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Natural Hazards and Earth System Sciences
Discussions

Interactive comment on "High-resolution modeling of tsunami run-up flooding: A case study of flooding in Kamaishi City, Japan, induced by the 2011 Tohoku Tsunami" *by* Ryosuke Akoh et al.

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GENERAL COMMENTS: The topic is suitable for the journal since it addresses an issue which could be of interest to the scientific community. The document is up to the international standards and the length of the paper is adequate. High-resolution modeling of tsunami run-up flooding: A case study of flooding in Kamaishi City, Japan, induced by the 2011 Tohoku Tsunami has been analysed with interesting conclusions. The results obtained with the developed numerical modelãĂĂpresent an interesting replication of the recorded data. However, some more explanations are needed in some chapters, in order make it easier the reading and understanding of the study. In

addition, the introduced indicator Z, is here discussed. The reviewer would like to give some comments and suggest corrections in order to increase its overall significance.

[Comment-1]

Abstract: Although the use of U to represent the flow velocity is quite common and it is explained in the chapter 5.2, the abstract must be standalone and thus, the definition of Hmax and Umax must be given.

[Reply]

We will add the definitions of the variables. Following another reviewer (#1), we changed the flow intensity indicator to (hU2)Max, the maximum of momentum flux, and we will add the explanation of h and U in the abstract, too.

The presence of the results of numerical simulations (lines 18-20) must be adequately presented. The addition of a sentence like "As a possible mitigation measure, the influence of the buildings in the flowing has been addressed…" would increase the text flow.

[Reply]

Following your suggestion, we will revise the sentence about the results. The English will be checked by an English native speaker before submitting the final manuscript.

As a possible mitigation measure, the influence of the buildings in the flowing has been addressed by a numerical experiment for solid buildings arrayed alternately in two lines along the coast. The results show that the buildings can prevent seawater from flowing straight to the city center while maintaining access to the sea.

[Revised] P.1 Abstract

[Comment-2]

1.-Introduction: The building array treatments are widely explained. But this wide explanation distract from the objective of the paper. A briefer explanation is suggested since the references are enough to study it if necessary. In addition, and this is something common all along the paper, the structure of the chapters is not clear. The inclusion of a paragraph explaining what the reader is going to find on each chapter is needed to improve the understanding. If not, although each part is well explained the reader lose their sense of the bigger picture.

[Reply]

We compacted the description of building array treatments and introduction of existing studies, and added the introduction of chapter-structure at the end. The new introduction will be checked by an English native speaker before submitting final manuscript.

In the introduction it is not mentioned that the model has been applied as well to study the influence of the concrete buildings. One of the main points of the study is the application of an alternative mitigation measure (not just a seawall) to reduce the tsunami action and to allow, at the same time, the normal work on marine industries.

[Reply]

We added a sentence about the numerical experiment on the influence of buildings along the coast on tsunami intrusion into the city.

Recent urbanization of low-lying coastal areas has increased the potential for property damage, human injury, and death caused by tsunamis. Visual data obtained during the tsunami run-up revealed that arrays of structures in urban areas induced large wave deformation and swift currents on streets, and that the currents washed objects such as garbage, cars, and debris from damaged structures, causing even more damage than tsunami run-up over uniform ground. Prediction of swift currents in urban areas by numerical flow simulation is expected to be important for evacuation programs and for city layout planning measures to mitigate tsunami damage.

Tsunami simulation models for forecasting wave propagation and deformation from the

seismic center to the coast have been developed and improved for decades. These models for high-speed calculations in a wide water body are often based on a set of shallow-water equations on a structured rectangular grid system (Imamura 1995). Models with a rectangular grid system were extended to calculate the tsunami run-up on land by formulating the wavefront propagation on a dry bed (TiTov et al. 1995, 1998; Synolakis et al. 2008). However, the tsunami run-up simulation described above requires more precise flow modeling by introducing the hydraulic effects of building arrangement.

Building array treatments in urban flood inundation models are classifiable into four types (Schubert et al. 2008; Schubert et al. 2012): building-resistance models (BR), in which large surface roughness is assigned to cells that fall within a building footprint (Liang et al. 2007) or developed parcels (Gallegos et al. 2009; Gallien et al. 2011); building-block models (BB), in which spatially distributed ground elevation data are raised to roof-top height (Brown et al. 2007; Hunter et al. 2008; Schubert et al. 2008); building–hole models (BH), in which building footprints are excluded from the flow calculation area with a free-slip wall boundary condition (Aronica et al. 1998; Aronica et al. 2005; Schubert et al. 2008); and building-porosity models (BP), in which the impact of buildings in a street block is expressed approximately by porosity and a drag coefficient in a street block (Guinot 2012; Sanders et al. 2008; Soares-Frazão et al. 2008).

The BR model is commonly adopted for tsunami run-up simulations (Gayer et al. 2010; Kaiser 2011; Suppasri et al. 2011; Bricker et al. 2015), although the model developers did not predict the velocity field. Komatsu et al.(2010), Conde et al. (2013) and Imai et al. (2013) applied the BB model for the tsunami flooding in Kota Banda Aceh of Indonesia caused by 2004 off the Indian Coast of Sumatra Island Earthquake, in two cities of Portugal caused by the 1755 Lisbon Tsunami, and in Kochi city of Japan by a historical tsunami run-up in 1707, respectively. Liu et al. (2001) applied the BH model to tsunami run-up flow caused by the 1896 Sanriku Earthquake Tsunami. Akoh et al. (2014) proposed a permeable wall model equivalent to the BH model when the permeability constant was zero, and applied the model to the tsunami flooding in Kamaishi city of Japan during the 2011 off the Pacific Coast of Tohoku Earthquake (2011 Tohoku Tsunami hereinafter). For BP model, no report of the relevant literature has described for tsunami run-up simulation, probably because it is not easy to identify the values of porosity and building drag coefficient for respective street blocks.

For this study, the permeable wall model based on shallow flow equations proposed by Akoh et al. (2014) was used to investigate tsunami run-up details in the Kamaishi city induced by 2011 Tohoku Tsunami using more field data than used in the earlier study. Chapter-2 describes the numerical simulation method; basic formulations and building array treatment. Chapter-3 was devoted to explain numerical modeling the tsunami flooding in Kamaishi City; explanation of study site, data sources for modeling, mesh generation, and calculation conditions. Calculation results are displayed in Chapter-4 with validation data. In Chapter-5, after discussing the influence of permeability constant on calculation results, the tsunami impacts on houses is examined by introducing an indicator, IF = (hU2)max, where h and U respectively denote the water depth and the flow velocity at each point, and the effect of rigid building arrays along the coast on the reduction of IF in the city center was tested numerically, as a possible mitigation measure instead of high continuous embankments which prevents the access to the sea.

[Comment-3]

3.- Methods and materials:

An introduction must be included (between 3 and 3.1) to explain to the reader what they are about to find in this chapter.

[Reply]

Following [Comment 4] of reviewer-2, we moved Site Description (Chapter-2 in the old

manuscript) to the beginning of Application (Chapter-3 in the new manuscript). The Method and materials (Chapter-3 in the old manuscript) will become Chapter-2 in the new manuscript. In addition, we will change the chapter title “Methods” because we move 3.2 – 3.4 (old manuscript) to the chapter for validation of calculation results your next suggestion. We will insert a short sentence between 2 and 2.1 as follows:

Considering the openings of wooden houses such as doors, windows or cracks and slits cause by tsunami impacts, shallow water BH model was improved to express the effects of wall permeability by introducing the “assumption of internal hydraulic conditions” on the line segments where the walls were located. The seawall overtopping was considered in a same way.

The characteristics of the model are well explained and referred. Is this model new or has it been presented before? If it is new it should be said clearly, or even named.

[Reply]

This is a new model. We will emphasize our original idea “assumption with internal hydraulic conditions” with double quotation marks in the introduction for Chapter-2 (see the above sentence).

In this chapter the characteristic of the numerical model, the application case data sources, and verification data sources are presented together.. These 3 different parts should be separated in order to make it easier the understanding, because they present independent parts of the study. In addition the verification data and the results can be explained together what would improve the overall understanding. This reviewer suggests the change of the structure of chapters 3 and 4 to:

Chapter 3. The numerical model (including chapters 3.1 and 3.2)

Chapter 4. Application case: Kamaishi port under 2011 event.

Introduction explaining the 2011 event

4.1 Mesh generation (including 3.3.1, 3.3.2, and 3.3.3)

4.2 Calculation condition (including 3.4)

Chapter 5. Validation of the results. Include an introduction explaining that the results of the numerical simulations presented in the previous chapter are here presented and compared to those real data recorded. 3 comparisons:

5.1 Tsunami wave height near the coast (including 3.5.1 and 4.1)

5.2 Local highest water surface (including 3.5.2 and 4.2)

5.3 Wave front propagation on streets (including 3.5.3 and 4.3)

[Reply]

Thank you for your comment. We thought in the first draft as you suggested. We will change the structure of final manuscript as follows:

1. Introduction

2. Method: 2.1 Numerical model, 2.2 Assumption of internal boundary conditions.

3. Application case: 3.1 Site description, 3.2 Model set-up (3.2.1 Topographical conditions, 3.2.2 Seawalls and building footprints, 3.2.3 Mesh generation), 3.3. Hydraulic condition for calculation.

4. Validation of results: 4.1 Tsunami wave height near the coast (4.1.1 Field data analysis, 4.1.2 Verification of results), 4.2. Local highest water surface (4.2.1 Field data sources, 4.2.2 Verification of results), 4.3 Wave front propagation on streets (4.3.1 Field data analysis, 4.3.2 Verification of results).

5. Discussion: 5.1. Permeability constant, 5.2. Tsunami effects on houses, 5.3. Tsunami reduction effects concrete buildings along the coast.

6. Conclusions

Again, each chapter must contain an introduction.

[Reply]

We will insert a short introduction for each chapter. These parts will be checked by an English native speaker before submitting the final manuscript.

[Chapter 3: Application case]

The 2011 off the Pacific Coast of Tohoku Earthquake with 9.0 in seismic magnitude hit the Northeast Pacific Coast of Japan on March 11, 2011. The total death toll including still missing reached about 18,000, 90 % of whom were killed by tsunami after the earthquake in low-lying urban areas on the coast. Kamaishi City was one of the most severely damaged municipalities. (It will be followed by “3.1 Site description”.)

[Chapter 4: Validation of results]

Many kinds of data were collected by the academic groups, the government and municipalities after the earthquake. The results obtained from the numerical simulation described in the previous chapter are here presented and compared to those real data.

[Chapter 5: Discussion]

The reasonable value of C, unknown parameter in the model, is discussed in this chapter based on observed data presented in the previous chapter. Then, the tsunami impacts on houses is estimated by introducing an indicator for tsunami run-up intensity, and effect of rigid building arrays along the coast is tested numerically, as a possible mitigation measure to reduce the hydraulic impact indicator in the city center.

5.- Discussion:

An introduction explaining the 2 aspects that are in this chapter (C and Z) is needed.

[Reply]

We will add the introduction as written above.

5.2. Here the indicator Z=U max*Hmax is presented. This is the product of the maximum inundation depth and the maximum flow velocity during the flood. However, the maximum water depth and the maximum flow velocity are not always simultaneous. The value that should be considered is Z=(U*H)max, which is the real maximum value of the product. The indicator must be recalculated or an explanation is needed to maintain the original expression.

This product is used to estimate the human instability hazard (Jonkman et al., 2008) Jonkman, S., Vrijling, J., and Vrouwenvelder, A.: Methods for the estimation of loss of life due to floods: a literature review and a proposal for a new method, Nat. Hazards, 46, 353–389, doi:10.1007/s11069-008-9227-5, 2008.

[Reply]

Thank you for the suggestion. As mentioned in the reply for the comment #2 of reviewer-1, we finally adopted (hU2)Max, which is flow momentum flux, for flow intensity indicator. The spatial distribution characteristics of the new indicator was basically same as the old indicator, and the points in discussion will be same as before.

SPECIFIC COMMENTS

Page 1 Line 10: shallow water equations

[Reply]

We will correct the mistake in the new manuscript.

Page 1 Line 39: The reference Gallinen must be Gallien

[Reply]

We will correct the mistake in the new manuscript.

Page 2 Line 34: permeability constant, C (from..

[Reply]

This part was eliminated from the introduction.

Page 6 Line 7: It is not included in the text the reference of the survey. In the reference chapter it is included the 2011 tohoku earthquake tsunami joint survey, but it must be referred in the text.

[Reply]

We will cite their work in the new manuscript and add the website to the reference list.

Page 6 Line 30: The influence of the port in the flooding was cited by Tomita in T. Tomita, G.-S. Yeom, M. Ayugai, T. Niwa, Breakwater Effects on Tsunami Inundation Reduction in the 2011 off the Pacific Coast of Tohoku Earthquake, J. Japan Soc. Civ. Eng. Ser. B 2(Coastal Eng. 68 (2012) 4–8. In view of this a comment on the no-consideration of the port in the simulation, as well as the citation of Tomita′s paper must be included.

[Reply]

We will add the following sentence at the beginning of section “3.2.1 Topographical conditions”, and will cite Tomita’s paper in reference list.

[Revised]:

Tomita et al. (2012) investigated the effect of breakwater on the tsunami propagation into the bay by comparing three calculations; with the breakwater before tsunami arrival; with damaged breakwater configuration measured after the tsunami; and without breakwater, while the actual process of breakwater destruction is still remained for future study. Therefore in this study, the damaged configuration measured after the tsunami (Takahashi et al. 2011) was assumed for calculation.

We also add the following sentence at the beginning of section “4.1.1 Field data analysis” to express our consideration about the breakwater destruction.

As mentioned earlier, the breakwater at the bay mouth was considered with damaged configuration measured after the tsunami due to the uncertainty of its destruction process. In this study, therefore, time series of tsunami wave height near the coast line were obtained by image analysis of digital photographs taken by residents in order to examine the calculated time series near the coast line could be used for the run-up calculation in the city center area.

Page 7 Line 10: Is this video available on the internet? If so, a reference would be interested.

[Reply]

We will add the URL of the website to the reference list.

Page 8 Line 1: The expression includes hmax, but in the rest of the manuscript it is called Hmax.

[Reply]

Equation (3) will be changed to (hU2)Max, as mentioned before, and we will write correctly.

FIGURES: Figure 11 is called for the first time in page 6 line10, but the symbols contained in it are not explained until Figure 15 is called in line 34. They should be explained in the foot of the figure.

[Reply]

We will add the explanation of the symbols in the foot of the figure.

Figure 14a. In this figure are depicted the water levels at 4 points, but just the results of the model for the P3 are represented. However there are just 3 points photographed in P3. Other points have many more dots so it seems logical to depict other point time series instead of P3. In addition, the fact that all the dots (even those from other points like P1, P2 and P4) agreed fairly well in the P3 time series is important as to be highlighted.

[Reply]

Calculated water levels at the four points were almost same because they were very close to one another. Therefore, we showed the calculation result at P3 which was at the center. We will mention it in the new manuscript.

The P3 located at the center of measurement area was selected for the plotting of calculation results because the four points were very close to one another and calculation results were almost the same.

REFERENCES: In page 11 line17 the reference of Water and Disaster management Bureau is not included in the manuscript text

[Reply]

The reference was cited for the Manning's roughness assumption listed in Table 1in the old manuscript. However, in the new manuscript, we adopted the values proposed by Bunya (2010) and recalculated, following the suggestion from Reviewer-1. Therefore we will add the Bunya's paper in the reference list.

In page 5 line 23 the reference called here Central disaster prevention council, is not included in the references list.

[Reply]

We will add the reference of Central disaster prevention council to the reference list.

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