Assessment of Submarine Landslide Susceptibility in the Sea Area of Zhoushan

Zhigang Shan\textsuperscript{1}, Fenfen Guo\textsuperscript{2,*}, Xianghua Lai\textsuperscript{2}, and Jingjing Xiao\textsuperscript{3}

\textsuperscript{1} Hydrochina Huadong Engineering Corporation, Hangzhou, China
\textsuperscript{2} Second Institute of Oceanography, MNR, Hangzhou, China
\textsuperscript{3} Zhejiang Climate Center, Hangzhou, China
* Corresponding author: geoguofen@sio.org.cn

Abstract. The research on the submarine landslide susceptibility has important guiding significance for the site selection and construction of marine engineering. The Zhoushan Archipelago New Area is dominated by the marine industry, and the marine engineering under its jurisdiction is densely covered. This research selected the surrounding sea area of Zhoushan island as the study area to evaluate submarine landslide susceptibility. The factors such as seismic peak acceleration, proximity to fault zone, average wave height, slope and sediment types were selected to construct the evaluation index system, all of which were considered to be influential in the occurrence of landslides. Meanwhile, the AHP method was used to calculate the weight of each index factor. In combination with geographical information system, the study area has been classified into five classes of relative landslide susceptibility, namely, extremely low, low, medium, medium-high and high. The research result showed that: (1) The high susceptibility zone in the evaluation result was consistent with the position of historical landslide. (2) The five classes in the result of submarine landslide susceptibility assessment for study area accounted for 1.17%, 1.97%, 9.08%, 56.05% and 31.74% of the total area from high to low, and the area with susceptibility above middle grade mainly distributed in the underwater bank slope around the islands or the slopes position of the tidal current scours. (3) This research was a preliminary study on the susceptibility assessment of regional submarine landslides. It was limited by the availability of evaluation index data and submarine landslide data accumulation in the region. Besides that, the evaluation model was influenced by experience greatly, so the evaluation result had certain subjectivity.

1. Introduction
Submarine landslide is a common sedimentary process, such as slumping and debris flow, which can transport sediments for hundreds of kilometres, seriously endanger deep-water oil and gas development platforms, submarine pipelines, ports and other facilities, and can also trigger tsunamis, endanger the life and property safety of the residents in coastal zone. Waterways are densely distributed in Zhoushan sea area, where the slope instability is widespread. At the same time, the Zhoushan Archipelago New Area is dominated by the marine industry, and the marine engineering under its jurisdiction is densely covered. The frequent submarine landslides pose a great threat to marine development activities. The susceptibility assessment was the basis of the risk assessment for submarine landslides. Research on the assessment of submarine landslides susceptibility in Zhoushan can provide a reference for site selection and disaster prevention of marine engineering in the region.
With the rapid development of GIS and computer technology, the assessment process of landslides susceptibility on land has gradually matured, and the assessment methods also have become more diverse. Multiple regional landslide susceptibility evaluation index systems and models have been established in key geological disaster prevention areas such as the Wenchuan earthquake disaster area, Three Gorges reservoir area and the mountain road. Because of the simple and practical characteristics of some evaluation methods such as analytic hierarchy process (AHP), fuzzy comprehensive evaluation and others were widely used in the landslide susceptibility evaluation models construction. But formation mechanism of submarine landslide is different from the land area. At present, the research about submarine landslide disasters just focused on single slope, there is still lacking the study on susceptibility evaluation of regional submarine landslide. Based on the availability of data, this research selected hazard-formative factors and hazard-formative environment of submarine landslide to construct the susceptibility evaluation index system, with AHP method to carry out quantitatively research on submarine landslide susceptibility assessment in the surrounding area of Zhoushan island.

2. Description of study area
This research took the surrounding marine of Zhoushan island as the study area (Figure 1). It extends to Xiushan island in the north, Jingtang island in the east, Beijilongshan island in the west, and Damao island in the south, including part of sea area of Lianhua ocean, Zhitou ocean, Hengshui ocean, Huibie ocean and Huangda ocean. The total sea area is 1505km², the length is about 67km from east to west, the width is about 45km from south to north, the maximum water depth is -123m and the average water depth is -27m. There are many large waterways in the area, such as Xihoumen waterway, Cizi waterway, Luotou waterway, Panzhi south waterway, Panzhi north waterway, Putuo waterway, Guanmen waterway, Fulimen waterway and Baisha waterway. The study area is located in the northern part of the southeast Zhejiang fold belt. The fault structure framework is mainly in NE direction, supplemented by NW direction. The value of seismic peak acceleration is between 0.05 and 0.15. The main type of sediment is clay silt. There is large area of sand gravel between Zhoushan island and Xiushan island, the south of Dinghai and the west of Zhujiajian island. The south of Jingtang island is mainly fine sand. and there are also many other types of sediment around it, which is named clay, silt, coarse sand and sand-silt-clay. The offshore tidal wave enters the study area from the southeast direction through the inter-island channel. And the flow velocity between the islands is relatively larger, and the flow direction is roughly consistent with the channel or isobath. Affected by strong north and northeast winds, the wave height in the study area is larger in east than that in the West. There were 11 obvious landslides in the study area, by referring to the previous investigation data from Lai Xianghua and Shan Zhigang. Figure 2 is the shallow stratum profile record of submarine landslide in southwest of Zhujiajian island.

Figure 1 Geo-environmental sketch of study area.
3. Method

3.1. Selection and quantification of evaluation index factors

Evaluation index factors selection is the basis of landslide susceptibility evaluation. Previous studies have shown that there are many factors of which are considered to be influential in the occurrence of landslides, and the relationship between them is complex. Lee summarized that the main factors causing submarine landslides are scarification, seismic activity, storm surge, rapid deposition of sediments, release of pore gas, decomposition of natural hydrate, tidal level change, seepage, volcanic activity and high latitude glacial activity. In addition to these triggers, there are also some factors do not play an initial destructive role, such as human activities and unloading. The above factors led to slope instability and submarine landslide occurrence by changing the characteristics of slope soil itself. Based on the availability of impacted factors of submarine landslides in Zhoushan islands, the types of sediment, slope and average wave height were selected as the index factors of hazard-formative environments, and the seismic peak acceleration, proximity to fault zone were selected as the hazard-formative factors in this research. According to the existing research results of slope instability and expert experience, the study found out the control relationship (critical value) of the five evaluation indexes for the submarine landslides occurrence, and the five evaluation index factors were judged and classified. At the same time, quantified as the index value between 0 and 1, based on the "contribution" of different indexes for the occurrence probability of landslides.

The data of fault zone in the research was from 1:500 000 sediment map of coastal zone in China (Shanghai part), the seismic peak acceleration data was from the 1:500 000 earthquake epicenter and seismic peak acceleration zoning map of coastal zone in China (Shanghai part), the data of sediment types was from 1:250 000 sediment map of Zhoushan area, the terrain data was from 1: 10 000 marine surveying and mapping results of Zhejiang Province, The average wave height data was from marine energy special project. The following Table 1 shows the quantification of the evaluation indicators in this study.

| Indexes types and weights | Indexes and weights | Index classification | Quantification value |
|--------------------------|---------------------|----------------------|----------------------|
| Disaster-causing indexes | seismic peak acceleration (0.222) | 0.05-0.1g | 0.1 |
| (0.334)                  |                     | 0.1-0.15g | 0.2 |
|                          | distance to the fault zone (0.112) | <5km | 1 |
|                          |                     | 5-10km | 0.9 |
|                          |                     | 10-15km | 0.8 |
|                          |                     | 15-20km | 0.7 |
|                          |                     | 20-25km | 0.6 |
|                          |                     | >25km | 0.5 |
| Disaster-pregnant environment indexes (0.666) | Average wave height (0.082) | <0.2m | 0.1 |
|                          |                     | 0.2-0.3m | 0.2 |
|                          |                     | 0.3-0.4m | 0.3 |
|                          |                     | 0.4-0.5m | 0.4 |
|                          |                     | 0.5-0.6m | 0.5 |
3.2. Evaluation model and method

The analytic hierarchy process (AHP) is a simple, flexible and practical multi-index weight calculation method, which will formally express and process the subjective judgement of experts, and gradually remove the subjectivity, it is a quantitative analysis method for qualitative problems. This study used AHP to build a judgment matrix of relative importance for evaluation indexes relying on the experience of experts, and the eigenvector corresponding to the largest eigenvalue of the judgment matrix was calculated to determine the weights of evaluation index factors (Table 1). Then the evaluation factors were weighted and accumulated to generate the regional submarine landslide susceptibility assessment model.

3.3. Assessment of submarine landslide susceptibility based on GIS

The spatial analysis function of ARCGIS was used to create the buffer zone for fault zone, classify and quantify the five evaluation factors according to the following table 1; According to the evaluation model constructed above, the quantitative evaluation of landslide susceptibility in the study area was realized through the spatial operation function. In order to analyse the spatial distribution characteristics of landslide susceptibility intuitively, the natural breakpoint method was used to classify the study area into five classes of relative landslide susceptibility, namely, extremely low, low, medium, medium-high and high.

| Sediment types (0.213) | >0.6m | 0.6 |
|------------------------|-------|-----|
|                        | Clay  | 0.9 |
|                        | Clay silt | 0.7 |
|                        | Silt  | 0.5 |
|                        | Fine sand | 0.3 |
|                        | Sand-silt-stick | 0.2 |
|                        | Coarse sand, gravelly sand | 0.1 |

| Slope (0.371) | <3° | 0.1 |
|---------------|-----|-----|
|               | 3-5° | 0.2 |
|               | 5-10°, >45° | 0.3 |
|               | 10-15°, 35-45° | 0.5 |
|               | 15-20°, 25-35° | 0.7 |
|               | 20-25° | 0.9 |

4. Result Analysis

Figure 3 shows the susceptibility zone of the surrounding sea of Zhoushan island. In order to analyze the rationality of result, there were 11 historical landslide position data and the evaluation results were overlapped in space. The results indicated that they have good consistency: 3 points were located in the...
high class zone, 7 points were located in the medium-high class zone, and only 1 point was located in
the medium class zone.

The assessment results showed that the five classes of high, medium-high, medium, low and
extremely low were 17.56km², 29.60km², 136.59km², 843.61km² and 477.67km² in sequence,
accounting for 1.17%, 1.97%, 9.08%, 56.05% and 31.74% of the total area respectively. The study sea
area is mainly low susceptibility zone. The proportion of susceptibility zone above the medium class is
a little, where are mainly distributed over the underwater bank slope around the islands or the slopes
position of the tidal current scours. The high class zone is concentrated in the sea area between the
southwest side of Zhujiajian island and Dengbu island, the sea area between the islands on the south
side of Zhoushan Dinghai, the west side and the south side of Xiushan island, where the place near tidal
current scours with large relief, short length, small width-depth ratio. On the contrary, it is relatively few
in the surrounding area of large tidal current scours, such as Luotou waterway, Cezi waterway,
Xihoumen waterway and other waterway areas.

5. Conclusion and discussion

This research took the surrounding sea area of Zhoushan island as the study area, selected five factors
from hazard-formative factors and hazard-formative environment of submarine landslide, which were
seismic peak acceleration, proximity to fault zone, average wave height, slope and undersea sediment
types, which constituted the evaluation index system of submarine landslide susceptibility. Meanwhile,
determined the weighting coefficients of each index factor through the method of AHP to construct the
evaluation model of susceptibility evaluation. Then classified the landslide susceptibility of the study
area into five classes: extremely low, low, medium, medium-high and high. The evaluation results were
consistent with the historical landslide position data. The evaluation method and process of this research
can be used as a reference for the assessment of the landslide susceptibility in other sea area.

The evaluation results showed that the low landslide susceptibility zone accounted for 87.79% of the
total study area, mainly covered by the flat area or the bottom of the tidal current scours dominated by
coarse sand and gravel sand. The landslide susceptibility zone above medium class accounted for 12.21%
of the total area, where mainly distribute in the underwater bank slope around the islands or the slopes
of the tidal current scours. The high landslide susceptibility zone is concentrated in the slop of the tidal
current scours with large relief, short length, small width-depth ratio. The results will provide a reference
for site selection and disaster prevention of marine engineering in the region.

This research is a preliminary study on the regional submarine landslides susceptibility assessment,
and there are still some deficiencies. Limited by the availability of reference, the adopted evaluation
indexes are not yet perfect, at the same time, the spatial scale of seismic, fault zone and average wave
height indexes were large, and the detailed information in the evaluation results was mainly affected by
sediment types and slope. With the expansion of investigation contents, such as natural resources,
ecological environment and other investigation contents, the accuracy of the assessment result will be
increased, and more high-precision landslide influence factors will participate in the evaluation, which
will further improve the reliability of the evaluation results.

Because of the limited historical disaster data collected in this study, the correlation between
landslide disaster occurrence and evaluation factors haven’t been analyzed effectively. In the research
process, the construction of the evaluation index relative importance judgment matrix and the index
factor grading and quantification depended on the experience of experts, which was subjective.
Therefore, the accuracy of evaluation results was also affected by expert experience, and the evaluation
model was not enough to promote. With the continuous progress of seabed geological environment
survey technology, automatic identification technology of special landforms and sediment types,
accumulated date for submarine landslide disaster, all that will provide conditions for the correlation
analysis between disaster occurrence and environmental factors. They will also provide sufficient
samples to construct an evaluation model based on machine learning algorithms, enhancing the
effectiveness of evaluation index system. The objectivity of the evaluation method will be conducive to
ensuring the accuracy of assessment results.
References

[1] Du Jun, Li P, Li P, et al. (2014) The seabed stability zonation based on the marine geohazards evaluation in China. Acta Oceanologica Sinica. 36(05):124-129.

[2] Jian H, Deqiang T, Qiao X. (2015) Geological Environment and Hazard Geology in Coastal Zone of China. Guangdong Chemical Industry. 42(15) 121-123.

[3] Xianghua L, Yincan Y, Qianchun X. (2000) A Study of the Distribution and Mechanism of Subaqueous Landslides in the Tidal Channel Region of the Northern Inshore, Zhejiang Offshore. Marine Geology & Quaternary Geology. 20(02) 45-50.

[4] Ke L, Jianhua W. (2017) Development characteristics and cause mechanism of the submarine landslides in Zhujiang River Mouth basin. Marine Science Bulletin. 36(01) 60-66.

[5] Hongcheng S, Tinglu C, Xiaoming X, et al. (2019) Distribution characteristics of subaqueous landslides in the sea area of Liuheng Island, Zhoushan. Journal of Marine Sciences. 37(01) 59-66.

[6] Lei W, Shiguo W, Qingping L, et al. (2016) Submarine slides and influencing factors in the continental shelf break area of the Pearl River Mouth Basin. Marine Sciences. 40(05) 131-141.

[7] Shiguo W, Shanshan C, Zhijun W, et al. (2008) Submarine Landslide and Risk Evaluation on Its Instability in the Deepwater Continental Margin. Geoscience. 22(03) 430-437.

[8] Yuanqin X, Lejun L, Peiying L, et al. (2015) Geology disaster feature and genetic analysis of typical islands, China. Acta Oceanologica Sinica. 37(09) 71-83.

[9] Xiaomei Z, Xueling W, DU Qingyun, et al. (2017) Research on Geo-informatic Graphic Methodology of Landslide Disaster Risk Zoning in Zhejiang. Geomatics World. 24(03) 19-24.

[10] Yangfei Z, Qinou L, Degen L. (2019) Research on mapping of landslide geological hazard risk map in Zhejiang region, China. Territory & Natural Resources Study. 2019(03) 34-41.