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This study is a comparative analysis of leveling instruments in the vertical control survey conducted on the Dhahran Test Range in Saudi Arabia. The vertical leveling observations for first-order were obtained using Zeiss Ni-1 and Wild NA3000 leveling instruments. The vertical control network was adjusted using a least square program developed at the United States National Geodetic Survey, (NGS).

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COMPARATIVE ANALYSIS OF LEVELING INSTRUMENTS WILD NA3000 AND ZEISS NI-1

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BIOGRAPHICAL SKETCH

Mr. Ackeret is currently serving as a physical scientist with the U.S. Army Topographic Engineering Center, Digital Concepts and Analysis Center. He was previously employed as a geodesist with the Defense Mapping Agency. In 1992, he served with Saudi ARAMCO in Dhahran, Saudi Arabia, as chief of a vertical control branch.

Mr. Veera was a Professor of Survey at the Sri Lanka Survey School. He has worked as a survey engineer for Saudi ARAMCO for the past 15 years dealing with computer science data reduction.

ABSTRACT

This study is a comparative analysis of leveling instruments in the vertical control survey conducted on the Dhahran Test Range in Saudi Arabia. The vertical leveling observations for first-order were obtained using Zeiss Ni-1 and Wild NA3000 leveling instruments. The vertical control network was adjusted using a least square program developed at the United States National Geodetic Survey, (NGS).

INTRODUCTION

This paper describes the usage of two types of leveling instruments, the conventional Zeiss Ni-1 and the new Wild NA3000, and the process involved in the data reduction for least square adjustment. The recent development of invar-bar code technology for use in leveling surveys has raised questions. Can this new technology perform precise leveling? How much time can be saved with the digital level?

Background

One of the Geodetic Survey Group's (GSG) key responsibilities is to reduce and evaluate precise leveling observations for the development of a vertical control network. Recently, the GSG was given the task of evaluating the NA3000 for precise leveling performance in the field and accuracy requirements for the vertical control network.

PURPOSE

The purpose of this study is to conduct a comparative analysis of the two types of leveling instruments used by our company. This comparative analysis report will:

Describe the vertical leveling instruments,
Discuss the methods of data reduction and
Provide a comparative analysis of the instruments in terms of time and precision.

METHODOLOGY

The methodology employed in this effort was to develop a test range that was surveyed by both the Zeiss Ni-1 and NA3000. First, the Zeiss Ni-1 data was first used in a least squares vertical adjustment. Then, the NA3000 was used in the same area to test its observations for production time, precision, and accuracy.

This report will document the results in a comparative analysis of these two instruments and provide a recommendation for the most desirable instrument for first order precise leveling.

DESCRIPTION OF LEVELING INSTRUMENTS

The Zeiss Ni-1 and NA3000 use different methods to observe differential vertical heights for establishing vertical control networks. A brief description of the instruments and the rods used in the field observations follows.

Zeiss Ni-1

This optical level (sometimes referred to as self-leveling) allows for the establishment of a horizontal line of sight by means of a system of prisms and mirrors by wires as in a pendulum. Light enters the objective lens and passes through the focusing lens and is reflected by the optical compensator. When the compensator is freely supported, the line of sight defined by the objective lens, compensator, and eyepiece is automatically horizontal. The measurement is based on leveling with a level line of sight and aiming at the solid division on the left and right-hand graduations of the rod, using the plane parallel micrometer. The Zeiss first order three (3) meter rods were used in the field work of this analysis.

Wild NA3000

The Wild NA3000 is the first Geodetic level with digital electronic image processing to determine height and distance that automatically records the observed field data. A detector diode array that replaces the surveyor's eye recognizes a bar code on the leveling staff. Within the digital level, a correlation technique is used to determine the pattern on the digital bar code staff. The instrument is able to process a reading from the staff and determine the distance in relation to the analytic

center. The measuring range of the instrument is 1.8 meters to 60 meters with the GPCL3 invar staff. The typical measuring time is approximately four (4) seconds. The temperature range for the instrument operation is -20C to +50C. The instrument displays the measured values in digital form and stores them simultaneously on a GRM 10 recording module. There are two types of dual face rods that can be used in the field. The first-order three (3) meter rods (GPCL3 with circular level) were used in the field work of this analysis.

DATA REDUCTION OF FIELD OBSERVATIONS

This section describes the data reduction procedures used for both the NA-3000 and Zeiss Ni-1 field observations.

Data Reduction of Field Observations Using The ZEISS Ni-1
The field data are recorded by hand on specified log sheets designed for field use. This data is reduced using the Hewlett Packard 42S programmable calculator, using programs designed and tested by the authors (Atch No.1). Also, the authors have designed and tested programs written in LOTUS 1-2-3 software that use an IBM compatible 386 personal computer. The field data has an acceptance test for precision which is 0.003 multiplied by the square root of the distance (k) in kilometers.

Data Reduction of Field Observations Using the Wild NA-3000
The field observations are recorded on a WILD GRM 10 REC module using the built-in programs with the NA3000. The raw field data are downloaded to a personal computer using the interface WILD GIF 10 unit. Software, designed by the authors and programmed by GSG personnel, was used to reduce the field data for observations to use in the least square program (Atch No.2). The field data has an acceptance test for precision which is 0.003 multiplied by the square root of the distance (k) in kilometers.

LEAST SQUARE ADJUSTMENT

The leveling least square adjustment for the Dhahran test range was performed by using the United States National Geodetic Survey (NGS) LEVEL 1 software for the Saudi Aramco vertical control network. The Level 1 program runs on the IBM 3390 and has been tested extensively for performing a least square adjustment of the vertical control network containing 2400 benchmarks. Since 1981, GSG has been using the NGS Level 1 least square program for the vertical control network.

ZEISS NI-1 AND NA3000 COMPARATIVE ANALYSIS

The NA3000, with its relatively new digital electronic image processing technology, required an evaluation on the GSG test range. The NA3000 was tested for precision and cost effectiveness in order to determine its validity as a new leveling system. The first step in the test was to survey the test range with the Zeiss Ni-1 instrument. The survey consisted

12:27 OCT 1992

ATTACHMENT NO. 1

MICROMETER LEVEL SECTION SUMMARY SHEET

SURVEY SERVICES

Aramco 8744-1 (10/83)

QUAD.	S.C. NO. 910009
SECTION	COMPILED BY VETERA
BM. FROM TEST # 10 TEST # 10	DATE 28 OCT 1992
BM. TO STA # 3796 STA # 3796	CHECKED BY
PROJECT	DATE 28 OCT 92

PAGES		OBSERVED ELEVATION DIFFERENCE ±	LEFT GRADUATION	±	RIGHT GRADUATION	DISTANCE LEVELED (Km.)	SET UPS	DIFFERENCE LEFT / RIGHT
1→2	FORWARD	-	4.22041 ✓	-	4.22044 ✓	0.475 ✓	9	+0.00003 ✓
3-4	BACKWARD	+	4.22185 ✓	+	4.22186 ✓	0.475 ✓	9	-0.00001 ✓
	FORE / BACK DIFFERENCE	+	0.00144 ✓	+	0.00142 ✓			+0.00002 ✓
	MEAN	-	4.22113 ✓	-	4.22115 ✓	0.475 ✓		+0.00002 ✓
	LEFT / RIGHT DIFFERENCE		+0.00002			Allowable Difference (0.003 √K)		MEAN DIFFERENCE
	ADOPTED MEAN		-4.22114			±0.00207 ✓		+0.00143 ✓

-4.22114 ✓

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COMMENTS

SUMMARY

****

FROM: TEST#10 TO: STA#3796

	OBSERVED ELEV.DIFF. LEFT GRAD	RIGHT GRAD	DIFFERENCE LEFT/RIGHT	DIST.(m) LEVELED
FORWARD	-4.22041	-4.22044	0.00003	475.29
BACKWARD	4.22185	4.22186	-0.00001	476.81
F/B DIFF.	0.00144	0.00142	0.00002	0.48
MEAN	-4.22113	-4.22115	0.00002	475.05
L/R DIFF.	0.00002		ALLOW.DIFF.	0.00207
			MEAN DIFF.	0.00143

ADOPT.MEAN -4.22114 ✓

DIST.(Km) 0.475

ATTACHMENT NO. 2

S U R V E Y I N G S E R V I C E S D I V I S I O N

DIGITAL LEVEL SECTION SUMMARY SHEET

SECTION : QUAD : QATIF

LOCATION : *DHAHRAN ROLLING HILLS*

PROJECT : DHAHRAN TEST (W/NA3000)

From : BM#5951 / 5951

To : BM#6686 / 6686

SC # : 910009

Crew # : 04

Instrument : WILD NA3000, SN#1558

Rods : WILD GPCL3, SN#6947, 6948

	OBSERVED ELEVATION DIFFERENCE	DISTANCE LEVELED Km	NUMBER OF SET-UPS
FORWARD	3.66940 /	0.449 /	5 /
BACKWARD	-3.66810 /	0.449 /	5 /
FORE/BACK DIFFERENCE	0.00130 /	0.000	0
MEAN	3.66875 /	0.449 /	5 /

+3.66875 / ADOPTED MEAN	ALLOWABLE DIFFERENCE	OBTAINED DIFFERENCE
3.66875	0.00201 /	0.00130 /

Disk no. : DHT-1 File no. : TEST3FB2.RAW

Compiled by : VEERA Checked by :

Date : 06 OCT 1992 Date : HMA 02/13/93

Veera

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of 16 sections with a total of 8.88 kilometers of leveling. The field data were checked and reduced in the office for data processing in the least square program. In the least square adjustment, three benchmarks were constrained as their elevations were obtained from the vertical control network database. The identical procedure was repeated with the NA3000 instrument in order to perform an unbiased comparative analysis of the two systems. All these measurements were carried out within a temperature range of +10C and +43C.

Data Analysis

The results of the comparative analysis of leveling with the NA3000 and Zeiss Ni-1 are summarized in Tables 1 to 4 (Atch No.3). Table 3 depicts the differences in the elevations after the least square adjustment which ranged between 0.00014 meters (minimum difference at Benchmark 5338) and 0.00104 meters (maximum difference at STA TEST#20). Table 4 depicts the NA3000 results with the standard deviations which varied from 0.15 millimeters (Benchmark 5338) to 0.45 millimeters (Benchmark 5395). Table 4 illustrates the Zeiss Ni-1 results with the standard deviations which varied from 0.18 millimeters (Benchmark 6654) to 0.36 millimeters (Benchmark 5395). The loop data has an acceptance test for precision which is 0.004 multiplied by the square root of the total loop distance (k) in kilometers (see Atch No.4 for loop reference).

Cost Effectiveness

One of the objectives in this analysis is to report the time and cost effectiveness of the two types of leveling instruments. During the field survey and data reduction segment of the work, the time element for both instruments was constantly monitored in order to estimate cost effectiveness. It was found that a 50% time savings was made both in the field survey and the data reduction in the office by using the NA3000. Normally, the field survey with the Zeiss Ni-1 for a one kilometer double run takes approximately 2 hours. The same survey work with the NA3000 took only 1 hour. In the data reduction stage, one kilometer sections would usually take approximately 1 hour to enter the field data from the Zeiss Ni-1 into the calculator or the computer software and to perform the computations. With the NA3000 field data, the data reduction stage is simplified by downloading the data via interface Wild GIF10 and then using software to perform the data reduction that usually takes about 1/2 an hour from start to finish.

CONCLUSION

The following conclusions are based on the results of the analysis in the field work for the final vertical adjustment of the test range network.

The WILD NA3000 represents the first successful attempt to automate GEODETIC LEVELING procedures. Exhaustive test measurements have confirmed that the NA3000 level still produces

TABLE 1

THE STANDARD DEVIATION OF THE SECTIONS OBTAINED AFTER LEAST SQUARE ADJUSTMENT USING ZEISS Ni-1 OBSERVATIONS

No.	FROM STA/BM	TO STA/BM	STANDARD DEVIATION (SIGMA) (mm)	LENGTH (Km)
1	BM 5339	BM 5338	0.1	0.03
2	BM 5338	BM 5394	0.1	0.34
3	BM 5394	BM 6654	0.2	0.16
4	BM 6654	BM 5951	0.3	0.54
5	BM 5951	BM 6686	0.3	0.45
6	BM 6686	BM 5999	0.3	0.76
7	BM 5999	BM 5395	0.4	0.75
8	BM 5339	STA 3796	0.2	0.09
9	STA 3796	STA TEST#4	0.3	0.28
10	STA TEST#4	STA TEST#7	0.2	0.17
11	STA TEST#7	STA TEST#23	0.2	0.14
12	STA TEST#23	STA TEST#20	0.2	0.22
13	STA TEST#11	STA TEST#10	0.2	0.16
14	STA TEST#10	STA TEST#20	0.2	0.10
15	STA TEST#20	STA TEST#4	0.2	0.16
16	STA STA#3	BM 6654	0.2	0.10
		TOTAL LENGTH =		4.44 Km

[ninat01.frm/12/1992]

TABLE 2

THE STANDARD DEVIATION OF THE SECTIONS OBTAINED AFTER LEAST SQUARE ADJUSTMENT USING WILD NA3000 OBSERVATIONS

No.	FROM STA/BM	TO STA/BM	STANDARD DEVIATION (SIGMA) (mm)	LENGTH (Km)
1	BM 5339	BM 5338	0.1	0.03
2	BM 5338	BM 5394	0.2	0.34
3	BM 5394	BM 6654	0.2	0.16
4	BM 6654	BM 5951	0.4	0.54
5	BM 5951	BM 6686	0.4	0.45
6	BM 6686	BM 5999	0.4	0.76
7	BM 5999	BM 5395	0.4	0.75
8	BM 5339	STA 3796	0.2	0.09
9	STA 3796	STA TEST#4	0.3	0.28
10	STA TEST#4	STA TEST#7	0.2	0.17
11	STA TEST#7	STA TEST#23	0.2	0.14
12	STA TEST#23	STA TEST#20	0.3	0.22
13	STA TEST#11	STA TEST#10	0.3	0.16
14	STA TEST#10	STA TEST#20	0.2	0.10
15	STA TEST#20	STA TEST#4	0.2	0.16
16	STA STA#3	BM 6654	0.2	0.10
		TOTAL LENGTH =		4.44 Km

[ninat02.frm/10/FEB 1993]

TABLE 3

DIFFERENCE BETWEEN THE ADJUSTED ELEVATION OF STA/BM OBTAINED USING ZEISS Ni-1 AND WILD NA3000 LEVELS

No.	STA/BM	(1) ELEVATION WITH ZEISS Ni-1 (m)	(2) ELEVATION WITH WILD NA3000 (m)	DIFFERENCE (1)-(2) (m)
1	BM 5338	77.02566	77.02552	0.00014
2	BM 6654	81.27474	81.27409	0.00065
3	BM 5951	72.38609	72.38519	0.00090
4	BM 6686	76.05689	76.05607	0.00082
5	BM 5395	76.76348	76.76296	0.00052
6	STA 3796	81.89028	81.89083	-0.00055
7	STA TEST#4	78.25262	78.25193	0.00069
8	STA TEST#7	79.49893	79.49834	0.00059
9	STA TEST#23	78.72536	78.72493	0.00043
10	STA TEST#11	87.78462	87.78409	0.00053
11	STA TEST#10	86.11094	86.10994	0.00100
12	STA TEST#20	85.20288	85.20184	0.00104
13	STA STA#3	89.58709	89.58764	-0.00055

The following THREE stations were constrained in the network.

STA	ELEVATION (m)
BM 5339	77.03100
BM 5394	79.91244
BM 5999	75.47646

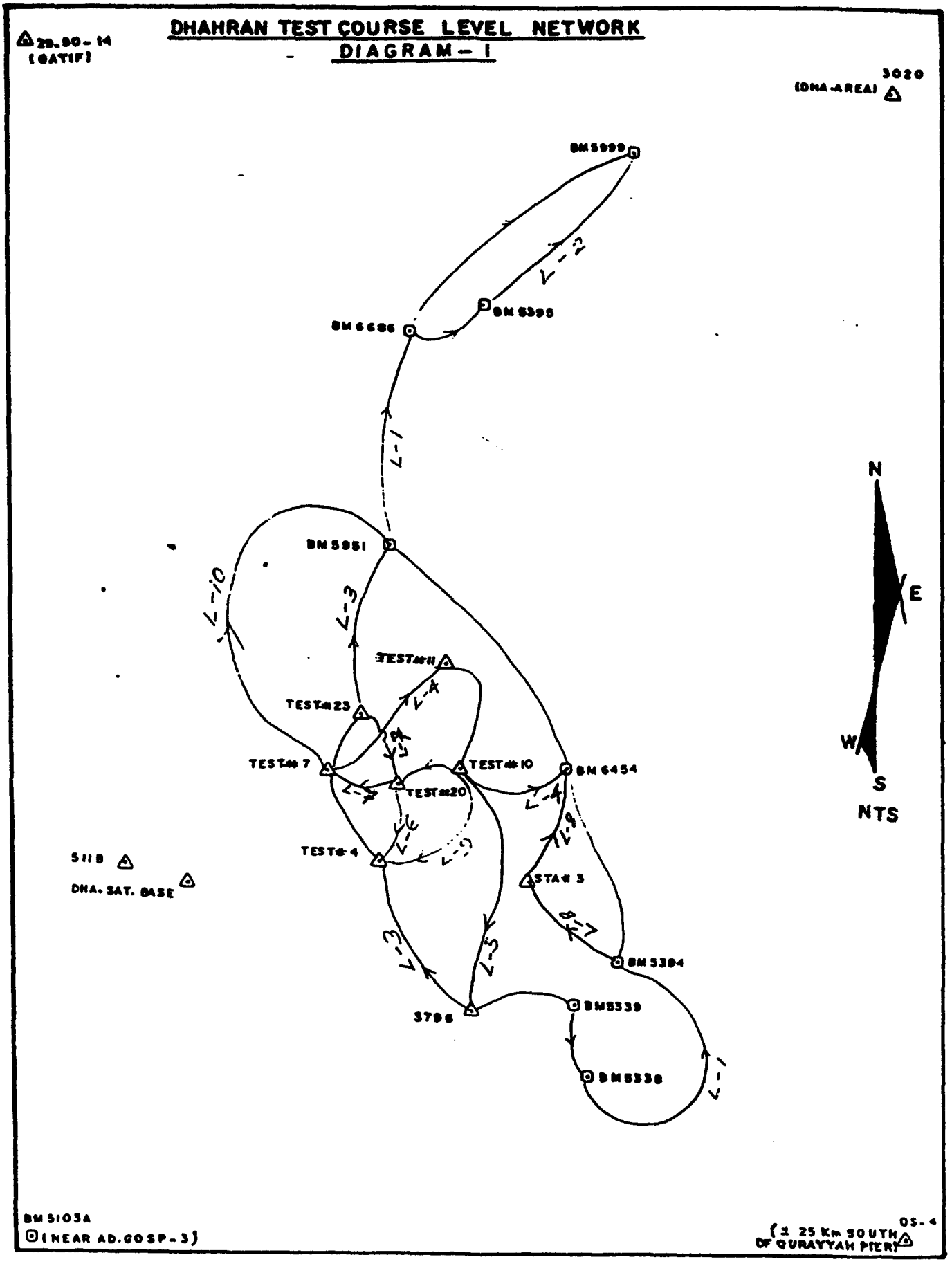
TABLE 4

THE COMPARISON OF THE SIGMA OBTAINED FOR STA/BM USING ZEISS Ni-1 AND WILD NA3000 LEVELS

No.	STA/BM	SIGMA(mm) OBTAINED WITH ZEISS Ni-1	SIGMA(mm) OBTAINED WITH WILD NA3000	REMARKS
1	BM 5339	0.04	0.04	CONSTRAINED
2	BM 5338	0.14	0.15	
3	BM 5394	0.04	0.04	CONSTRAINED
4	BM 6654	0.18	0.25	
5	BM 5951	0.28	0.38	
6	BM 6686	0.34	0.43	
7	BM 5999	0.04	0.04	CONSTRAINED
8	BM 5395	0.36	0.45	
9	STA 3796	0.21	0.23	
10	STA TEST#4	0.27	0.34	
11	STA TEST#7	0.28	0.35	
12	STA TEST#23	0.32	0.39	
13	STA TEST#11	0.32	0.41	
14	STA TEST#10	0.26	0.32	
15	STA TEST#20	0.27	0.35	
16	STA STA#3	0.23	0.28	

[ninat04.frm/10/FEB1993]

ATTACHMENT NO. 4



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results within the first order accuracy specification even though considered a less precise instrument than the Zeiss Ni-1 optical level.

The most advantageous aspect of NA3000 is the speed of leveling in the field. Also, the computations in the office were accomplished with 50% time savings as compared to the Zeiss Ni-1. Furthermore, the Wild NA3000 reading and transfer errors are completely ruled out, and it demands less on the operators' manipulations as it stores the results directly in the field.

In considering operational aspects and the 50% time savings, digital levels can be used in first order surveys and may replace the conventional optical levels in the near future.

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Wild NA3000 user manual

Davis, Raymond E., Foote, Francis S., Anderson, James M., Mikhail, Edward M., Surveying Theory and Practice, (sixth edition).

Mikhail, Edward M., Gracie, Gordon, Analysis and Adjustment of Survey Measurements.