Research Journal of Applied Sciences, Engineering and Technology 13(11): 807-814, 2016
DOI:10.19026/rjaset.13.3422
ISSN: 2040-7459; e-ISSN: 2040-7467

Submitted: April 2, 2016 Accepted: August 9, 2016 Published: December 05, 2016

Research Article

Fault Activity in the Surrounding Sea Areas of the Nuclear Power Plant in Cang-Nan, China

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Abstract: The fault activity in the area surrounding a nuclear power plant is crucial and critical for site selection. This study aims to analyze the fault activity in the surrounding sea areas of the Cang-nan nuclear power plant. The strata information is obtained by both a high-resolution multi-channel seismic survey and a single-channel seismic survey. Based on the processed seismic data, the seismic profiles are interpreted by combining the regional tectonic background and the exploration data from the neighboring nuclear power plant. Seven seismic reflection interfaces are obtained by using the seismic stratigraphy method. According to the active fault criterion, no fault is found in the Quaternary sedimentary layer, indicating that no breakpoint exists. The results show that there is no Quaternary active fault in the concerning area of the Cang-nan nuclear power plant (<25 km) and the site can meet the requirements of the industry standard.

Keywords: Fault activity, nuclear power plant, site selection, seismic survey

INTRODUCTION

Withincreasing population and rapid economic development, traditional hydrocarbon fuels will face the risk of depletion, as they are non- renewable resources. Renewable energy resources, which must be evaluated as the main alternative to hydrocarbon fuels, can have a lower impact on the environment and are receiving increased attention. However, there are still some restrictions (Pei *et al*., 2004; Polatidis and Haralambopoulos, 2007; Savvanidou *et al*., 2010; Baños *et al*., 2011), such as their stage of technical development, policy support and production costs, in using some of renewable energy sources, especially wind, solar, hydropower and biomass energy.

Nuclear energy, as a high efficiency source (Shi, 2007; Zhou *et al*., 2011), could satisfy the needs for increase energy production and has an important role in changing the global situation regarding resource shortages. Unlike the traditional hydrocarbon fuels, a nuclear power plant does not discharge SO_2, NO_x, dust, or the greenhouse gas-CO_2, so it has little influence on the environment and human health in its normal operating state.

However, because of the radioactive material in the reactor, there is still a potential threat for serious damage to the environment and humans if a nuclear leak occurs (Chapman *et al*., 2014). Therefore, security is a primary issue for a nuclear power plant, which must be considered in the selection of the plant site. The determination of active faults since the Quaternary near the plant site and its surrounding area is required before the site is finally chosen (Bengang and Hbnglin, 1993; Zhao *et al*., 2001; Xiangdong, 2006; Wang *et al*., 2013; Aurelio *et al*., 2013).

A nuclear power plant in Cang-nan of Zhejiang province of China has been approved to relieve the power supply pressure in Wenzhou area which is an economically developed region in China. At the present time, the feasibility study for the site selection has been completed. In order to make sure that the seismic safety evaluation could satisfy the corresponding regulations and guidelines, the fault activity study in the surrounding areas of Cang-nan nuclear power plant is carried out. This study introduces the main work of the offshore engineering geophysical survey and the conclusions obtained based on the seismic interpretation.

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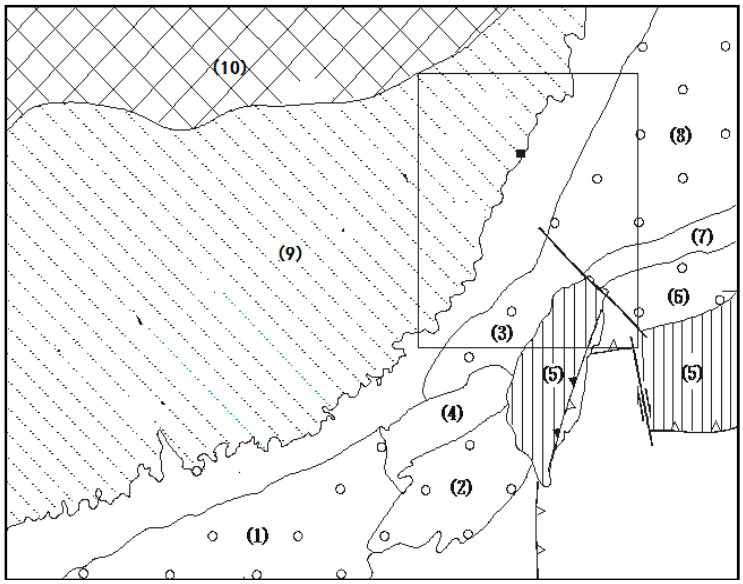

Fig. 1: Regional tectonics and the plant site; (1): Pearl River mouth basin; (2): Southwest Taiwan basin; (3): West Taiwan basin; (4): Penghu-beigang uplift; (5): Taiwan-ryukyu island arc; (6): Okinawa trough; (7): Diaoyu Island folded belt; (8): East China Sea basin; (9): South China Caledonian fold belts and (10) Yangtze platform

REGIONAL SETTING

The study area is located in the southeast coastal area of China andis part of the South China Caledonian fold belts (Fig. 1) from a geotectonic point of view. The crust structure of the South China Caledonian fold belts has experienced several stages of tectonic evolution cycles and forms the present overall pattern. The tectonic evolution of the crust usually shows a general trend from unstable to stablewith the active belt moving gradually to the southeastward. The regional modern tectonic and the crustal movements are weak in South China Caledonian fold belt, as it is located in the interior of the tectonic block during the neotectonic movement.

The main faults in the study area can be divided into two groups according to their direction: a NNE-NE strike and a NW strike. The NNE-NE strike faults such as the Haijiao-dongyin Fault, Zhenhai-wenzhou Fault and Yuyao-lishui Fault, generally have a long history of development over large scales. They can play a definite role in controlling the development of tectonic units of different orders. The NW strike faults are smaller in scale with discontinuous extensions. Combined with the faults in other directions, some can control the late Paleozoic-Mesozoic sedimentary basin. Both the NNE-NE strike and the NW strike faults intertwined with each other, which have formed the basic structure for the neotectonics, with the features of a strip to the Northeastward and a block to the Northwestward.

MATERIALS AND METHODS

Data acquisition: The submeter differential GPS was used for the marine positioning, with a static orientation precision of less than 1m. The HYPACK® MAX was used for the navigation, which can supply the real-time monitoring of speed, course and the distance of the deviation from the design route. Both the single-channel seismic method and the high-resolution multi-channel seismic method were adopted during the survey with an underway method. The layout of the survey lines is shown in Fig. 2.

A GEO-SPARK1000 spark source manufactured by the GEO-RESOURCE Company of the Netherlands and a SIG-5M electric spark source manufactured by the SIG Company of France were both used for the single-channel/multi-channel seismic exploration. The spark source was chosen based on previous tests to ensure the resolution and penetration depth. The seismic acquisition system, DELPH WIN developed by the SIG Company, was chosen for the single channel seismic survey. Two receiving cables, GEO-SENSE/24 (with a frequency response of 10 to 10 kHz) and SIG100 (with a frequency response of 10 to 3 kHz) manufactured, respectively, by GEO-RESOURCE and SIG, were also used for the single-channel seismic survey. For the multi-channel seismic survey, a 96-channel seismic acquisition system and a 48-channlreceiving cable (with a frequency response of 10 to 3000 kHz) were used, which were all designed and developed by the First Institute of Oceanography, State Oceanic Administration, China (FIO) and the East China Petroleum Group Co., Ltd., Xi'an Geophysical Exploration Geophysical Equipment Branch.

Data processing: Considering the environmental condition in the surveying area, a key problem in the post-processing of the seismic data was to eliminate the influence of surge and improve the signal-to-noise ratio. The software DELPHWIN was used for the processing

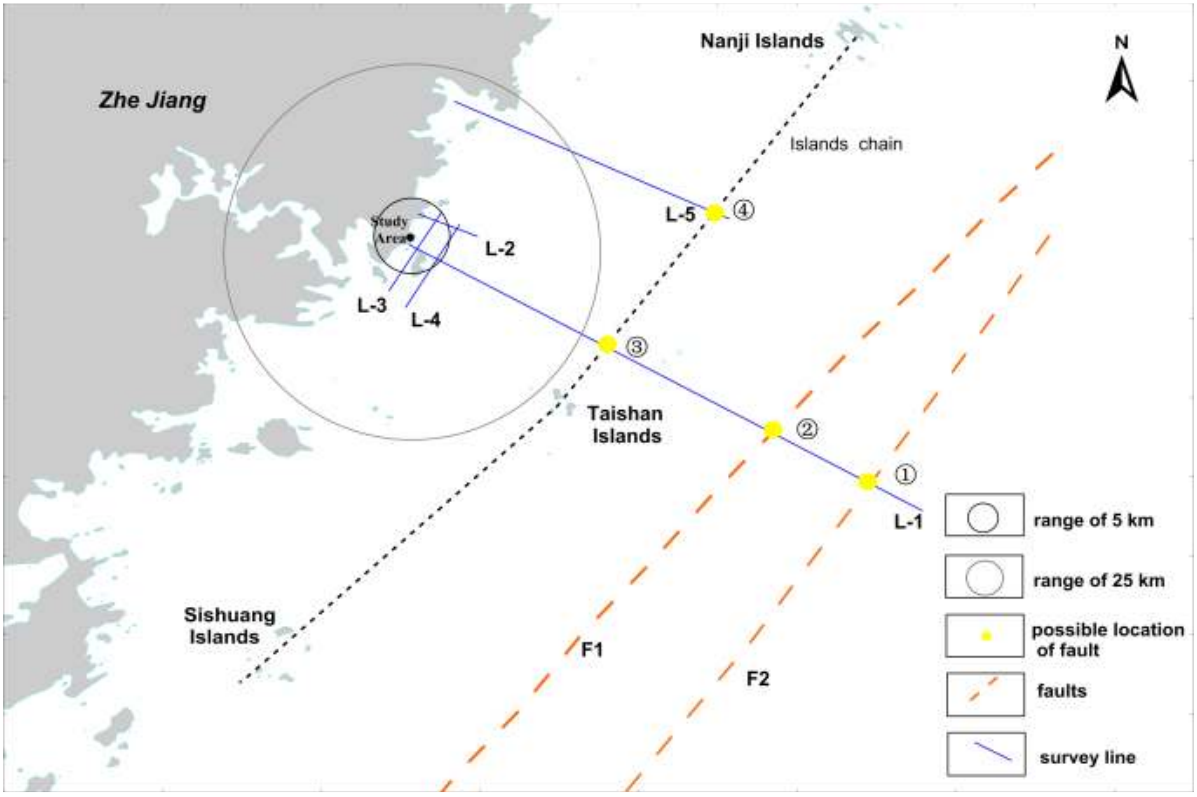

Fig. 2: Layout of the survey lines

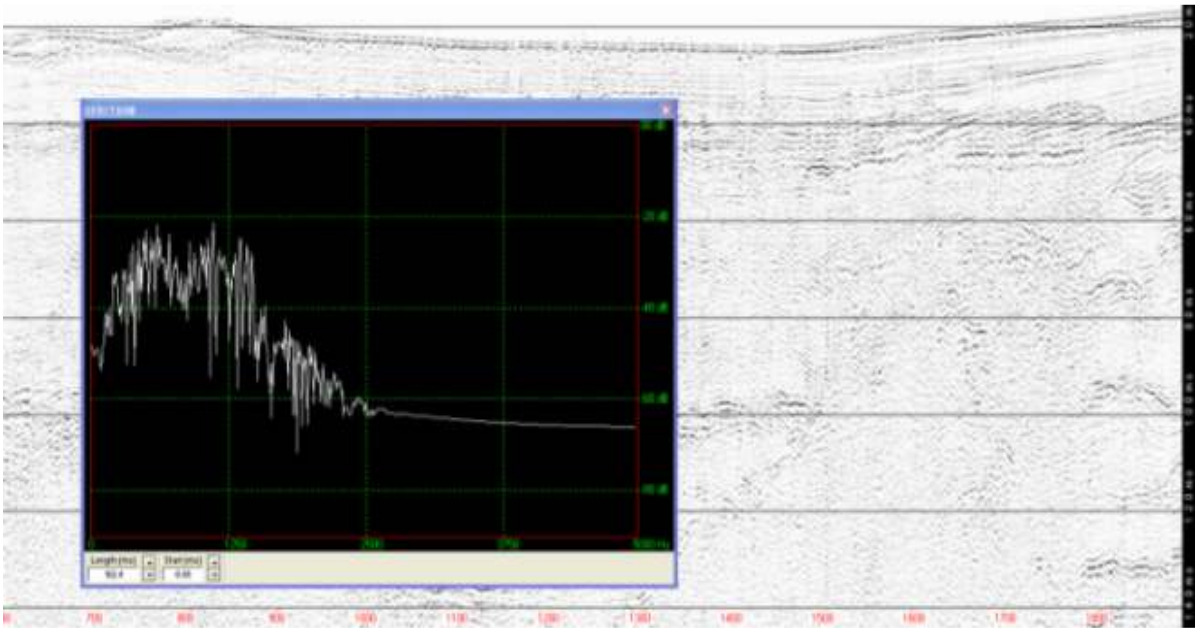

Fig. 3: Processed single-channel seismic profile

of the single channel seismic data, while for the multi-channel seismic data processing, the software, GEOSEIS developed by the FIO and Ocean University of China was adopted as it could retain the high frequency information in the shallow strata (less than 400 ms). Both the software programs have the functions of surge filter, automatic gain control, which can be helpful for improving the noise ratio.

According to the processed seismic data, the single channel seismic reflection data provides a vertical resolution about 1 m (Fig. 3). For the multi-channel seismic reflection data, the GEO-SPARK spark source

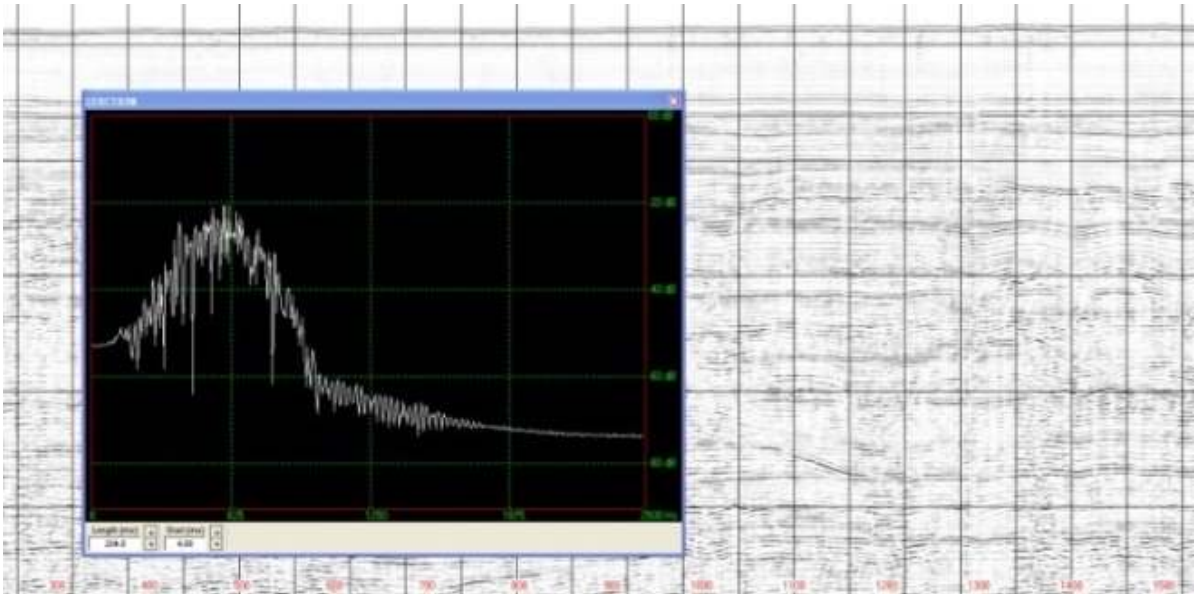

Fig. 4: Multi-channel seismic profiles with GEO-SPARK

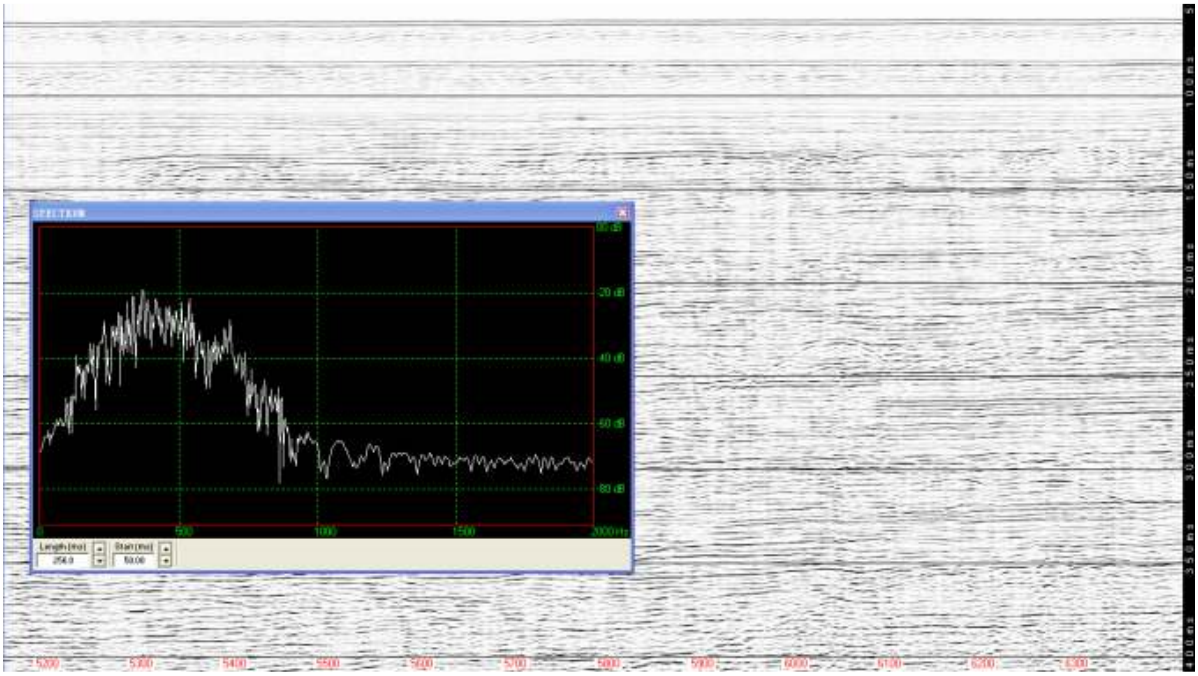

Fig. 5: Multi-channel seismic profiles with SIG-5M

with a dominant frequency of about 650Hz can supply a vertical resolution of 1-2 m (Fig. 4) and the SIG 5M spark source with a dominant frequency of about 500Hz can supply a vertical resolution of 2-3 m (Fig. 5).

RESULTS AND DISCUSSION

By combining the obtained seismic data with the regional geologic data and the seismic data in neighborhood area, the seismic stratigraphy characteristic and faults in the study area are analyzed.

Seismic-stratigraphic division: By comparing the obtained profiles, seven main seismic reflection interfaces are identified by using the seismic stratigraphy method (Payton, 1977). Interfaces shown in Fig. 6, from top to bottom are SB, R_1, R_2, R_3, R_4, R_5 and R_g respectively. SB and R_g denote the modern seabed and the top surface of bedrock respectively. Based on the seismic reflection interfaces, seven seismic sequences are divided from top to bottom, which are designed as A, B, C, D, E, F and G (below R_g), respectively.

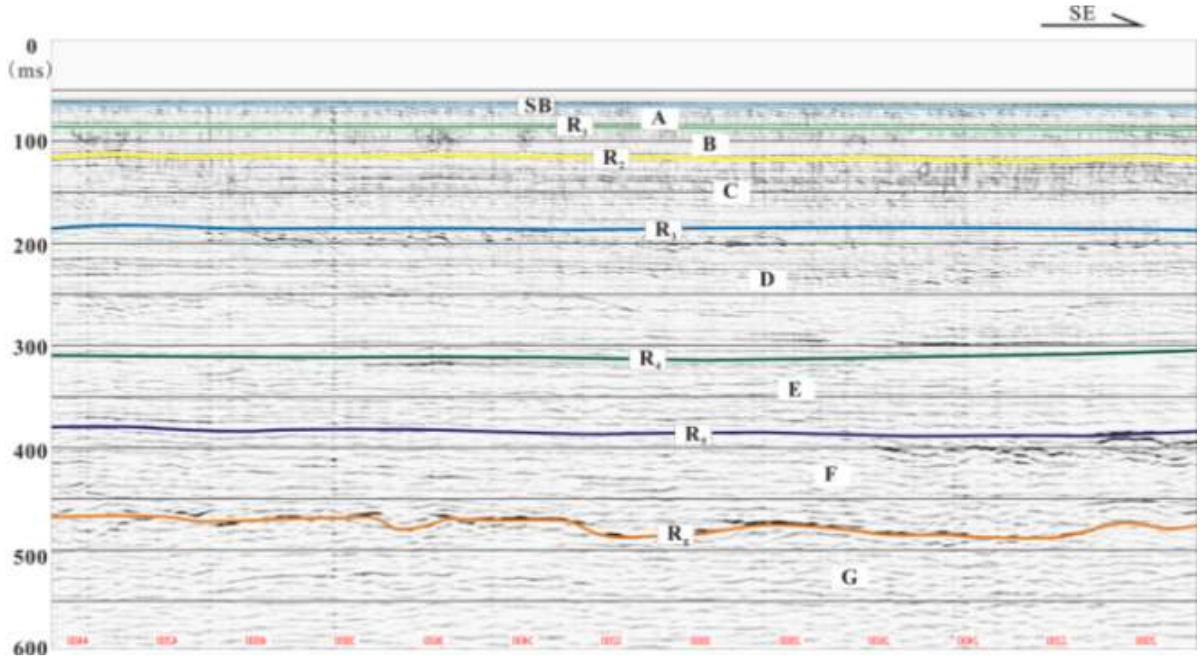

Fig. 6: Stratigraphy and sequence based on multichannel seismic profile

According to the engineering feasibility study result of the Ningde nuclear power plant which is close to the Cang-nan nuclear power plant (China Earthquake Administration, 2006), the different strata are divided considering the significant difference in the reflection characteristics between the continental deposit and marine deposits.

The Quaternary stratum consisting of four seismic stratigraphic units (A, B, C and D) has a thickness of 150m -180 m with an increasing trend in the seaward direction. The Pliocene strata (E) and Miocene strata (F, without penetration) overlying the bedrock, also have a thickness that increases in the seaward direction, while they become thinning and pinch out in the shore ward. In addition, the Miocene strata are also found to occur on the outside of Taishan Islands.

Submarine fault structure: The activity of faults in this study is determined based on both the age of the seismic sequence and the cutting relationship of the seismic sequences. The cutting relationship can be obtained according to the reflection features on the seismic profile, in which faults basically represent the following reflection features (China Earthquake Administration, 2009):

- A dislocation of the reflected wave event
- A sudden increase or decrease of the number of the reflected wave events
- Sudden changes in configuration or feature of the reflection wave event
- The occurrence of messy reflection waves or blank anomaly zone
- A reverse of strong phase of the reflected wave event.

The whole study area is divided into three zones: the Haijiao-dongyin Fault, the islands chain area and the area near the plant (<5 km). The fault activity in each zone is analyzed individually.

Haijiao-dongyin fault: The Haijiao-dongyin Fault presents an obvious linear anomaly of both gravity and magnetic fields. It is also considered to be an extension of the Binhai Fault, which is along the coast of southern China with a NEE strike (Jia *et al*., 2008). During the survey for the Ningde nuclear plant, the location of the Haijiao-dongyin Fault was determined (the fault denoted by F1 and F2 in Fig. 2), based on the multi-channel seismic data of this fracture zone. Based on that work, the survey in the study area is intended to determine the fault activity by using the high-resolution seismic data and a special long survey line, L-1, is designed to be basically perpendicular to this fault zone.

For the proposed fault location, a perpendicular seismic profile is chosen for the analysis. Figure 7 and 8 are part of the seismic profiles of the survey line L-1 and the symbol, "▼," which has also been marked in Fig. 2, denotes the position where breakpoints may be found. As we can see from the two figures, the bedrock fluctuates up and down at the marked locations, while the seismic reflection interface above the bedrock is clear and continuous, indicating no fault movement.

Considering both the characteristics of the gravity and magnetic field and the fault investigation results of

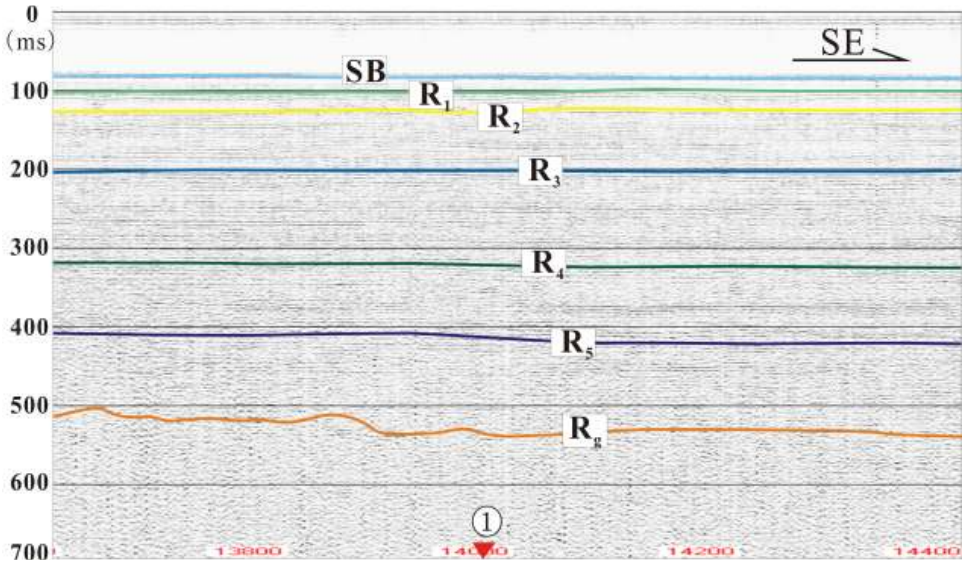

Fig. 7: Seismic profile near the intersection position of the survey line L-1 and fault F2

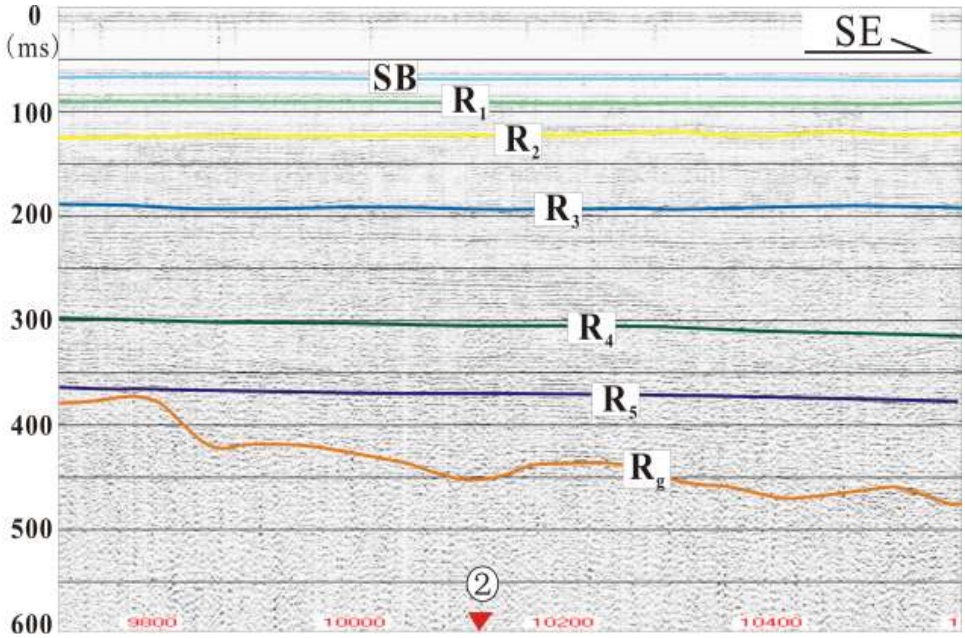

Fig. 8: Seismic profile near the intersection position of the survey line L-1 and fault F1

the Ningde nuclear plant, we conclude that the Haijiao-dongyin Fault is a large scale fault zone in which the faults are found mainly in the Mesozoic volcanic rocks with no penetration of the Neozoic sedimentary stratum in the study area. As the strata are mainly Neogene(N1-Q), with no Paleogene strata found above the bedrock, it can be concluded that the Haijiao-dongyin Fault zone has not shown activity since the Late Miocene(N1).

Fault activity in the islands chain area: The islands chain, including the Nanji Islands, Taishan Islands and Four-Shuang Islands, has a NE direction and is nearly parallel with the shoreline. One purposes of this study is to determine if a fault zone exists along the islands. Two survey lines are designed to be nearly perpendicular to this islands chain and to intersect with the survey lines L-1 and L-5. The profiles are shown in Fig. 9 and 10 and we can see that the bedrock undulates near the islands, while the strata above the bedrock show good continuity with no obvious deformation. Therefore, there is no breakpoint in the sedimentary strata above the bedrock. Considering that only the strata of N2-Q were found in above the bedrock near the islands, we suggest that there are no active faults from the late Pliocene to Quaternary period.

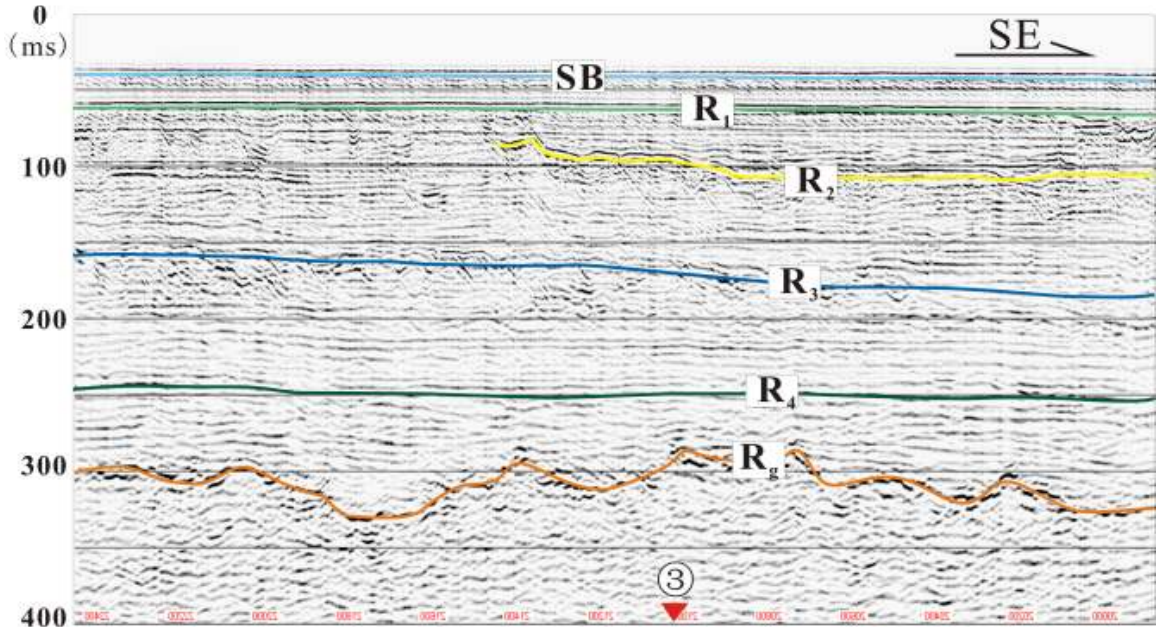

Fig. 9: Intersection position of L-1 and the islands chain

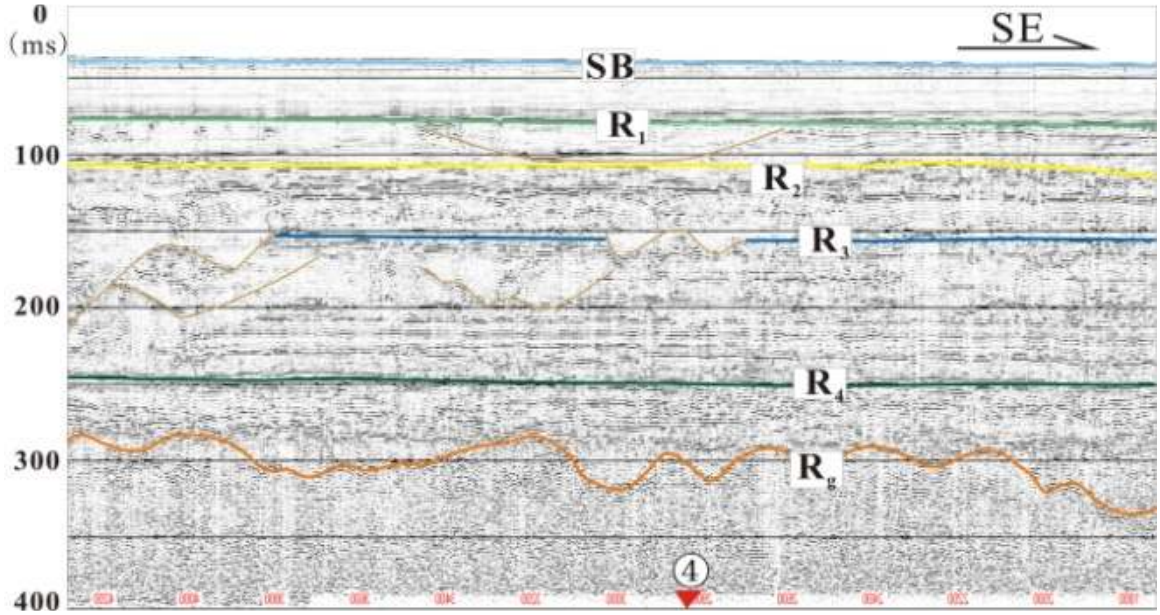

Fig. 10: Intersection position of L-5 and the islands chain

Fault activity in the area near the plant: Five survey lines have been designed in the area near the Cang-nan nuclear plant (<5 km). Based on the survey results and the characteristics of the nearby onshore faults, the fault activity in the area of can be analyzed. The profiles show that the bedrock surface of the nearby area of the plant site is from tens of meters to 150 m below the seabed with apparent undulations. However, there are no obvious deformations or dislocations found in the Quaternary sedimentary layer; therefore, no breakpoint exist. It is concluded that there is no active fault in the study area since the Quaternary.

CONCLUSION

According to the geophysical exploration data and the interpretation of the seismic data, the fault activity in the Cang-nan nuclear power plant site and its surrounding area is obtained. There is no Quaternary active fault in the surrounding area of the Cang-nan nuclear plant; while in the area near the northeastward island chain, which including the Nanji Islands, Taishan Islands and Four-Shuang Islands, there is no active fault from the late Pliocene to Quaternary. The Haijiao-dongyin Fault in the study area has only been found in

the Mesozoic volcanic rocks, which is the basement of the Cenozoic sedimentary strata and it has not shown activity since the Late Miocene. The area of the Cang-nan nuclear power plant site can meet the requirement for stratum stability.

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