Natural Hazards
and Earth System
Sciences

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Discussions

Interactive comment on "Development of fragility curves for railway ballast and embankment scour due to overtopping flood flow" *by* R. Tsubaki et al.

R. Tsubaki et al.

rtsubaki@gmail.com

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Anonymous Referee 1

Comment 1-0: General comment

In this paper, fragility curves for railway ballast and embankment scour are developed based on two different real-life examples. The topic is interesting, however, I cannot say the paper is clear and well written. In fact, in many cases sentences are not clearãĂĂand the same terminology changes in each section thus undermining the readability ofãĂĂthe paper. I found very difficult to follow the methodology section. In particular, I have many doubts about the method used to estimate the fragility curve which doesn't not consider geometrical and geotechnical characteristics of the sys-

tems and it is looks strongly based on the specific case study considered in this paper. Considering the importance of a proper estimation of the overtopping water depth in case of fragility curve, a detailed description of the hydrological and hydraulic model and flood events, which is extremely poor in this manuscript, has to be provided for both cases study. I cannot recommend the manuscript for publication in NHESS in the present form. To help the authors to improve their manuscript, I have provided a set of comments and suggestions.

Reply: We'd like to express our sincere thanks to the referee for carefully reading the manuscript and for being interested in the topic. Comments and suggestions from referee 1 regarding the readability of the manuscript were quite helpful to us when revising the manuscript.

Explanations in the manuscript relating to the geotechnical property and how the overtopping water depth was estimated were short in the original version and will be revised. Here, we'd like to explain why these two points are not critical for this study and why we originally chose to provide limited explanations.

In Japan, the materials and construction of railway embankments are regulated by construction standards, so the range of geotechnical properties for railways is limited by the standards. The presence of upper structures, consisting of a ballast layer and rails and sleepers, on top of an embankment are unique for railway embankments as compared to other earthen embankments. Upper structures remain after a railway embankment has been severely damaged by flooding flows. Ballast is regularly maintained by railway operator management. In the manuscript, we focused on two, single-track, non-electrified railway embankments with upper structures, and these two could be assumed to be practically uniform. Since this point was not well documented in the original version of the manuscript, we added this explanation in the revised version.

Overtopping water depth was an input parameter for development of our fragility curves. Understanding the uncertainty of the overtopping water depth was as es-

sential for our work as the method used for its estimation. Therefore, in the original manuscript (lines 263-279) we focused on a quantitative discussion regarding the uncertainty surrounding water level estimates. Based on your comment, we now recognize that our original explanation for the method employed for estimating water depth was too short and we added a description of the method in the revised version.

Introduction:

Comment 1-1: Line 73: Piping it is not only sensitive to the height of the embankment but also to its width. In fact, narrow embankments are more prone to failure than large ones;

Reply: The slope of railway embankment is regulated by the construction standard and the width is proportional to the height. (lines 121-125 in the revised manuscript with edit-track)

Comment 1-2: I found the review of fragility curve method very short and sloppy. The Authors should provide more references referred to the embankment breach due to overtopping;

Reply: Three references treating river embankment breach will be cited.

Dawson, R., Hall, J., Sayers, P., Bates, P. and Rosu, C., 2005. Sampling-based flood risk analysis for fluvial dike systems. Stochastic Environmental Research and Risk Assessment, 19(6), pp.388-402.

Apel, H., Thieken, A.H., Merz, B. and Blöschl, G., 2004. Flood risk assessment and associated uncertainty. Natural Hazards and Earth System Science, 4(2), pp.295-308.

Apel, H., Merz, B. and Thieken, A.H., 2009. Influence of dike breaches on flood frequency estimation. Computers Geosciences, 35(5), pp.907-923.

Cases study:

Comment 1-3: In figure 2.a the Authors referred to "Ballast breach". Is there any difference between Ballast breach and scour? I would suggest to write "Ballast scour" since a breach is referred mainly to the embankment itself;

Reply: The caption has been modified.

Comment 1-4: Line 118: change "causing" with "caused"; Line 118: change the text in "Asa River including section M (see Figure 3) in the basin, caused. . .. ."

Reply: We have edited the manuscript (lines 164-166).

Comment 1-5: Line 121 "A hydrological model". No detail about such hydrological model is reported. The Authors have to describe the type of hydrological model they are using. In fact, since the method used to estimate the fragility curve is based on the overtopping water depth, an appropriate description of the hydrological model is fundamental in order to understand the uncertainty behind the water depth estimation. In addition, is the maximum flow rate related to the boundary condition or the river itself (hydraulic model)? Line 122: It is not clear to me if the value of 811m3/s comes from the model or from a personal communication. How the inflow value of 110m3/s was estimated?

Reply: The flow rates were used in the hydraulic analysis that provides the overtopping water depth. The manuscript will be edited to make clear this relation. A basic explanation of the hydrologic model used to determine the river flow rates has been added to sections 2.1 and 2.2. Figure 3 is added to graphically shown the relationship between sections.

Comment 1-6: Lines 123-125 are not clear, and I do not understand how this information can add more value to the estimation of the fragility curve;

Reply: This implies the estimated flow rate is reasonable and the maximum flow rates of the Asa River and the Zuiko River converged almost simultaneously since no major tributaries exist between the confluence of the two rivers and this measurement point. This explanation will be supplemented in the manuscript. (lines 178-181)

Comment 1-7: Line 142: Which type of hydrologic and hydraulic analyses?

Reply: A rainfall-runoff simulation was conducted for the Sayo River Basin upstream of the Enkouji observation station (Tsubaki et al. 2012b, Fujita et al. 2012). The 50-m-resolution distributed model that simulates both rainfall-runoff processes from mountainous slopes and flood routing in river channels based on kinematic wave equations (Tachikawa et al. 2006, Sayama et al. 2010) was used to estimate the runoff during the event. The equations applied to the mountainous slopes were the lateral components of unsaturated, saturated subsurface and surface flows and the water mass balance equation (Tachikawa et al. 2006, Sayama et al. 2010). The Enkouji gauging station is located 1 km downstream of section S and the observed peak runoff was 1360 m3/s. The peak discharge estimated by the model was 1320 m3/s. This explanation was added in the revised manuscript. (lines 197-207)

Comment 1-8: Replace Bounrady with Boundary in Figure 3;

Reply: We corrected the label in the figure.

Methods:

Comment 1-9: Line 150: the Authors referred either to surcharge and overtopping water depth. Please homogenize the terminology within the manuscript;

Reply: We consolidated "surcharge" to "overtopping water depth".

Comment 1-10: Lines 155-158 are not clear, rephrase;

Reply: The sentence was edited for more detailed description. (lines 227-234)

Comment 1-11: One of my main concern is related to the method used to estimate the fragility curve. In line 177 the Authors mentioned that damage level is expresses as overtopping water depth. Does this means that for each recorded damage, the corresponding overtopping water depth generating such damage was also available? In hydrology/hydraulic damage is expressed as the consequence of water level on the floodplain area while in this study it is related to the specific damage on ballast and/or embankment. How the observed damage probability was assessed?

Reply: Definition of parameter "a" as "damage level" in line 177 should be "hazard level" and this has been corrected.

Comment 1-12: The proposed method is based on observed damages values obtained from the two cases study. Such study is interesting but I believe that the Authors have to propose a general method to estimate fragility curve also in case of no damage observations. Such approach should use physically-based equation (as equation 9 of this manuscript) related to the scour processes in case of overtopping. In addition, the geometrical and geotechnical characteristics of the system (roughness of the embankment, type of ballast, embankment cover quality, etc.) are key factors in the fragility curve estimation;

Reply: This study was designed to be a deductive research on the railway failure. Non physical based but on-site damage record based fragility curves are quite common and substantially contributed to the natural hazard science, e.g.

Suppasri, A., Koshimura, S. and Imamura, F., 2011. Developing tsunami fragility curves based on the satellite remote sensing and the numerical modeling of the 2004 Indian Ocean tsunami in Thailand. Natural Hazards and Earth System Sciences, 11(1), pp.173-189.

Suppasri, A., Mas, E., Koshimura, S., Imai, K., Harada, K. and Imamura, F., 2012. Developing tsunami fragility curves from the surveyed data of the 2011 Great East Japan tsunami in Sendai and Ishinomaki plains. Coastal Engineering Journal, 54(01), p.1250008.

Mas, E., Koshimura, S., Suppasri, A., Matsuoka, M., Matsuyama, M., Yoshii, T., Jimenez, C., Yamazaki, F. and Imamura, F., 2012. Developing Tsunami fragility curves using remote sensing and survey data of the 2010 Chilean Tsunami in Dichato. Natural Hazards and Earth System Sciences, 12(8), pp.2689-2697.

We conducted an inductive research on this topic, partially reported in

Tsubaki, R., Kawahara, Y. and Ueda, Y., 2012a. An experimental study on railway embankment breach and its critical flow condition, 18th Congress of the Asia and Pacific Division of the IAHR, Jeju, Korea, August 2012.

and mentioned in the discussion on Figure 9 in the context of no-damage criteria. The geometrical and geotechnical parameters are key factors in the fragility curve estimation and usually accounted for in the slope and shape of the fragility curve as is in this study. The failure probability is dependent on the geometrical and geotechnical parameters and these parameters are highly variable in space and practically having large uncertainty (e.g. Apel et al. 2004, Dawson et al. 2005) and to manage this difficulty, the fragility curve concept has been used to describe the possibility of embankment failure. This point will be described in section 1 and section 3.

Comment 1-13: Lines 180-189: the estimation of the damage level is fundamental in this study to estimate the fragility curves. The Authors has to provide additional information about the damage level and in particular on the approach used to assess such damage;

Reply: For Asa River flood, locations of ballast and embankment fill scour are determined by investigating photos showing the status of the railway ballast/embankment

scour just after the flood and the status after the recovery works (personal communication with the factory and downloaded from the internet) as well as aerial photos of the area obtained in February 2012 and ortho-rectified in 0.5 m resolution. The ballast and embankment after the recovery had different color compared with the section not scoured because of the weathering, iron dust due to railway passage and vegetation cover alter the surface color. For Sayo River flood, the damage record was mainly based on Kaneko (2010). Site survey data (personal communication with I. Ario), photos from the internet, and aerial photos, taken in October 2009 (immediately after the flood) and ortho-rectified in 0.2 m resolution, were also utilized to detail damage along the length of the section of railway. These explanations have been added to the manuscript. (Lines 272-290, Figure 7)

Comment 1-14: Line 191: Estimation of the overtopping water stage. No indication about the hydrologic model is provided. How the upstream boundary conditions of the hydraulic model are estimated?

Reply: For Asa River flood, the upstream flow rate was determined based on the hydrologic analysis. The storage function model which parameters were calibrated with the previous major events was used and an event dependent model parameter Rsa (a saturation criteria to start runoff) was determined to best fit the discharge hydrograph at the gauge station based on four error criteria (Ube construction office, Yamaguchi Prefecture, 2012). For Sayo River flood, the inflow rate was based on the result of the rainfall-runoff simulation conducted for the Sayo River Basin upstream of the Enkouji observation station (Tsubaki et al. 2012b, Fujita et al. 2012). The 50-m-resolution distributed model that simulates both rainfall-runoff processes from mountainous slopes and flood routing in river channels based on kinematic wave equations (Tachikawa et al. 2006, Sayama et al. 2010) was used to estimate the runoff during the event. The equations applied to the mountainous slopes were the lateral components of unsaturated, saturated subsurface and surface flows and the water mass balance equation (Tachikawa et al. 2006, Sayama et al. 2010). These

explanations have been inserted in section 2 and the relationship between section 2 and 3 has been explained in the revised manuscript.

Comment 1-15: Line 211: Asa River was always described as first one while now is Sayo River the first. Please, invert the description putting first Asa and then Sayo river in order to be consistent within the paper;

Reply: We have rearranged the order of section to improve structural consistency.

Comment 1-16: Line 219: n=0.02. How the Authors estimated this value? Was it compared to literature values? Model calibration is an essential step in order to reduce model uncertainty and it has to be properly addressed in this manuscript;

Reply: The river channel roughness was determined based on the bed material size and the surface cover status. The area covered by trees plant in the channel was considered vegetated. It is true that the roughness calibration was essential for 1D (e.g. HEC-RAS) or 1D/2D coupled model with simplified 2D model (e.g. LSFLOOD-FP) since not only physical friction loss but also the energy loss due to planform variations (e.g. variance in cross-sectional velocity distribution causes vertical momentum mixing and increase total energy loss) (Horritt and Bates, 2002). On the other hand, two-dimensional shallow water model with fine calculation grid is substantially less sensitive to the roughness coefficient (Horrit, 2000, Horritt and Bates, 2002, Tsubaki and Kawahara, 2012) and the roughness coefficient reflect more physical basis (Horritt and Bates, 2002) compared with the simplified models. So the roughness coefficients in this study were determined by physical basis.

Horritt, M.S. and Bates, P.D., 2002. Evaluation of 1D and 2D numerical models for predicting river flood inundation. Journal of hydrology, 268(1), pp.87-99.

Horritt, M.S., 2000. Calibration of a two-dimensional finite element flood flow model using satellite radar imagery. Water Resources Research, 36(11), pp.3279-3291.

Comment 1-17: Line 221: Again, which type of hydrological model was used? Hydraulic model results are influenced by the upstream boundary conditions and a detailed description of the hydrological model used in this study has to be provided;

Reply: The description of the hydrological model was described in section 2 and referred here to make clear this relation (line 342).

Comment 1-18: Line 224: is this precipitation or direct runoff? Please explain;

Reply: The description has been edited.

Comment 1-19: Line 232: Also in this case, the value of the manning coefficient has to be properly motivated;

Reply: This river channel roughness equals that used by Yamaguchi Prefecture in historical analyses. The citation has been added.

Comment 1-20: Line 240: from where it comes the recorded inundation area? Remote sensing observation or in-situ measurements?

Reply: The recorded inundation area was based on the field survey. The description has been added. (line 366)

Comment 1-21: Line 252-254: where are these 2 locations in figure 3? What do the Author mean with presence of vortices over the floodplain?

Reply: Two locations were omitted by mistake and will be depicted in the revised manuscript. The vortices over the floodplain are shown in the plan-view figure 1 attached to this document. The sentence will be edited to be more detailed description of the flow situation.

Comment 1-22: Line 263: this section should be called 3.3.3 and not (c);

Reply: We have rearranged the structure of section.

Comment 1-23: Lines 271-279: I do not think this is the reason of the uncertain results. Instead, the reason might be connect to the inappropriate calibration of the hydrological and hydraulic model. Please provide more information about such models and their parameter estimation;

Reply: The hydrological and hydraulic models were validated with the available data. For Asa River hydrologic analysis, the storage function model which parameters were calibrated with the previous major events was used and an event dependent model parameter Rsa (a saturation criteria to start runoff) was determined to best fit the discharge hydrograph at the gauge station based on four error criteria (Ube construction office, Yamaguchi Prefecture, 2012). The maximum flow at a point 3 km downstream of the confluence was estimated as 967 m3/s by the hydrologic model and this flow rate closely matches the peak flow rate of 957 m3/s estimated from high water marks measured in the field. For Sayo River hydrologic analysis, the discharge hydrograph at the Enkouji gauging station, located 1 km downstream of section S, were validated. The observed peak runoff was 1360 m3/s and the peak discharge estimated by the model was 1320 m3/s. For the shape of discharge hydrograph is reported in Tsubaki et al. 2012b. The validation of the hydraulic models is described in section 3. The descriptions above has been provided in the revised manuscript.

Results:

Comment 1-24: Line 282: is H the head loss (as reported in line 206)?

Reply: The sentence "Difference between H and the elevation z of the railroad track in overtopping water depth Δh" was the definition of H, namely, $H=z+\Delta h$. And this will be explicitly noted in the revised manuscript. (lines 400-403)

Comment 1-25: Line 289-290: How the Authors defined damage? It is still not clear to me how the Authors estimated the damage from water level. I think this is an important point that is unclear within the all manuscript.

Reply: In this paper, we use overtopping flood water level as an explanatory variable for railway overtopping damage (section 3.1). To deduce this relation, the pairs of the local damage level in the field (Section 3.2) and the estimated overtopping flood water level were collected. The sentences in sections 3.1 and 3.2 have been revised.

Comment 1-26: Line 295: Are these numbers of samples related to both case studies? Please specify and describe the calibration and validation samples in the case study or method description;

Reply: Samples from two areas were used and this point will be explicitly described. These 32 data points, which damage level was described in section 3.2 and the overtopping water depth was estimated in section 3.3, were used as samples to fix parameters in the fragility curves. This explanation has been added. (lines 518-520)

Comment 1-27: Line 296: Is embankment fill scour indicating a probability equal to 1? Is this case related to the embankment breach? What is the difference between embankment scour damage and embankment fill scour?

Reply: Damage on embankment has been described uniformly as "embankment scour" in the revised version.

Comment 1-28: Lines 302-304: I think it would be nice to show this comparison;

Reply: We dropped the figure because two curves are quite identical as shown in figure 2 but we will show the comparison here.

Comment 1-29: Lines 304-306: The Authors has to explain why fragility curve for ballast scour has a larger mean and smaller standard deviation. Is this because ballast scour is more sensitive to water depth overtopping and a small variation of it might significantly increase the probability of damage?

Reply: Why fragility curve for ballast scour has a larger mean and smaller standard deviation is discussed in section 5.3. We separated result and discussion sections.

Comment 1-30: Figure 8: In figure 7 the observed samples used to assess the fragility curve are reported while this is not the case of figure 8. However, in line 319 the Authors mentioned that a limited number of samples (7) of ballast damage was used. I suggest to add a figure similar of figure 7 in case of ballast damage;

Reply: We have added a figure showing two fragility curves and sample plotting. (Figure 11)

Discussion:

Comment 1-31: Line 328: Why in case of only ballast scour such experimental bound (critical flow rate) does not corresponds to the initial rise? I would expect both curves starting at the same point to then have different gradient and achieve higher probability of damage for short water depth in case of only ballast scour;

Reply: We agree your expectation, and we obtained the different result from an available data. Discussion on this point was conducted in section 5.3, and this point has been mentioned at the end of section 5.1. It may be possible to change the coefficient to better fit the rise of the fragility curve to the experimental critical value but such an analysis was not conducted in this paper.

Comment 1-32: Line 338: I am confused. The upper limit (double line) indicates already a probability of damage of about 0.8-0.9 while the authors mentioned

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that no-damage was observed. Please, clarify this sentence providing additional information;

Reply: The upper limit indicates the largest overtopping water depth with no-damage record in the field. We guess the reviewer is confusing why the damage probability of the hazard level that no-damage was observed is not zero, because of the no-damage was observed. Not only no-damage record (data point a in Figure 3 below) but damage record existed (data points c in Figure 3) in the range that no-damage was record so the damage probability did not 0 nor 1. We will add the description about this point.

Comment 1-33: Line 370-371: are the "actual damage records" the same used to assess the fragility curve? Is this a new sample? As I stated in my previous recommendation, please specify and describe both calibration and validation samples in the case study or method description;

Reply: Thirty-one irregularly spaced data points used in section 4 to obtain the fragility curves were selected where the damage level was recorded with confidence (e.g. the damage level was clear), but a regular array at 10 m intervals was used in the validation. This has been described in the revised manuscript. (lines 517-520)

Comment 1-34: Line 372: how such distribution was assessed as most feasible? According to what? Please provide details motivating this sentence

Reply: Base on the discussion in section 5.1 to 5.3. Namely, the lower limit to start ballast/embankment scour would correspond to the critical flow rate to start ballast scour obtained by the experiment (section 5.1) so the ballast scour model is not feasible. The overtopping water level larger than 0.4 m is quite an intense flow from the viewpoint of earthen embankment overtopping (e.g. Apel et al. 2004) and the damage probability on the condition above 0.4 m would be almost 1, so the embankment/ballast scour model is feasible (section 5.2). The ballast scour model seems to have to too small variance compared with the amount of the uncertainty for the water level esti-

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mation so the ballast scour model is not feasible. Accordingly, we assessed that the ballast/embankment scour model is the most feasible.

Apel, H., Thieken, A.H., Merz, B. and Blöschl, G., 2004. Flood risk assessment and associated uncertainty. Natural Hazards and Earth System Science, 4(2), pp.295-308.

Comment 1-35: Line 373: Is this a probability of damage or failure? The previous fragility curves were estimated based on observed damage and they do not relate the water depth to the probability of failure. If so, provide additional details and try to clarify this aspect in the manuscript;

Reply: The probability of damage was discussed here and the sentence will be edited. In this study, the probability of failure was related to the water depth as Dawson et al., 2005 and Apel et al. 2009 did for the river embankments. This point will be explained in the method section.

Apel, H., Thieken, A.H., Merz, B. and Blöschl, G., 2004. Flood risk assessment and associated uncertainty. Natural Hazards and Earth System Science, 4(2), pp.295-308.

Dawson, R., Hall, J., Sayers, P., Bates, P. and Rosu, C., 2005. Sampling-based flood risk analysis for fluvial dike systems. Stochastic Environmental Research and Risk Assessment, 19(6), pp.388-402.

Comment 1-36: Figure 10 refers to probability of damage while in the text is probability of failure, be consistent with the term across the whole manuscript;

Reply: We will make the terms consistent.

Comment 1-37: Line 375: Does damage curve mean fragility curve? Why it is lumped? Please explain

Reply: "the lumped damage curve" was "the fragility curve for ballast and embankment

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scour". The sentence will be described so in the revised manuscript to avoid confusion (line 522).

Comment 1-38: Lines 374-375: This sentence it is not clear, please rephrase;

Reply: The sentence will be rephrased as " Damage probability in Figure 14 (left) is calculated without regard to the type of failure (ballast or embankment scour), but is calculated with the fragility curve for ballast and embankment scour; however, the actual damage record of the right-hand figure distinguishes the type of damage" (Lines 520-523)

Comment 1-39: Lines 376-377: I do not agree with Author comment. It can be seen that higher damage probability is located in the area where ballast failure occurred while just few points has high damage where embankment failure occurred. Which fragility curve was used? The log-normal for ballast and embankment scour?

Reply: We used the log-normal fragility curve for ballast and embankment scour. The sentence will be edited as "calculated with the fragility curve for ballast and embankment scour" to make clear our intention. About the description of the agreement between calculated and observed record, we will describe as "the area where ballast and embankment scour were observed is predicted as a high damage probability area." (lines 523-524)

Comment 1-40: Line 405: The Authors are mixing the concept of hazard with damage, be consistent across the paper;

Reply: The hazard in this paper was "overtopping water depth" and will be pointed out again here. (lines 553-554)

Comment 1-41: Line 406: it is not clear to me how uncertainty in hazard level can be accounted using fragility curves. The explanation in lines 405-407 it is not

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clear, provide more details;

Reply: How uncertainty in hazard can be accounted in the fragility curve concept was described in section 3.1. The document below may be a good reference for explaining the fragility curve concept and will be added to support this point. The sentences in lines 405-407 will be revised.

Mander, J.B., 1999. Fragility curve development for assessing the seismic vulnerability of highway bridges. Research Progress and Accomplishments, Fragility curve development for assessing the seismic vulnerability of highway bridges, pp.91-100.

Conclusion:

Comment 1-42: Line 424: What do you mean with "type of curve"? Probability distribution?

Reply: Types means normal vs. log-normal distributions and this point will be explicitly described in the revised manuscript. (line 576)

Comment 1-43: Line 426: What do you mean with "the least serious type of damage investigate"? Please rephrase;

Reply: The sentence will be replaced as "expected to be the initial phase of damage leading to embankment scour". (lines 577-578)

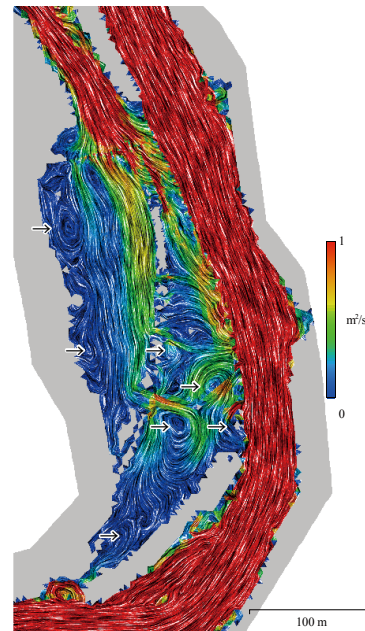Interactive comment on Nat. Hazards Earth Syst. Sci. Discuss., doi:10.5194/nhess-2016-167, 2016.

Figure 1 Presence of vortices over floodplain depicted using Line-Integral Convolution (LIC) visualization method. The direction of texture corresponds to the flow direction. The density of texture represents the magnitude of flow (unit discharge q).

Fig. 1. Presence of vortices over floodplain depicted using Line-Integral Convolution (LIC) visualization method. The direction of texture corresponds to the flow direction. The density of texture represents
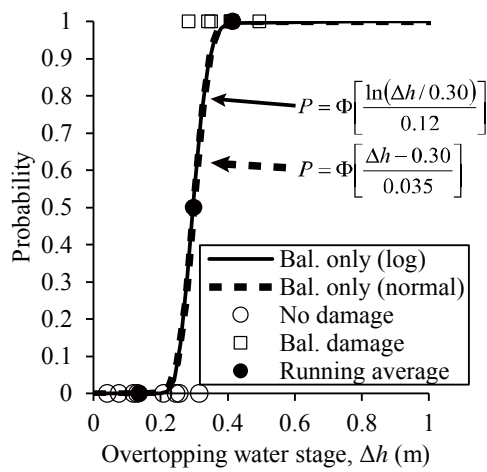
$$P = \Phi\left[\frac{\ln(\Delta h / 0.30)}{0.12}\right]$$

$$P = \Phi\left[\frac{\Delta h - 0.30}{0.035}\right]$$

Figure 2 Fragility curves for ballast scour damage described by normal and log-normal distributions.

Fig. 2. Fragility curves for ballast scour damage described by normal and log-normal distributions.
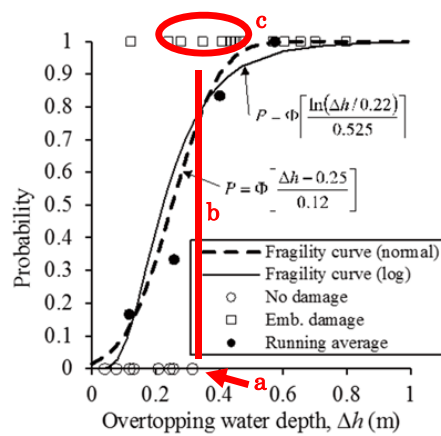
$$P = \Phi\left[\frac{\ln(\Delta h / 0.22)}{0.525}\right]$$

$$P = \Phi\left[\frac{\Delta h - 0.25}{0.12}\right]$$

Figure 3 Why the damage probability of the upper-limit of no-damage observation is not zero.

Fig. 3. Why the damage probability of the upper-limit of no-damage observation is not zero.