Re-investigating Liquefaction Case Histories from the 1976 Tangshan Earthquake

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ABSTRACT :

The authors performed subsurface field investigations at liquefaction/non-liquefaction sites from the 1976 Tangshan Earthquake. These sites were re-investigated because the previous CPT data was collected using a now obsolete cone without sleeve measurements. Sites that experienced high ground shaking intensity and/or contained high fines content were the focus of this investigation. Field measurements were made using the seismic cone penetration test (SCPT) as well as spectral analysis of surface waves (SASW) and subsurface soil sampling techniques. This collaborative effort by researchers in China and the U.S. resulted in increasing the worldwide CPT case history database on the order of ten percent. Preliminary results are presented in this paper.

KEYWORDS: liquefaction, case history, SCPT, SASW, earthquake

1. Introduction

The 1976 Tangshan earthquake resulted in wide spread liquefaction that was well documented at the time by Chinese researchers (Zhou and Guo 1979; Zhou and Zhang 1979). The reports accurately documented case histories of liquefaction and non-liquefaction with SPT (Standard Penetration Test), CPT (Cone Penetration Test), and subsurface samples for water content, unit weight, and grain size analysis. The CPT measurements however were made using what is now an obsolete cone that measured only tip resistance. Current CPT-based liquefaction triggering procedures (e.g. Moss et al. 2006; Youd et al. 2001). require sleeve friction measurements to make accurate liquefaction predictions. This report documents the efforts to re-acquire subsurface information using a modern cone (capable of measuring tip, sleeve, pore pressure, and shear wave velocity) so that these valuable case histories can be included in the worldwide CPT liquefaction database (Moss et al. 2003). Focus was on acquiring data at sites that experienced high estimated ground shaking with soils that contained high fines content. High priority was given to non-liquefaction sites because these tend to be underrepresented in the worldwide database. Preliminary investigations are presented in this manuscript, complete results of the investigations can be found in a report currently under preparation (Moss et al. 2008).

This investigation was a collaborative effort between researchers in the United States and China. Collaborators from California Polytechnic State University San Luis Obispo (Cal Poly), United States Geological Survey (USGS), Southeast University in Nanjing (SEU), and the China Earthquake Administration-Institute of Engineering Mechanics at Harbin (CEA-IEM) participated over the span of two summer field seasons to collect the data. This field research resulted in a number of high quality data points that well represent high fines content and high ground shaking case histories.

2. The 1976 Tangshan Earthquake

The Tangshan earthquake, M_S=7.8, occurred on July 8, 1976. The epicenter was located in the southern part of the city of Tangshan, and surface fault rupture progressed through the town predominantly to the northeast, with some additional rupture to the southwest. The fault rupture was primarily right lateral strike slip in nature. The event occurred in the early hours of the morning and collapse of unreinforced masonry (URM) structures was the primary cause for the loss of life that has recently been reassessed at upwards of 500,000 lives. A detailed compilation of reports on the event and the aftermath can be found in (Huixian et al. 2002).

The area affected by the earthquake is a piedmont region with many rivers and streams flowing to the Bay of Bo which is connected to the Yellow Sea. The low hills inland from the current coast are the source of river sediment. It is apparent from the subsurface soil conditions that migrating river channels dominate the depositional environment. Flood plain silts are interlayered with sands having varying silt content. At certain locations there are clay deposits indicating either past lacustrine depositional environment or sea level rise resulting in a marine depositional environment. Most of the liquefaction occurred in the upper deposits of loose to medium dense silty fine sand or fine to medium clean sand. Most of the non-liquefaction sites were underlain by very dense clean sand. The sites around Tangshan City are in the Stone River watershed. The sites in the city of Lutai are in the watershed of the Li Yun River.

3. Seismic Loading

A calibrated attenuation relationship was used to improve estimates of peak ground acceleration (PGA) at each site. There were six recordings (Huixian et al., 2002) of the event that were used along with correlated intensity contours to fit an intraplate attenuation relationship. The nearest recording was at 148 km epicentral distance so the near source fitting was made using rock PGA estimates from Chinese isoseismal intensity contours (Figure 1). Shibata and Teparaska (1988) correlated Chinese intensity to PGA using the following approximation from the Chinese building code; IX~0.4g, VIII~0.2g, and VI~0.1 g. To account for soil nonlinearity from basement rock to the ground surface, amplification factors by Stewart et al. (2003) were applied. An epicentral distance of 10 km was used as a minimum or lower cap because of the uncertainty in the location of the epicenter with respect to the sites.

A depth to rupture of 14 km (Huixian et al., 2002) was used to convert between hypocentral and epicentral distance. Three intraplate attenuation relationships were investigated with respect to how well they fit the data. By inspection, the Atkinson and Boore (1995, 1997) relationship provided the best fit to mean PGA for both small and large epicentral distances. This attenuation relationship was then calibrated to the data (Figure 2) to provide an improved estimate of the ground shaking that occurred during the Tangshan event.

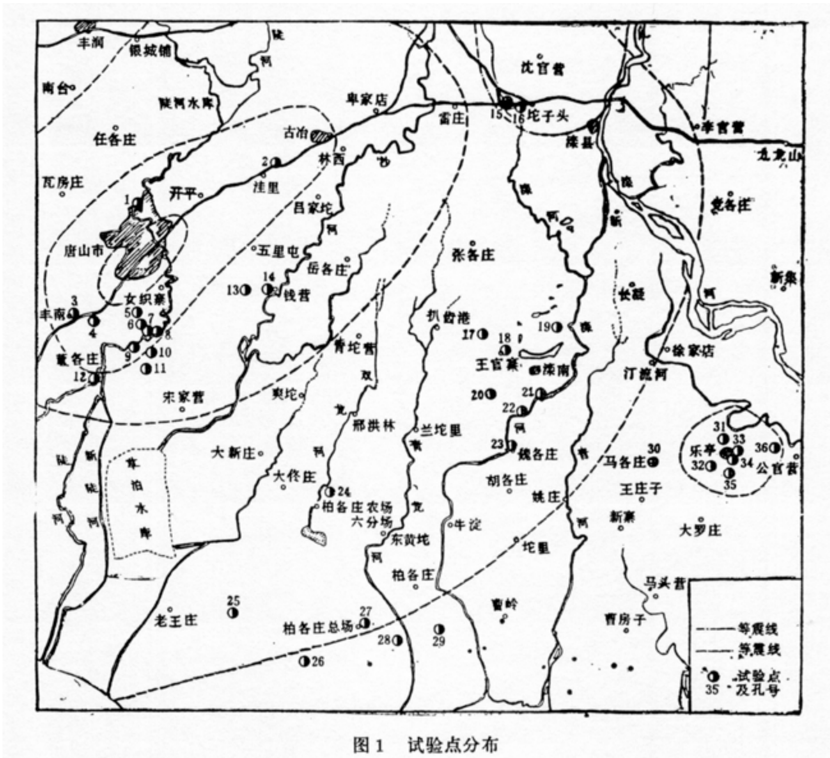

Figure 1. Chinese Intensity map from Zhang and Zhou (1979). Intensity scale is correlated to PGA using Chinese Building Code. Sites are shown as circles with the associated site number.

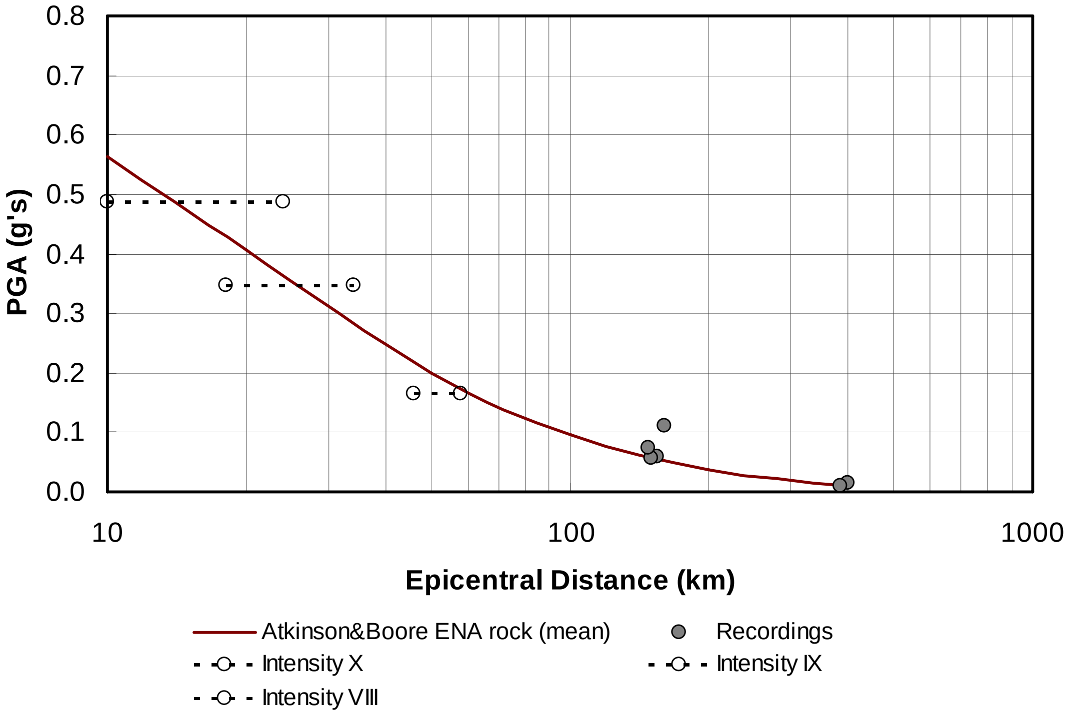

Figure 2. Atkinson and Boore (1995, 1997) attenuation relationship is shown calibrated to the recordings and estimated rock PGA ranges. The attenuation relationship has been converted from hypocentral to epicentral distance using a depth to rupture of 14 km.

3. Investigations

Determining the location of the previously documented case histories was a nontrivial step in this research. The case histories were generally located in rural agricultural areas where there has been little in the way of land development. Surface elevations are considered to be close to the 1976 elevations, or post earthquake elevations. Locating the sites consisted of driving to the town or landmark named in the logs by Zhou and Gou (1978) and Zhou and Zhang (1979), asking residents who survived the earthquake to recall the event and subsequent subsurface investigations, and arriving at a group consensus as to the location of the previous investigations. This appears to be an *ad hoc* method but keep in mind the impression that a devastating earthquake and aftermath can have on people. Not only was this most likely the largest single impressionable event that occurred in people's lives but in the aftermath these people were host to a group of investigators with government credentials and large sophisticated testing equipment who asked them detailed questions about their experiences and drilled into the ground to collect subsurface information. In most cases there was little disagreement between the residents as to where the previous location was, and when there was disagreement the difference was usually on the order of a few meters (e.g. this side of the pea patch of the other). Further issues related to pre- and post-earthquake stress and water table conditions are described in the EERC report in preparation (Moss et al. 2008). The geo-referenced locations of the sites can be seen in the regional map Figure 3.

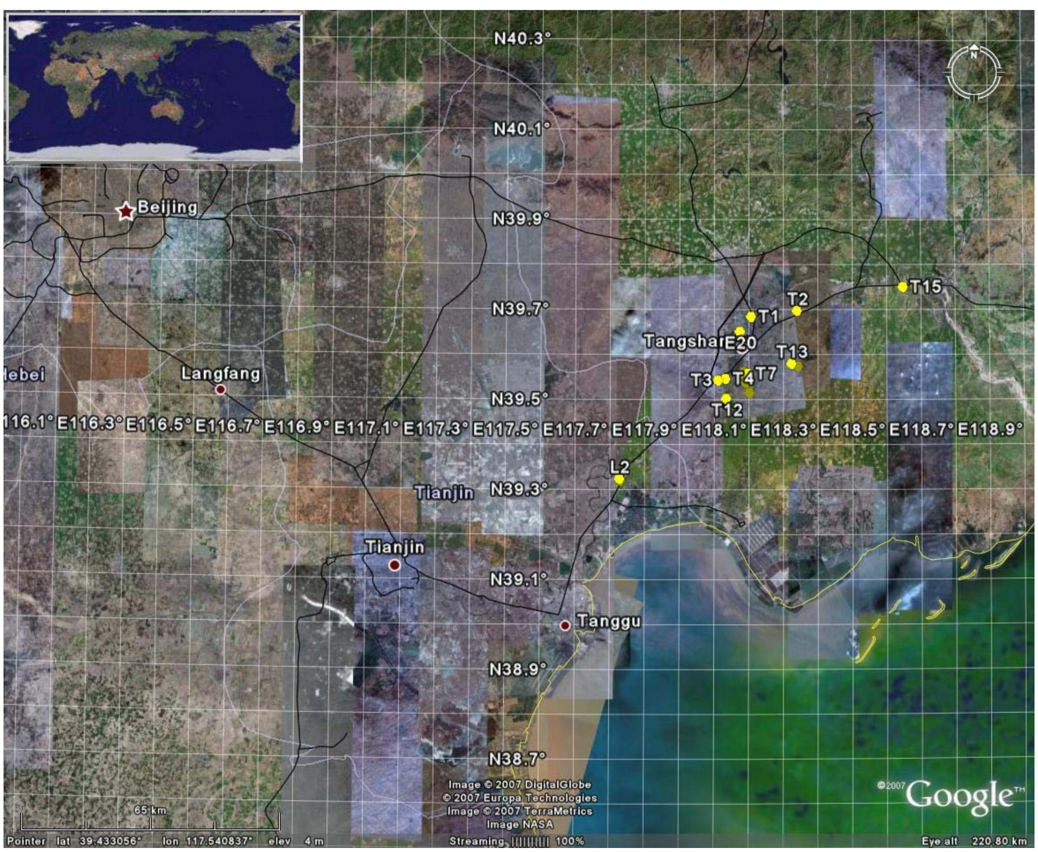

Figure 3. Regional map showing the sites investigated around Tangshan and Lutai Districts.

Data collection involved using the SCPT to measure tip resistance (q_c), sleeve friction (f_s), pore pressure (u), and incremental shear wave velocity (V_s). Soil samples were retrieved using a CPT soil sampler and hand auger. SASW (spectral analysis of surface waves) were made at the sites using two different techniques, however, in this paper only the CPT results are presented. The CPT rig used was a Vertek-Hogentogler 200kN (20 ton) seismic piezocone penetrometer. The cones used in this study (adhering to ASTM D-5778) have a 10 cm^2 base area with an apex angle of 60º. A friction sleeve, located behind the conical tip, has a standard area of 150 cm^2. A geophone or accelerometer located inside the cone, measures shear wave velocities. Data was collected at 50 mm intervals. Seismic shear wave velocity measurements were made every 1 m during brief pauses in the cone penetration.

4. Results

Eighteen case histories were investigated using the SCPT. Processing of the case histories adhered to the procedures presented in Moss et al. (2006) and also excerpted in the forthcoming data report. An important step in processing case histories is to have each case reviewed by at least two other liquefaction experts. This panel review is currently underway with the reviews being conducted by Prof. S.M. Zhang, Dr. R.E. Kayen, and Dr. J. Wu. Once the panel review is complete the case histories can be considered vetted and as accurate as possible. Preliminary results show that of the eighteen case histories, thirteen pass the screening criteria and are of high enough quality to be included in the world wide database. The remaining five case histories were screened out due to location uncertainty, unacceptably high measurement uncertainty, or soil failure physics other than liquefaction (e.g. cyclic failure of plastic soils). Figure 4 shows the preliminary results of the thirteen case histories against existing probabilistic liquefaction triggering curves and liquefaction/non-liquefaction database. Liquefied case histories are shown as closed symbols and non-liquefied case histories are shown as open symbols. The existing worldwide database is shown as circles and the sites investigated in this research are shown as squares.

These case histories are significant to the worldwide database because of the high seismic demand (i.e. high CSR) they experienced and the high fines content present in the deposits. For the purpose of refining the triggering curves the case histories that fall near the 50% probability of liquefaction line will have the most impact. The two non-liquefaction case histories with high CSR are particularly important because they provide a bound on the triggering curves where previous data is lacking. Overall the effort to acquire these case histories was a worthwhile investment in terms of the quality and importance of the results.

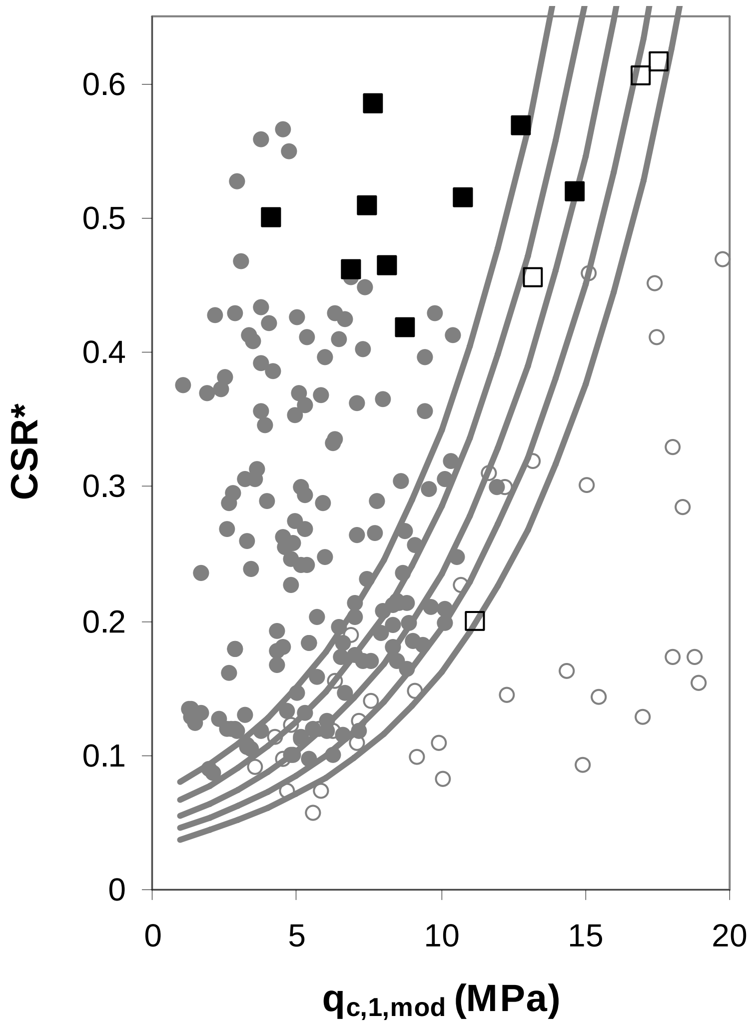

Figure 4. Tangshan District (squares) case histories shown against the Moss et al. (2006) probabilistic liquefaction triggering curves and the worldwide CPT liquefaction database (Moss et al. 2003). The x-axis is the cone tip resistance normalized for effective overburden pressure and corrected for "apparent" fines content. The y-axis is the cyclic stress ratio corrected for magnitude. The triggering curves are shown for 5%, 20%, 50%, 80%, and 95% probability of liquefaction. All curves and case history data are corrected to a magnitude of 7.5 and 1 atmosphere of vertical effective stress.

5. Summary

This paper describes a collaborative effort by U.S. and Chinese researchers to re-acquire liquefaction/non-liquefaction case histories from the 1976 Tangshan Earthquake. A team effort was required to mobilize the equipment, garner the expertise, work through the logistics, and acquire the data. The CPT data needed to be re-acquired at these sites because the previous CPT measurements were made using a now obsolete sleeveless cone. Preliminary results show thirteen case histories (nine liquefied, four non-liquefied) that can be added to the world wide CPT liquefaction database. These case histories are particularly important because they represent soil deposits generally of high fines content that were subjected to high seismic loading.

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