SEISMIC REFLECTION IMAGING IN URBAN SETTINGS

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ABSTRACT

Multi-stacked (MSF) seismic reflection data can be used in an urban environment for imaging the subsurface, since MSF data are not plagued by noise from an active city. The MSF method consists of a source and receiver, akin to a spot or jump correlation survey common in the 1930's. Walk-away tests document that ground roll is eliminated from the near-source receiver. Two MSF seismic reflection profiles from 2 active urban sites in the southwestern portion of the USA show excellent resolution.

INTRODUCTION

A major concern with the collection of seismic data within a city is the cultural noise associated with the urban environment. The noise issue is compounded with the deployment of an array of cables that can be destroyed by careless drivers.

Back in the 1920s and 1930s, seismic records were collected with the shot and receiver at the same location. This form of data collection is called "spot" or "jump" correlation data. Back then, a series of "spot correlation" records were collected at the center and at each corner of a section and manually compared. This comparison would then determine where in the section additional data was needed. Now, through digital data collection methods, multiple records can be collected at the same source and receiver location, summed (similar to trace gathers), and processed as a multi-fold seismic line thus improving resolution and reducing noise.

The collection of multi-stacked data can be completed in the urban environment since the source and the receiver are within 1 meter of each other. Initially, surface waves were a concern; however, "walk-away" surveys show that surface waves impact the reflection data from between 2 and 3 meters from the source (Figure 1).

METHODS

Data Collection

The MSF technique involves collecting elastic reflection data near the source and stacking numerous events to create a single record. Locations for all seismic records were acquired and logged in the field with a Trimble ProXRS DGPS unit. Recording station occurs every 10 meters along the transect.

Data were acquired using one active channel of a Seistronix seismograph and a Mark Products geophone (Mark 40A). Data were recorded at a 1/4-millisecond (ms) sample interval and a record length of 500 ms. Data acquisition utilized a proprietary method of seismic reflection surveying that employs near vertical ray paths rather than multiple source and receiver stations that have common depth points (CDP). The CDP method sums a collection of recorded traces from common source-receiver offsets to increase the signal to noise level while the MSF method sums a number of vertically acquired traces at a single station to increase the signal to noise ratio.

The system operates by using propane-and-air combustion as a seismic energy source (Figure 1). A small propane bottle is connected to the source; propane gas is injected and exploded in a combustion chamber attached to a shock tube. The expanding gas forms a pressure ridge inside the shock tube that strikes the ground forming an elastic shock wave. A geophone, placed 0.3 meters away from the base of the seismic source, records the returning reflected elastic energy.

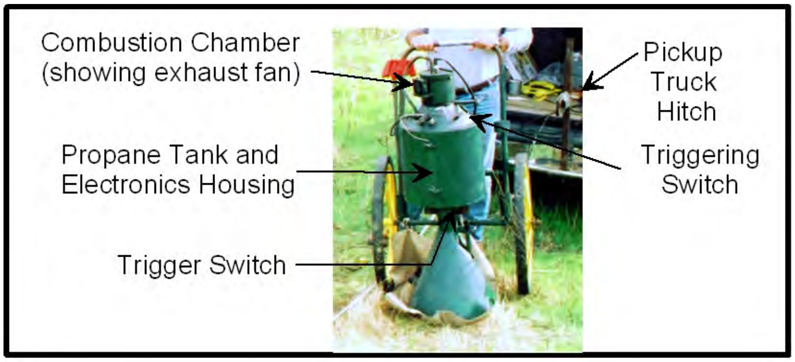

Figure 1: Seismic gun in preparation for a shoot, showing compactness and portability. The triggering switch initiates the filling of the combustion chamber with propane gas and subsequent firing of the gun through an automobile spark plug. The trigger switch adjacent to the vertical sonic or exhaust tube starts data collection. Exhaust fan purges the exhaust gases from the combustion chamber in preparation for the next event.

Six seismically-induced events were collected for each recording location or station. The entire time of collection at each station is approximately 1 minute, including the time to collect digital global position system locational data. These events were edited and then summed together to increase the signal to noise ratio. This method assumes that all the reflective energy arrives at the same time and thus will be additive, while noise is random and will not be additive.

The records were collected at a 10-meter station interval. Individual seismic reflection "picks" of events were made at the first reflection (real event) beneath the source signature.

Velocity data were acquired from commercially-available vertical seismic profiles from oil-and-gas wells near Austin, Texas. The velocity for the Austin Chalk ranged from 2,300 m/sec to 4,600 m/sec.

Depth was calculated from the following formula:

$$V = \frac{2d_1}{t}$$

Where, velocity (***V***) is a function of the depth ($\boldsymbol{d_1}$) the 2-way time (***t***) to the event of interest. Velocity of the Austin Chalk is estimated at 2,300 m/sec ($\pm$ 30 m/sec).

Processing

The seismic data processing was completed on a microcomputer using WinSeis; a set of commercial data processing algorithms (Kansas Geological Survey, 2000). The initial data processing flow was similar to that used to process seismic data in oil and gas exploration with the exception of the algorithms necessary to provide time-variant filtering, migration, and spectral whitening. The processing sequence is:

- Set field geometry, remove dc bias;
- Automatic Gain Control;
- Butterworth filter 24/65 18db roll off
- Trim statics;
- Pre-stack fk migration (removes noise);
- Trace sum;
- Common Mid Point;
- Post-stack fk migration;
- Spatial noise filter;
- Amplitude equalization;
- Spectral whiting; and,
- Automatic Gain Control.

The MSF method of seismic survey uses the positive aspects of both the common mid-point seismic reflection technique and the optimum offset method of seismic data acquisition. If there is no separation between the source and receiver, then groundroll and the air wave will pass over the receiving geophone before the arrival of significant data; however, from a practical point, some separation is necessary because of potential saturation of the geophone. Another benefit of the close source-geophone separation is that the phase and group velocities of the ground roll do not dominate strong reflective arrivals if the receiving geophone is close to the source (Figure 2). Also, the velocity of the airwave is such that its effect has passed before usable data are acquired. The ground roll reverberation (continued bouncing of a mass) is suppressed by the physical constraints of the source being an elastic (deformable) wave. Thus this method is similar to that used in the optimum offset method.

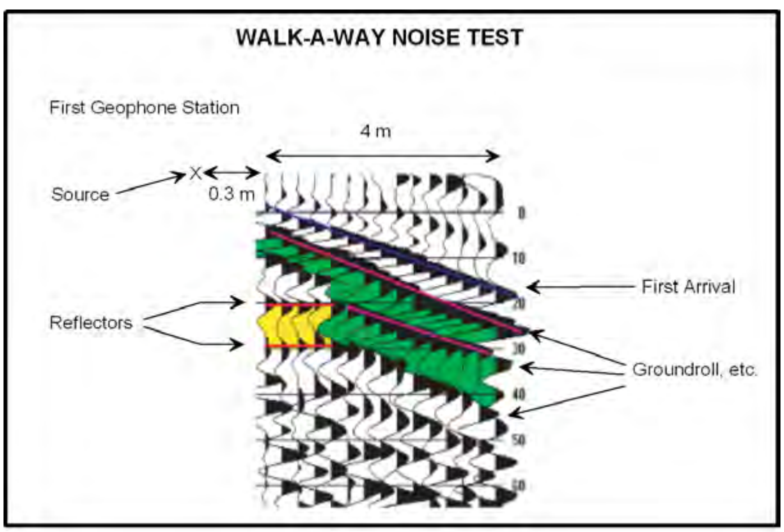

Figure 2: Walk-away test for MSF system where the phase and group velocities are in-phase approximately 1.2 meters from the source. The geophone-source separation must be less than 1.2 meters to assure that the event observed at 20 ms is a reflector and not ground-roll or other type of wave form.

Contrary to the optimum offset technique, a walk-a-way noise test is conducted not to determine the optimum window, but rather to ascertain that reflective energy is in fact being recorded as opposed to the source signature or ground roll (EPA, 2000).

Quality Assurance and Quality Control

The quality of shallow seismic data acquisition is assured through a walk-away noise test (Figure 2). The walk-away noise test provides assurance that data acquired are a reflection and not another source of wave energy. This test is conducted by providing a stationary source and by moving a geophone (receiver) at 0.3-meter increments away from the source to a distance of 4 meters. Ground-roll (the direct surface wave between the source and receiver), moving at a constant velocity, will appear sloped while a real reflector typically appears coherent and flat. Interpretation of the walkaway noise test indicates that a 0.3-meter geophone offset from the seismic source will allow identification of a reflector that is deeper than 10 ms.

Project Scope

The project consists of collecting seismic data in Downtown Austin, Texas to determine the locations of faults prior to installation of a proposed 1,600-meter storm water sewer line (Figure 3). The proposed storm water sewer line will ameliorate storm water drainage from the Waterloo Park area of downtown Austin, Texas. The proposed tunnel will discharge storm water to Town Lake to the west.

The purpose of the seismic data collection was to determine the locations of subsurface faults, not follow the alignment. Consequently and due to difficulties with collecting seismic data along the alignment, which is partially located beneath Waller Creek, seismic data were collected along Red River and several other roads in downtown Austin, Texas.

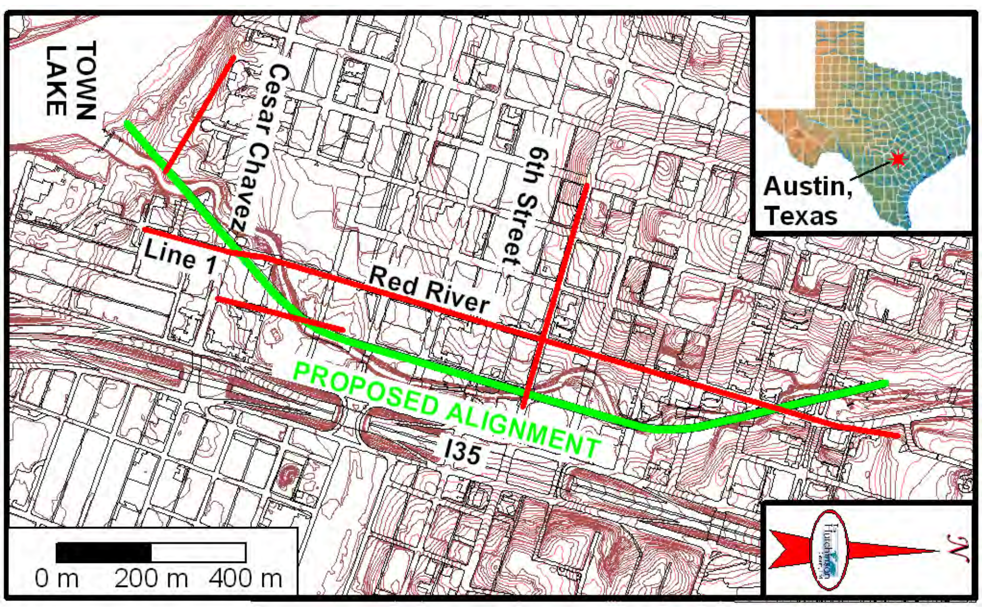

Figure 3: Base map of downtown Austin, Texas showing the alignment (green), seismic profiles (red; Line 1 is Figure 4), and several roads (Red River, Cesar Chavez, I35 and 6th Street).

GEOLOGY

Up to 10 meters of fluvial or Quaternary-aged sediments unconformably overlie Cretaceous-aged sediments of the Austin Chalk (approximately 30 meters thick), Eagle Ford Shale (11 meters thick), Buda Formation (15 meters thick), Del Rio (15 meters thick), Georgetown, and Edwards Formation. Borings in the area document that Austin Chalk resides beneath a veneer of up to 10 meters of Quaternary-aged sediments.

Post-depositional faulting created a series of normal faults as part of the Mount Bonnell Fault System of the Balcones Fault Zone (Figure 4). These Miocene-aged faults show dip-slip displacement of up to 165 meters, but less than 10 meters in the project area, and are now quiescent. The Austin Area Plate VII Geologic Map shows 2 faults, covered by Quaternary alluvium, crossing the area of interest (Garner and Young, 1976). The seismic program was designed to image these faults and determine if other faults are present.

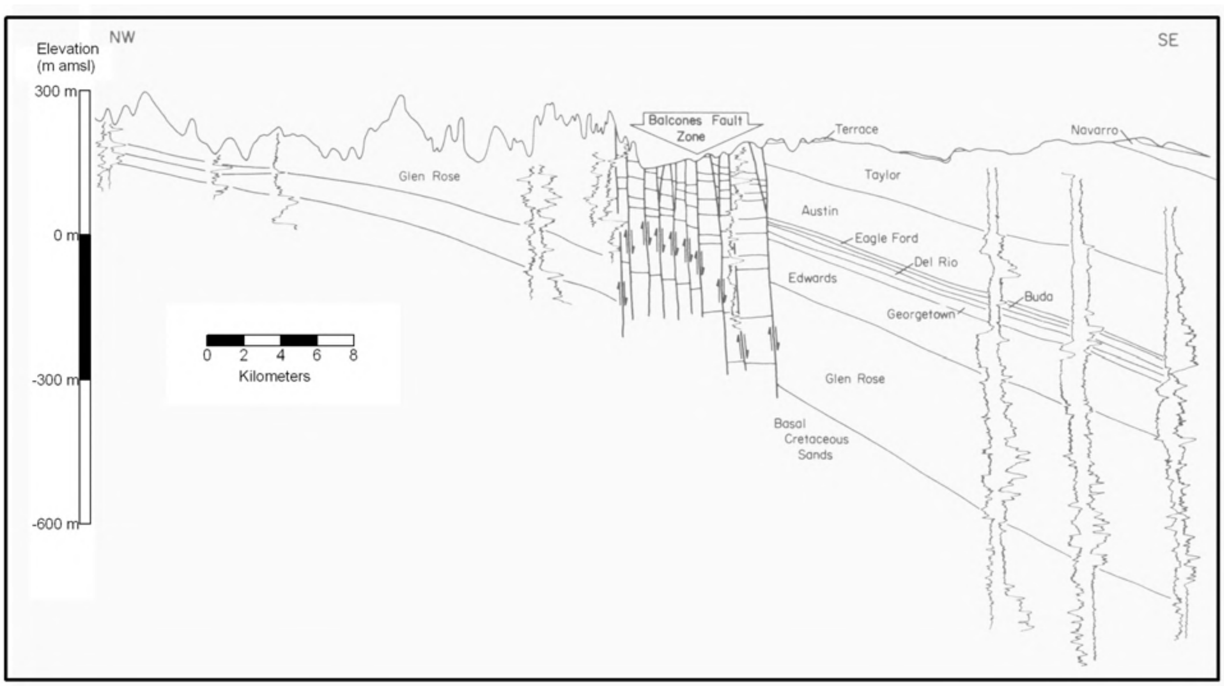

Figure 4: Northwest-southeast structural profile across Austin Texas (from Garner and Young, 1976).

The stratigraphy in the alignment area consists of unconsolidated Quaternary alluvial deposits on bedrock composed in descending order of Cretaceous-aged Austin Chalk, Eagle Ford Shale, Buda, Del Rio, Georgetown and Edwards Limestone (Figure 4). The Edwards Limestone is the most dominant reflector and much of this interpretation has been projected from this event. The Edwards is a clean limestone that is overlain by rocks that provide no well-developed seismic event (i.e., shale, chalk and argillaceous limestone); consequently, the Edwards Limestone is an excellent mapping horizon. The following work is derived from an interpretation of the top of the Edwards Limestone.

All faults are normal faults with down-to-the-basin throws. Small antithetic faults are present and accommodate the net loss in volume from the down-to-the-basin faults.

DISCUSSION

Seismic Profile

The study area includes roads that parallel the proposed alignment for the construction of the tunnel. Approximately 1,500 meters of seismic reflection profile data were collected that imaged to approximately 135 meters below grade (Figure 5).

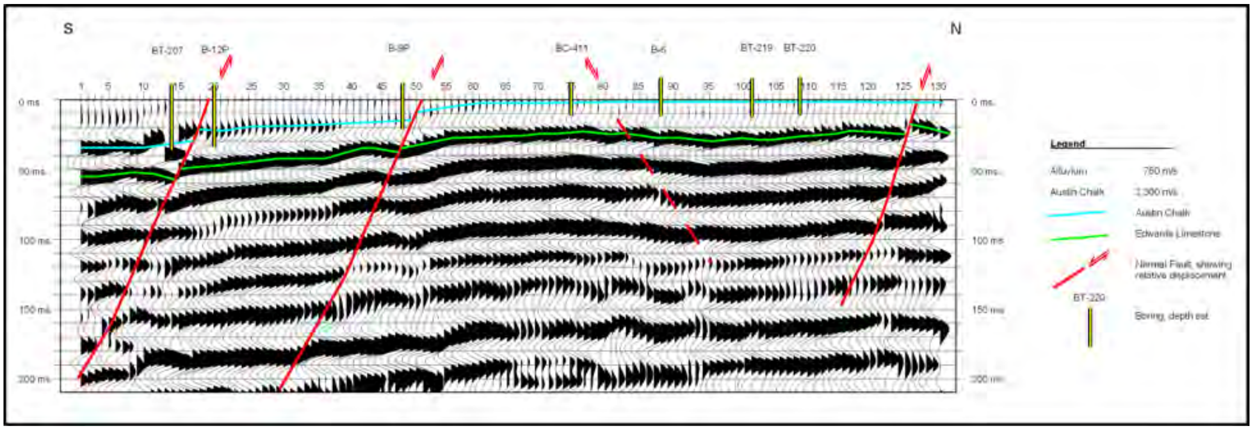

Figure 5: MSF profile collected from south to north along Red River Avenue, showing interpreted faults. Note that the apparent dip is consistent with field measurements of rock strata. Profile was collected on a relatively horizontal road (<2 m elevation change across profile).

Line 1 is approximately 1,500 meters long and was collected south to north along Red River Avenue. The profile starts at Davis Street and ends at the entrance to the hospital across from Waterloo Park. Line 1 is interpreted to have a thick sequence of Quaternary fill near Davis Street that thins rapidly to a thin veneer near record 50, which is the location of an interpreted fault. The Waller Creek Fault crosses this profile at record 18 and has a throw estimated at 14 meters. The seismic profile indicates that the area adjacent to this fault is broken up and tunneling may encounter difficult drilling conditions.

Another fault, the Waterloo Park Splay Fault, crosses this profile at record 49. The Waterloo Park Splay has an estimated throw of 12 meters. At the end of the profile a fault crosses the line at record 125; this fault is called the Waterloo Park Fault. The Waterloo Park Fault has a throw of 15meters. A small poorly developed antithetic fault to the Waterloo Park Fault is located at approximately record 83. This antithetic fault has no expression in the Austin Chalk, but may cause intense fracturing that can create difficult conditions for the tunneling work (Figure 6).

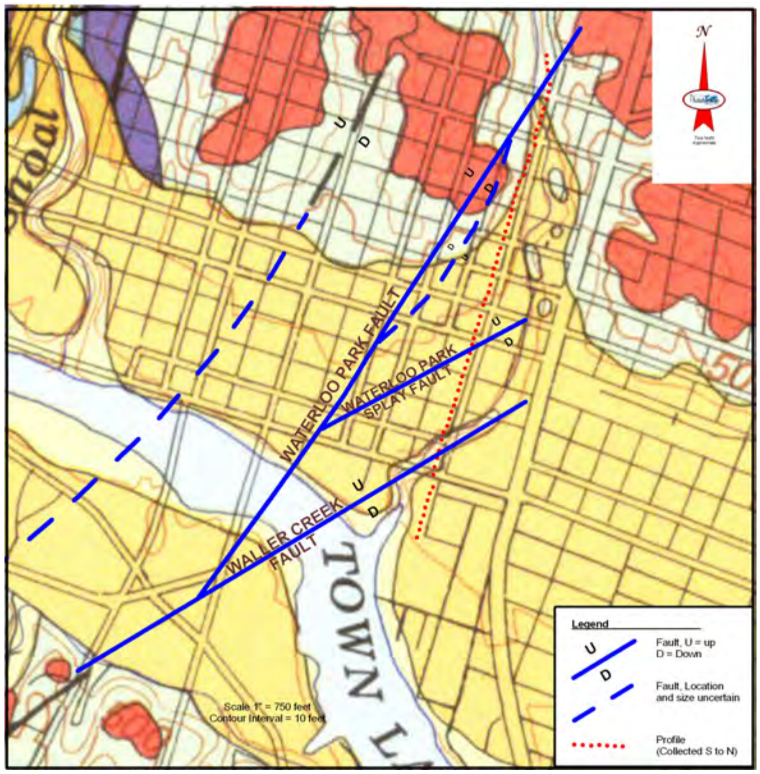

Figure 6: Interpretation of subsurface faults superimposed upon the Austin Geologic Map (Garner and Young, 1976). Scale 1 cm = 120 meters.

Drilling Results

The seismic reflection line identified the Waterloo Park Fault through careful data analysis and interpretation. Subsequent to this information, the boring BT-220 was installed adjacent to Line 1 (Figure 7). The boring was drilled 30 meters below grade. The fault was located at approximately 20 meters below grade, according to the drillers boring log. This proves that the seismic reflection data were useful in identifying faults near the survey area.

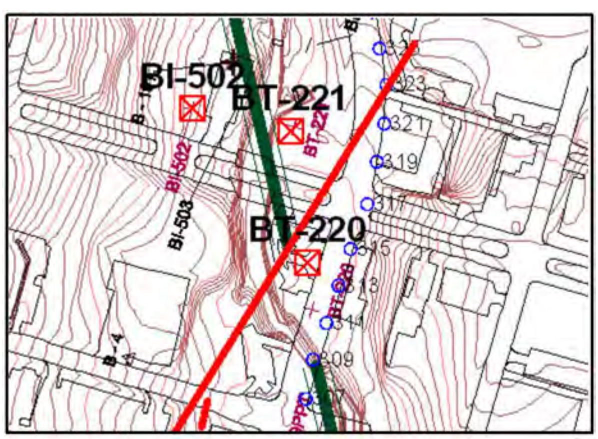

Figure 7: Boring location BT220 in relation to the Waterloo Park Fault (in red, throw is down to the right). Alignment (in green) passes through this fault (base from KBR, 2008). Scale 1 cm = 18 meters; true north to top of page.

CONCLUSION

Defensible seismic reflection data can be collected within an urban setting using a modern version of an age-old method. The MSF method can be successfully deployed in an active urban environment to image the subsurface. The MSF method was used along a proposed tunneling alignment in Austin, Texas to image faults in the Cretaceous-aged rocks.

A MSF seismic reflection profile was shot (approximately 1,500 meters) along Red River Avenue, Austin Texas to find unmapped faults. The velocity of the Austin Chalk was estimated to be approximately 2,300 meters/sec, consistent with VSP data collected in oil-and-gas wells drilled in the vicinity. The interpretation of the seismic profile is also consistent with the published geologic maps. Three predominant (i.e., approximately 14 meters of throw) down-to-the-basin normal faults were mapped and named from west to east; the Waterloo Park Fault, the Waterloo Park Splay Fault, and the Waller Creek Fault. Subsequent to this work, a boring (BT-220) confirmed the location of the Waterloo Park Fault that intersects with Red River Avenue to the north.

REFERENCES

1. EPA, 2000. Kelly Air Force Base, San Antonio, Texas: Innovations in Site Characterization: Geophysical Investigations at Hazardous Waste Sites. EPA-542-R-00-003, August 2000, Pg 79-89.

2. Garner, L. E. and Young, K. P., (1976). Environmental Geology of the Austin area: An aid to urban planning: The University of Texas at Austin, Bureau of Economic Geology, Report of Investigations No. 86, 39p.

3. Kansas Geologic Survey, (2000). WinSeis Turbo. Seismic processing software for use with Microsoft Windows. Kansas Geological Survey, Lawrence, Kansas.

4. KBR, (2008). Unpublished Topographic Map of Downtown Austin, Texas. KBR, Austin Texas.