Acoustic Surveying Technology and Research on the Haihe Buried Fault in Tianjin


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ABSTRACT: A Survey was carried out [to find] the structure of the shallow part of the Haihe River and information on the faulted strata in Haihe Fault in Tianjin by using acoustic Surveying methods such as the single-channel seismic technique. The result shows that this method works well in the part where the river is wide and deep. It also shows that in Tanggu area of Tianjin, the upper breakpoint of Haihe Fault is about 30m underneath the riverbed and the corresponding latest active period is Qp3-Qh1, which is consistent with the result of the previous borehole Surveys. In the offshore area of Bohai Sea, the Haihe Fault presents as a NWW-NEE strike dense fault zone and its upper breakpoint is less than 30m underneath the seabed. It shows that movements of Haihe Fault in Bohai Sea is basically the same as those in Tanggu area.

1 INTRODUCTION

Although the geophysical methods cannot be used to detect the age and speed of the fault movements directly, they can be used to find the trace of the fault, and obtain fault structure and information on the faulted strata intuitively by studying the differences of the geophysical characters of the fault surface and plane. The artificial seismic method works very well. Its resolution is related to the velocity and frequency of seismic waves (Zhao 2003). Within a certain range of wave velocity, the higher the dominant frequency of seismic wave is, the higher the resolution is. As we know, the dominant frequency of seismic waves in earthquake Surveys is usually 70Hz-120Hz, and the corresponding resolution is about 6m-8m. With this level of resolution, it is difficult to determine the upper breakpoint and the actual forms of the geometric structure of the shallow strata. The acoustic stratum surveying technique primarily uses sub-sound wave or sound wave in surveying, with the dominant frequency being more than 1000Hz, which is much higher than that used in land earthquake Surveys. The resolution achieved can be as high as 1m or more. Such high resolution can be used in studies of the fine structure of shallow strata and details of the stratum faults. Therefore, by combining it with the borehole geological prospecting method, the characteristics of the fault movements can be detected. WANG Kuiyang (in1999) and DENG Qidong (in 2002) used the acoustic surveying technique in marine environments to detect fault activities, and have achieved very good results.

In the active fault surveying project in Tianjin, which is a part of the tenth "Five-year Plan", marine acoustic surveying techniques, such as the single-channel earthquake and shallow strata surveying techniques, were applied in exploring buried faults in Haihe River and around the marine area in Dagukou. We overcome many technological difficulties and environmental disadvantages, such as difficulty in stimulating sparks in in-land freshwater rivers, lower buoyancy in freshwater, narrow and shallow river-ways, multiple reflection effects, background interference, and obtained shallow acoustic stratum profile with high resolution, which is very useful in detailed study of shallow strata dislocation of Haihe Fault.
2 EQUIPMENTS AND METHOD

2.1 Navigation and Positioning

The navigation system consists of the DGPS locator and the real-time controlled computer location system, which is composed of antenna, DGPS receiver(s), navigation and positioning software, computer(s) and monitor(s) The Trimble DSMPRO’s RB/DGPS system produced by Trimble Co., Ltd. is used in our positioning system, and the HYPACK MAX software produced by Coastal Oceanography C ., Ltd., is used in the navigation software.

2.2 Seismic Source System

The seismic source system uses is the GeoPulse single-channel source system produced by GeoAcoustics Co., Ltd., which is composed of source box(es), electromagnetic pulse board for transmitting signals and catamarans, etc.

2.3 The Set-up of the Single-channel Seismic Observation System

The single-channel seismic surveying method uses impulsive sources stimulated by sparker seismic sources and the single-channel receiver to collect the reflected waves from the river bed and the geological interfaces. The observation system is composed of the seismic source system, the single-channel receiver and seismic data acquisition system.

2.4 Single-channel Seismic Data Acquisition System

The DelphWin data acquisition system produced by Elics Co. is adopted to carry out real-time digital recording of the seismic reflection signals collected by the above devices and monitoring of the seismic operation. As for the receiving cables, GeoPulse single-channel seismometer cables are used. The sensitivity level is -202dB, and the frequency response spectrum is 5Hz-3kHz.

3 CHARACTERISTICS OF THE SEISMIC REFLECTIONS IN ACOUSTIC PROFILES

The characteristics of the seismic reflections in the acoustic profiles are obtained by processing the data. To make the analysis easier, by experience we simplify the average transmitting speed of the sound velocity in shallow sediments in the inspected area to a fixed 1600m/s, and 1500m/s in water. And use this data to transform the distance-time profile into distance-depth profile.

The reflections can be divided into groups according to the continuity, waveform phase and the similarity of amplitude. According to the acoustic reflection profile of Gegu-Dengshangu section, many marine strata that are displayed with the characteristics of parallel or horizontal reflections, and the waves show a great continuity and strong amplitude, and are easy to trace. They can be identified as regional seismic reflections. However, because of severe erosion of marine strata during the marine regression, the marine strata have been badly damaged and incomplete in some places. Between the marine sequences are the continental sequences, which are in mixed stages, showing less continuity of reflections, and are difficult to trace. Plus, there are many V-shape river ridges and filling sequence sediments due to frequent changes of watercourses. Otherwise, fault movements also increase the difficulty of continual identification of the seismic reflections, and determining the age of the reflections in fault blocks becomes a key issue.

In order to further understand the physical properties and age of the reflections, the data from HP3 and HP4 in Gegu-Dengshange area and acoustic strata profile are used to analyze the correlation inter-borehole strata. As shown in Fig.1, there are four marine sequences strata in Tianjin area since the Quaternary, and they are all stable, with large wave amplitude, and are easy to trace, as is obviously different from the Quaternary strata. So, they can be used as the symbolic layers for study of the shallow strata structure and fault researches.
In the typical profile, R1, R2, R3, R4, R5, R6, R7, R8, R9 reflection interfaces beneath the river bed can be identified, and can be considered as interfaces of the Holocene strata, the marine strata, the marine-continental mixed strata, continental strata, the II marine strata, continental strata, the III marine strata, continental strata and the IV marine strata. For better comparison, the resistivity curve is also shown in Fig.1, in which there is good correspondence between resistivity and lithology and marine strata. The resistivity of clay is obviously higher than that of the sand layer, and the marine strata are often mainly composed of fine clay with high resistivity.

![Fig. 1 Contrasting figure between seismic reflection sequences in acoustic profile and boring stratum](image)

4 TIME-DEPTH TRANSFORM

The single-channel seismic profile recorded is a two way travel-time of sound wave reflections. When contrasting these profiles with the relevant borehole data and mapping analytical diagrams, it is necessary to determine a suitable sound wave velocity to transform the distance-time profile into distance-depth profile (time-depth transform in short). Because the components of shallow sediments are complex and the velocity in a sequence of sediments is also greatly scattered, it is very difficult to get an accurate velocity in these sediments.

The survey lines mainly lay in the river-course, and the related data show that the shallow sediments are mainly silty-clay, silt and silt-sand, with thick granularity and complex lateral variation, so the velocity is not stable. Based on former experience, in order to simplify the analysis, the velocity is fixed at 1600m/s in shallow sediments, and 1500m/s in water.

5 ANALYSIS OF EXPLORATION PROFILES

5.1 Gegu-Dengshangu Profile

This profile is from the east of Xinigu to the north of xiaoliangzi village in Dengshangu and is about 15km long in total. This purpose of the survey is to get the shallow sediment profile feature of the intersection of the Cangdong fault and Haihe fault, and to obtain data concerning the buried fault activity.

Fig.2 shows the acoustic profile of Gegu-Dengshangu area of source 2000 to 3000. The reflections are obvious near the source 2740(fault Fg1) . Upward the continental strata are difficult to identify, but
downward there is enough evidence of the incising phenomena in the second and third marine strata. Also, the breaking distance gradually increases from upside to downside, reaching 3ms at the bottom of the second marine strata and breaking the third marine strata to a distance of 5ms-8ms. The upper breakpoint in Fault Fg1 is located at about 50ms underneath the river surface (equals to 39.9m in depth).

Similar to Fig.2, there are fault strata reflection wave phenomena near source No. 8300(Fig.3). The fault is very steep, with the upper breakpoint located at about 52ms (equals to 41m in depth) underneath the river surface, which cuts the many layers of strata reflections downwards. There is also a slump structure with a clear slump surface in the upper strata of the fault. Strata are inclined sediments with phase continuity on the north side, and discontinue on the south side, which indicates that the strata were exposed on the surface at corresponding age. Because of fault activity or other tectonic activity, the strata slumped for more than 200m, and later received terrigenous accumulation and sedimentary. Also there is a V-shape structure in the upper strata formed by paleo-channels, which indicates that the fault Fg2 moved many times after the corresponding geological age and caused the slump structure and paleo-channels in the upper strata.

Moreover, there are traces of activities of the shallow fault (Fg2) near source 10100. The upper breakpoint of Fault Fg3 is located at about 55ms underneath the river surface (equals to 43.4m in depth), which cut all the reflections downwards.

Properties of each fault in the profiles above are displayed in Table.1. Faults Fg1, Fg2, and Fg3 are all inclined to the south, with steep dip angles, and their upper breakpoints are all at the 50ms-55ms range underneath the river surface, and all incised the same strata, which is speculated to be the main fault of Haihe fault zone. As each profile incises the fault from different angels, the dip angles are different, but the depths of their upper breakpoints are very close.

![Fig 2. Acoustic stratigraphic time and interpretation profiles of Gegu-Dengshangu survey line (source series between 2000 and 3000)](image-url)
Fig. 3 Acoustic stratigraphic time and interpretation profiles of Gegu-Dengshange survey line (source series between 7900 and 8700)

Table 1. Features of Gegu-Dengshangu Fault profile/upper breakpoints

<table>
<thead>
<tr>
<th>Fault No.</th>
<th>Fault Location (Source No.)</th>
<th>Orientation</th>
<th>Upper breakpoint depth (ms / m)</th>
<th>Basis of Judgment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fg₁</td>
<td>2740</td>
<td>NNW</td>
<td>50 / 39.3</td>
<td>Obviously distortion of the II, III MS and typical reflection</td>
</tr>
<tr>
<td>Fg₂</td>
<td>8300</td>
<td>NW</td>
<td>52 / 41.0</td>
<td>Dislocation and distortion of reflected waves of typical marine strata</td>
</tr>
<tr>
<td>Fg₃</td>
<td>10100</td>
<td>NNE</td>
<td>55 / 43.4</td>
<td>Distortion of reflected waves of typical marine strata</td>
</tr>
</tbody>
</table>

5.2 Xingang-Dagukou Profile

The profile is about 15km long, from about 6 nautical miles outside of Dagukou to about 6 nautical miles north-east of Luju river. The purpose of the survey is to find about the extension of Haihe Fault towards the sea and the profile feature of the shallow strata fault, and to show the activity feature of the Late Quaternary.

According to the acoustic seismic profile obtained(Fig.4), seven reflection groups( T1, T2, T3, T4, T5, T6, T7) can be identified from the seabed, which are corresponding to the late Quaternary strata, continental-marine mixed strata, continental strata, marine strata, continental strata and marine strata. By analysis, the features of the upper breakpoints of the faults in the Bohai sea area from Xingang to the northern section of Dagukou(Tab.2) were obtained from the profile. As shown by Fig.4 etc., the fault is located at 30m underneath the seabed, with erosion trenches formed by paleo-channels over the
fault, so the fault had a controlling effect and impact on the formation of paleo-channels and erosion trenches. According to the result of the study on the age and strata sequences before, the age of the fault dislocation was in the early-med Holocene, which is almost the same age as the Dengshangu area of Haihe fault.

![Fig.4 Faults feature in northern part of the Xingang-Dagu profile](image)

Table 2. Features of Bohai Seal Area in the North of Xingang-Dagukou Fault profile/upper breakpoints

<table>
<thead>
<tr>
<th>No. of Fault</th>
<th>Orientation</th>
<th>Depth of upper breakpoints (ms / m)</th>
<th>Distance between upper breakpoint and seabed(m)</th>
<th>Basis of Judgment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fn1</td>
<td>SW</td>
<td>53 / 41.7</td>
<td>31.2</td>
<td>Dislocation or distortion of reflected wave events between two side of fault</td>
</tr>
<tr>
<td>Fn2</td>
<td>NNE</td>
<td>78 / 61.7</td>
<td>51.2</td>
<td>Dislocation or distortion of reflected wave events between two side of fault, totally erosion of the IIIMS and dislocation of the III MS</td>
</tr>
</tbody>
</table>

6 COMPARATIVE ANALYSIS OF SURVEY DATA

CHEN, Y.K. had make a comparative analysis between the shallow seismic survey and the borehole strata data (in 2004). The result is consistent with the acoustic profile. The fault location from the two surveyes are basically the same. As for the depth of the fault’s upper breakpoint and its active age, The depth by the shallow seismic exploration method is about 100m, and the breaking distance is 3m-5m, but the real depth of the upper breakpoint should be much more shallow(Fig.5). The acoustic profile shows that the upper breakpoint is less than 30m from the seabed at the shallowest part, which corresponds to the late Pleistocene (65,000-79,000B.P.). If the slump structure is a result of the fault’s activity, the depth of Haihe fault’s effect would be more than ten meters underneath the riverbed, which corresponds to the Holocene. Through the comparative study of the borehole exploration and
stratigraphic correlation, the buried depth of the upper breakpoint is at the 16.4m, and the corresponding active age is 7200±140 or 9550±105a B.P (Fig.6).

Fig. 5 Interpreted seismic profile across Haihe fault in Dengshangu area. T_0\text{-}T_8 are nine reflections, among which T_0\text{-}T_4 represent reflections produced by the lithologic interfaces in the quaternary; T_5 is the reflection of the interface of quaternary; T_6\text{-}T_8 represent reflections produced by the lithologic interfaces in the neogene; F_p represents the main fault of Haihe fault zone; F_p_3 and F_p_2 are the secondary faults of Haihe fault zone.

Fig. 6 Stratigraphic correlation of bore holes in Dengshangu area across Haihe fault

7 CONCLUSION

The great consistence of results obtained in the acoustic survey and the borehole stratigraphic correlation indicates that, with the improving of resolution, the upper breakpoint would increasingly reach the real point. The acoustic survey not only obtains a high resolution continual profile, but also displays information about the fault palaeogeomorphology and ancient activities, which is a great advantage that borehole profile can never achieve. It also shows that the acoustic exploration technology can be applied at places where the borehole method does not work, such as under water. This paper presents an exploration and comparative study of the activities of Haihe fault in Tanggu and Bohai area, and shows that the upper breakpoint of the fault is about 30m underneath the river bed.
in Tanggu but less than 30m in the Bohai sea area. The Haihe fault presents itself as a zone of series of NWW-NEE faults. The active age is in early-mid Holocene, which is basically the same as that of the Dengshangu area in Haihe.

REFERENCES


