Tide and storm surge simulation for Ryo-Mong invasion to Hakata Bay

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Abstract

The second battle of Hakata Bay, known as the battle of Koan, was the second attempt by Koryo (Korea) and Mongol to invade Japan in the summer of 1281. In August 1281, Ryo-Mong invasion attempt failed due to the typhoon which sunk a sizable portion of the Mongolian fleets. The Japanese called this typhoon as divine wind (Kamikaze in Japanese). In this study an integrally coupled wave-tide-surge model was used to the simulation of wave and storm surge due to the typhoon in August 1281. The track and strength of this typhoon are reported to be similar to those of typhoon Songda recently experienced in 2004 (typhoon 200418) (Imamura, 2005). Because of the lack of observations and historical records for 1281, the meteorological data in August 1281 were estimated using the Dynamic Holland model and information of typhoon Songda. The tide and storm surge simulation for typhoon Songda using the same method to acquire meteorological data as that of the typhoon in August 1281 (the battle of Koan) was performed for the model validation. The model based on this method reproduced reasonably the water levels in Kyushu and the Seto Inland Sea, Japan. This study estimated the wind field, wave properties and tide and storm surge for August 1281. It is supposed that the maximum wave height was almost two times higher than the significant wave height computed by the model, i.e., the maximum wave height was approximately 4-6 m, which was sufficiently large damaging river-run flat-bottomed fleet, and the high surge storm surge did not arise due to the counter-clockwise wind of the typhoon in 1281.

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Keywords: Ryo-Mong invasion ; wave ; tide ; storm surge ; coupled wave-tide-surge model ; unstructured mesh

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1. Introduction

There were two Ryo-Mong (Koryo and Mongol joint forces) invasion attempts in 1274 and 1281. Koryo was a Korean dynasty established in 918, and then lasted until 1392. The first and second Ryo-Mongol invasions are known as the first and second battle of Hakata Bay. In addition, taking Japanese era name, those two are called the battle of Bunei (1274) and the battle of Koan (1281) in Japanese, respectively. Both two invasions had failed due to the typhoon, therefore the Japanese called these typhoons which chased away their invaders divine wind (Kamikaze in Japanese) afterwards. Ultimately, the invasion attempts ended in failure, but these events are regarded as the macro-historically important ones, because Mongol expansion in the world was restricted.

During the first battle of Hakata Bay in 1274, the troops of Yuan, which was found by Mongols, withdrew and took refuge on their ships due to the typhoon which occurred on someday night. They were threatened by the typhoon, so returned to Korea. Many of returning ships sank that night, and as a result the Yuan lost roughly one-third of their force due to that typhoon. In the spring of 1281, corresponding to Koan 4th year of Kamakura period (1192 - 1333) during the second invasion, the Mongols dispatched two separate forces. An impressive force (northern fleet) of 900 ships containing 40,000 – 56,989 men set out from Happo (currently Masan), Korea, whereas a much larger force (southern fleet) of 100,000 men who were loaded in 3,500 ships sailed from southern China. The Ryo-Mongol’s force with about 140,000 – 156,989 men and 4,400 ships in total was unprecedentedly the world’s largest force. Their Mongol fleet set sail, suffered heavy losses at Tsushima, Japan, and returned. During the summer of 1281, the fleet attacked Iki Island (Iki-shima), moved to Kyushu and then landed at several different places in Kyushu. In a number of individual skirmishes, known collectively as the battle of Koan or the second battle of Hakata Bay, the Mongol forces met with a repulse to their ships, because the Japanese army was greatly outnumbered by the Mongol forces but constructed fortified area along the coastline, and enable auxiliaries that were launched against it to repulse. Beginning August 15, the massive typhoon, called as Kamikaze, scorched the shores of Kyushu for two days, and destroyed many Ryo-Mongol fleets. The typhoon sunk a considerable portion of the Ryo-Mongolian fleets. In addition to the typhoon, the additional factors for the destruction of the Ryo-Mongol fleet are currently mentioned. Most of the invading army was composed of flat-bottomed Chinese riverboats that were obtained hastily and ships that were made in Koryo. According to history of Koryo, Southern Song, which is Chinese era name, ships cost was too high and their production was too slow, so they were obliged to produce ships using traditional types instead. Consequently, like the riverboats, these ships had a curved keel to avoid the overturn, so they were prone to be shipwrecked by high waves, let alone powerful typhoon. The typhoon which happened in 1281 was said to be much stronger than that in 1274, so the damage in 1281 was much larger. According to hydrography journal (Imamura, 2005), the track and strength of the typhoon on 15 August 1281, are similar to those of typhoon Songda recently experienced in 2004 (typhoon 200418). We reproduced the typhoon which occurred on 15 August 1281, sunk and destroyed enormous ships using the integrally coupled wave-tide-surge model and wind field created by Holland model (Holland, 1980). We also, as a real case, the tide and storm surge simulation for typhoon Songda using the same method as the typhoon which occurred in the summer of 1281 (the second battle of Hakata) was performed for the model validation. The wave and storm surge in August 1281 estimated using the integral
simulation of wave-tide-surge modeling are presented and discussed with the speculated meteorological conditions of those days.

2. Numerical model

We used SWAN and ADCIRC model as wave and tide-surge models in this study. SWAN (Simulating WAves Nearshore) predicts the evolution in geographical space and time of the wave action density spectrum, with the relative frequency and the wave direction, as governed by the action balance equation (Booij et al., 1999). The details of model have been described in the previous studies (Booij et al., 1999; Holthuijsen et al., 2003). ADCIRC (the ADvanced CIRCulation model) is a continuous-Galerkin, finite-element, shallow-water model that solves for water levels and currents at a range of scales (Luettich and Westerink, 2004). The details of this solution have been published widely (http://www.nd.edu/~adcirc/manual.htm to see Users Manual and Theory Report) and will not be restated here.

SWAN is driven by wind speeds, water levels and currents computed at the vertices by ADCIRC. Marine winds can be input to ADCIRC, and these winds are adjusted directionally to account for surface roughness (Bunya et al., 2010). ADCIRC interpolates spatially and temporally to project these winds to the computational vertices, and then it passes them to SWAN. The water levels and ambient currents are computed in ADCIRC before being passed to SWAN, where they are used to recalculate the water depth and all related wave processes (wave propagation, depth-induced breaking, etc.). The ADCIRC model is driven partly by radiation stress gradients that are computed using information from SWAN. ADCIRC and SWAN run in series on the same local mesh and core. The two models “leap frog” through time, each being forced with information from the other model. The coupling interval is taken to be the same as the SWAN’s time step. The basic structure of this coupling system (ADCIRC+SWAN) was developed by Dietrich et al. (2010). In this study, the SWAN time step and the coupling interval were 600 sec. Also, the simulation used the default settings, and the version of SWAN was 40.85.

3. Model setups for typhoon

3.1. Mesh generation

The coastlines of major battlefields and landing places in the second Koryo-Mongol invasion in 1281 were created on the base of historical literatures and used to generate meshes covering the coastal areas such as Hakata Bay and the neighboring seas of Hirado and Taka Islands. The generated meshes for the entire model domain and near the
north-west of Kyushu, which is the third largest main island of Japan, are illustrated in Fig. 2. This mesh incorporated local resolution down to 50 m, but also extended to the Yellow, East Seas and the western Pacific Ocean, including hundreds of islands, with the sufficient resolution of the wave-transformation zones near the coasts and intricate representation of various natural and man-made geographic features that collect and focus the storm surge in this region, and contained 191,949 vertices and 355,754 triangular elements. As for the entire model domain excluding the study area of interest, the modeled water depth was made by using GEBCO (Jones, 2003), and as for the neighboring seas of Hakata Bay and Hirado and Taka Islands that was made by using the bathymetry and topography data with 50 meter resolution from Japanese Government (Central Disaster Management Council, 2003). The bathymetry and topography data are the ones at the present day, while the coastlines are the ones of the past. Thus, in case that the sea was altered to the land due to the reclamation project now but the sea in 1281, e.g., the area was regarded not as the sea but as the land, the incorrect water depth was necessarily imposed in those areas. To avoid these inevitable errors, we set the minimum water depth to 4 m for the entire model mesh system.

3.2. Prediction of tide in 1281

Open boundary forcing was applied in the form of specifications based on NAO’s (National Astronomical Observatory) tidal predictions (Matsumoto et al., 2000) along the model’s open water boundary. The NAO’s tidal prediction program is based on modified Julian day (MJD), but its routine to calculate MJD is available from 1990 to 2100, thus the routine was modified in order to reproduce the tide in 1281. The modified program is called NAOmod in this study. The previous study that performed tidal hindcast for the naval battle of Noryang (1592 - 1598) using NAOmod predicted reasonably the tide and tidal current in past years (Choi et al., 2013). Therefore, we predicted the tide and tidal current in the second Koryo-Mongol invasions in 1281 using the old tide prediction system obtained through modification and validation described above.

According to the historical literature, the date when the north-western Kyushu was hit hardest was July 30, 1281 in old Japanese calendar (Senmyoreki). This date corresponds August 15, 1281 in Julian calendar (http://www.wagoyomi.info/wagoyomi.html). Therefore, we set the tide predicted from August 13, 1281 using NAOmod to be entered into the open boundary with considering the spin-up time of simulation.

3.3. Estimation of meteorological data

There is no available meteorological data for 1281, so we estimated the meteorological data such as the wind velocity and atmospheric pressure using the well-known Dynamic Holland model (Holland, 1980). To obtain the wind velocity and atmospheric pressure data to drive the typhoon-related model, the following typhoon information is necessary: the location of center of typhoon, the minimum (mean sea level) pressure, \( P_{\text{min}} \), the maximum wind speed, \( V_{\text{max}} \), and the radius of maximum wind, \( R_{\text{max}} \). We acquired the typhoon information from Digital Typhoon (http://agora.ex.nii.ac.jp/digital-typhoon/news/2013/TC1330/) except for \( R_{\text{max}} \). Both JMA (Japan Meteorological Agency) and JTWC (Joint Typhoon Warning Center) do not provide \( R_{\text{max}} \) information. The radius of maximum wind can be estimated by the series of related equations (Eq.1) including Rankin equation and the radiuses of storm wind, \( R_{50} \), and gale wind, \( R_{30} \).

\[
W = V_{\text{max}} \times \left( \frac{R}{R_{\text{max}}} \right)^{\alpha}, \quad \alpha = \log \left( \frac{V_{50}}{V_{30}} \right) / \log \left( \frac{R_{50}}{R_{30}} \right), \quad R_{\text{max}} = R_{50} \left( \frac{V_{50}}{V_{\text{max}}} \right)^{\frac{R_{50}}{R_{30}}}
\]

where \( W \) is the wind speed, \( R \) is the distance from the center of typhoon, \( V_{50} \) is the wind speed of 50 knot (=25.7 m/s) and \( V_{30} \) is 15.4 m/s. We obtained the wind velocity and atmospheric pressure information at that time that corresponds to two simulation periods, i.e. the typhoon Songda in September 2004 and the typhoon in August 1281, through the above procedure.

4. Model results for the typhoon Songda (T200418)

The track of typhoon Songda (T200418) is illustrated in Fig. 3. A low pressure system developed roughly 390 km northeast of Kwajalein on August 26, 2004. According to JMA and JTWC, the storm was rapidly intensified to
attain its peak ten-minute sustained wind of 175 km/h and one-minute sustained wind of 230 km/h by August 31.

Early on September 5, typhoon Songda swept the northern coast of Okinawa Island of Japan, where a recorded

barometric pressure was 925 hPa. The storm curved toward the northeast, gradually weakened and made landfall near Nagasaki, Japan. The system accelerated toward the northeast, weakened and transitioned into a severe tropical storm and then cyclone. Several islands were damaged with typhoon Songda passing. Throughout Japan, typhoon Songda resulted in catastrophic damage and significant loss of life, mainly due to rain-related events. Losses were about $9 billion, and 41 people were killed by the storm mainly in Kyushu, Japan. The storm was ranked as the costliest storm and one of the most destructive in the western Pacific. We performed the reproduction of typhoon Songda using the meteorological data estimated by the previously-described Holland model in order to evaluate if our approach to acquire the meteorological forcing is acceptable. The water levels calculated by this method were compared with the ones observed at several tide stations provided by JMA (Japan Meteorological Agency) in Kyushu and the Seto Inland Sea, Japan (Fig. 4). Generally, the model slightly overestimated water elevations, but reproduced phases well. The differences between the measured and calculated water levels came from that the grid resolution of
the model area including the tide comparison stations was not fine enough to be matched the tide station. The parameters like the bottom friction applied to these areas may be inappropriate.

5. Model results for the typhoon in 1281

Fig. 5 shows the assumed track of typhoon in the second invasion of Ryo-mong in 1281. Its track was the same as one of typhoon Songda until the typhoon Songda were approaching Kyushu and while it passed near Hokkaido, however that was slightly shifted to the north when the typhoon was passing the East Sea located in the north of Kyushu in order for the typhoon to pass with the north-western Kyushu lying in the right of typhoon track. Also, the typhoon parameters such as $V_{\text{max}}$ and $R_{\text{max}}$ were tuned as follows: $V_{\text{max}}$ increased by 50% and $R_{\text{max}}$ decreased by 30% compared with the ones used in the simulation of typhoon Songda. It is because the wind generated from the original track and parameters of typhoon Songda was not threatening when considering a historical literature describing that the considerable ships were sunken and people were killed by typhoon in 1281. The above factors were obtained from some experiments that examine what extent the wind field, wave properties and water change with typhoon parameters changing. Fig. 6 illustrates the time-series of reproduced wind, water and storm surge elevation, significant wave height, wave period and current vectors due to the typhoon in 1281 at four sites that were chosen because of historical significance. Hirado-shima (Hirado Island) Station is located near the site where the Mongolian southern fleets coming from the mainland of China and the northern fleets coming from Iki-shima (Iki
Island), originally from Happo (Masan) of Koryo met and stayed. Taka-shima-north (the northern Taka Island) and Hakata Stations lie near the ferocious battlefields. Lastly, Taka-shima-south (the southern Taka Island) Station is situated in the shelter of fleets from the storm and shipwreck zone. There were the strong southerly winds at all four stations. At Hirado-shima Station, the maximum surge elevation was calculated as about 0.2 m, and the maximum significant wave height was about 3 m around 12:00 UTC Aug. 15. The regular current direction was fluctuated at this time. At Hakata Station, the water elevation reached 2 m with the surge elevation of about 1.2 m around 15:00 UTC Aug., 15. The strong northeastward currents with a maximum of about 0.8 m were found around this time. At Taka-shima-north and -south Stations, the wind speeds and directions were nearly the same, but the current at Taka-shima-south Station, which is located in the inner bay, was more sensitive to the wind so increased by about 1 m/s northeastward. The reproduced maximum surge elevations were 0.2 m and 0.6 m, and maximum significant wave heights were 3 m and 2 m at Taka-shima-north and -south Stations, respectively. Fig. 7 shows the wind fields on 13:00 and 14:00 UTC Aug., 15 estimated in this study. The wind exceeding 50 m/s was estimated near the northwestern Kyushu including Hirado and Taka Islands, and in the Hakata Bay. Figs. 8 - 9 show the distribution of calculated maximum water elevation and significant wave height during the typhoon event in Aug., 1281. Focusing on the neighboring sea of Taka Island which was the shelter from the storm and numerous

Fig. 7. Wind field on 13:00 - 14:00UTC 15 Aug. 1281. Contour: wind speed (m/s)

Fig. 8. Maximum water elevation during the typhoon in Aug. 1281.

Fig. 9. Maximum significant wave height during the typhoon in Aug. 1281.
6. Conclusions

This study attempted to reproduce the wave, tide and storm surge due to the typhoon occurred during the second invasion of Ryō-Mong joint forces in August 1281 (battle of Koan) using the integrally coupled wave-tide-surge model based on the same unstructured mesh. The track and intensity of typhoon in 1281 was said to be similar to those of typhoon Songda (T200418) in 2004, thus the meteorological data of those days in August 1281 was generated based on the information of typhoon Songda and the dynamic Holland model. The impact of typhoon Songda was also simulated by using the same approach as the one introduced for the simulation of typhoon in 1281 for the model validation, and as a result, the impact of typhoon Songda was reasonably reproduced comparing the observations in Kyushu and the Seto Inland Sea. On the basis model results for the typhoon in 1281, the maximum wave height was guessed to reach approximately 4 - 6 m, which was sufficiently large damaging flat-bottomed fleet, and it seems that the high surge height was not caused due to the counter-clockwise wind of the typhoon in 1281.

Acknowledgements

This study was supported by the China-Korea cooperative research project for nuclear safety funded by CKJORC and a major project titled a study on the dispersion of radioactive materials and their influence on marine biota following the accidental release to the ocean funded by KIOST. This study was supported by the project of KISTI for the development of HPC-based management system against national-scale disaster.

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