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Attention: Mr. Chuck E. Rogers, P.E.

Fault Delineation Study
Widening of Bunker Hill Road
Houston, Texas

Introduction

Fugro Consultants LP is pleased to present the results of our study to delineate the Long Point Fault at the location where it crosses Bunker Hill Road. This report includes responses to comments received on a draft submitted for review.

Site Description. It is planned to rebuild and widen Bunker Hill Road, including the portion where it crosses the Long Point Fault between Westview and Cedardale. We understand the project will include replacing the existing 2-lane asphalt (ditch drainage) pavement with a new 4-lane concrete curb-and-gutter pavement and the associated buried utilities.

Purposes and Scope. The purposes of this study were to develop information and recommendations to guide design of the pavement and utilities with respect to the fault. To accomplish these purposes, we performed a detailed study of faulting, that included the following tasks.

- We reviewed geologic literature and our files pertaining to documented surface fault activity within the site vicinity.
- We visited the site to observe the fault, marked the locations of key points on the fault for recovery by the project surveyors, and developed instructions for the surveyors.
- We interpreted the results of surveys and observations of the fault.
- We developed recommendations for design of the pavement and utilities with respect to the fault.

Limitations. This report is intended to be used solely for the project described above. The scopes of the investigation, observations, analyses, interpretations, and recommendations were tailored to the needs of this project as described and are not necessarily appropriate for other uses. Any use of this report for other purposes or for other projects is misuse and shall be at the sole risk and responsibility of the user. If there are any changes to the project, we recommend that we be consulted to see if revisions or additional investigation is needed.

Literature on Surface Faulting

Our surface faulting literature review was divided into two parts: faulting in the Houston area and faulting in the vicinity of the site.

Surface Faulting in the Houston Area. In the Houston area, several hundred faults are known or suspected to be active. Over 80 percent of these faults are located within the Houston-Galveston area subsidence bowl. Evidence of modern activity of these faults includes changes in elevation of the ground surface, sharp linears on aerial photographs, offsets in pavements, and damage to buildings and other structures.

These faults are manifestations of subsurface movements which began several miles below the ground surface. They were formed by extremely slow movement of the very thick sediments under the Gulf Coastal Plain towards the Gulf of Mexico and also by the rise of very deep salt into domes at lesser depths.

Although these faults are all ancient, natural features, most of the modern fault activity is induced by man's actions. Nearly all of the faults that have moved in the past 60 to 70 years are located in areas where declines in pressures of groundwater, oil, or gas have been sufficient to cause subsidence of the ground surface. The percentage of faults now moving in subsidence areas is far greater than elsewhere in the coastal plain. Also, modern fault movements greatly exceed average rates over geologic time. In the mid 1970's various users in parts of Galveston, Chambers, Brazoria, and southeastern Harris Counties began ongoing programs to reduce groundwater pumpage. Those reductions have caused groundwater levels in affected portions of the principal aquifers to stop declining or even rebound substantially, and a number of faults in that area are known to have responded by slowing or stopping their current movements. In the northern and western parts of Harris County and in parts of adjacent counties, pumpage is continuing or increasing and the faults are continuing to move or accelerating. In addition, newly activated or previously undetected faults or fault segments are occasionally discovered, particularly in areas where pumpage is continuing or accelerating.

Movements of faults in the coastal plain tend to be small and frequent and do not cause earthquakes, because the sediments are not hard rock and are not able to store significant amounts of strain energy. There is evidence to suggest that some faults may move slightly in response to surface waves from large, distant earthquakes. In the case of the so-called Mexico

City earthquake of September 19, 1985, some faults that had not moved appreciably for several years appeared to move one-quarter inch or so in response to the earthquake[1]. Some faults that were moving might have slipped more, and other faults clearly remained stable during the event.

According to the traditional definition used in the Houston area, a fault that has broken or displaced man-made structures or has a clear, well-defined scarp is considered to be active. The vertical movement of typical active faults averaged over a number of years ranges from less than 0.1 inch to slightly more than 1.0 inches per year. Horizontal movements are extensional and are thought to depend upon the dip of the fault. The most common dips should produce horizontal movements in the range of about one-sixth to one-third the vertical movement. The surface movements generally occur in a band of significant width, which is likely to be different for each fault and to vary along the length of a particular fault. Bandwidths of 30 to 50 feet are common, but wider or narrower bands are also found.

Surface Faulting near the Site. Our review of the literature on surface faulting and unpublished information from our files reveals that the Long Point Fault crosses Bunker Hill a short distance north of Cedardale. The Long Point Fault is one of the largest and best known faults in Houston. It extends mostly in a northeast to east-northeast direction from a point within or near the Forest Park Cemetery about 6 miles southwest of the site, to a point east of Afton Street between Long Point Drive and Hempstead Highway. The fault is downthrown to the southeast. At the site, the fault is shown[2] to trend basically east-west, but the fault makes a 20-deg northeasterly turn immediately east of the site.

Observations

I conducted a site reconnaissance on 13 October 2006 to observe the fault at the crossing and to look for evidence of fault activity at other locations. During that visit, I made general observations of the fault, took notes, set four marks on the fault for later recovery by the project surveyors, and developed recommendations for data to be gathered by the surveyors. My observations are discussed below.

In this area, Bunker Hill runs nearly due north. It is an old 2-lane asphalt street with ditch drainage. According to TCB, the latest overlay was completed in March 2001, making it about 5.6 years old at the time of my visit.

The location of the fault can be seen by a variety of indicators that include the following.

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[1] Mastroiani, J. J. (1991), "A Study of Active Fault Movement, Houston, Texas and Vicinity," unpublished Master of Science Thesis, University of Houston, pp. 53 – 55.

[2] Verbeek, E. R., Ratzlaff, K. W., and Clanton, U. S. (1979), " Faults in Parts of North Central and Western Houston Metropolitan Area, Texas", *Map MF-1136*, U S Geological Survey, Denver.

1 There is a sharp, highly visible fault scarp in the concrete sidewalk on the west side of Bunker Hill. Although some parts of the sidewalk at the fault have been replaced, the sidewalk on each side of the fault is obviously much older, and it appears that the sidewalk comes very close to a true representation of the shape and width of the deformations caused by the fault. I set Point A on the largest crack in the sidewalk, which I interpreted at the time to be the principal crest crack caused by the fault (See Plate 1). Point A is the beginning (zero) point on an elevation section that runs across the fault, along the center of the sidewalk.

2 There is also a highly visible fault scarp in Bunker Hill Road, but it is much wider than the scarp in the sidewalk, because it has been "feathered" over a substantial distance, perhaps 20 ft to the north and 100 ft to the south of the fault, by previous work on the street. From Point A, the crest of the fault passes eastward across the pavement of Bunker Hill, where the pavement shows some minor cracking from either movement of the fault or from reflection of fault-induced cracks in the underlying older pavement. The surface cracks extend across perhaps half of the width of the pavement, are open less than about 1/16 in., and show little vertical offset at or within 6 in. of the crack. Despite the subtle nature of the cracks, we consider it highly likely that they represent the crestal cracks of the fault, so I marked them at the edges of the pavement as Points B and C for recovery by the surveyor. The locations of both are shown in the plan on Plate 1.

3 On the east side of the street, utility work has removed the old sidewalk and obliterated the location of the fault within the right of way, except for the far eastern edge. There, where a fence formerly stood along the property line, the fault scarp has been largely (but definitely not fully) preserved. I placed Point D at a location that appeared to correlate with the other three points (very near the high side of the fault scarp) within a tolerance of about 5 ft or less.

4 Further to the east, the fault scarp can be seen extending across the first two lots on the north side of Cedardale, where both residences have been razed because of severe damage caused by the fault.

5 None of the other locations I visited both to the east and west of Bunker Hill showed evidence that could be readily used to provide more insights on recent activity of the fault.

Surveys

Surveying services in support of this assignment were provided by the project surveyors, under a separate contract to TCB. They surveyed the locations of the four marked points and elevations along the section line and drew a fault baseline defined by Points A and D. TCB provided a drawing (Plate 1 was developed from that drawing) and data to us based on those surveys. The location of the fault baseline was tied to the project stationing; we extracted the angle between the project baseline and the fault baseline from the drawing file. The locations of the points were referenced to the baseline stationing using conventional right-angle stationing and offset; for the special needs of this assignment, we changed the references to station and offset parallel to the project baseline, as shown on Plate 1.

Interpretation of Fault Location and Offset

We have drawn a bold line on Plate 1 as our interpretation of the approximate location of the principal shear of the fault, as defined by Points A through D. The filled triangles on the line point to the downthrown side of the fault.

We interpreted the fault scarp from the elevation section on Plate 2. At that location, the interpreted fault scarp is about 1.9 ft high and 24 ft wide along the line of section and about 18 ft wide perpendicular to the fault trace. We extrapolated the interpreted scarp to the other three points where the fault was located. To further account for questions about possible differences in the width of the fault scarp in the curve, we added 4 ft of uncertainty on the north side at the two middle points. We also included the estimated 5-ft uncertainties in locating the fault at the point on the east right of way line. Coordinates of the scarp (with uncertainties), the recommended fault hazard band, and the approximate location of the principal shear are listed in the table below.

Fault Baseline Station	Distance* (Ft) North of Fault Baseline to				
	South Side of Hazard Band	South Side of Scarp	Principal Shear	North Side of Scarp	North Side of Hazard Band
1+00	-46	-19	0	5	18
1+19.53	-50	-26	-7	2	14
1+43.08	-48	-26	-7	2	13
1+85	-45	-24	0+/-5	10	21

***All distances are measured parallel to the project baseline.**

TABLE OF POINTS ON THE FAULT

Fault Mitigation Measures

Fault Deformation Zone. To assist in design of the pavement and utilities with respect to the fault, we interpreted a fault deformation zone that spans the area where we believe the vertical fault movements are concentrated, including our estimates of the uncertainties in the location of the fault and the width of the zone. This zone does not include any clearances to provide a margin of safety, so it is not a recommended fault hazard band. We also calculated a recommended fault hazard band that includes standard clearances of 10 ft to the north side and 20 ft to the south side, measured perpendicular to the fault trend.

The locations of the fault, its deformation zone, and a recommended fault hazard band are shown in the plan on Plate 1. The coordinates of the points that define the scarp and a recommended fault hazard band are listed in the table on Page 5 with respect to the fault baseline shown on Plate 1.

Siting and Design Considerations. We consider it likely that virtually all of the deformations caused by the fault will take place within the interpreted deformation zone. We recommend that the fault deformation zone be treated as an area where there is a risk of concentrated surface deformations caused by the fault. We recommend that the utilities be designed considering the possible movements of the fault, both horizontal and vertical, as described below in the section on "Fault Activity".

We recommend that the design of the drainage for the new pavement consider the possibility of vertical movements of the fault described below and their impact on the slope of flow lines. In some areas, we have seen evidence that the ground surface on the downthrown (south) side of the fault scarp rotates downward toward the fault, a deformation pattern called "sag". The elevation section shows no suggestion of such deformation, so we recommend no consideration of sag at this location. We see no reason that the fault should govern the placement of drop inlets, except that they should not be placed within the interpreted fault deformation zone.

All underground pipes should be designed to survive the potential fault movements, based on the assumption that they will occur within the fault scarp. However, pipe that does not have slip joints near the scarp to accommodate the horizontal extension will stretch for some distance either side of the fault scarp, depending on the strength and modulus of the pipe and the shear strength of the bond between the pipe and backfill. We recommend that taps, ells, and tees be placed outside that distance.

For new sewer pipes, we suggest that you consider placing manholes on each side of the fault scarp and that the pipe between the manholes be designed to slip in the manhole to accommodate the horizontal movement. The pipe should also be strong enough to resist the horizontal and vertical loads from the movements. For the existing box storm sewer, we suggest inspecting it and responding to the results of the inspection based on the recommended activity rates.

Considering the expected low movement rates of the fault and the design life of the pavement, we suggest that you consider the possibility that the fault will not move enough to warrant significant extra expense to defend against fault-related damage. We suggest you consider the relative life-of-pavement costs of a standard design that will be repaired as necessary (such as slab jacking or an overlay to smooth out the fault-induced "bump" in the pavement) against some built-in defensive measure, such as an asphalt panel in the movement zone.

Fault Activity. There is little numerical information on the current activity of this fault. However, it seems obvious from observations for this assignment (as mentioned above) and from other jobs in the area that the fault has been moving slowly for at least the past 5 years and perhaps for 15 years or more, compared to its much faster prior movements. Based on those observations, we would be surprised if the movement rate over the past several years exceeded an average of about 0.1 to 0.2 in. per year.

There is no numerical method for predicting movement rates of faults. We can only make educated guesses (i.e. speculate), largely by extrapolating such historical data as may be available from the fault in question and from others in the area. In the past it was common to simply extrapolate the historical movement rate of the fault. We believe that near-stable or rising water levels in the principal aquifers are not conducive to future movement rates anywhere near as large as those that the Long Point Fault experienced during the 1960s and 1970s. Because of the extensive conversions to surface water, principally in the ship channel industrial area and much of the City of Houston, groundwater levels in much of the western Houston area have stopped declining or have rebounded, and the faults in those areas appear to have reduced their movement rates. We expect this trend to continue.

We speculate that future vertical movements of the fault will be less than 0.1 to 0.2 in. per year when averaged over a period of 50 years or more. We recommend that design of the street and utilities consider an assumed vertical movement rate of 0.2 in. per year for the life of the project. This recommendation may be exceeded if the Harris-Galveston Coastal Subsidence District ceases or reduces its regulation of groundwater withdrawals within the District. On the other hand, it might be conservative if the current regulation continues.

We have no direct information on the horizontal component of the fault movement, because we do not know the dip of the fault here. We recommend that you assume a horizontal extension component of as much as one-third the vertical movement, which approaches the high side of the normal range of movements we have seen. We also recommend that you assume that the horizontal extension will be perpendicular to the trace of the fault, which will impose movements in all three dimensions on the street and buried utilities.

Highlights

The highlights of this study are listed below.

(1) The Long Point Fault, which extends generally in an east-northeast direction at the site, is downthrown to the south and crosses Bunker Hill a short distance north of Cedardale.

(2) We located the fault at four points by means of observations of the fault-induced distress in the street and the sidewalk on the west side, and a fault scarp in the ground surface at the east right of way line.

(3) In the sidewalk, we found the fault has a vertical offset of about 1.9 ft, and that occurred within a band about 24 ft wide, measured parallel to the street (Plate 1). Modifications to the pavement to feather the fault scarp have obscured any evidence of its width in the street.

(4) We used the information from this study to develop an interpreted fault deformation zone, where special design should be considered for the street and utilities.

(5) We recommend that you assume the fault will experience vertical movements of as much as about 0.2 in. per year averaged over the life of the street and utilities, and horizontal movements perpendicular to the trace of the fault of as much as one-third of the vertical movement.

The text of this report includes other information and discussions that are important to the understanding of this assignment.

* * *

The following illustrations are attached and complete this report.

	Plate
Site Plan and Fault Hazard Band	1
Elevation Section along Sidewalk	2

Closing

We appreciate the opportunity to be of service to LAN and TCB on this project. Please call when we may be of further assistance.

Sincerely,

FUGRO CONSULTANTS, INC.

Bill R. Elsbury, P.E.
Senior Geotechnical Consultant

12 Jun 07

Copies Submitted:

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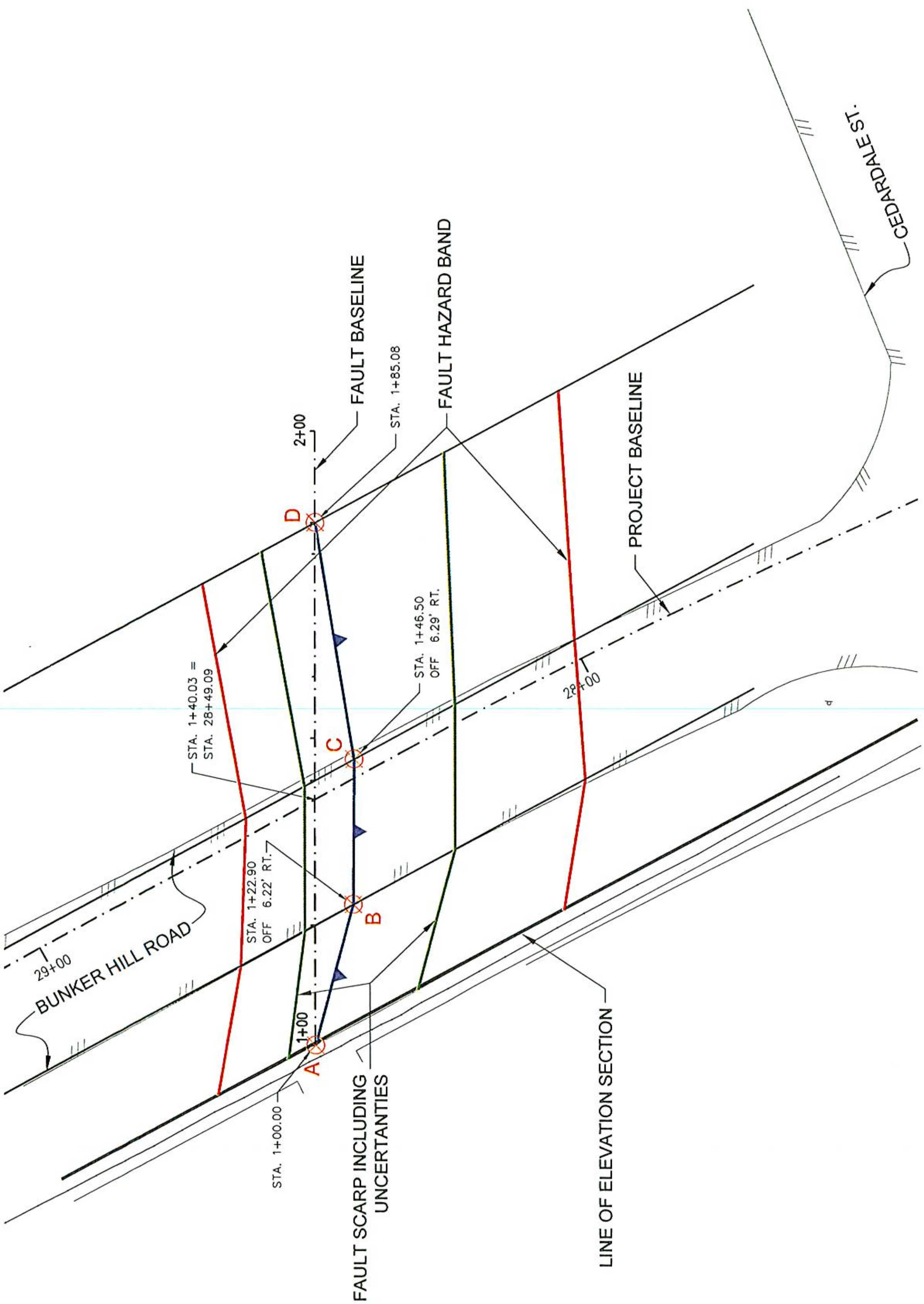
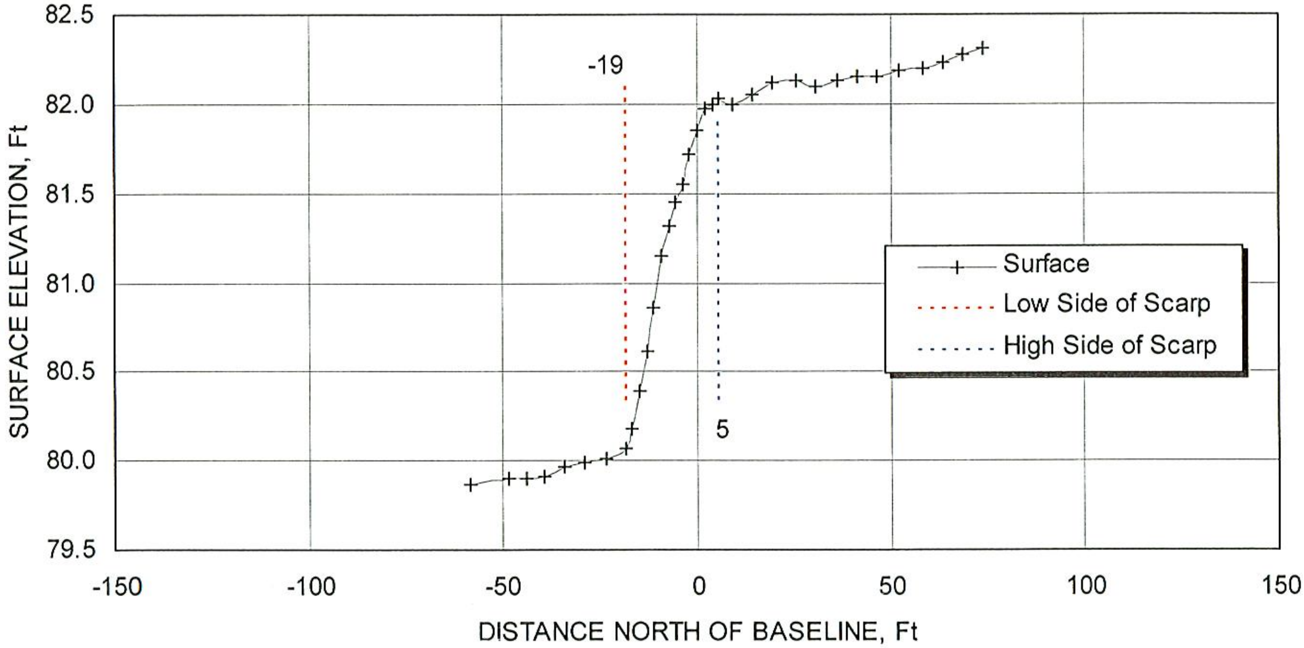
TCB, Attn: Ms Janette Sweeney (1)



FAULT LOCATION PLAN
LONG POINT FAULT AT BUNKER HILL ROAD
LOCKWOOD, ANDREWS & NEWNAM, INC.
HOUSTON, TEXAS

0 25 50 FEET



ELEVATION SECTION ALONG SIDEWALK