MOVEMENT ALONG THE BATON ROUGE FAULT

A Thesis

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ABBREVIATIONS

Benchmarks……………………………………………………………..BM

Difference…………………………………………………………….Diff.

Elevation...……………………………………………………………Elev.

National Geodetic Survey…..…………………………………………NGS

National Oceanic and Atmospheric Administration…………………NOAA

Latitude………………………………………………………………LAT

Longitude…………………………………………………………….LON

Permanent Identifier (NGS identification of benchmarks)…………..PID

ABSTRACT

The Baton Rouge fault is one of two faults (the other being Denham Spring-Scotlandville fault) that traverse the city of Baton Rouge and has long been thought to be active. Structural damages to buildings, streets and sidewalks near the fault have previously been attributed to movement of the fault. Although the presence of the fault has been known for nearly 60 years, previous investigations have failed to determine its rate of movement. This study was aimed at determining the rate of modern movement along the Baton Rouge fault. Using a precise geodetic leveling technique, the current elevations of NGS (National Geodetic Surveying) benchmarks near the fault were determined and the values obtained were compared to 1994 elevations of the benchmarks. The investigation has shown that the Baton Rouge fault is active at the present time with measurable vertical movements still occurring at the land surface. The results of the study have also indicated that the fault crosses the Mississippi River and is currently disrupting it.

CHAPTER 1
INTRODUCTION

1.1 Background

There are at least two faults in Baton Rouge --- the Baton Rouge fault and the Denham Springs-Scotlandville fault [2]. Damage done to structures located on or near these faults has previously been attributed to movements along the faults. An investigation was conducted in 1981 to assess damages related to the Baton Rouge fault [1]. In the investigation, structural damages to one hundred thirty nine buildings and/or houses were attributed to the movements along the fault.

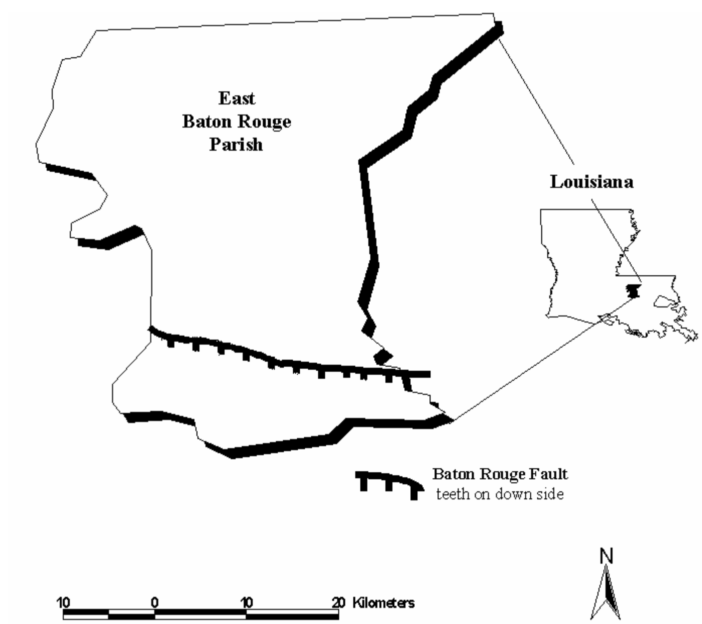

Fig 1.1 The Baton Rouge fault (Modified from [2])

The Baton Rouge fault extends E-W fourteen miles from the Mississippi River to the Amite River within East Baton Rouge parish [1]. Over most of this distance, it is readily traceable by its distinctive fault-line scarps, created by the cumulative movement along the fault since the underling surface material was deposited. The fault is also considered to extend west into the West Baton Rouge Parish but has not been mapped on the surface [1]. The height of the escarpment ranges from 4 to 7 meters along the fault [1].

Fig 1.2 Fault escarpment near the intersection of College Drive and Corporate Blvd

Previous investigations conducted on the Baton Rouge fault focused mainly on other geological and engineering aspects (precisely locating and mapping the fault, damage assessment, etc). None of the previous studies was directly aimed at investigating the nature of the faults movement. Therefore, there are only rough estimates about the rate of movement along the Baton Rouge fault.

The purpose of this study was to investigate the nature of modern movement along the Baton Rouge fault. This study is the first to be directly aimed at investigating the rate of movement along the fault. Roland [1] recommended establishing new benchmarks along the fault and leveling them periodically to learn more about the rate of movement along the Baton Rouge fault. However, since then no new benchmarks have been established for the purpose of studying the faults movement. In this study, NGS benchmarks located near the fault were used instead.

Our original idea was to reoccupy benchmarks around the fault surveyed by Wintz in 1970 [3]. The plan was to determine the elevation changes that have occurred to the benchmarks since they were last surveyed. Unfortunately, except for one benchmark, we were not able to locate any of the benchmarks in our area of interest. They all had either been destroyed or could not be found. It was then decided to use NGS benchmarks. Information about all the NGS benchmarks that are located around the fault was downloaded from the NGS website [4]. We then recovered the benchmarks and identified the ones that could be included in our study. To be included, the benchmarks had to be in close proximity to the fault. This was mainly to isolate the effects of the fault from other factors that could also cause subsidence, e.g. pumping of ground water, oil extraction, etc.

We were fortunate to find nine NGS benchmarks at three different locations in close proximity to the fault ---two locations east and one location west of the Mississippi River. There are fewer benchmarks than anticipated, but the benchmarks are very close to the fault. Elevations of the benchmarks derived from precise leveling and adjusted in September of 1994 are also published on the NGS website. After the benchmarks were physically located, geodetic leveling was carried out to determine the current elevations of each benchmark. The published elevation values were compared to those obtained from the fieldwork in this investigation to determine the displacements of the benchmarks since 1994.

1.2 Objective

A detailed investigation of a faults movement is a lengthy and challenging endeavor. To use the technique in this study (geodetic leveling) would require establishing a substantial number of control points along each side of the fault and periodically leveling them. Since the number of benchmarks that are currently found around the fault is limited, this investigation is only able to address the basic aspects of the faults movement. However, the work presented in this document and the conclusions drawn from the study are vital for better understanding of the fault and devising strategies to cope with the effects of the faults movement.

The main purpose of this study was to test the assumption that the Baton Rouge fault is currently active. The study also investigated other aspects of the faults movement, namely:

1. If it is active, what is the rate of vertical movement along the fault?
2. Does western extension of the fault end at the Mississippi River?

1.3 Scope of the Study

The number of benchmarks that could be found near the fault and the amount of time allotted for the investigation were the two main factors that governed the scope of this study. The following is a general overview of some important aspects that were beyond the scope of this investigation:

1 The investigation did not consider the effects of other factors that can also cause subsidence, including pumping of ground water and regional movement. It is assumed that these effects equally affect all the benchmarks on both sides of the fault.

2. The study only dealt with vertical displacements. Due to the complexity of the task and the amount of time it would take to determine other displacement vectors

(horizontal, fault slip), other kinds of movements were not considered in this study.

3. Movement of the fault was determined by measuring benchmark displacements (elevation changes) over a period of time. The changes in elevation were divided by the amount of time in order to find the rate of vertical displacement of the fault. Hence, linear displacement of the fault over time was assumed.

4. Due to the limitation in the number of benchmarks that could be found in our area of interest, it was not possible to determine the exact displacements of the fault at every location along the fault.

1.4 Significance of the Study

Active faults displace one or both of the rock masses lying on either side of them. The movement can have profound effects on local geological structures and so on surface features, which, correspondingly, will affect engineering works built upon them. Even if small, a fault can dictate major changes in design and cause considerable trouble to construction projects. Even the faintest possibility of movement taking place upon a fault plane under any engineering structure is one that has to be avoided at all costs, even to the extent of abandoning a proposed building site [5]. Therefore, the determination of whether or not a fault is currently active is a matter of considerable engineering importance.

Direct and best evidence of activity of a fault is furnished by seismographs and the disruption of benchmarks [6]. If the seismograph records show that earthquakes occur along a fault, it should be regarded as active. Similarly, if accurately located benchmarks exhibit horizontal or vertical displacement, proximal faults known to exist in the area should be regarded as possibly active [6]. This study followed the latter approach and used NGS benchmarks to investigate the activity and the rate of movement along the Baton Rouge fault.

The movement along the Baton Rouge fault is so gradual and devoid of seismicity that many residents who live close to the fault are not aware of its existence. However, the movement of the Baton Rouge fault is a major concern because the fault traverses city streets, infrastructure and homes affecting an urban area. In spite of this concern no previous investigations were directly aimed at investigating the faults movement. The findings of this study are, among others, crucial from the point of view of urban development. The fault was precisely located and mapped by previous investigations. Now that the fault is determined to be currently active with a measurable vertical movements still occurring at the land surface, the fault must be kept in mind in all site studies for future engineering works in the vicinity of the fault.

CHAPTER 2
LITERATURE REVIEW

2.1 General Works

Several investigations have been conducted on the Baton Rouge fault over the years. Most of the previous investigations focused on different geological and engineering aspects (precisely locating and mapping of the fault, effects of the fault on ground water, damage assessments…). None, however, directly intended to determine the nature of movement along the fault. McNiel [7] catalogued vegetational differences across the Baton Rouge fault. Durham [8] located the Baton Rouge fault on the ground. Meyer and Rollo [9], Rollo [10], and Smith [11] investigated the effects of the Baton Rouge fault on groundwater flow. Wintz investigated subsidence in the Baton Rouge area and the effect of the fault [3]. Durham investigated damage to buildings in Woodlawn High School that were apparently caused by the movement of the Baton Rouge fault [12]. A study conducted by the Department of Public Works on structural cracks in houses in the College Park subdivision area concluded that some of the structural cracks were caused by the Baton Rouge fault [13]. McCulloh analyzed and gave a summary of what is known about the Baton Rouge fault systems [14], [15], [2].

2.2 Investigation on Movements Along the Fault

None of the investigations conducted in the past on the Baton Rouge fault were intended specifically to determine the rate of movements along the fault. Therefore, there are only rough estimates about the actual rate of movements along the fault. Some of the literature on the fault, including recent publications, give estimates for the rate of movements along the fault without indicating the exact data on which the estimates were based, or simply say, "The fault is believed to be active". These include:

"Movement (along the Baton Rouge fault) will continue at about the present rate, possibly as much as 0.02 ft (about ¼ inch) per year." --- [3]

"These faults (referring to the Baton Rouge and Denham Springs-Scotlandville faults) are known to be active…", "The current rate of movement along the Baton Rouge fault was estimated to be several centimeters (a few inches) per decade…" --- [2]

The investigation by Wintz in 1970 was the first to detect displacement across the Baton Rouge fault [3]. The investigation concluded that the Baton Rouge fault is active based on an unexpected differential movement observed in a surveying study that was conducted on a single line of benchmarks. The surveying was conducted from a benchmark on one side of the fault to another benchmark on the other side of the fault connecting other benchmarks in between. The ground immediately south of the fault was found to have subsided more than the ground north of the fault. This indicated that the fault is active. The study indicated that the downthrown (south) side is dropping at a maximum rate of about 6 mm per year.

Damage to the Woodland High School apparently caused by the Baton Rouge fault was investigated in 1975 [12]. The average movement at Woodlawn was estimated to be 3 inches (8 cm) over 15 years --- and average of 0.2 inches (5 mm) per year. The investigation also mentions that nearby benchmarks surveyed in July 1973 and July 1975 showed a movement of 0.3 inches (8 mm) annually. Another estimate of the faults movement was proposed by Roland based on the height of the escarpment along the fault [16]. His proposed average displacement for the fault was 1 inch (2.54 cm) per 400 years (less than one mm per year) during the geological past.

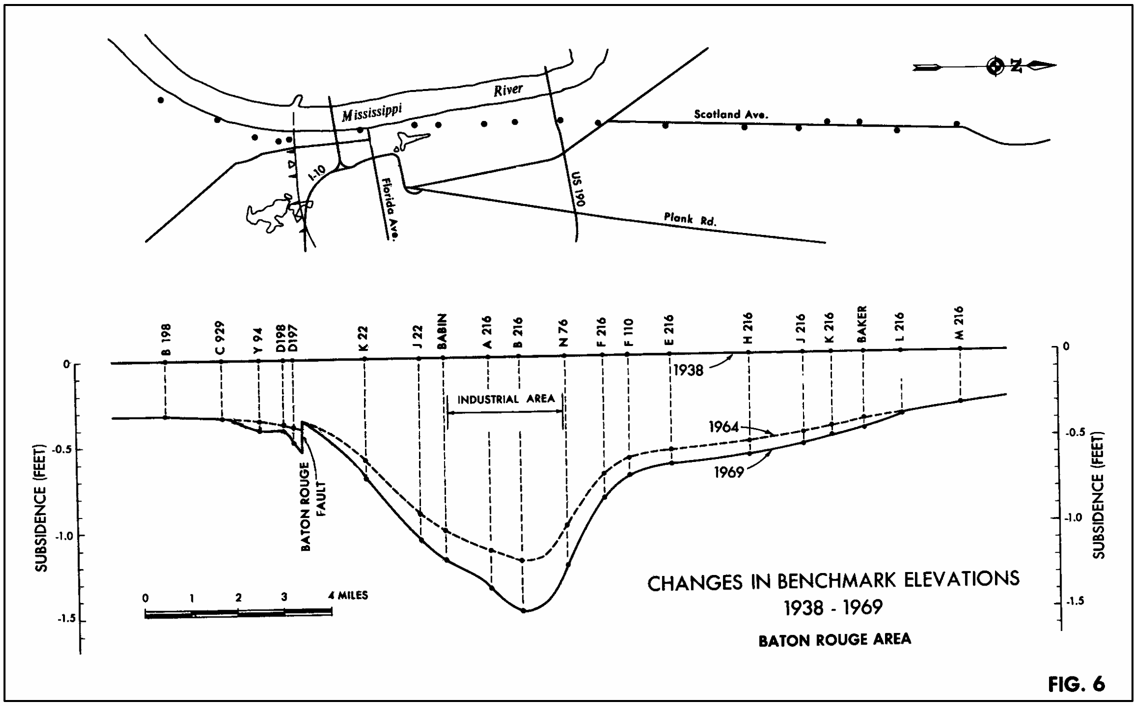

Fig 2.1 Line of level conducted by Wintz (adopted from [3])

Table 2.1 Summary of previous estimates

Rate (mm/year)	Source	Method
6	[3]	Surveying
5	[12]	Building offsets
8	[12]	Surveying
<0.1	[1]	Height of escarpment

CHAPTER 3
METHODS AND EQUIPMENT

3.1 Micrometer Leveling

Micrometer leveling, a highly precise form of geodetic leveling, was utilized to measure the change in elevation of selected benchmarks since 1994. Geodetic leveling was used because it is the most accurate and reliable means for measuring precise elevation differences [16]. In this form of precise leveling, the observing team limits the magnitude of error by using calibrated instruments in combination with a rigorous, symmetrical observing procedure. The technique is generally used to establish vertical control points for localized construction projects and studies of motions of the earth's crust.

In this study, the main lines of levels were conducted from a benchmark on one side of the fault to another benchmark on the other side of the fault. Leveling was carried out in an unbroken series of setups made between the two benchmarks. A setup consists of a point supporting the first (backsight) rod, a point supporting a second (foresight) rod, and leveling instrument positioned between them. Two heights are measured by sighting through the instrument toward a scale on each rod and recording the values intercepted on the rods. The height difference, backsight minus foresight, corresponds to the elevation difference between the two points. The foresight point of one setup becomes the backsight point of the next; thus, the sum of the elevation differences of the series of setups is the elevation difference of the section (the two benchmarks).

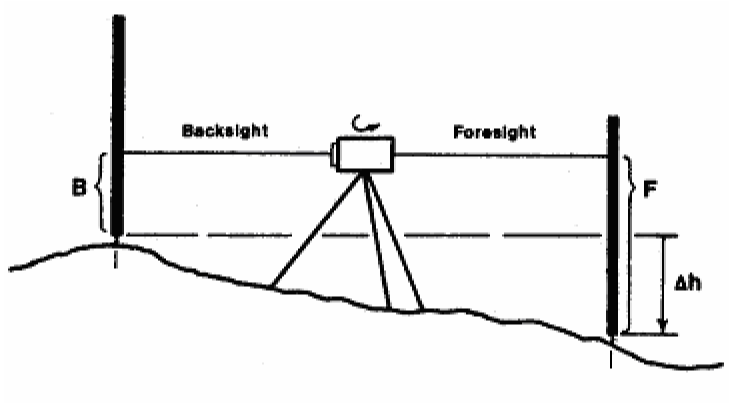

Fig 3.1 Leveling setup (adopted from [16])

The following is a brief summary of the micrometer leveling procedure. A complete description of the procedure can be found in NOAA Manual for geodetic leveling [16]. In micrometer leveling two elevation differences are measured during every setup. The first difference is measured from backsight to foresight, the second from foresight to backsight. Since two runnings are completed in opposite directions during every setup, each section is leveled twice. The elevation difference of the section would be the average of the two elevation differences determined from the two runnings.

Certain conditions must be satisfied for this technique to provide reliable elevation differences. First, the line of sight from the instrument to the rods must be level. In other words, the lines of sight must be parallel at all times to the reference surface. Second, the values observed on the scales must accurately indicate heights above the point on which the rods rest. Finally, the points in turn must be stable with respect to the topography. These conditions cannot always be perfectly satisfied. However, they may be approximated by limiting the known sources of error [16]. Leveling is classified by the degree with which error magnitudes are limited. In this study, procedures necessary for first-order class I leveling (leveling with the highest accuracy standard) were followed.

3.2 Study Area

The study areas and the benchmarks used in this project are shown in Fig A.1**.** Three study areas were identified along the fault where benchmarks were found that could be included in the study. The first site is near the Interstate Highway 10 overpass at College Drive. Three benchmarks were found at this site --- two located north and one located south of the fault. Two lines of leveling were measured from each of the benchmarks north of the fault to the one located south of the fault crossing the fault at two different locations.

The second study area is on the east side of the Mississippi River near the I-10 overpass at River Road (Mississippi Bridge). Three benchmarks were surveyed in the study --- one north and two others south of the fault. One line of leveling was conducted from the benchmark north of the fault to one of the benchmarks south of the fault, which crossed the fault at one location. Because the two benchmarks south of the fault are near each other (~ 8 m), no other leveling could be done across the fault. However, their elevation difference was determined to check for relative movement.

The third study area occurs in Port Allen, west of the Mississippi River near the I-10 overpass. Three benchmarks were surveyed in the study --- one north and two others south of the fault. One line of leveling was conducted from the benchmark north of the fault to one of the benchmarks south of the fault, which crossed the fault at one location. Once again, because the two benchmarks south of the fault are in close proximity to each other (250 m), no other leveling could be conducted across the fault. However, their elevation difference was also determined to check for relative movement between benchmarks on the same side of the fault.

3.3 Equipment

The geodetic equipment used in this study included a leveling instrument, two leveling rods, one tripod, and tow turning plates. The complete list of equipment and material used during the fieldwork is given in Appendix B.

- **Leveling Instrument**

The leveling instrument used in this study is a Zeiss Ni1 precision automatic level. (Integral micrometer; setting precision: $\pm 0.1''$)

- **Leveling Rods**

Leveling rods provide accurate heights above turning and control points (benchmarks). Two 3.5m, half-centimeter Invar (Steel-nickel alloy) rods were used in the study. Invar rods have a very small coefficient of thermal expansion. Half-centimeter refers to the interval indicated by the graduations on the rod, termed rod units. It is the recommended interval for geodetic leveling [16]. The interval is compatible, as required, with the units of the micrometer in the leveling instrument used in the study (Zeiss Ni1).

- **Tripod**

A wooden tripod with non-adjustable legs was used in this study, as recommended by NGS [14]

- **Turning Points**

A turning point is the temporary support on which a leveling rod is placed during a setup. The foresight point for one setup becomes the backsight point for the next, holding the elevation while the leveling instrument is moved between setups. In this study two metal turning plates were used as turning points.

	
a. Leveling instrument	b. Turning plate

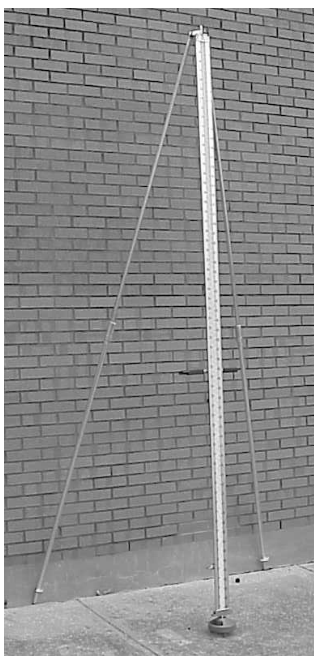	
c. Leveling rod with bipod	d. Tripod

Fig 3.2 Equipment

3.4 Procedure

The procedures outlined in the NOAA manual for geodetic leveling and tolerance values for first order class I geodetic leveling were followed for carrying out the leveling in this study. Strict attention was paid to the precautions and guidelines presented in the manual. At the start of each day, a collimation check was made to determine if the instrument was properly adjusted within the standard of accuracy required for the survey. The instrument was sent to a qualified repair company for adjustment before we started the fieldwork, and it did not require any other adjustment during the entire leveling period.

Leveling was conducted by a four persons team consisting of an observer-leader, data recorder, and two rodmen. During the surveying and collimation check, observations were recorded in a laptop PC running an Excel program designed for this study. The program was a substitute for NOAA Form 76-191, which is typically used for recording observations. Using the computer program observations were checked at the time they were made. This helped prevent reading and recording blunders in addition to allowing much faster computation of the measurements.

The following is a summary of the micrometer leveling procedure followed in every setup during the fieldwork.

1. Balance setup.
2. Point instrument at backsight.
3. Level instrument and plumb rods.
4. Read backsight, low scale: wedge and stadia.
5. Point to and read foresight, low scale: wedge and stadia.
6. Check sighting distances and imbalances against tolerances.
7. Dislevel-revel.
8. Read foresight, high scale: wedge.

9. Check low- and high-scale elevation differences against tolerance.
10. Check low- and high-scale elevation differences against tolerance.
11. Check accumulated imbalance against tolerance.
12. Move to next setup.

CHAPTER 4
RESULTS

The results of the leveling and the comparisons of the observed values with elevation values published previously for the benchmarks by NGS are presented in this section. The rates of change observed reflect motion that occurred over the eight-year interval from 1994 to 2002. Data are summarized in Table 4.1. The location and other information about the benchmarks used in this study are given in Appendix A.

4.1 Main Lines of Levels

- **BM1 to BM2**

The published NGS elevations for BM1 and BM2 in 1994 are 13.699 m and 11.661 m, respectively. These values yield an elevation difference (BM1 minus BM2) of 2.038 m. The elevation difference obtained from our occupation is 2.077 m. The change in elevation since the last adjustment in 1994 is thus 0.039 m (39 mm).

- **BM3 to BM2**

Previously measured elevations are 12.914 m for BM1 and 11.661 m for BM2, this results in an elevation difference (BM3 minus BM2) of 1.253 m. The elevation difference obtained during this study is 1.282 m. Hence, the change in elevation since the last adjustment is 0.029 m (29 mm).

- **BM4 to BM5**

Previously determined elevations for BM4 and BM5 are 10.721 m 9.857 m, respectively. The elevation difference (BM4 minus BM5) is 0.864 m. In contrast, the elevation difference obtained from the fieldwork is 0.884 m, yielding a change in elevation of 0.020 m (20 mm) since the last adjustment.

- **BM7 to BM8**

The published elevations for BM7 and BM8 are 9.885 m and 7.758 m, respectively. This yields an elevation difference (BM7 minus BM8) of 2.127 m. The elevation difference obtained during this study is 2.166 m. The change in elevation since the last adjustment in 1994 is thus 0.039 m (39 mm).

4.2 Additional Lines of Levels

In addition to the above lines of levels, three more levels were conducted. The first two (BM5 to BM6 and BM8 to BM9) were conducted to check for relative movement between benchmarks on the same side of the fault. The third level (BM5 back to BM4) was conducted to check for error of closure.

- **BM5 to BM6**

The published elevations are 9.857 m for BM5 and 9.212 m for BM6. The elevation difference (BM6 minus BM5) is -0.645 m. The elevation difference obtained from this study is -0.643 m, yielding a change in elevation of 0.002 m (2 mm) since the last measurement.

- **BM8 to BM9**

The elevations are 7.758 m and 15.845 m for BM8 and for BM9, respectively. These values yield an elevation difference (BM9 minus BM8) of 8.087 m. The elevation difference obtained from our measurement is 8.084 m. Hence, the change in elevation since the last measurement is 0.003 m (3 mm).

- **BM5 back to BM4**

The published elevations are 9.857 m for BM4 and 10.721 m for BM5, as mentioned above. This yields an elevation difference (BM4 minus BM5) of 0.864 m. The elevation difference obtained the measurement in this study is 0.885 m, yielding a change in elevation of 0.021 m (21 mm). Error of closure BM4 to BM5 back to BM4 is 0.1cm (1 mm).

4.3 Summary of Results

Table 4.1 Summary of results

From - To	Distance between BMs (~ km)	Published Elev. Diff. (m)	Current Elev. Diff. (m)	Change in Elev. Per eight years (mm)	Error * (mm)	Change in Elev. Per year (mm)
Main leveling						
BM1 - BM2	1.9	2.038	2.077	39	±4.1	5
BM3 - BM2	2.3	1.253	1.282	29	±4.5	4
BM4 - BM5	0.8	0.864	0.884	20	±2.7	3
BM7 - BM8	1.2	2.126	2.166	39	±3.3	5
Additional leveling						
BM5 - BM6	10 m	0.645	0.643	2	±0.3	0.3
BM8 - BM9	0.2	8.087	8.084	3	±1.3	0.4
BM5 - BM4	0.8	0.864	0.885	21	±2.7	3

* Errors are calculated using the tolerance values given for First Order Class I geodetic leveling: error= $\pm 3\times\sqrt{k}$, where k is one-way length between benchmarks [16].

CHAPTER 5
DISCUSSION

5.1 Activity of the Fault

The Baton Rouge fault has previously been considered active mainly based on investigations of damage to built structures. One of the best ways to determine activity of a fault is to examine the behavior of benchmarks [6]. If accurately located benchmarks exhibit horizontal or vertical displacement, any faults known to exist in the area should be regarded as active [6]. In this study four lines of levels were conducted --- all crossing the fault. The results obtained from all four levels resulted in a positive relative displacement between benchmarks on either side of the fault --- benchmarks south of the fault (downside of fault) have moved down relative to those north of the fault. This indicates that the fault has been active between 1994 and 2002.

5.2 Rate of Movement Along the Fault

The displacements obtained at the four locations in this study are 40 mm, 32 mm, 24 mm, and 40 mm over eight years --- a range between 24 mm and 40 mm. These displacements are somewhat less than previous estimates based on damage assessments (6 mm and 5 mm per year) ordinary leveling [3].

5.3 Fault West of the Mississippi River

The result obtained from the one line of leveling conducted across the Mississippi River in west Baton Rouge Parish (relative displacement of 39 mm over eight years between BM7 and BM8) is consistent with the results obtained from leveling conducted east of the river in East Baton Rouge Parish. This indicates that the fault crosses the Mississippi River into West Baton Rouge Parish. This may be a very significant finding since the movement can have serious effects on the Mississippi River and the levee confining the river.

5.4 Discrepancies in the Results

The relative displacements obtained from the second and third lines of levels (BM3-BM2 and BM4-BM5) are significantly different from the ones obtained from the first and fourth lines of levels (BM1-BM2 and BM7-BM8) --- outside of the error range. The discrepancy could have resulted from one or more of the following factor:

1. Distance of the benchmarks from the fault is different. This could result in different displacements since the effect of the fault decreases with distance.
2. Depth of the benchmarks and the extent to which they cross the faults deformation zone might be different.
3. The displacement of the fault is not uniform at every location.

CHAPTER 6
CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The objective of this study was to test the assumption that the Baton Rouge fault is currently active, and, if active, to investigate the nature of the faults movement. Based on the findings of the investigation the following conclusions were drawn about the Baton Rouge fault:

1. The fault is currently active with a measurable vertical movements occurring at the land surface.
2. The rate of vertical movement along the fault is about 3-5 mm/year.
3. The data suggest that the fault crosses the Mississippi River to the west.

6.2 Recommendations

Based on the results from this investigation the following recommendations are made:

1. The potential effects of the faults movement to surface and subsurface structures, such as sewers, roads, bridges, and pipelines must be evaluated and strategies should be devised to minimize the effects of the fault movement on existing structures.
2. The effects that fault movement could have on the Mississippi River and the levee around it should be investigated. This is especially important because of the possibility of levee failure and flooding.

3. In planning of future public works, the movement of the fault and its potential effect must be taken into consideration in all site studies for engineering works in the general vicinity of the fault.
4. For future investigations of the faults movement, other control points (benchmarks) should be established around the fault. The location and number of benchmarks should be planned in advance depending on the nature and scope of the intended investigation.
5. The technique used in this investigation, reoccupying NGS benchmarks around the fault, can also be used to investigate movements such as the Denham Springs-Scotlandville fault and other faults.

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[16] M. Christie Schomaker, Lt., NOAA, and Ralph Moore Berry, 1981. NOAA Manual NOS NGS 3, 1981. National Geodetic Survey, Rockville Md.

APPENDIX A
STUDY AREAS AND BENCHMARK INFORMATION

A.1 Map of Study Area

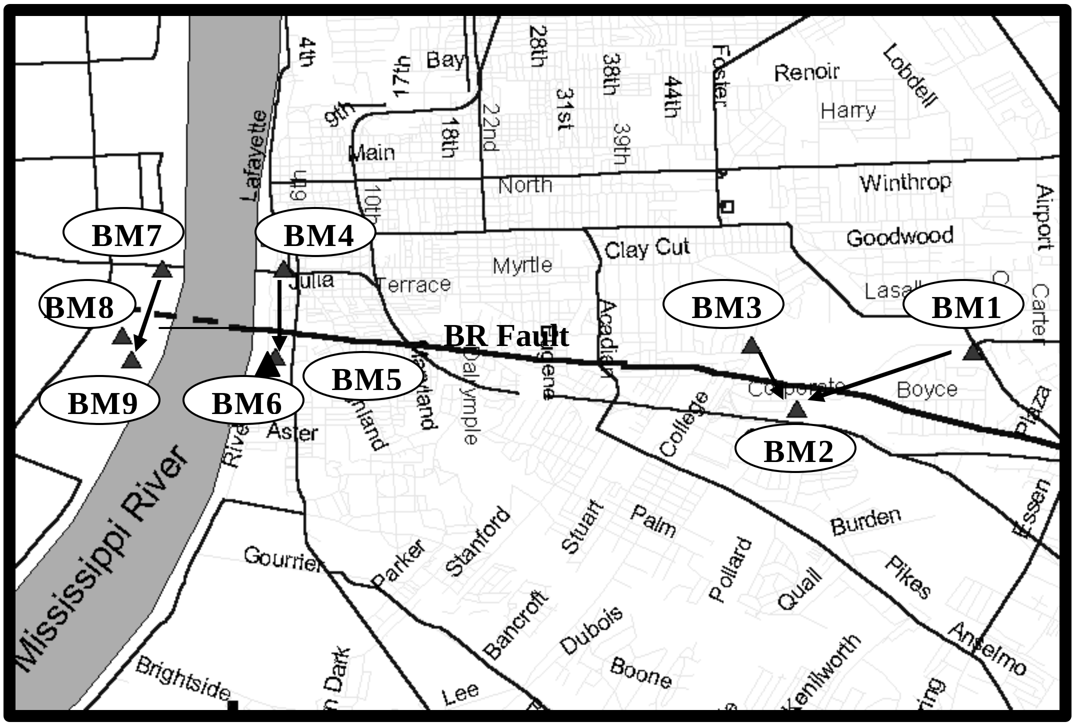


Fig A.1 Map of study area

A.2 Index of Benchmarks

Table A.1 Index of benchmarks

BM Nr.	PID	Elevation (m)	LAT (North)	LON (West)
BM1	BJ3910	13.699	30 25 50.0	091 06 25.0
BM2	BJ3911	11.661	30 25 49.0	091 07 30.0
BM3	BJ3939	12.914	30 26 04.0	091 08 06.0
BM4	BJ0988	10.721	30 26 20.0	091 11 24.0
BM5	BJ0990	9.857	30 25 56.0	091 11 25.0
BM6	BJ3919	9.216	30 25 56.0	091 11 25.0
BM7	BJ0558	9.885	30 26 22.0	091 12 08.0
BM8	BJ0559	7.758	30 25 55.0	091 12 25.0
BM9	BJ0560	15.845	30 25 48.0	091 12 22.0

A.3 Benchmark Description

The following is a description of the benchmarks used in this investigation. The description is for the most part taken from the information published by NGS [4].

- **BM1**

The benchmark is located at the intersection of Old Hammond Highway and Jefferson Highway. It is set in the northeast quadrant of the intersection near the Hibernia bank, 1.8 m northeast of the inside edge of sidewalk, and 0.91 m northwest of power pole. The mark is 0.30 m southeast from a witness post, and it is 0.31 m above highway.

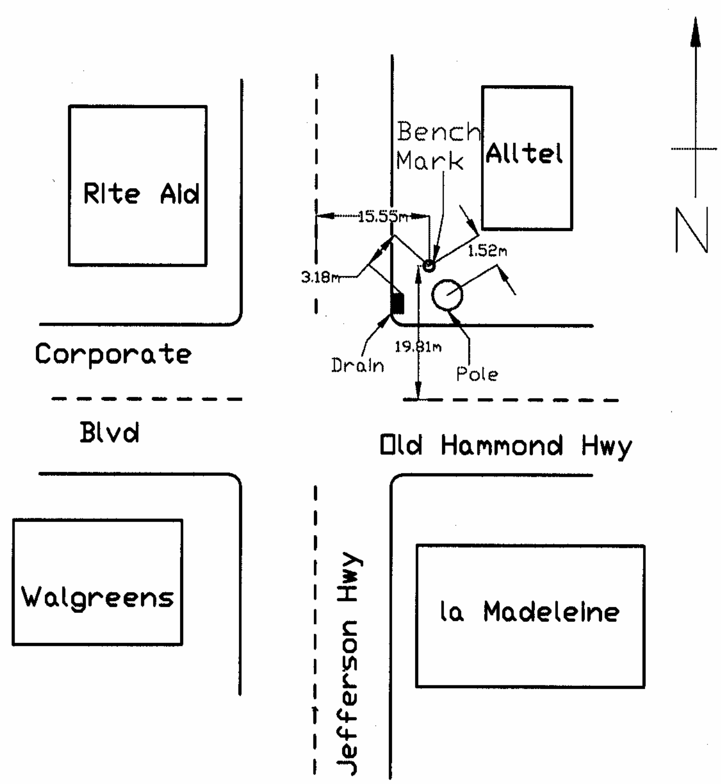


Fig A.2 BM1

- **BM2**

The mark is located about 1.5 km east on Corporate Boulevard from the intersection of Corporate Boulevard and College Drive to the mark set at the northeast corner of the approach slab on the west bound lane, about 0.61 m west of the northeast corner of bridge. The mark is 0.61 m southwest from a witness post.

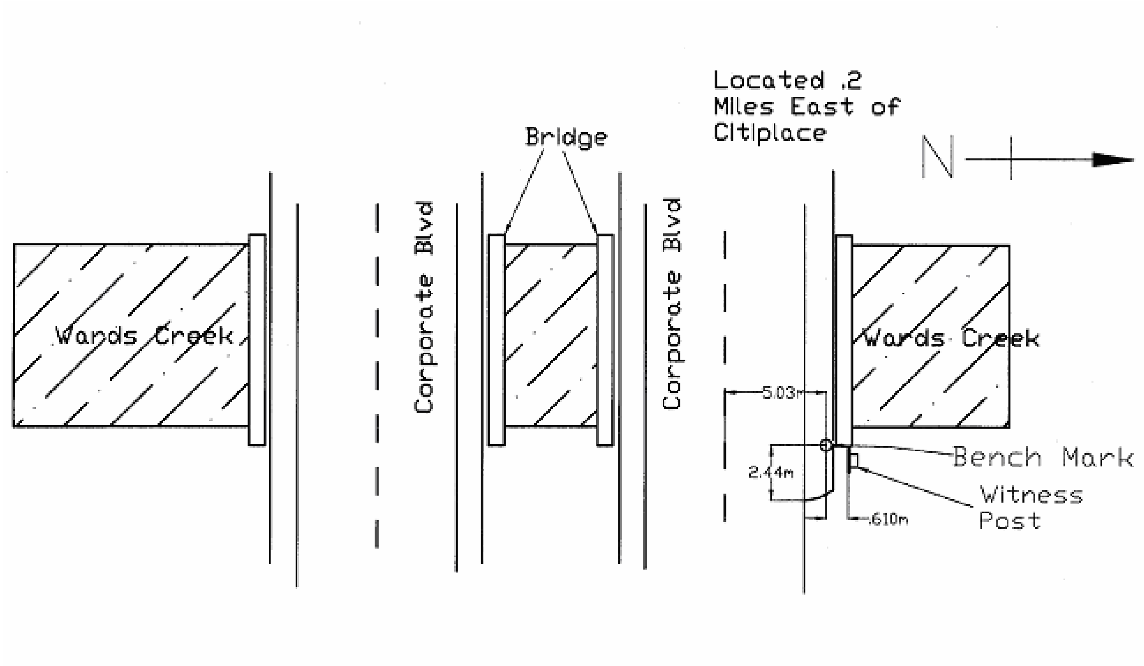


Fig A.3 BM2

- **BM3**

BM3 is found about 1.2 Km north on College Drive from the Interstate Highway 10 over College Drive to the mark set in the southeast corner of a bridge at the Webb golf course, just north of a signal light and a crosswalk going from golf course to golf course about 0.61 m north of the southeast corner of bridge set near the bridge rail. The mark is 2.03 m northeast from a witness post and 0.31 m above road.

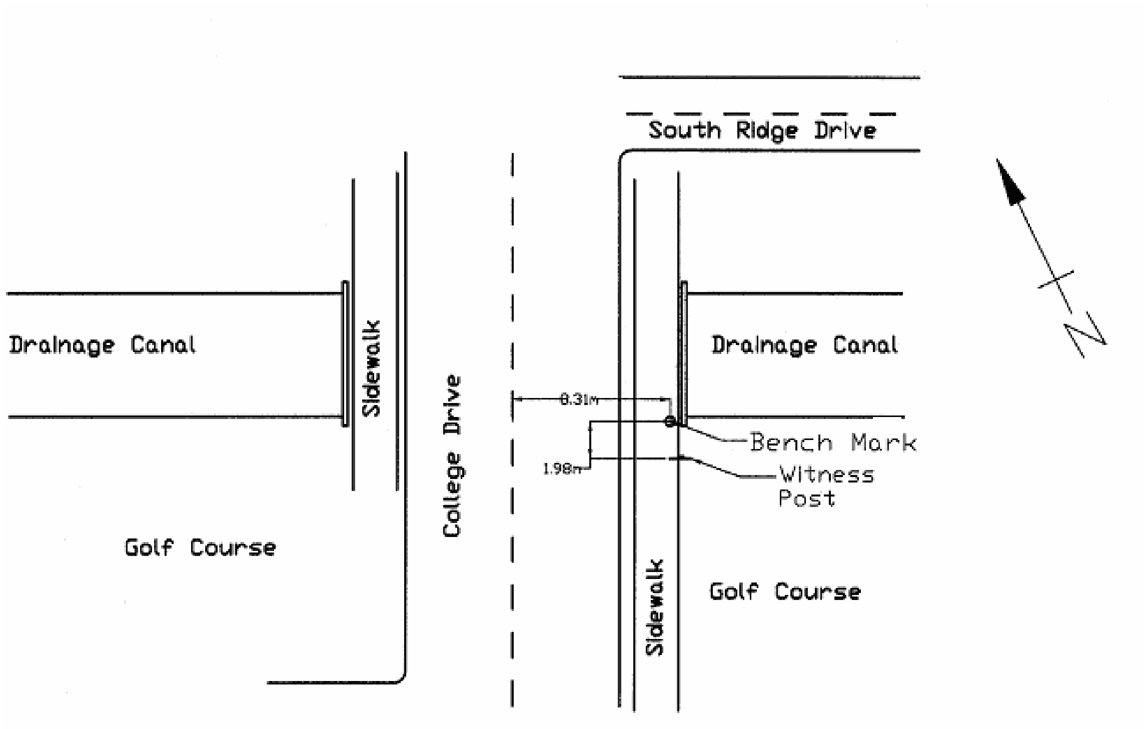


Fig A.4 BM3

- **BM4**

The benchmark is located on the east side of the Mississippi River, set vertically in the east face of the south concrete pier supporting the steel truss under the east bound lane of Interstate Highway 10 over the Mississippi River, 16.9 m east of the centerline of River Road, 44.5 m west of the west rail of the ICG railroad, set about 1.2 m above the ground and River Road. The mark is 1.2 m above River Road.

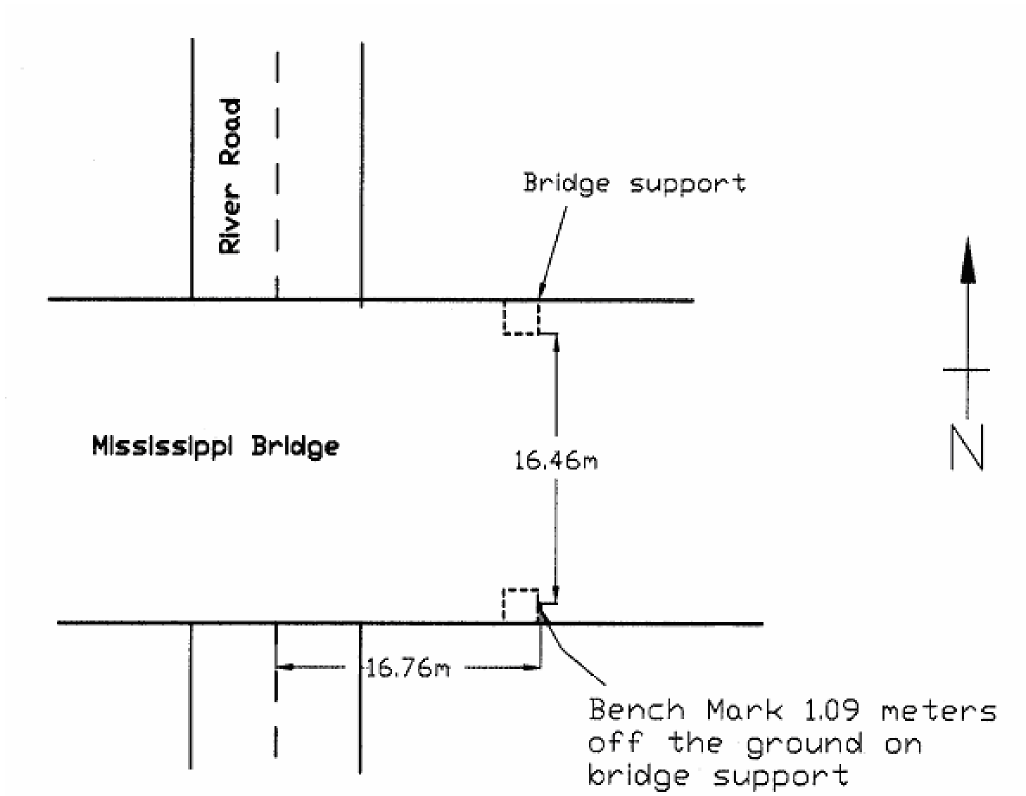


Fig A.5 BM4

- **BM5 and BM6**

The benchmarks are located 0.6 Km south along River Road from the Interstate Highway 10 bridge overpass. BM5 is set in top of the northeast end of the concrete ramp and loading platform at the north end of Garig warehouse, 0.3 m west of the west side of metal building, 12.0 m east of the center line of River Road, 9.3 m of power pole number 21 with lines running north and south and west, 3.2 m south of the south side of the white block Phillips 66 Home Oil Company Incorporated, 3 m north of the center line of the first loading door.

BM6 is set 0.3 m west of the west side of metal building, 12.0 m east of the center line of River Road, 9.3 m from power pole number 21 with lines running north and south and west, 3.2 m south of the south side of the white block Phillips 66 Home Oil Company Incorporated, 3 m north of the center line of the first loading door.

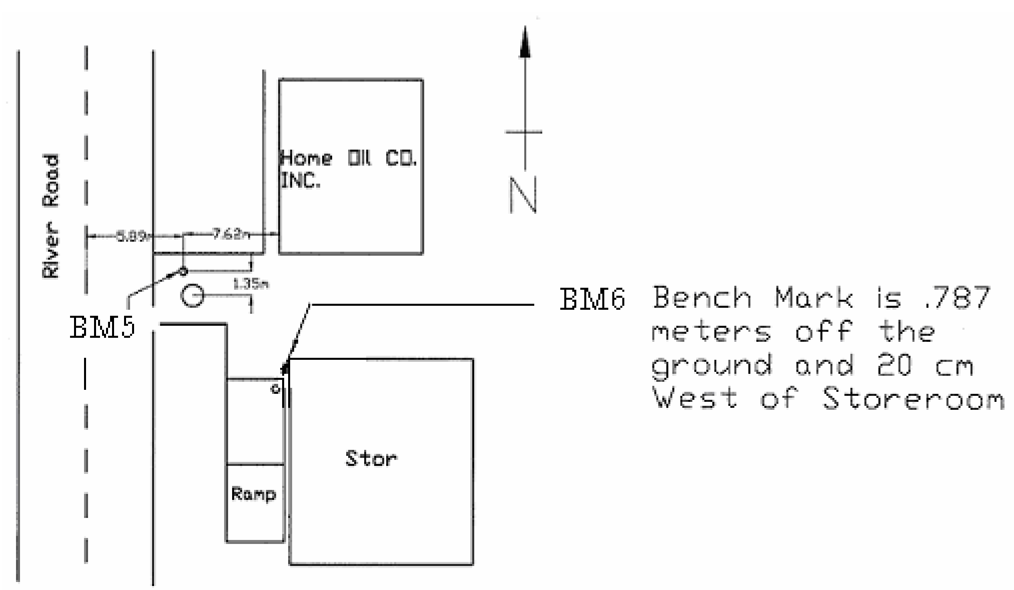


Fig A.6 BM5 and BM6

- **BM7**

The mark is located 0.6 Km south along the along Earnest Wilson Drive from the junction of Commerce and Oaks Avenues, at the Interstate Highway 10 bridge over the Mississippi River, 14 m west of the center line of the drive set vertically in west face of the north one of the first row of piers.

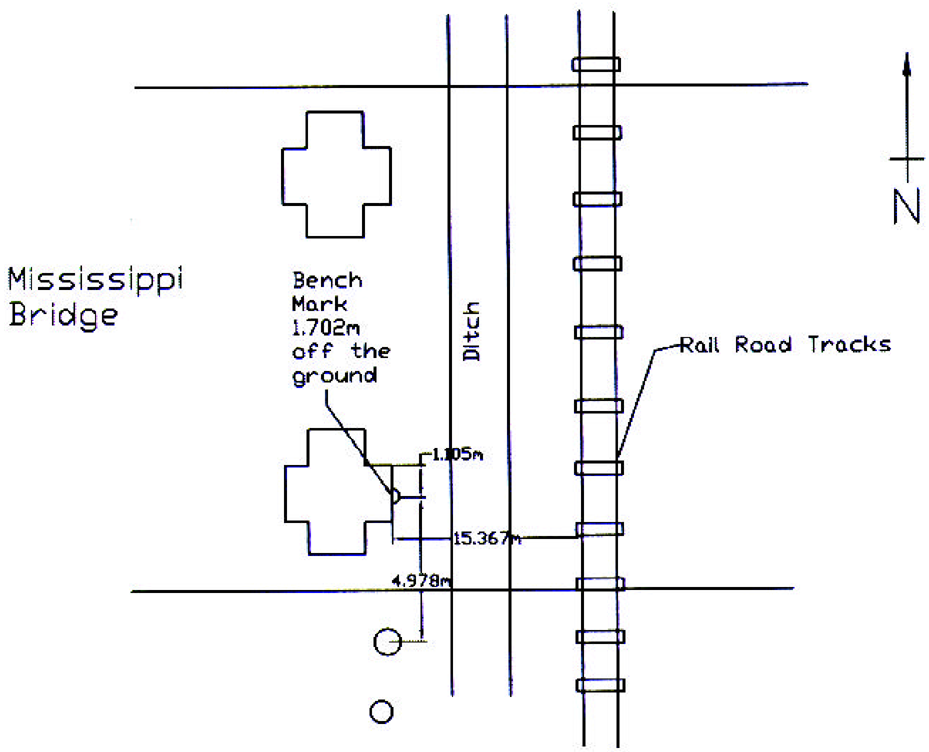


Fig A.7 BM7

- **BM8**

The mark is set 1.8 km south from Port Allen, 1.4 km south along Earnest Wilson Drive from the junction of Commerce and Oaks Avenue, thence 0.3 Km northwest along North Canal Road, 0.08 km northwest of the junction of Elevator Road, 14 m southwest of the center line of the road, 36 m northeast of the approximate center of a radio tower, 2.6 meter southwest of the northwest boundary fence of the Port Allen lock, A 5 cm iron pipe cap encased in 8 cm iron pipe, which is protected by a 4 cm plastic pipe with a removable cap for access. The 5 cm pipe is flush with the ground. The 8 cm pipe projects 8 cm. The depth of the pipe is about 0.5 m.

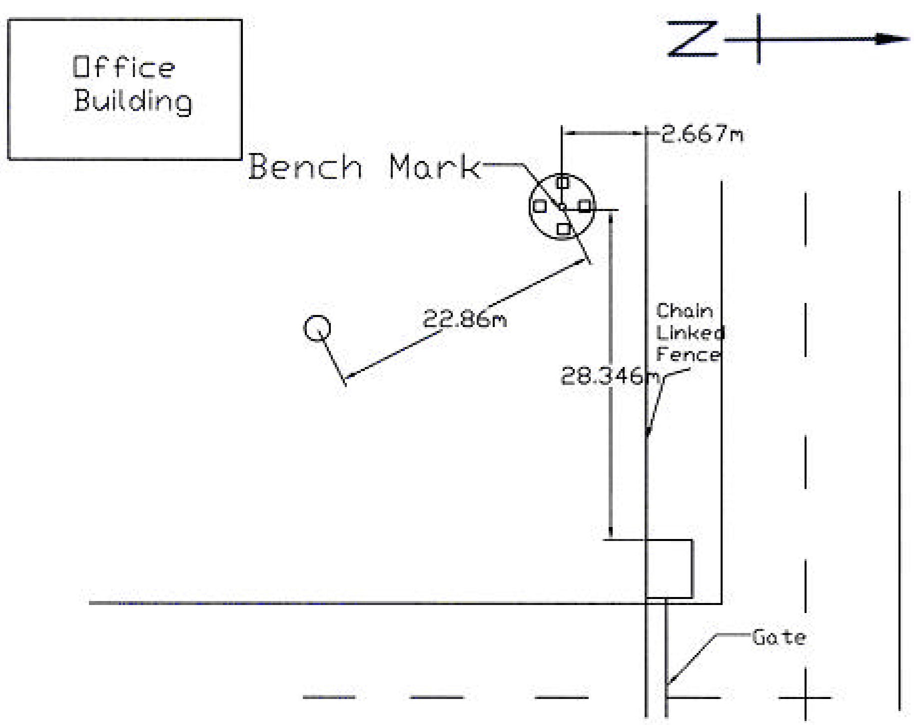


Fig A.8 BM8

- **BM9**

The benchmark is located 2 km south from Port Allen, 1.4 km south along Earnest Wilson Drive from the junction of Commerce and Oaks Avenues, thence 0.3 km northwest along North Canal Road, thence 0.3 km southeast across country, at the Port Allen Lock for the intercoastal waterway, 5.3 m east of the center of the south end of the north access concrete walkway, in the top of the northeast corner of the north lock wall, 2 m northeast of the northeast corner of a large steel winch cover, 0.4 m southwest of the northeast corner of the wall.

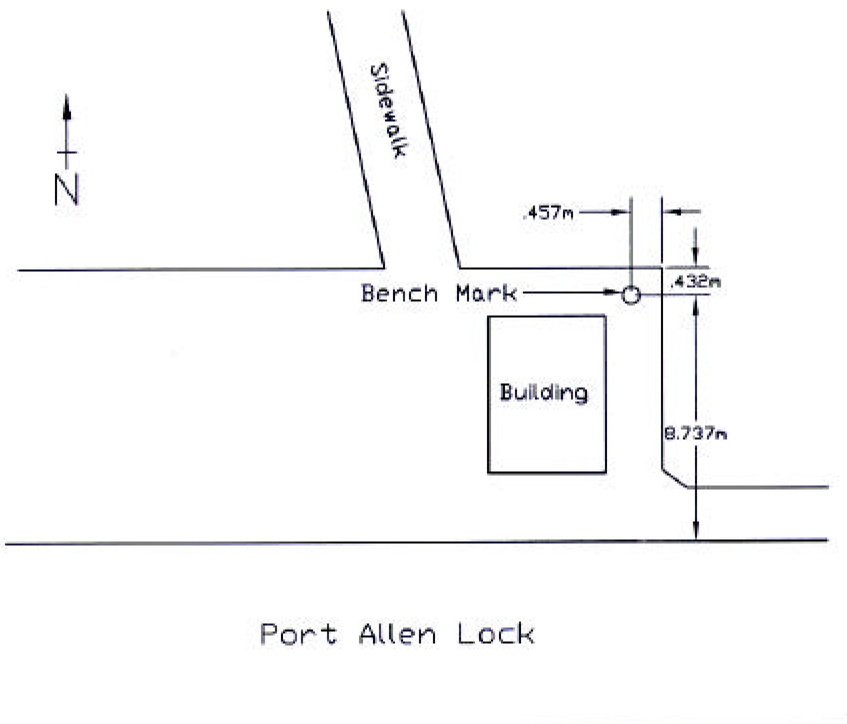


Fig A.9 BM9

APPENDIX B
LIST OF EQUIPMENT

- **Equipment**
  - 1 leveling instrument – Zeiss Ni1
  - 1 wooden tripod
  - 2 leveling rods, in wooden protective storage box
  - 2 heavyweight turning plates

Fig B.1 Field equipment

- **Computer-recording equipment and supplies**
  - Laptop computer
  - Computer bag, for storing computer and backup forms
  - Car battery, power supply for laptop
  - Dolly to carry laptop and batter
  - Power - supply cord and hookup
  - Floppy disks
  - MS Excel program to record and compute recorded surveying data on the field (Program was specifically prepared for this research)

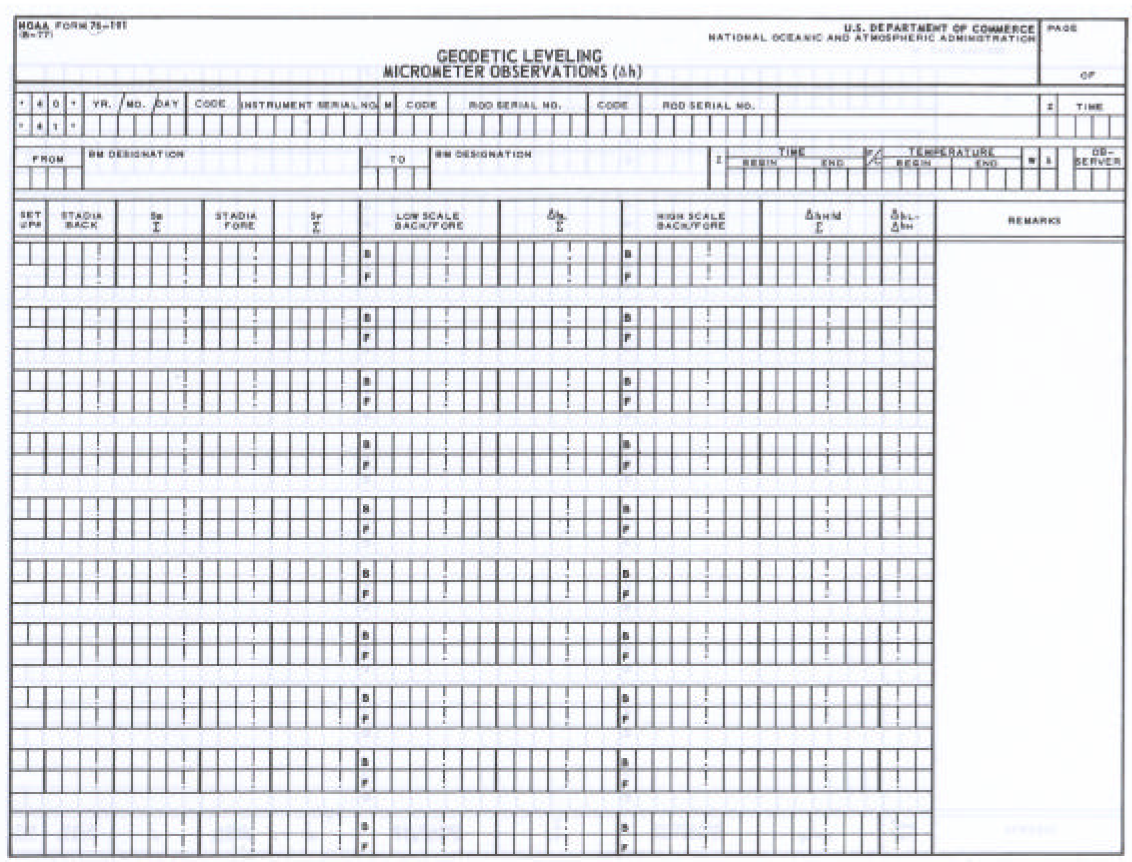
- Backup-recording forms: Geodetic Leveling Micrometer Observation --- NOAA Form 76-191 [16]

- **Other Supplies**
  - Truck to transport surveying team and equipment
  - 4 brilliant yellow safety vests (one per unit member)

APPENDIX C
EXCEL PROGRAM

C.1 NOAA Form 76-191

A laptop PC running an Excel program was utilized to record and compute measurements during the surveying and collimation check. The program was a substitute for NOAA Form 76-191, which is typically used for recording observations.



NOAA FORM 76-191

U.S. DEPARTMENT OF COMMERCE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

PAGE OF

GEODETIC LEVELING
MICROMETER OBSERVATIONS (Δh)

YR. MO. DAY | CODE | INSTRUMENT SERIAL NO. | CODE | ROD SERIAL NO. | CODE | ROD SERIAL NO. | TIME

FROM | BM DESIGNATION | TO | BM DESIGNATION | TIME BEGIN END | TEMPERATURE BEGIN END | OBSERVER

SET UPS	STADIA BACK	Sв Σ	STADIA FORE	SF Σ	LOW SCALE BACK/FORE	Δh Σ	HIGH SCALE BACK/FORE	ΔhHM Σ	ΔhL-ΔhH	REMARKS

Fig C.1 NOAA form 76-191 (Adopted form [16])

C.2 Excel Program for Surveying

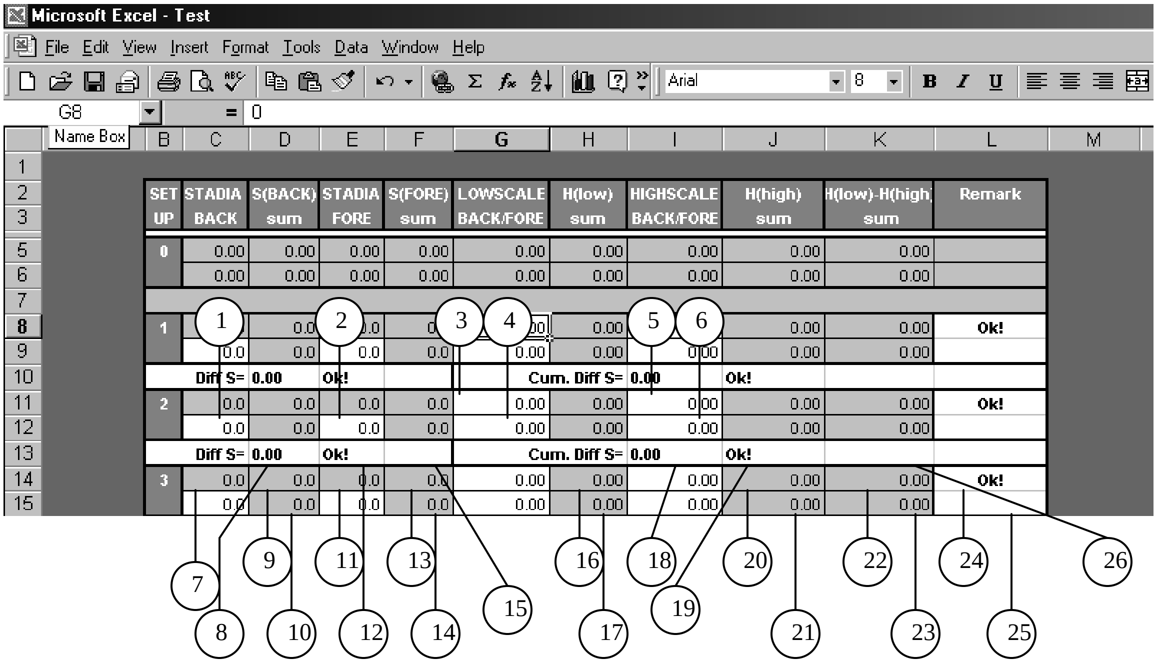


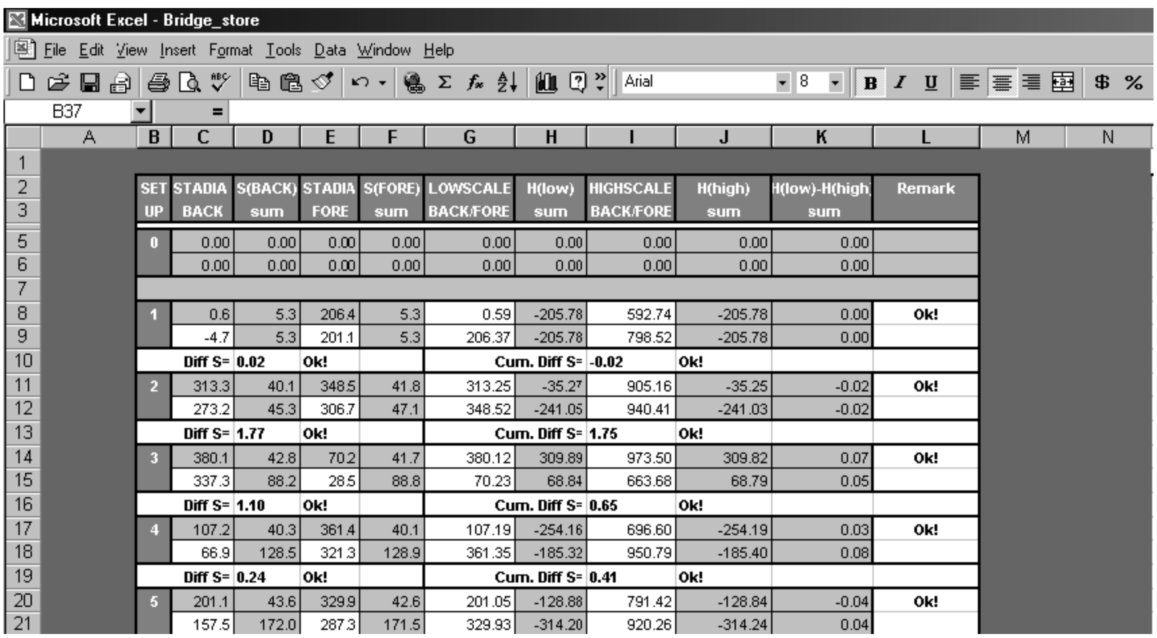
Fig C.2 Surveying Form

Table C.1 Formulas used in surveying form

Nr.	Formula/Description
1	Stadia backsight [1]
2	Stadia foresight [1]
3	Low-scale backsight [1]
4	Lo-scale foresight [1]
5	High-scale backsight [1]
6	High-scale foresight [1]
7	=G14
8	=Abs(F11-D11)
9	=C14-C15
10	=D14+D12
11	=G15
12	=IF(D13<2.5,"Ok!","")
13	=E14-E15
14	=E14+E12

[1] Observed values

Nr.	Formula/Description
15	=IF(D13>=2.5,”Not Ok!”,””)
16	=G14-G15
17	=H14+H12
18	=F12-D12
19	=IF(I13,4.5,”Ok!”,””)
20	=I14-I15
21	=J14+J12
22	=H14-J14
23	=K14+K12
24	= IF(Abs(K14)<0.085,”Ok”,””)
25	= IF(Abs(K14)>=0.085,”Not Ok”,””)
26	=IF(I13>4.5,”Not Ok”,””)



SET UP	STADIA BACK	S(BACK) sum	STADIA FORE	S(FORE) sum	LOWSCALE BACK/FORE	H(low) sum	HIGHSCALE BACK/FORE	H(high) sum	H(low)-H(high) sum	Remark
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
1	0.6	5.3	206.4	5.3	0.59	-205.78	592.74	-205.78	0.00	Ok!
	-4.7	5.3	201.1	5.3	206.37	-205.78	798.52	-205.78	0.00	
	Diff S=	0.02	Ok!			Cum. Diff S=	-0.02	Ok!		
2	313.3	40.1	348.5	41.8	313.25	-35.27	905.16	-35.25	-0.02	Ok!
	273.2	45.3	306.7	47.1	348.52	-241.05	940.41	-241.03	-0.02	
	Diff S=	1.77	Ok!			Cum. Diff S=	1.75	Ok!		
3	380.1	42.8	70.2	41.7	380.12	309.89	973.50	309.82	0.07	Ok!
	337.3	88.2	28.5	88.8	70.23	68.84	663.68	68.79	0.05	
	Diff S=	1.10	Ok!			Cum. Diff S=	0.65	Ok!		
4	107.2	40.3	361.4	40.1	107.19	-254.16	696.60	-254.19	0.03	Ok!
	66.9	128.5	321.3	128.9	361.35	-185.32	950.79	-185.40	0.08	
	Diff S=	0.24	Ok!			Cum. Diff S=	0.41	Ok!		
5	201.1	43.6	329.9	42.6	201.05	-128.88	791.42	-128.84	-0.04	Ok!
	157.5	172.0	287.3	171.5	329.93	-314.20	920.26	-314.24	0.04	

Fig C.3 Sample surveying form

C.3 Excel Program for Collimation Check

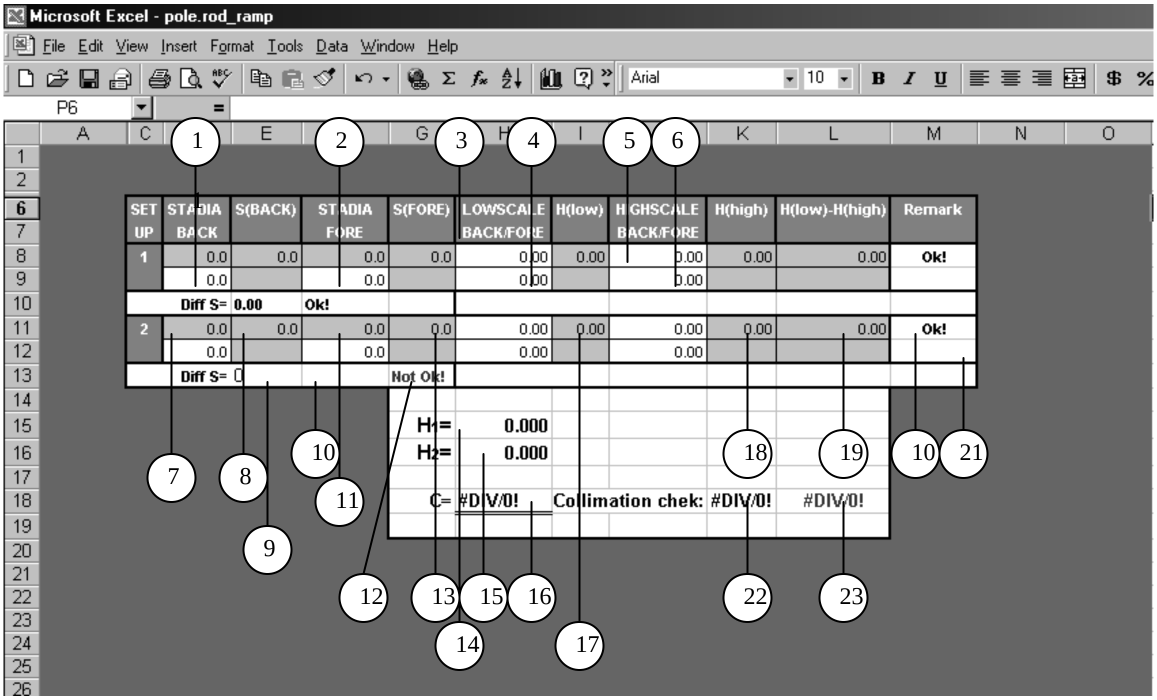


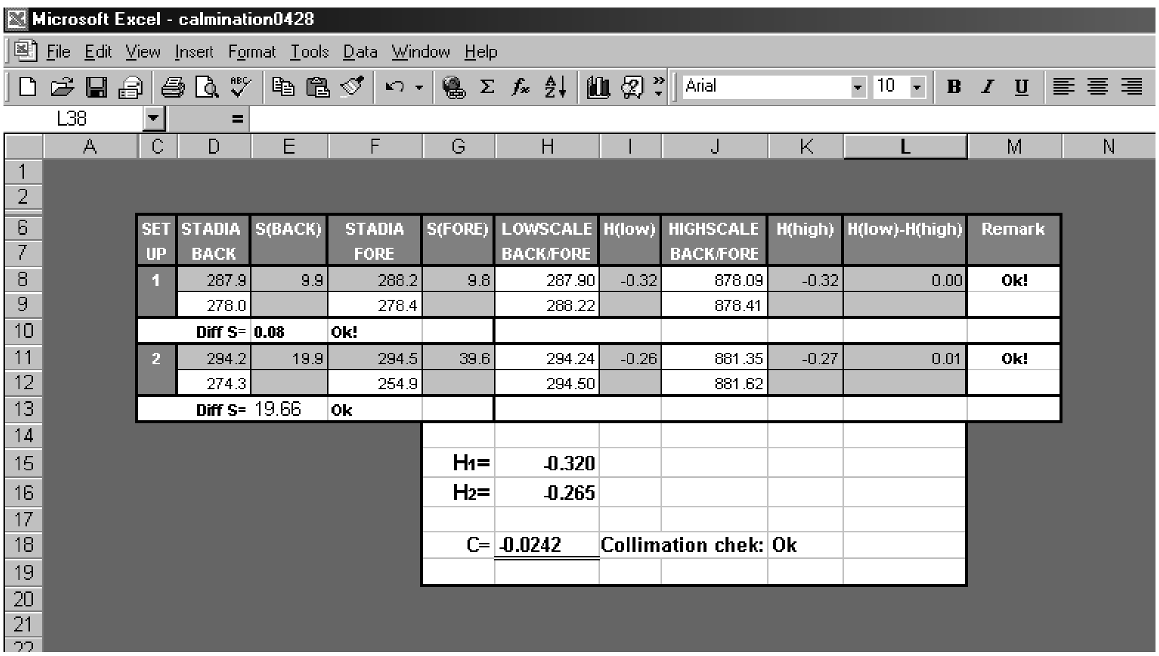
Fig C.4 Collimation check form

Table C.2 Formulas used in collimation check form

Nr.	Formula/Description
1	Stadia backsight [2]
2	Stadia foresight [2]
3	Low-scale backsight [2]
4	Lo-scale foresight [2]
5	High-scale backsight [2]
6	High-scale foresight [2]
7	=H11
8	=D11-D12
9	=Abs(G11-E11)
10	=IF(Abs(20-E13)<0.45,”Ok!”,””)
11	=H12
12	=IF(Abs(20-E13)>=0.45,”Not Ok!”,””)
13	=F11-F12
14	=(K8+I8)/2

[2] Observed values ---directly entered in the form

Nr.	Formula
15	=(K11+I11)/2
16	=(((H15-H16)*5)+(-.02))/E13
17	=H11-H12
18	=J11-J12
19	=I11-K11
20	=IF(Abs(L11)<0.055,"Ok!","")
21	=IF(Abs(L11)>=0.055,"Not Ok!","")
22	=IF(Abs(H18)<0.055,"Ok!","")
23	=IF(Abs(H18)>=0.055,"Not Ok!","")



Microsoft Excel - calmination0428

SET UP	STADIA BACK	S(BACK)	STADIA FORE	S(FORE)	LOWSCALE BACK/FORE	H(low)	HIGHSCALE BACK/FORE	H(high)	H(low)-H(high)	Remark
1	287.9	9.9	288.2	9.8	287.90	-0.32	878.09	-0.32	0.00	Ok!
	278.0		278.4		288.22		878.41			
	Diff S=	0.08	Ok!							
2	294.2	19.9	294.5	39.6	294.24	-0.26	881.35	-0.27	0.01	Ok!
	274.3		254.9		294.50		881.62			
	Diff S=	19.66	Ok							

H1= -0.320

H2= -0.265

C= -0.0242 Collimation chek: Ok

Fig C.5 Sample collimation check form

VITA

Araya Kebede was born and raised in Addis Ababa, Ethiopia. After graduating form high school in September 1989, he attended aviation maintenance training school, graduating with a diploma in aviation maintenance in January 1992. After graduation, he worked for Ethiopian Airlines until September 1995. He then went to Germany and attended Technical University of Berlin, where he graduated with a “Vor-Diplom” (B.S.) degree in "Wirtschaftsingenieurwessen" (Industrial Engineering), concentrating in Civil Engineering, in July 1999. He began his master’s program in civil engineering with specialization in geotechnical engineering at the Louisiana State University, Baton Rouge, Louisiana, in August 2000. He is also currently working on a second master’s degree in engineering science. Both degrees will be awarded at the December 2002 commencement ceremony.