We appreciate Dr. Zhao for the careful review of our paper and the constructive comments.

Reply to the specific comments

1. In the introduction, there are no methodology and approach discussions in this study. Is it experiment in flume, numerical modelling?

Re: Thank you for the comments. Detailed description of methodology and approach discussions are added at the end of the part as follows:

Levee breach is quite different from the breach of embankment constructed normal to the flow in morphology, hydraulics and inflow variation characteristics (Kakinuma and Shimizu, 2014). Moreover, measured data of cohesive levee breach have not been reported until now. There for, four groups of experiments on cohesive levee breach were performed in a bend flume with varied inflow discharge, soil water content and porosity. In these experiments, levees were constructed in the flume with an initial breach. Different stages of levee breach process and flow characteristics near the breach were analyzed. The levee breaching flow rates process, simulated by a depth averaged 2-D flow model, was also studied with detail.

2. Give a detailed explanation of the design of flume experiments. Why were they conducted in a bending channel flume? Why not do the tests in straight channel flume?

Re: Flow in the bend was affected by both gravity and centrifugal force. That makes the water surface at the concave bank higher than that at the convex bank. So levees at the concave bank are more likely to be breached by overflow than that at convex bank or straight channels. So this kind of breach has more research value and that is why the experiments were conducted in a bending channel flume. In this study, the initial breach was set just at the concave bank of the bend. Moreover, the transverse water-surface gradient of the bend flow produces the bend circulation, with flow directing toward the concave bank in the water surface. This provides the initial velocity of levee breach flow. River flow can flow into the land region easily. The above explanation has been added in the paper now.

3. ADV has been used in the velocity measurements in the flow with sediment. Has ADV been validated or calibrated since ADV has good accuracy in flow but not in the sediment-laden flow?

Re: In fact, ADV works better in sediment-laden flow than in clean water. When ADV is working, the probe emits supersonic wave, which is reflected by a water sample about 5 cm far from the probe. The reflected wave is accepted by the probe again. If the water sample moves, the emitted and accepted wave frequency by the probe is different. The measured velocity is acquired just based on the frequency discrepancy. The reflected wave accepted by the probe must be with certain strength to surpass the noise strength around. The rate of reflected signal strength versus noise strength is defined as Signal to Noise Ratio (SNR). SNR is determined by the particle concentration of the water and transmit length. Larger particle concentration and transmit length result in a larger SNR, and accordingly a higher measuring accuracy. When the water is cleaner, the transmit length and sampling volume should be set larger to increasing measuring accuracy.

4. In Line 40, please give references to “Many researchers”.

Re: Thank you for your suggestions. Some references have been added as follows:

Many researchers (Ralston, 1987; Powledge et al., 1989; Hanson et al., 1999; Wahl, 2004) have found that headcut retreat is a predominant mode during the overtopping breaching process of cohesive embankments and many prediction models of headcut retreat rate were put forward (Hanson et al., 2001; Stein and LaTray, 2002; Zhao et al., 2013).

References

Ralston, D.C.: Mechanics of embankment erosion during overflow, in: Proceedings of 1987 ASCE National Conference on Hydraulic Engineering, Williamsburg, Virginia, USA, 733-738, 1987.

Powledge, G.R., Ralston, D.C., Miller, P., Chen, Y.H., Clopper, P.E., and Temple, D.M.: Mechanics of overflow erosion on embankments II: hydraulic and design considerations, J. Hydraul. Eng., ASCE, 115, 1056-1075, 1989.

Hanson, G. J., Temple, D. M., and Cook, K. R.: Dam overtopping resistance and breach processes research, in: Proceedings of Association of State Dam Safety Officials Annual Conference 1999, St. Louis, Missouri, USA, 1999 (CD-ROM).

Wahl, T. L.: Uncertainty of predictions of embankment dam breach parameters, J. Hydraul. Eng., ASCE, 130, 389-397, 2004.

5. In Line 80, can you give a reference to the classification of “silt clay”?

Re: Thank you for your carefulness. There is a mistake here. The term “silt clay” should be “silty clay”. The term “silty clay” comes from Code for design of building foundation of China (GB50007--2002). In the code, the cohesive soils are defined as soils with the plastic index larger than 10. Cohesive soils can be classified into clay and silty clay. If the plastic index is larger than 10 and less than 17, the soil is defined as silty clay and clay otherwise. The plastic index of the soil used here is 10.5, so it belongs to silty clay according to this criteria.

But the soil used in the experiments are not called “silty clay” according to the unified soil classification system (USCS). Instead, it is classified as clay with low plasticity (CL) according to Fig. 1. More specifically, it is named as “lean clay” according to Fig. 2. For better communication, “silty clay” in this paper is modified into “lean clay”.

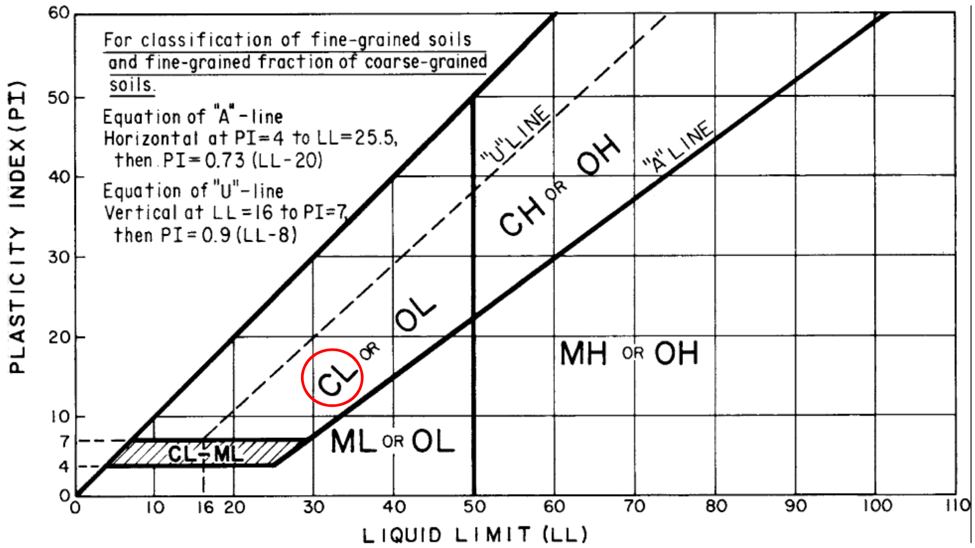

Fig. 1 Plasticity Chart

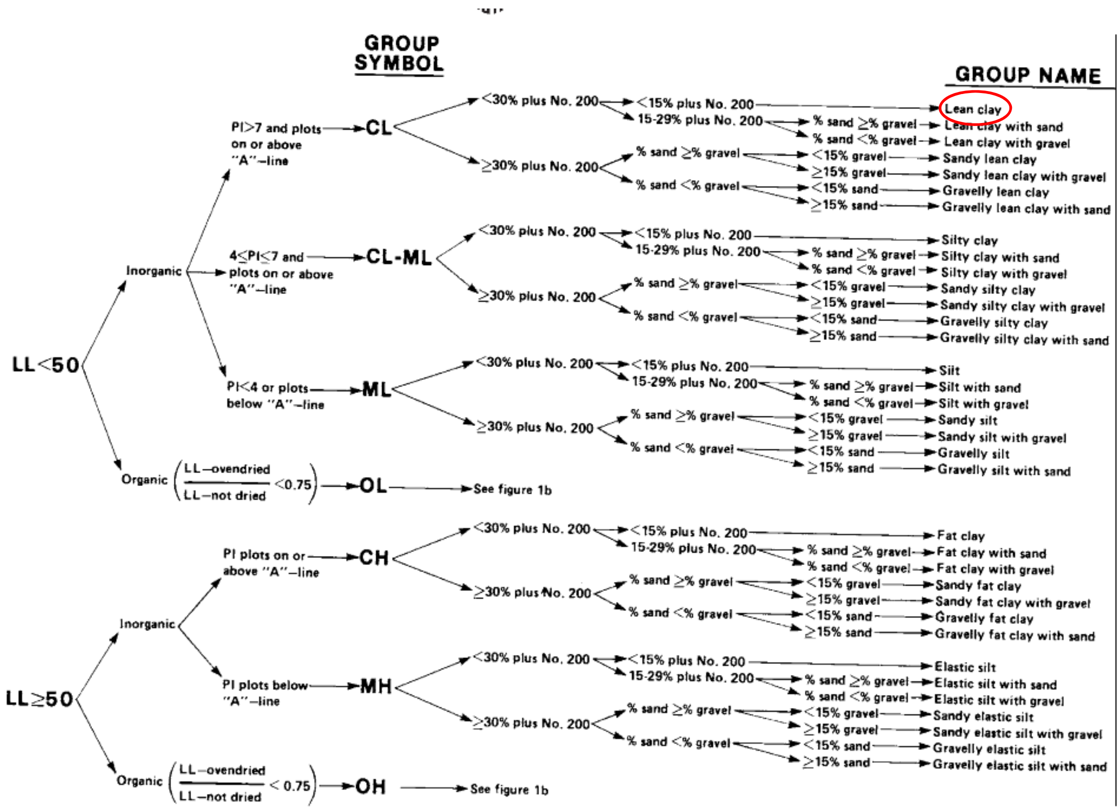

Fig. 2 Flow Chart for Classifying Fine-Grained Soil (50 % or More Passes No. 200 Sieve)

6. In Line 83, can you give more detailed explanations of "other soil parameters"? Or have you measured these values?

Re: Other soil parameters here are density ρ, dry density ρ_d, soil cohesion c and initial friction angle φ. They are affected by soil porosity e and soil water content w. Before experiments began soil samples were selected from the levee to test ρ, ρ_d, c, φ, e and w. They have been listed in Table 1.

Table 1 Experiment cases and parameters

Case	Q (L/s)	w (%)	e (%)	ρ (kg/m^3)	ρ_d (kg/m^3)	c (KPa)	φ (°)
1	14.64	21.2	41.2	1920	1590	22.22	25.79
2	14.64	21.07	42.88	1870	1540	21.85	25.13
3	14.64	19.8	40.8	1910	1600	20.94	25.77
4	28.53	19.9	40.8	1920	1600	21.07	26.4

7. In Line 199, please give the reasons of choosing numerical model. In practice, the measurement should be chosen in the breaching test.

Re: In the experiments for overtopping breaching of embankment, the breach discharge are hardly to measure directly because of the unsteady characteristics of the breaching flow. There are no equipment that is suitable to measure real-time breach discharge in open channels. Although the weirs can be used to measure discharge, it is not proper to place it just at the embankment toe. And it is unable to measure the discharge when water level is lower than the weir height.

Generally, indirect methods are usually used to evaluate the breach discharge. There are two common methods. The first one is the method by broad-crested weir formula, in which the embankment breach is assumed as a broad-crested weir. The other one is the method of water volume balance. And the second method utilizes the balance of either the reservoir water or the downstream water. When using the balance of the reservoir method, the breach discharge equals inflow discharge minus reservoir volume variation per unit time. While when the balance of downstream water is utilized, the breach discharge equals the outflow discharge plus downstream water volume variation per unit time.

In the experiments described in this paper, the morphology of the breach is irregular and the surface of the breach is not smooth. It is difficult to confirm accurate discharge coefficient. So the breach discharge could not be evaluated by broad-crested weir formula. On the other hand, the method of water volume balance is also not suitable. In the river region, except for the inflow discharge and breach discharge, there also exist the flow out from the sluice gate, which is not easily measured because it is mixed with the flow out of the sluice gate in the land region. And because the channel is too long, it is hard to evaluate the water volume change accurately. Similarly, evaluating the breach discharge by water volume balance method in the land region is also not viable.

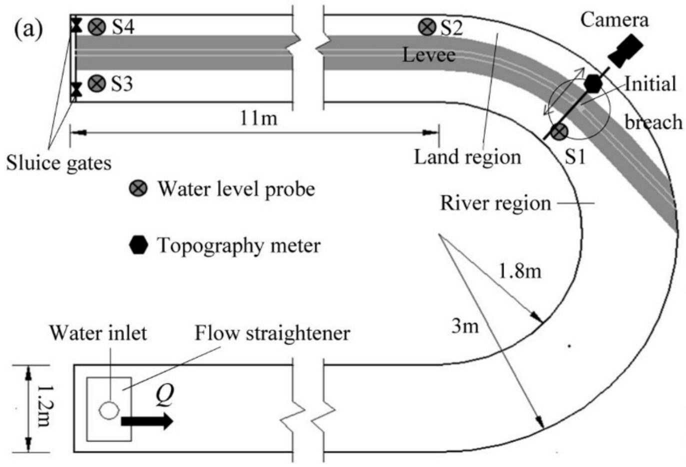

Fig. 3 Experiments layout

8. In line 199, you proposed to use a 2D flow model. Can you give a reference of this model? Has the model been validated to apply in the breaching flow? Does the model a non-hydrostatic module or a hydrostatic module?

Re: The depth-averaged 2-D flow model used here is based on the assumption of hydrostatic pressure. The 2D flow model proposed in this paper has been used by Dou et al. (2014) to simulate non-cohesive levee breach in the same flume. In this model, the numerical fluxes were calculated by WENO–Roe method based on Riemman solvers that can capture flow discontinuity. This ensure the model suitable for dam break simulation, which has been validated in these following examples.

Example 1

Consider a rectangular area 1200 m long and 100 m wide with flat and smooth bottom. The dam location is 500 m from the upstream. The initial water depth in the reservoir is 10 m. To verify that the model can simulate dam break flow in both wet and dry bed, the water depth in the downstream of the dam is set as 1 m and 0.001m, respectively. Transient dam break is considered. Grid size of 5 m is selected.

Calculating water level and flow velocity after 30 s for wet bed are shown in Fig. 4. It can be seen that the calculated results match well with the analytical solutions and are without obvious numerical oscillations.

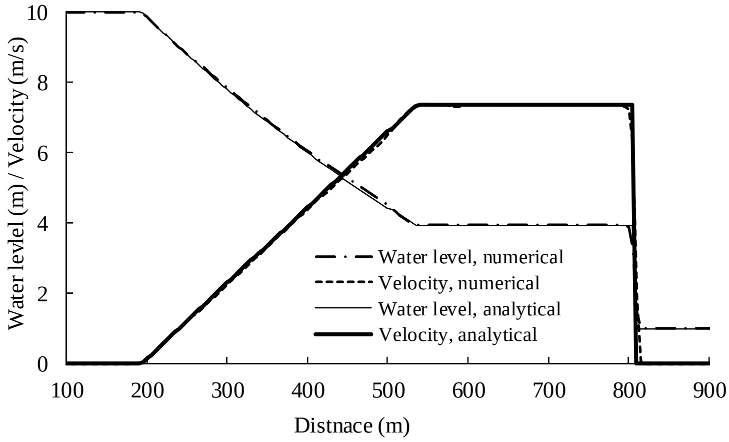

Fig. 4 Numerical results for wet bed

Results for the dry bed are shown in Fig. 5. The calculated water level matches well with the analytical solution. There are small deviations between the calculated flow velocity and the analytical solutions near the area where dam break flow arrives, that is, the junction area of wet and dry bed. This is generated by the assumption of the minimum water depth when calculating flood propagation on dry bed. Generally, the discrepancy is very small.

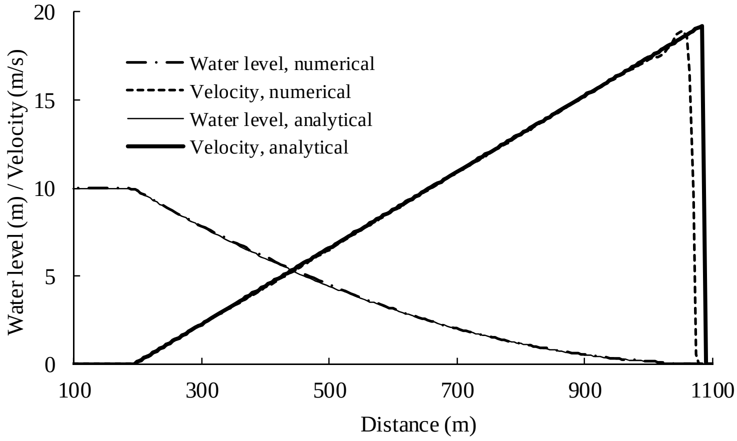

Fig. 5 Numerical results for wet bed

Example 2

Assume a square area with the length of 200 m. The dam is 100 m from the upstream and the width of the breach is 35 m shown in Fig. 6. The water level is 10 m in the reservoir and 5 m downstream of the dam. Transient dam break is considered. Calculated flow field and water level contour are shown in Fig. 6 and Fig. 7. The results are generally in accordance with those acquired by Alcrudo and Garcia-Navarro (1993) and Wang and Liu (2000).

Reference:

Dou, S. T., Wang, D. W., Yu, M. H., and Liang, Y. J.: Numerical modeling of the lateral widening of levee breach by overtopping in a flume with 180° bend, Nat. Hazards Earth Syst. Sci., 14, 11-20, 2014.

Alcrudo, F., and Garcia-Navarro, P.: A high-resolution godunov-type scheme in finite volumes for the 2d shallow-water equations, International Journal for Numerical Methods in Fluids, 16, 489–505, 1993.

Wang, J. W., and Liu R. X.: A comparative study of finite volume methods on unstructured meshes for simulation of 2D shallow water wave problems, Mathematics and Computers in Simulation, 53, 171-184, 2000.

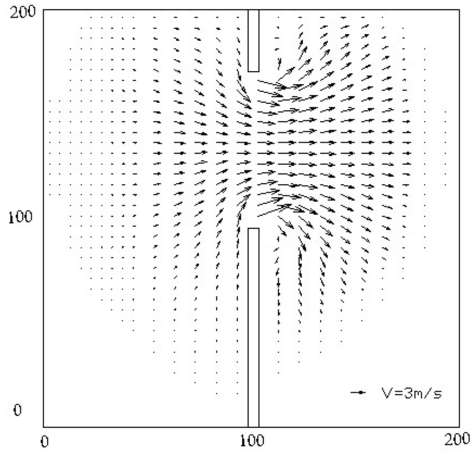

Fig. 6 Flow field

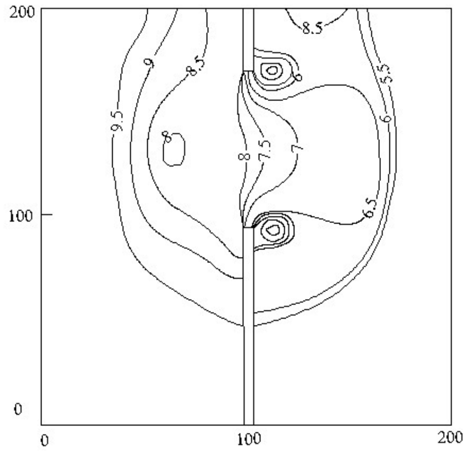

Fig. 7 Water level contour

9. In Line 281, eq. (12) has a different format with the traditional weir formula. Would you check eq. (12) from literatures?

Re: Traditional weir flow formula is in the form of $Q_b = C_d\sqrt{2g}Bh_0^{1.5}$, where Cd is dimensionless discharge coefficient. Eq. (12) $Q_{b*} = 0.34B_*h_*^{1.5}$ in this paper takes for $C_d\sqrt{2g}$ as a single coefficient for simplicity when analyzing the fitting relation of Q_{b*} and $B_*h_*^{1.5}$.

10. It is better to have a discussion section before the conclusion section in Line 289 to discuss the experimental results and numerical modeling results with the past research.

Re: Thank you for your suggestions. The discussion section has been added as follows:

The main factor resisting flow erosion of non-cohesive soils is the effective gravity of sediment particles. While for compacted cohesive soils, the main factor is the cohesive force between soil particles, which is usually much larger than the effective gravity of non-cohesive sediment particles. This make the affecting factors for overtopping breaching of non-cohesive and cohesive levees quite different. Non-cohesive levee breaching rate is mainly affected by the particle diameter (it is consumed the sediments are with the density). While for cohesive levee breach, the main factors are those affect the cohesive force such as soil composition, compaction degree and soil water content. And the breaching processes of the two kinds of levees are quite different because of the different resisting force. Compared with non-cohesive levees, the overtopping breaching of cohesive levees are much slower and it consists two special stage-the slope erosion stage and headcut retreat stage. This can be attributed to the strong anti erodibility of cohesive soils. The cohesive levee crest and land-side levee slope are eroded with slower rate and hardly form erosion gully, thus the slope erosion stage exists for a period. And because the erosion rate of the levee crest is smaller and the land-side levee slope are hard to collapse, the morphology of headcut forms. For non-cohesive levees, the fast-eroded sediment materials from the levee crest deposit at the land-side levee slope toe and frequent collapse in the land-side slope occurs. This makes the breach a gentler slope and seldom form abrupt elevation changes like headcut.

Reply to Technical corrections

Line 47: Check the confusing sentence.

Re: Thank you for your suggestion. The sentence has been divided into two sentences as follows:

Both the IMPACT project (Morris et al., 2005) and Zhang et al. (2009) conducted a series of experiments on cohesive dam break. And Zhang et al. (2009) also studied the cause of headcut erosion, double spiral flow at the dam crest and the effect of soil cohesion on breach process.

Line 50: “There exist” should be “there are”.
Re: “There exist few” has been changed into “There are limited”.

Line 55: check the strange sentence.
Re: The sentence has been modified as:
Compared to the limited studies on non-cohesive river levee breach, studies on cohesive ones are scarcer.

Line 58: Too many space before “To obtain”
Re: Redundant spaces have been omitted.

Line 129: it is not suitable to use abbreviations of “FSE” and “JIE”. And please check other abbreviations.
Re: The abbreviations of “FSE” and “JIE” has been modified into their full name “flow shear erosion and “jet impinging erosion”.

Line 134: in “0.2 m/s”, there should be a space between value and unit.
Re: A space has been added between 0.2 and m/s and all other similar problems have been checked throughout the paper.

Line 249: “et al.,” should be deleted “,”.
Re: The “,” has been deleted.

Check the sizes and formats of formulae in the text. They are not in the same format.
Re: The sizes and formats of formulae are checked and modified.

The revised version has been uploaded as the form of a supplement.