The application on the towed-type shallow high-accuracy seismic detection for coastal tidal flats

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Abstract. Restricted by the geological exploration equipment and tidal time, the deep seismic detection technology with large offset for exploration of oil and gas resources is often used in the seismic survey of the coastal tidal flats. Furthermore, the coastal tidal flats are only treated as the transition belt of the paralic zone, resulting in the low degree of geological exploration and low detection accuracy, which cannot meet the requirement for high-accuracy exploration in the coastal tidal flats. Conventional shallow seismic exploration technology can detect effectively the bottom interface and internal horizon of the shallow Quaternary system in the coastal tidal flats, but the equipment for data acquisition is complex, and the acquisition efficiency is low, restricting directly the seismic exploration in the coastal tidal flats. Therefore, a shallow high-accuracy seismic detection technology has been developed in this study, which is suitable for the coastal tidal flats. By making full use of the characteristics of the flat terrain in the coastal tidal flats, the method for towed data acquisition has been used, and the seismic detection equipment has been simplified in the tidal flats. With this method, the exploration cost has been reduced, and the data acquisition efficiency has been improved. The detection accuracy can reach the level of meters, and the detection depth is more than 800m with this method. With this technology, the shallow stratigraphic structure and interface in the coastal tidal flats can be detected effectively, and the location of paleochannels, concealed faults and shallow gas can be determined, which support effectively the geological survey of the coastal zone and offshore engineering, being of great practical significance for scientific disaster prevention and mitigation.

1. Introduction
Coastal tidal flats generally refer to the tidal zone between the high tide line and the low tide line of the coastal spring tide. In the well-developed coastal areas, the tidal flats can reach more than 10 km in width, with small slope, generally only about 0.2‰. The tidal flats are composed mainly of fine silt to fine grain clay sediments. The generalized tidal flats also include some undeveloped supratidal zones and underwater shoals that are difficult to be exposed at low tide. Among the coastal provinces of China, Jiangsu Province has a large number of coastal tidal flats, the distribution of coastal tidal flats is the widest, accounting for a quarter of the total tidal flats area of the country. Coastal tidal flat is an important reserved land resource for the future development of China, with great economic, environmental,
ecological and energy values, having great potential for development and utilization [1-4]. Because of the special surface condition, complex surface structure and the influence of tide, it is difficult to collect the geological exploration data. In addition, the effective time for data acquisition is very short. Therefore, it is impossible to solve the geological exploration problems in the coastal tidal flats with the simple land surface or marine detection technologies. It is a worldwide problem to collect geological data in the coastal tidal flats, resulting in insufficient geological surveys in the coastal tidal flats, and the lacking in overall management of the marine and land geological surveys.

Overseas geological exploration and study have been carried out in the coastal tidal flats at very early time. According to the surface differences in the tidal flats, different sources, geophones and instruments had been selected, and the data collected by different instruments had be corrected by filtering method in a single seismic record [5]. In China, a lot of geological researches have done in the coastal tidal flats by many oil companies, but mainly for the deep oil and gas resources. In addition, the coastal tidal flats are often treated as the transitional belts of the paralic zones during operation. In study about coastal tidal flats, by combing land and shallow sea seismic exploration technology, a set of shallow high accuracy seismic exploration technology for oil and gas resources has been developed for paralic zone by using multiple shooting sources and geophone receivers, as well as land and sea observation system and targeted seismic data processing methods [6-11]. Through the above mentioned exploration technologies, the requirements for shallow sea oil and gas exploration can be met. However, the coastal tidal flat has not been studied as a single target area, resulting in the low detection accuracy in such areas, and the requirements for high-accuracy geological survey, the determination of shallow stratum structure, and delineation of concealed active fault distribution cannot be reached.

The shallow high-accuracy seismic detection technology, combined with seismic effective reflection signal extraction technology, have been used widely to identify accurately the shallow underground geological structures, the location of active faults, the urban underground space detection, urban active fault detection, land natural gas hydrate and metal ore exploration[12-22]. However, few studies have been done on shallow seismic detection in coastal tidal flats. Institute of Geophysical and Geochemical Exploration from Chinese Academy of Geological Sciences has carried out the study in the coastal tidal flat with shallow seismic detection method in Rudong County, Jiangsu Province, China. The rolling array seismic detection method was selected during the ebb tide, with a hammering source and 60Hz geophone. Through this study, the location of the bottom interface of the Quaternary System in the survey area has been detected effectively, and internal layer of the Quaternary System has been divided in the survey area. In addition, the existence and distribution of concealed active faults and shallow gas have been made clear in the survey area [23].

The above-mentioned seismic exploration equipment in the tidal flat is complex, which requires a lot of manpower, material resources and time to arrange the equipment. At the same time, due to the tidal time constraints, the daily data acquisition efficiency is low, and it is difficult to carry out large-scale work. Therefore, it is urgent to develop a new set of shallow seismic detection technology that can acquire field seismic data of the coastal tidal flats quickly and efficiently. In view of the above difficulties and the surface characteristics of the coastal tidal flats, a towed-type shallow high-accuracy seismic detection has been designed, which is suitable for this area.

2. Overview of the study area
The study area is located in Rudong County, Nantong City, Jiangsu Province, which is one of the areas with rich coastal beach resources in China. As shown in Figure 1, this area is close to the Yellow Sea. The surface of the coastal tidal flats is mainly composed of consolidated silt. After the ebb tide, the vertical tidal flats can extend more than 10km from west to east, and the overall terrain is flat with an elevation drop of less than 1m. In the study area, the time interval between ebb and flood tide is about 5 hours every day, people and vehicles can walk and drive on the coastal tidal flats during this period, which is favorable for seismic exploration. In addition, the Quaternary strata are well developed in the study area, with a thickness of about 300m. The buried depth of bedrock is relatively deep, about 700-1400m. The surface consists of mainly coastal-shallow marine sediments and delta frontal-tidal flat
sediments, and the lithology is mainly silt, sand clay, fine sand, coarse sand and gravelly coarse sand. The thickness of each lithology is as thin as a few meters and as thick as tens of meters. Due to the flood and ebb tides in the coastal tidal flats, which is often submerged by the sea water, the surface and the underground are saturated with water, which is favorable for the propagation of seismic waves, and there is basically no influence on the surface low-velocity zone.

Figure 1. Location of coastal tidal flat in the study area

3. Towed-type shallow high accuracy seismic exploration

It is quite difficult to carry out complex seismic exploration work in the tidal flats due to the short interval between daily flood and ebb tides, which is no more than 5 hours every day. How to ensure the quality of seismic data acquisition and workload of the task design within a limited time every day, which is a key factor for improving the efficiency of seismic data acquisition in the tidal flats. In this paper, the advantages of this technology are discussed in three aspects, including instrument and equipment, data acquisition efficiency and effectiveness analysis.

3.1. Instrument and equipment

The instrument and equipment for towed-type shallow high-accuracy seismic detection in coastal tidal flats mainly include electric spark source shooting system and towed ship type geophone string receiving system, as shown in Figure 2. The work includes drilling a well with a depth of 1m on the tidal flat surface, burying the shooting cable head of the 40000J electric spark source into the well, and filling it with water as the shooting point, with a unilateral shooting method. At the same time, the conventional geophone strings are fixed in the self-made ship type metal device to form the towed ship type geophone strings, which are connected to the Geode acquisition station by using the towed cable with a fixed channel spacing, and the seismic data acquisition work is carried out in the tidal flats by using the towable vehicles. In addition, in order to adapt to the surface environment of coastal tidal flats, all seismic data acquisition equipment and instruments have been treated with waterproof transformation.

In order to achieve the purpose of fine detection of the shallow geological structure in the coastal tidal flats, through repeated tests, the parameters of the towed shallow high-accuracy seismic detection technology for field seismic data acquisition in the coastal tidal flats are listed in Table 1, that is, the channel interval is 3m, shot interval is 6m, the minimum offset is 6m, sampling interval is 0.25ms, receiving gather is 24, and the maximum folds is 6.
Table 1. Basic parameters of field seismic data acquisition

| Parameter                  | Value   |
|----------------------------|---------|
| Channel interval/m         | 3       |
| Shot interval/m            | 6       |
| Minimum offset/m           | 6       |
| Sampling interval/ms       | 0.25    |
| Receiving gather/channel   | 24      |
| Maximum folds/times        | 6       |

Figure 2. Towed-type shallow high-accuracy seismic detection equipment in coastal tidal flats. (a) Drilling on tidal flat surface and electric spark source shooting cable; (b) Electric spark source shooting system; (c) Towed ship type geophone; (d) Towed shallow high-accuracy seismic receiving system in tidal flats

3.2. Data acquisition efficiency

In order to make full use of the effective seismic data acquisition time of less than 5 hours per day in the coastal tidal flats, the same data acquisition parameters were used, and statistics analysis has been conducted on the instruments, equipment and personnel required for the conventional rolling type detection and the towed-type detection proposed in this paper, as well as the daily completed workload in the tidal flats, as shown in Table 2 and Figure 3.

Table 2. Statistics of seismic data acquisition equipment and personnel

|                  | Rolling-type | Towed-type |
|------------------|--------------|------------|
| geophone/channel  | 168          | 24         |
| Digital cable/pcs | 14           | 1          |
| Mesh line/pcs    | 6            | /          |
| Geode acquisition station/pcs | 7          | 1          |
| Technicians and workers/pcs | 14         | 5          |

It is found from Table 2 that for conventional rolling-type shallow seismic detection in the coastal tidal flats, in order to save effective working time to the greatest extent, 168 geophones, 14 digital cables, 6 mesh lines, 7 Geode acquisition stations and 14 technicians and workers are needed. In contrast, for the towed-type seismic detection, only 24 self-made ship type geophones, 1 drag cable, 1 Geode acquisition station and 5 technicians and workers are needed to complete the field seismic data acquisition task in the coastal tidal flats. That is to say, with the towed-type shallow seismic detection technology, the investment in instruments and equipment and personnel has been reduced, the detection
cost is lower, and the data acquisition mode is simple, which can save a lot of time for seismic source shooting, seismic data receiving and recording.

Figure 3. Statistic data of the daily completed workload

Figure 3 shows the daily workload of rolling-type and towed-type seismic detections for five consecutive days. In rolling-type, a daily maximum and minimum data acquisition workload are of 72 shots and 60 shots for five consecutive days respectively, with an average of 65.8 shots. In towed-type, a daily maximum and minimum data acquisition workload are of 130 shots and 120 shots for five consecutive days respectively, with an average of 124.2 shots, which has improved nearly doubled the workload.

3.3. Efficiency analysis
The continuous single-shot seismic record and its frequency spectrum with towed shallow high-accuracy seismic detection technology in coastal tidal flats for field quality control are shown in Figure 4. Bandpass filtering and gain compensation have been used for field data quality control.

Figure 4. Field data quality control. (a) Continuous single-shot seismic record; (b) Effective reflected wave spectrum

It can be found that with this technical method, although the seismic record has obvious interference noise, the effective reflected wave of hyperbolic type is good in continuity in phase axis, with strong energy. The two-way time of effective reflected wave can reach 0.8s, and the effective detection depth in the coastal tidal flats can reach more than 800m. At the same time, the main frequency of the effective reflected wave is about 130Hz, and the effective frequency band is mainly distributed in 80-240Hz. Therefore, it is further confirmed by the continuous single-shot records with field quality control and the spectrum characteristics of effective waves that the efficiency is high for the towed-type shallow high-accuracy seismic detection method proposed in this paper, which lays a foundation for the subsequent extraction of seismic detection signal in coastal tidal flat.
4. **Practical application**

By using the towed-type shallow high-accuracy seismic detection technology proposed in this paper, the shallow geological fine structure of the coastal tidal flats has been detected effectively, the location of the palaeochannel has been determined, the concealed active fault and the submarine shallow gas have been made clear, and the practical application effect of this technology has been verified.

4.1. **Shallow geological structure**

Figure 5 shows the depth profile of a survey line in the coastal tidal flat and the lithology data of geothermal borehole near the survey line. In the time section, 10 groups of reflection interfaces are interpreted respectively. According to the strength and continuity of the wave group, drilling data and other regional geological data, as well as the stratum with thick clay aquiclude in the middle and lower reaches of the Yangtze River are used as identification marks for the bottom interface of the Quaternary System, it is concluded that T0 reflected wave group is the Quaternary bottom interface, T0-4, T0-3, T0-2 and T0-1 are the Quaternary internal stratigraphic interfaces, T1, T2, T3 and T4 are the Neogene internal stratigraphic interfaces, T5 is the top interface of bedrock, and the coincidence rate with the interface of geothermal borehole lithologic information is more than 90%. At the same time, a palaeochannel is inferred according to the seismic facies.

![Interpreted seismic section of shallow geological structure in coastal tidal flat in depth domain](image)

**Figure 5.** Interpreted seismic section of shallow geological structure in coastal tidal flat in depth domain

4.2. **Concealed active faults**

![Interpreted seismic section for effective identification of concealed active faults in coastal tidal flat](image)

**Figure 6.** Interpreted seismic section for effective identification of concealed active faults in coastal tidal flat
Based on the fault relationship of the reflected wave group, the existence of faults on the seismic time section can be judged, the conversion of strong phase, the relationship of the upper and lower wave groups, and the obvious increase or decrease or disappearance of the seismic phase axes can be made clear. However, the reflected wave group on the seismic section in costal tidal flat is the soft soil stratum without cemented diagenesis, and the fracture zone has not developed by the slipping of the fault, which makes it more difficult to determine the fault in the soft soil stratum than in the cemented diagenesis stratum. According to the strength and continuity characteristics of the wave group on the seismic section, two groups of faults F1 and F2 have been identified effectively on the shallow high-accuracy seismic time section of the coastal tidal flat shown in Figure 6, and the two faults have the same tendency as SE. F1 makes T0 reflection interface to fault, but does not extend upward or downward. F2 makes T1 reflection interface to fault, and continues to extend upwards, the shallowest fault is T0-3 reflection interface with the depth of 100m. For the construction of coastal tidal flat, the existence of concealed active faults is induced easily offshore geological disasters, which poses a serious threat to the stability of infrastructure construction in the tidal flat. Therefore, the location should be far away from the concealed active faults when constructing offshore engineering in the coastal tidal flat.

4.3. Submarine shallow gas

Shallow gas is a kind of marine geological disaster, which generally refers to the gas accumulated in the shallow layer of seabed, sometimes existing as gas bearing sediment, sometimes as an air bag in a supernormal pressure state, sometimes directly ejecting to the seabed. A shallow gas is successfully detected in the coastal tidal flat research area by using the towed-type shallow high-accuracy seismic detection, as shown in Figure 7.

![Figure 7](image-url)

Figure 7. Interpreted seismic section for effective identification of shallow gas in the coastal tidal flat

It is obviously found that there is no continuous and traceable reflected wave group between the CDP point of 700-1050 below 0.1s, and a blind zone of reflected information appears, while the phase axis of shallow reflected wave above 0.1s is continuous and clear, indicating that the ground shooting and receiving conditions are good, and the acquisition method, parameters and acquisition environment of this line section are the same as other sections. It is inferred that the seismic wave cannot penetrate the occurrence stratum of the shallow gas on the seabed during downward or upward propagation. At the same time, the reflection information of the underlying stratum is also missing. Therefore, a blind zone of reflected information appears on the seismic section, which may be caused by the shallow methane gas reservoir formed by the decomposition of the marine organism by the methane bacteria during seabed deposition and gradual transform into gas. The natural gas in the deep seabed rose to the shallow seabed along the fault planes, fractures and pores of the rock layer, which was covered by the impervious stratum such as clay, cannot moved upwards to release, and gathered in this area to form a high pressure
shallow air bag. The existence of shallow seabed gas in the tidal flat is a great potential safety hazard in offshore engineering construction, and easy to induce offshore geological disasters. Therefore, it is necessary to avoid such areas for dam construction, port location, and wind power infrastructure in the coastal tidal flat.

5. Conclusions
In this paper, the towed-type shallow high-accuracy seismic detection technology for coastal tidal flats is proposed. According to the characteristics of the flat terrain in the coastal tidal flats, the towed method is used to collect the seismic data. The advantages of this technology are discussed from three aspects, including field instruments and equipment, data acquisition efficiency and effectiveness. This seismic detection technology is characterized by good benefits in economy, high efficiency and reliability.

The practical application results show that the towed-type shallow high-accuracy seismic detection technology is an effective exploration method for the coastal tidal flats that seriously affected by tides. The detection accuracy can reach meters, and the detection depth can reach more than 800 m. It can be used to accurately detect the shallow Quaternary and Neogene stratigraphic structures and interfaces in the coastal tidal flats, to determine the location of paleo-channel, concealed faults and shallow gas, and to support effectively the coastal geological survey and offshore engineering, which has great practical significance for scientific disaster prevention and mitigation.

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