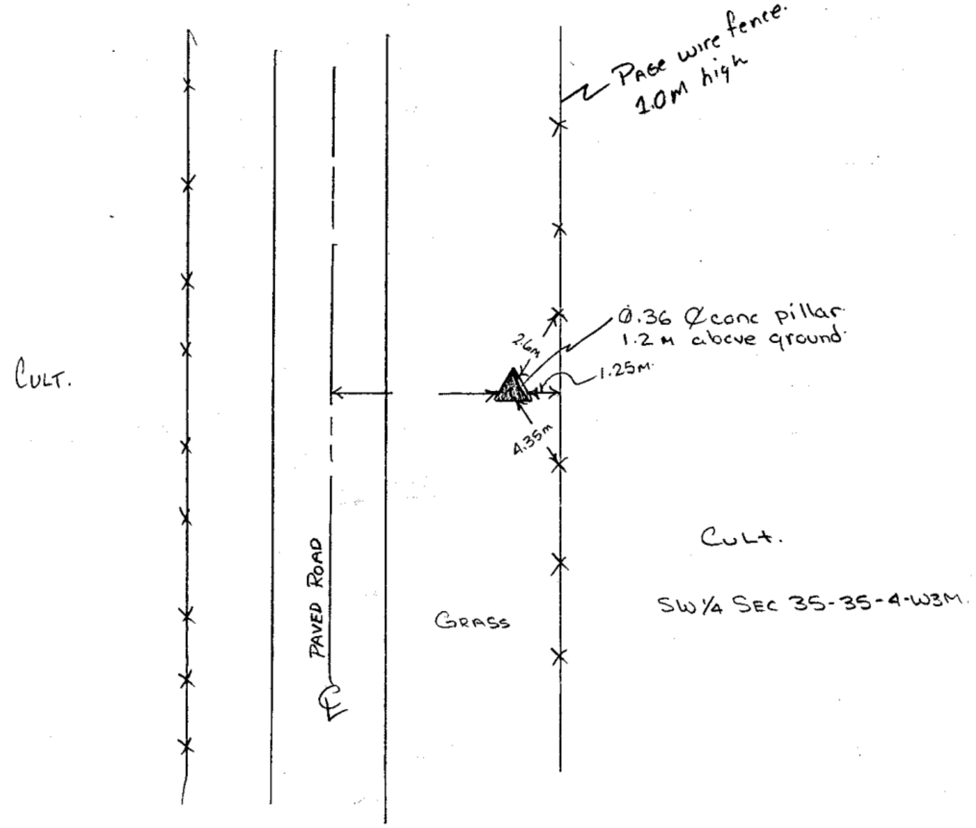
Location SW¼ Sec 35-35-4-3.

Height Above ~~Depth Below~~ Grade 1.20m.

Target Date

Target Height

Approx. N 52°02'42.8" E 106° 28' 47.1" ~~Zone~~ Elevation.



Document Name

Central Survey and Mapping Agency, Saskatchewan

Page No.

Form No. F203/83

88V055

STATION DESCRIPTION

PROJECT SASKATOON CALIBRATION BASE LINE

Project No.

Date

Prepared By GNF

Map Sheet No. 073B01

Station No. 88V055

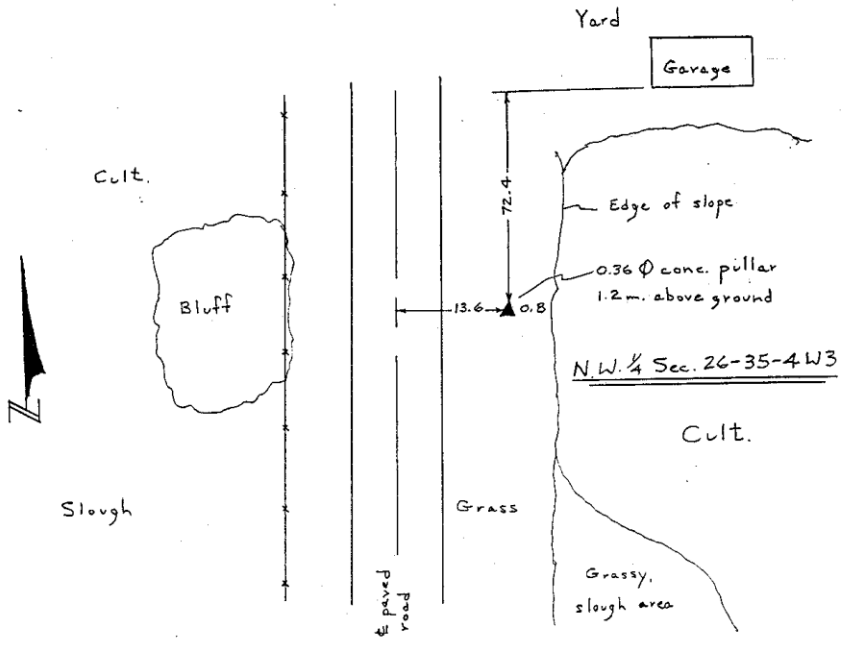
Monument Type CONC. PIER; F.C. PLATE [✓ Old]/New

Est. Agency #158, CSMA Mon. Cond. GOOD

Location NW26T35R04W3M

Depth Below Grade +1.2M Target Date Target Height

Approx. UTM Co-ords. N E Zone



Document Name Page No.

Central Survey and Mapping Agency, Saskatchewan Form No. F203/83

88V056

STATION DESCRIPTION

PROJECT SASKATOON CALIBRATION BASE LINE

Project No. ____ **Station No.** 88V056

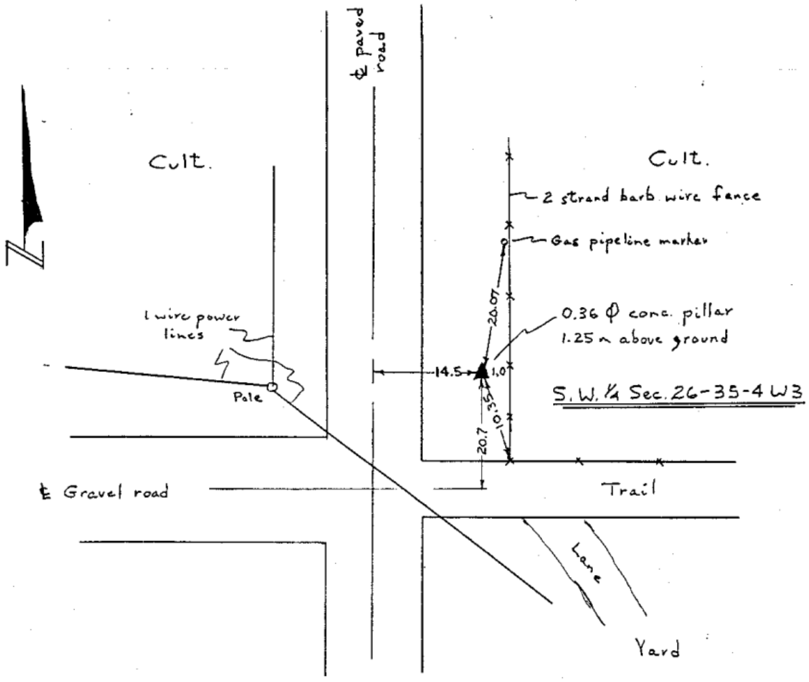
Date ____ Monument Type CONC PIER & F.C. PLATE [✓ Old]/New

Prepared By GNF Est. Agency #158 CSMA Mon. Cond. GOOD

Map Sheet No. 073B01 Location SW26T35R04W3M

Depth Below Grade +1.2M Target Date ____ Target Height ____

Approx. UTM Co-ords. N ____ E ____ Zone ____



Document Name ____ Page No. ____

Central Survey and Mapping Agency, Saskatchewan Form No. F203/83

APPENDIX F

Considerations in Using an EDM Calibration Base Line

Considerations
in using an
EDM Calibration Baseline

prepared by

D.R. Junkins
Geodetic Survey Division

for the

4th In-House R & D Symposium

March 1989

1. INTRODUCTION

Background

- provincial agencies have been using high-accuracy baselines for many years to calibrate EDM instruments
    - piers are established by the agencies
    - inter-pier measurements are made by Geodetic Survey
    - measurements are processed and inter-pier distances produced by Geodetic Survey
- many of these agencies require that all work done under their jurisdiction use instruments calibrated on these baselines
    - two instrument parameters can be estimated by the calibration process:
        - a constant or additive bias
        - a scale or proportional bias
    - corrections for these biases are then applied to distance observations to assure that they conform to a standard

      OR

    - the instrument is deemed to be acceptable "as is", since the difference is within its measuring tolerance
- recent examples indicate that a calibration procedure in common use may produce biased results

Purpose

- this presentation will:
    - outline the procedure in common use
    - indicate the type of problem and the reason for it
    - explain a preferred approach

2. LINEAR REGRESSION

Application

- the linear regression technique is commonly applied to solve for the instrument parameters
    - makes use of "known" inter-pier distance

Description

- difference between "known" and observed distance is charted for each observation (see slide #3)
- pier combinations are usually selected to give a variety of inter-pier distances (see slide #4)
    - this gives a good distribution of points along the X-axis of the graph, and is the main reason why piers are irregularly spaced during baseline construction
- a straight line is fitted to the data using a "best fit" criteria, usually least squares (see slide #5)
    - the y-intercept of the line is taken as the constant bias of the instrument
    - the slope of the line is taken as the scale bias of the instrument

Problem

- a pier may have undergone some disturbance and been displaced since the time when the observations which produced the published inter-pier distances were made
- a small displacement will bias the results of a linear regression computation (see slides #6, 7 & 8)
    - this bias will probably not be noticed since it is the same order of magnitude as the observing error of the instrument

Reasons

- linear regression does not take into account the geometry of the baseline
    - inter-pier distances only are considered
    - a pier that is common to various distances is not constrained to being the same point
- "known" inter-pier distances are used that do not reflect the current relative positions of the piers

3. LINEAR COMBINATION

Assumptions

- all distance observations have the same constant error
- all distance observations have the same scale bias with respect to some standard
    - Note: these are the same assumptions that must be made for linear regression modelling

Constant Bias

- the piers are laid out in a straight line, and distances can be observed between various pairs of piers (see slide #10)
- a distance between a pair of adjacent piers can be considered as an "elementary" distance
    - there are (n-1) of these "elementary" distances
- a distance between a pair of piers spanning one or more intermediate piers can also be determined by adding together the appropriate elementary distances, giving a "linear combination" equation (see slide #11)
    - there are (n-1)(n-2)/2 of these "linear combinations"
- since the constant bias is a common to all observations, it can be factored out of a linear combination equation
- the effect of scale bias on the constant is negligible, since it is the product of the two quantities

Scale Bias

- all observed distances are then corrected by the value determined for the instrument constant bias
- the difference between the "known" and the corrected observed distance is charted for each observation (see slide #12)
- a straight line is fitted to the data points
  - the y-intercept of the line will always pass through zero, since the constant bias has been removed
  - the slope of the line is taken as the scale bias of the instrument

Pier Movement

- if movement has occurred at one of the piers, then:
  - scanning the list of scale differences will reveal a large group that has consistent values (see slide #13)
  - the remainder that are not consistent will usually all be associated with a common point
  - the scale computation is then repeated with the data for this point removed (i.e. the inconsistent values)
  - at the inconsistent data points:
    - compute predicted values using the revised scale
    - compare differences between the corrected observations and predicted values
    - these differences will be consistent and are the amount by which the pier has moved (see slide #14)
    - the signs of the differences will vary depending on which direction from the pier the observations were made (see slides #15 & 16)

4. CONCLUSIONS

Disadvantages of Linear Regression Technique

- ignores geometry of the network of observations
- sensitive to pier movement

Advantages of Linear Combination Technique

Constant Bias:

- does not assume any prior knowledge of inter-pier distances
- solution is virtually independent of scale bias

Scale Bias:

- since the constant bias has already been independently estimated, a constraint for the intercept of the fitted line can be applied
    - the high correlation between constant and scale seen in linear regression or in simultaneous solution in a network adjustment is thus eliminated
    - this is a particular advantage if movement has occurred at a pier involved with short lines
- piers which have moved are more easily identified
    - distances involved with piers that have moved can be removed from the computation of scale bias

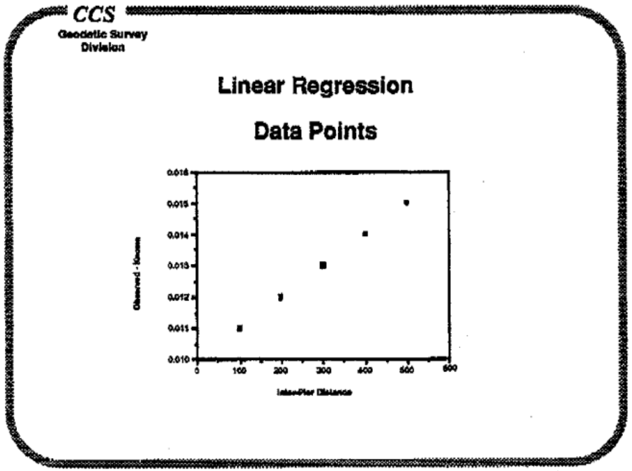
Considerations

in using an

EDM Calibration Baseline

Purpose

1) to determine instrument parameters
   - constant bias
   - scale bias
2) to apply corrections for these biases



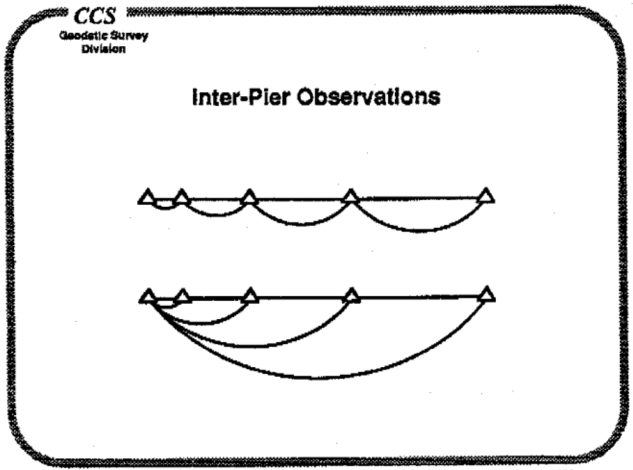
CCS

Geodetic Survey Division

Linear Regression

Data Points

R&D Symposium - March 1989

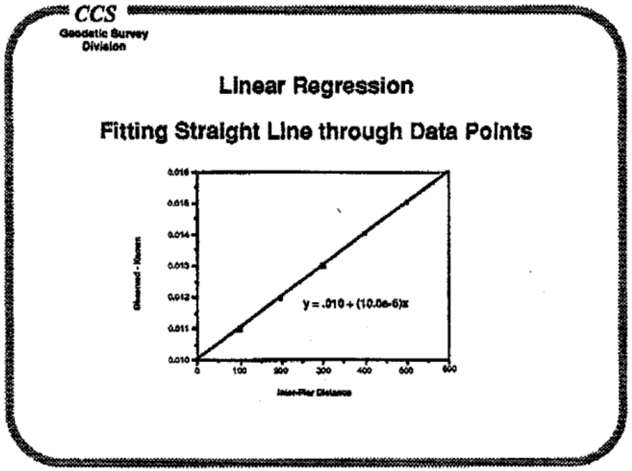


CCS

Geodetic Survey Division

Inter-Pier Observations

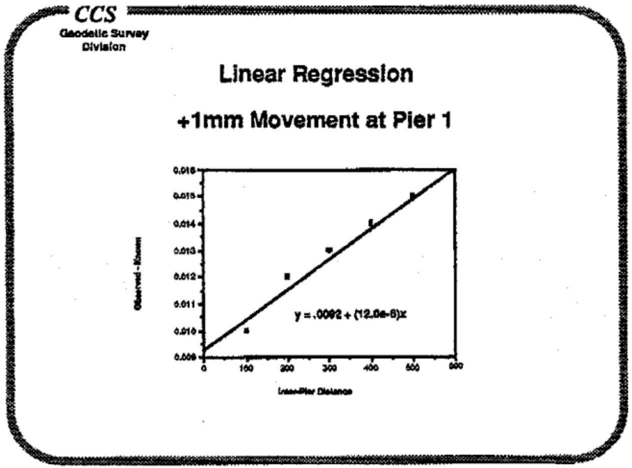
R&D Symposium - March 1989



CCS
Geodetic Survey
Division

Linear Regression

Fitting Straight Line through Data Points



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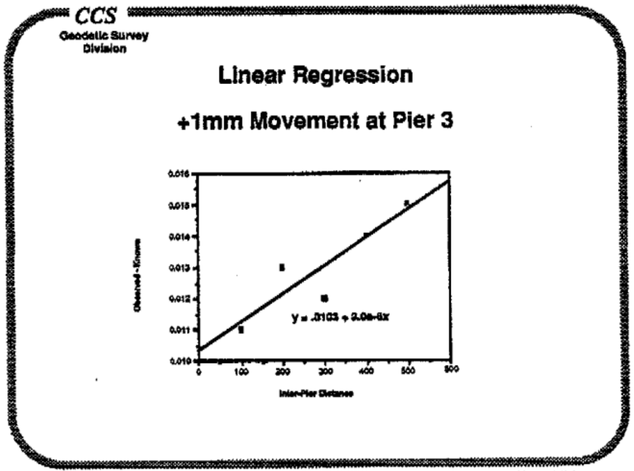
Division

Linear Regression

+1mm Movement at Pier 1



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Division

Linear Regression

+1mm Movement at Pier 3

Slide # 7

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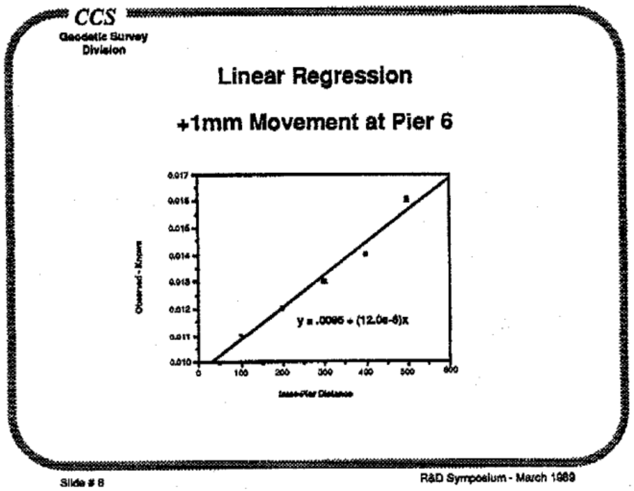

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Geodetic Survey
Division

Linear Regression

+1mm Movement at Pier 6

Slide # 8

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Problems with Linear Regression

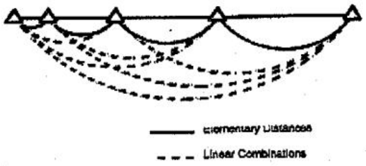
in the Presence of Pier Movement

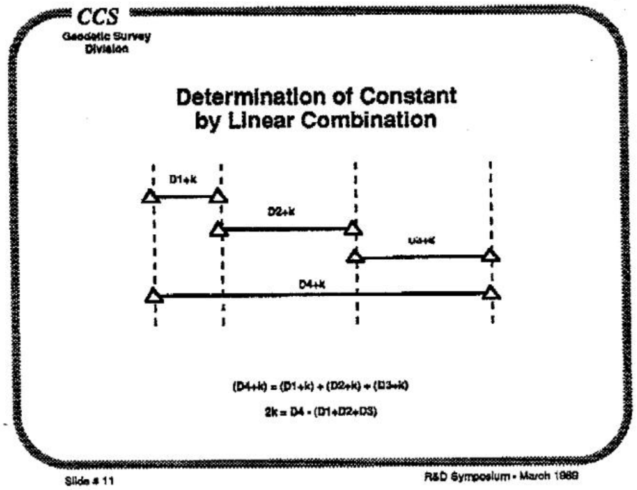
1) linear regression does not take into account the geometry of the baseline
   - inter-pier distances only are considered
   - a pier that is common to various distances is not constrained to being the same point

2) "known" inter-pier distances are used that do not reflect the current relative positions of the piers

---

Inter-Pier Observations



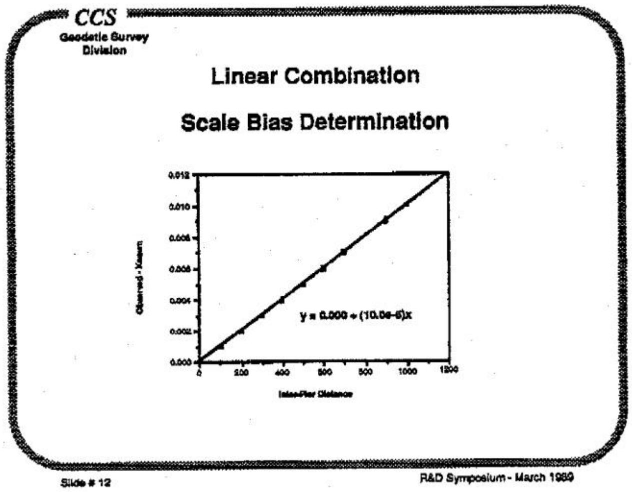


CCS
Geodetic Survey
Division

Determination of Constant by Linear Combination

$$(D4+k) = (D1+k) + (D2+k) + (D3+k)$$

$$2k = D4 - (D1+D2+D3)$$



CCS
Geodetic Survey
Division

Linear Combination

Scale Bias Determination

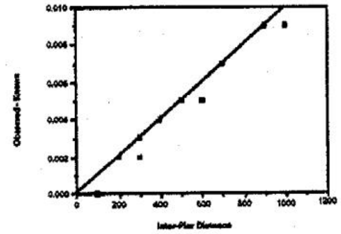
Linear Combination

+1mm Movement at Pier 1

Obs #	From Pier	To Pier	Published Distance	Observed Distance	Combined Obs'ns	Diff/ Nobs-1	Corrected Obs'ns	Scale Diff
1	1	2	100.000	100.010			100.000	1E-10
2	2	3	200.000	200.012			200.002	10
3	3	4	300.000	300.013			300.005	10
4	4	5	400.000	400.014			400.004	10
5	1	3	300.000	300.012	300.022	0.010	300.002	6.667
6	1	4	600.000	600.015	600.035	0.010	600.006	8.333
7	1	5	1000.000	1000.019	1000.049	0.010	1000.009	9
8	2	4	500.000	500.015	500.026	0.010	500.005	10
9	2	5	900.000	900.019	900.039	0.010	900.009	10
10	3	5	700.000	700.017	700.027	0.010	700.007	10
10		<-Totals->	5000.000	5000.146	4000.197	0.060	5000.046	94
					Constant =	0.0100	Scale =	9.4

Linear Combination

+1mm Movement at Pier 1



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Advantages of Linear Combination Technique

Constant Bias Computation

1) does not assume any prior knowledge of interpier distances

2) solution is virtually independent of scale bias

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Advantages of Linear Combination Technique

Scale Bias Computation

1) a constraint for the intercept of the fitted line can be applied
   - the high correlation between constant and scale is eliminated

2) piers which have moved are more easily identified
   - distances involved with piers that have moved can be removed from the computation of scale bias