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A STUDY ON FAULT MODELING FOR THE JAPAN SEA AREA BASED ON THE OFFSHORE FAULTS RESEARCH PROJECT

T. Ohsumi(1), H. Fujiwara (2)

(1) *Principal Research Fellow, Integrated Research on Disaster Risk Reduction, National Research Institute for Earth Science and Disaster Resilience (NIED) t_ohsumi@bosai.go.jp*

(2) *Director, Integrated Research on Disaster Risk Reduction, National Research Institute for Earth Science and Disaster Resilience (NIED) fujiwara@bosai.go.jp*

Abstract

To investigate fault modeling in the Off shore Fault Evaluation Group, the Japan Agency for Marine-Earth Science and Technology (JAMSTEC) has collected marine seismic industry, velocity structure, and observational well data to create a three-dimensional structure database under high quality control. The marine seismic industry data from the Japan Sea have been re-processed since 2014. By combining these and past data, a new analysis of the fault data was made and a unified fault interpretation was developed. Based on the results, continuous fault configurations were confirmed against structural geology and topography measurements. By interpreting the finished model, the National Research Institute for Earth Science and Disaster Resilience (NIED) is presently creating a list of main faults from a distributive fault in the Japan Sea. The validity of the fault model was examined by constructing a model for the 1940 Shakotan-Oki earthquake.

Keywords: seismic profiling; fault; Japan Sea; Shakotan-Oki earthquake, linkage fault

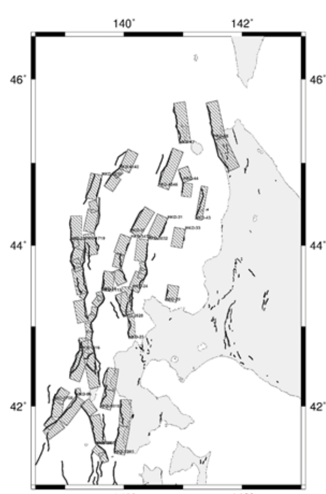
1. Introduction

In 2013, the Japan Ministry of Education, Culture, Sports, Science and Technology launched the "Project for fault evaluation in the sea around Japan". The purpose of the project is to contribute to the hazard assessment of earthquakes and tsunamis in the Japan Sea. At the moment, tomographic information for the area obtained from previous surveys conducted by various agencies around the Japan Sea is insufficient. The collection of reflection seismic data and their re-analysis with the latest data processing technology in a unified manner is also intended to develop tomographic information in a standard format.
In this project, we collected offshore fault survey data, analyzed the data using a uniform method, and constructed a database. This study was carried out as a subtheme of project for fault evaluation in the sea around Japan. The purpose of this work was to construct a fault model based on the geological fault information analyzed by the Japan Agency for Marine-Earth Science and Technology (JAMSTEC). We constructed two types of fault model: primary and consolidated. The primary model is based on the fault information from project for fault evaluation in the sea around Japan. The consolidated model is considered the possibility of continuing on the fault distribution and consolidates the deeper part of the fault. This model is represented as the combination of specific primary models.

2. Fault Database

To construct the primary model, we defined the following guidelines for each parameter setting that consider epistemic and aleatory uncertainties.

The “position, length, and strike of the fault” is based on geological fault information from project for fault evaluation in the sea around Japan and “depth at the top of fault” is at the seabed. We constructed two types of settings for “fault dips”. One type of setting defines the basic values of a thrust fault as 45 deg., normal fault as 60 deg., and strike/slip fault as 90 deg. Another setting is used for the “apparent dips” from project for fault evaluation in the sea around Japan where the shallow part of the fault steeply dips, set by the apparent dips from geological data, and the deeper part has gradual dipping that is adjusted to 45 deg. or 60 deg., based on the average of all of the fault dips. The “bottom depths of the fault” are two patterns, one of which uses a 3D velocity structure model provided by this project, and another that is based on a previous study of the Japan Sea area. “Fault width” is set based on the relationship between the bottom depth of the fault and the dip angle, and the “fault rake” is set as 90 deg. for a thrust fault, 270 deg for a normal fault ., 0 deg for a right lateral fault., and 180 deg for a left lateral fault . The “average of fault slips” is set by the empirical relationship between the fault area and M_w by Irikura and Miyake, 2001. We also considered large slip areas to account for 30% of the fault area and a twofold average of slip. Fig.1 shows a fault modeling example.



Geological fault information by JAMSTEC

Rectangle multiplied by the hatch shows the fault models.

Fig.1 Fault modeling example. Solid line indicates the fault trace by JAMSTEC, and the shaded rectangle shows the fault model set by the present study.

3. Validity of the Fault Model

The purpose of this study was to verify the fault modeling in the source region of the 1940 Shakotan-Oki earthquake, which was caused by active marine faults offshore from Japan. The tsunami wave heights simulated by fault models proposed by previous studies [1, 2] have been lower than the observations, which has made it difficult to explain the historical tsunami records of the Shakotan-Oki earthquake. However, the application of appropriate slip magnitudes in the fault models may be able to explain these differences. In this study, a new fault model was constructed using marine seismic industry data, and geological and geophysical data compiled from the "Project for fault evaluation in the sea around Japan". The marine seismic industry data included information from a new fault that was located to the north of the existing fault, investigated in previous studies. The geometrical continuity of these faults was adjusted, whereby the magnitude of the fault slip was increased. We applied the standard scaling laws based on strong ground motion for the fault parameters. The validity of the fault model was examined from a comparison of tsunami wave heights on the Japanese coastline between historical observation records and the tsunami simulation analysis, and quantified with scale and variance parameters referred to as Aida's K and κ. Based on these results, the simulated tsunami wave heights using the new model approached the heights observed in the historical records. This indicates the validity of the model for accurately modeling the source region. In future studies, more reasonable results are expected by considering asperities and the fault parameters located in the shallow part of the source region.

3.1 Methodology

The fault model was distributed across the epicentral area of the Shakotan-Oki earthquake about $M7.5$ ($M_w7.7$) that occurred on August 2, 1940. The fault model using the fault trace was the basis of the observational data by marine seismic industry data with JAMSTEC, approximating the fault plane in a rectangular model. The validity of the fault model was compared with the observed record of the tsunami that occurred during the 1940 Shakotan Peninsula-Oki Earthquake and the maximum tsunami water level on the Japan Sea coast obtained by the tsunami propagation analysis using this fault model. The validity of the fault model was assessed by quantifying the size and dispersion of the tsunami wave heights along the Japanese coastline between historical observations and the tsunami simulation analysis, and quantified with scale and variance parameters, referred to as K and κ values, respectively, by Aida (1977) [3]. The K value ranges from 0.95 to 1.05. The κ value is satisfied below 1.45, and considered to be well adapted at 4, which is a measure of reproducibility [4].

3.2 Fault Model Setting

The rectangular fault model was considered to approximate the fault plane from the fault trace of the sea. The fault model/fault model group, as the minimum unit, is referred to as a basic model. Each basic model constructed in the offshore faults on the west coast of Hokkaido was labeled HKD-xx (where xx is a number). The basic mode, which is located at the epicenter of the 1940 Shakotan-Oki Earthquake, is HKD-38. The basic models, which are located to the north and south, are HKD-39 and HKD-22, respectively.

3.3 Validity of the Fault Model

To validate the fault model of the fault trace of the sea created in this project, we used the basic HKD-38 model corresponding to the closest fault trace in the epicenter of the 1940 Shakotan-Oki Earthquake. The model was compared with the observed record of the history of the tsunami traces and observations from an automatic tide-gauge station by evaluating the reproducibility.

However, the basic model HKD-38 was not similar to the 1940 Shakotan-Oki Earthquake, or the observed record. The basic model is therefore not sufficient in the vicinity of the epicenter, and the linkage model is a possibility in conjunction with a basic model. Therefore, we applied the rupture model to reproduce the 1940 Shakotan-Oki Earthquake. We also considered the basic model HKD-38 with the linkage model, the HKD-39 model and two linkage fault north of HKD-38 (HKD-3839), and HKD-22 and two linkage fault to the south of HKD-38 (HKD-2238). HKD-38 was also compared with the observations recorded to the north, and three of the linkage patterns of faults, and three linkage fault to the south (HKD-2239).

3.4 Evaluation of the Fault Models

The maximum wave levels were compared along the west coast of Hokkaido with trace data and tide gauge records using the tsunami propagation analysis for the basic model. We evaluated the fault models based on the value of K-κ.

We used the trace data and tide gauge records of the 1940 Shakotan-Oki Earthquake from the International Research Institute of Disaster Science (IRIDeS) of Tohoku University. We used 61 out of 116 records [5] and inundation heights, except for the records that overlap in this study.

The Honshu records were located only six points from the epicenter. Records from the west coast of Hokkaido were used to verify the reliability. In this area, because the high level of reliability of the records (reliability of the A and B levels) is only three points, it is difficult to estimate a value of K-κ. Therefore, it was difficult to determine whether the measure was statistically accurate or not. Based on the confidence levels of the trace data of C and D levels, this study used all 49 records that include C and D levels. These 47 trace data and two tide gauge records were near the coast, and all of the observation records used correspond to the 50 m computational grid.

3.5 Comparison with Previous Studies

We compared our model with those from previous studies by Okamura (2005) [4] and Satake (1986) [5]. From the comparison with these two models, different trends can be seen in the scale of the coastal tsunami wave height caused by the difference in the geometries of the fault models. The parameters of the fault model used in this study are listed in Table 1. Fig. 2 shows the fault models.

Table 1 Parameters of the fault model

Fault Name	Mw	Upper depth km	Rakes deg	Dips deg	Slip deg	Length km	With km	Slip ave.,m
HKD-38	7.1	0.0*	176 189	45*	90*	22.3 30.3	16.9	1.50
HKD-2238	7.2	0.0*	176 189 167	45*	90*	22.3 30.3 28.9	16.9	2.20
HKD-3839	7.2	0.0*	189 162 189	45*	90*	33.9 15.1 30.3	16.9	2.10
HKD-2239	7.4	0.0*	189 162 189 167	45*	90*	33.9 15.1 30.3 28.9	16.9	3.00
F07_C	7.4	2.4	176 201 167	45	54 76 48	29.0 21.6 25.3	17.9	3.70
F07	7.2	2.4	176 201 167	45	54 76 48	29.0 21.6 25.3	17.9	2.20
Okamura2005	7.5	0.0*	22 184 162 0	45	90*	42.0 42.0 37.0 53.0	16.0	1.64 2.23 2.74 0.58
Satake 1986	7.4	0.0*	167	50	90*	100.0	35.0	1.50
Fault Name	Mw	Upper depth km	Rakes deg	Dips deg	Slip deg	Length km	With km	Slip ave.,m

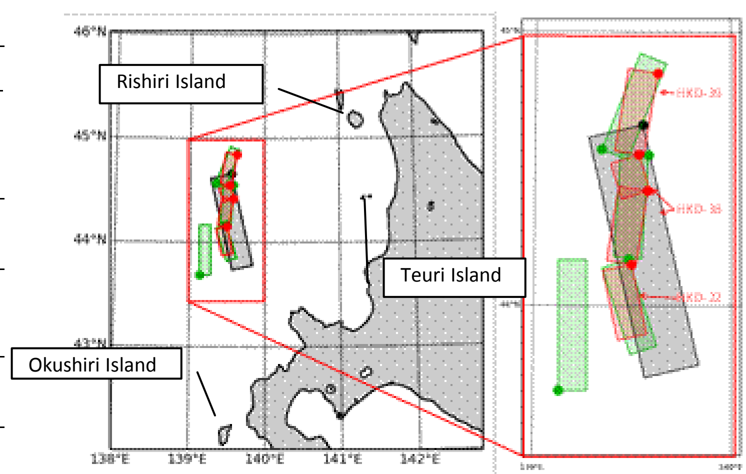


Fig. 2 Fault models

3.6 Calculation of the Tsunami Propagation Analysis

The governing equations of the numerical calculation and the tsunami simulation with non-linear long-wave theory takes into account the friction and advection on the seabed using the Leap-frog finite-difference method (FDM) of a staggered grid. The computation time interval of the FDM for each computational grid spacing was appropriately set based on a consideration of the CFL with the stability of the calculation.

For boundary conditions, we used a full non-reflective transparent boundary for the incoming tsunami reaching and running up an inland area. The initial water level was set as the vertical component obtained from the vertical direction, and we calculated the seabed variation considering the horizontal level [6, 7]. The tide conditions of the tsunami propagation analysis were T.P. = 0.0 m. The maximum wave level was calculated at the target area. To verify the maximum wave level, we compared the calculation and the observed value at the coastal zone. This level was corrected by the tide during the occurrence of the tsunami during the Kamui-Oki Earthquake. The computation time was defined from the arrival time of the reflected wave of the tsunami at the coast. The first wave of the tsunami based on the tide gauge records [5, 8, 9] was confirmed to have reached the Noto Peninsula and Shimane Prefecture coasts within 2 hours of the earthquake.

In the 1993 Hokkaido Nansei-Oki Earthquake and the 1983 Nihonkai-Chubu Earthquake, the tsunami propagation time of the maximum wave level was between 5 hours from 2 after the earthquake occurred because of the reflected wave from the continent [10, 11]. Therefore, the calculation time was set at 6 hours at 5 hours/more.

4. Results

Fig.3 shows the maximum wave levels in the tsunami propagation simulation on the west coast of Hokkaido. The maximum tsunami water level on the coast was relatively high along the coast from Area 9 to Area 11. However, this level was lower in parts of Area 10. We conclude that the wave direction line was dependent on the sea topography and the location of Teuri Island. Other models also showed the same tendency.

Fig. 4 shows simulation levels of the maximum wave level along the west coast of Hokkaido (blue) and the observation records (red) with average wave heights (grey).

The Shakotan Peninsula peak was observed as equal to, or greater than, 3 m along the coast (Table 1; Parameters of the fault model [12]) to Wakkanai (Area 7). A maximum value of 5 m or more occurred on the west coast of Teuri Island (Area 11) caused by the use of fault models HKD-2238, HKD-2239, and Okamura (2005) near HKD-39, which is located slightly to the north. The waves produced by the fault were concentrated in the west coast of Teuri Island. The simulated maximum wave level was 2 m on Okushiri Island (Aria 17). This result occurred in fault models HKD-3839, HKD-2239, and Okamura (2005). We conclude that this was caused by the significant effects of rakes and slip models, which are located in the southern part of the area close to HKD-22.

Table 2 shows the K-κ values of the simulated maximum wave levels and observational records. In any fault model where the K value became greater than 1.0, the simulated maximum wave level was below the observations. K values of the linkage fault models (HKD-2238, 3839, and 2239) ranged from 1.1 to 1.5. The K value of the basic fault model HKD-38 was 1.9. By considering the linkage, the rupture area was widely, because the seismic moment and the average slip were also increased by the scaling law [13]. In this study, as the tsunami scale increased, the K value decreased.

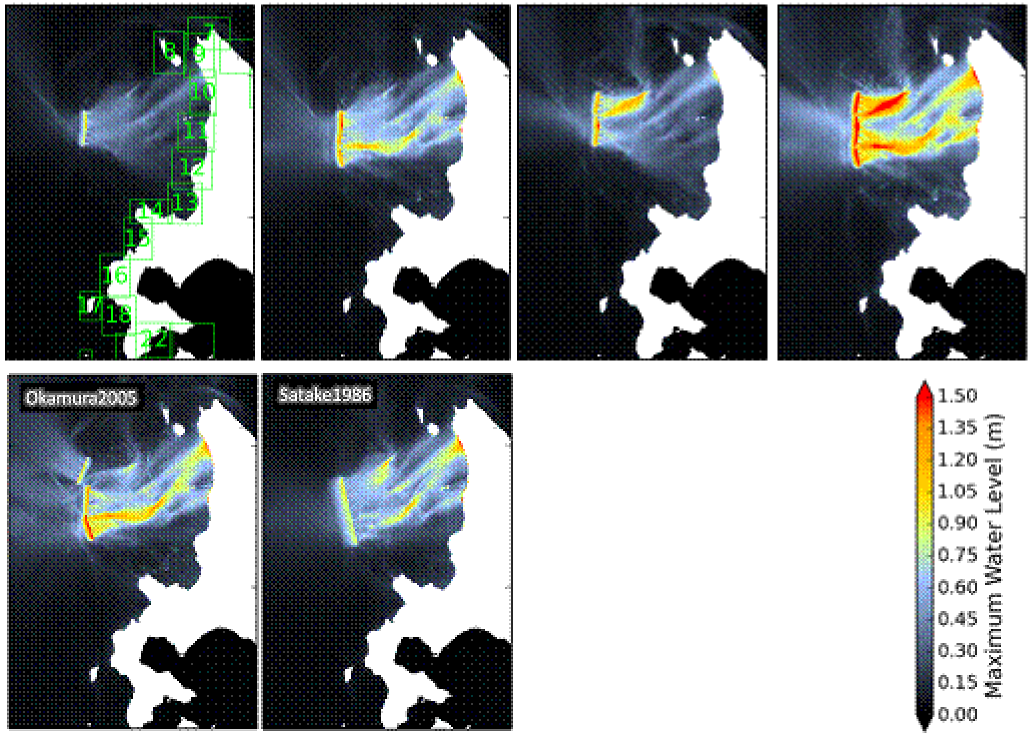


Fig.3 Maximum wave levels based on the tsunami propagation simulation on the west coast of Hokkaido.

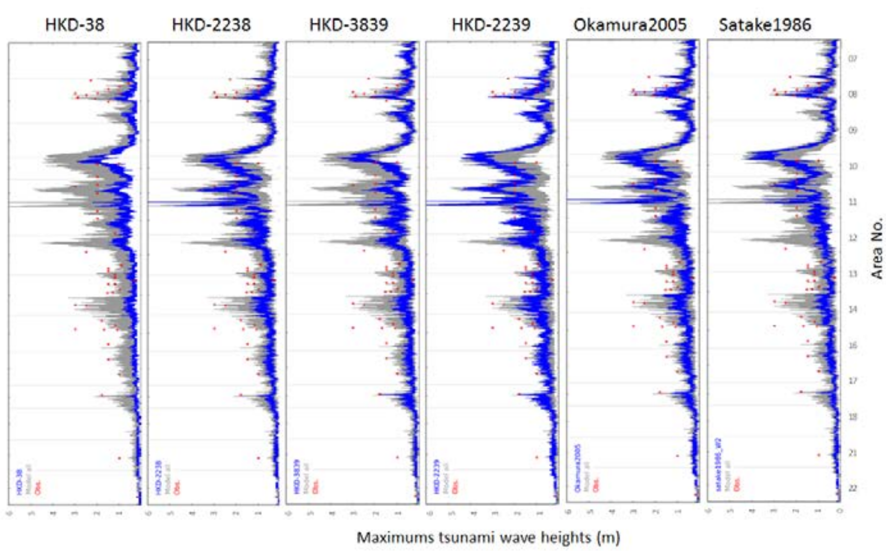


Fig. 4 Simulation levels of maximum tsunami wave height along the west coast of Hokkaido (blue) and the observation records (red) with average wave heights (gray).

5. Conclusions

This study aimed to verify the validity of a fault model based on the rupture area of the 1940 Shakotan-Oki Earthquake. To test the model's validity, we conducted a tsunami propagation analysis based on a fault model presented in this study [4, 5] and a fault model from previous work [12]. The maximum wave level and the trace of the coast were used to calculate the K-κ [1] values from the data and tide gauge records. We then discussed the scale of the tsunami evaluation.

The simulation results in this study increased, and all K values of the fault models were over 1.0. For the six fault models, verification showed that all cases had been underestimated. The linkage model HKD-2239 was not placed in a large sliding region, and the average slip amount was used based on the scaling law [13], which has been used for the purpose of a strong ground motion scaling law. The resulting K value was 1.17. This result need to increase the reproducibility depending on the setting of the fault model.

In future work, the seabed topography should be incorporated into the model setting. It should also be verified so that tsunamis caused by earthquakes in the past can be explained.

6. Acknowledgements

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