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Earth Surface Dynamics
Discussions
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Interactive comment on "The formation processes and development characteristics of sandbars due to outburst flood triggered by landslide dam overtopping failure" *by* Xiangang Jiang et al.

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Response to the Reviewer 1 General Comments: The manuscript by Dr. Jiang and colleagues summarizes results of an experiment investigating bar dynamics following breach of a landslide dam. The manuscript appears to be a re-working of results from a similar paper published by the same lead author in 2020 in the journal 'Landslides' (Jiang et al., 2020, cited in the manuscript). The experimental design appears sound, the experiment is well documented, and the results appear different enough from that paper to justify a separate publication. Nonetheless, the current manuscript suffers from a confusion of terminology and formative processes of the primary sedimentary

body being investigated (fluvial bars), is lacking in scientific justification, and does not effectively communicate the novel scientific contribution of the experimental results. It is my judgement that the results of the experiment could make a contribution to the scientific community, but the manuscript needs very substantial revision to meet the aims and scope of Earth Surface Dynamics.

Thanks a lot for the reviewer's comments. In the revised manuscript, we have pointed out this manuscript's contributions to the scientific community: "Therefore, results in this paper can be applied to the river channel's geomorphological characteristics analysis triggered by overtopped landslide dam failure". Please see lines 31-33 in the revised manuscript. And we re-examined the results of the experiment and confirmed that the boulder bar was formed in the experiment instead of the sandbar. We also have made other revisions to the manuscript based on the reviewers' comments. Please see the revision.

Specific Comments: 1.The use of the term 'sandbar' is ill-founded. The experiment does, in fact, use a substrate that is approximately 40 percent sand. However, because of the scale and high Froude conditions (>2), the experiment best represents a canyon, gravel bed system. The formative processes of 'sandbars' in this experimental design are entirely different than the sedimentary bodies described in lines 54 to 108 of the Introduction. In that section, there is extensive review of sedimentary bodies that are not genetically nor stratigraphically related to the sandbodies formed in these experiments which, at the scale of the experiment are gravel alternate bars. The fact that the bars in the experiment migrate in the upstream direction is evidence that the experiments are simulating Froude-supercritical (diffusive) conditions (Shaw and McElroy, 2016), whereas most of the sandbars described in the Introduction (except those formed by landslide dams) are formed by translative depositional processes. I would suggest the authors re-visit the process scaling of the experiments to re-frame and strengthen the experimental justification and basis, and the scientific contributions of the results. Kleinhans et al. (2014) and Shaw and McElroy (2016) provide excellent discussions on linkages between sedimentary processes in flumes and those in rivers.

Thanks a lot for the reviewer's comments. The authors have discussed this comment and agreed with the reviewer. We reviewed the experimental screen and confirmed that the bars formed in the experiment were boulder bars, which correspond to the boulder bars in the field (Wu et al., 2020; Turzewski et al., 2019). We have corrected the term "sandbar" to "boulder bar". The Introduction has been rewritten focused on boulder bars, the literatures have been recited, and lines 54-108 of the introduction of the original article have been revised by us to ensure accurate description of the boulder bar. The rewritten Introduction is as follows: "Activities such as rainfalls and earthquakes often cause landslides, which block the river to form a water-retaining body similar to a reservoir dam, called a landslide dam (Takahashi, 2007; Costa and Schuster, 1988; Casagli, 2003). According to statistics, 85 % of the dams failed within one year after formations, and more than 50 % of the dams breach with overtopping mode (Costa and Schuster, 1988). When the dam breach, the storage water erupt and flow to the downstream riverbed. Many studies on the influence of flood geomorphology and sedimentary characteristics have proved that the outburst flood energy is huge, and it can entrain and transport materials of various sizes, from clay to boulders. A large number of boulders gather in the river to form bars, namely boulder bars. The downstream riverbed's geomorphology will be significantly affected and undergo significant changes (Lamb and Fonstad, 2010; Maizels, 1997; Russell and Knudsen, 1999; Marren and Schuh, 2009; Benito and O'Connor, 2003; Carling, 2013; Wu et al., 2020). Boulder bars are one common landform formed during the outburst flood evolution (Turzewski et al., 2019; Jiang and Wei, 2020; Wu et al., 2020). For example, in the 2000 year, Yigong outburst flood, due to its huge lake storage, formed many huge boulder bars on the river bed. The boulder bars had a significant impact on the development of the river. And Wu et al. (2020) investigated the impact of this event on river morphology and analyzed the shapes and geometric characteristics of the boulder bars caused by the overtopping flood. And they found that the boulder bar components are poorly sorted. Turzewski et al. (2019) studied the particle gradation of the boulder

bars during the Yigong River landslide dam failure process. They found that the boulder bars' particle sizes decrease along the lower reaches of the river bed. But they did not analyze the evolution characteristics of boulder bar's size in detail. Lamb and Fonstad (2010) suggested that the rising and falling stages of the outburst flood had a greater impact on riverbed geomorphology and analyzed the characteristics of the median diameter of material in boulder bar. Because lack of field investigations about the growth characteristics of boulder bars during the landslide dam failure process in the field, some researchers had conducted landslide dam failure experiments in the lab (Jiang and Wei, 2020; Ashworth, 1996). Ashworth (1996) used flume experiments to study the boulder bar's growth. However, in their experiment, the inflow conditions are quite different from the outburst flood. Therefore, the research results' applicability to the boulder bar formed by the outburst flood remains uncertain. Jiang and Wei (2020) qualitatively analyzed the formation process of boulder bar in the evolution of overtopping outburst floods using dam failure experiments and initially discussed the characteristics of geometric dimensions of boulder bars after dam failure. However, the characteristics of the boulder bar's positions and geometric sizes during the dam failure process have not been analyzed. Above all, no matter whether it is field observations or indoor experiments, the boulder bar's development characteristic during the landslide dam overtopping failure process has not been proved. This paper focuses on the formation processes, the geometrical size characteristics of boulder bars in the downstream channel during the overtopping failure process, and how the dam volume and the released flood volume affect boulder bars' total volume. Firstly, through flume experiments, boulder bars' formation processes on the downstream channel under the dammed lake failure condition were reproduced. Then, based on the experimental data, the development characteristics of boulder bars' upstream and downstream edges were analyzed. Furthermore, statistical analysis of boulder bars geometrical dimensions at each moment during the failure process, such as length, width, height, and volume, had been carried out to obtain boulder bars' size characteristics. And then, by analyzing the total volume of the boulder bar under different dam volumes and the released flood volumes, the influences of the released flood volume and dam volume on the boulder bar total volume were obtained. Finally, compare the boulder bar formed by the Yigong outburst flood and the boulder bar formed by the experiment to verify this experiment's reliability." In addition, as the reviewer said, the boulder bar in the experiment is indeed formed by the translational deposition of bedload. As shown in Figure 1, when the discharge is reduced, some gravel will stay on the river bed and hinder the advancement of the upstream flow, and part of the sediment in the flow will be deposited. As time goes by, the accumulation of sediment on the side of the boulder bar increases, and the boulder bar appears to develop upstream. We have added the explanations as the reviewer's suggestion in section 3.2. The revised section 3.2 is given in the response to the next reviewer's comment.

Figure 1. boulder bar obstructs the outburst flow to the river bed lower reaches

Reference: Wu C.H., Hu, K.H., Liu, W.M., Wang, H., Hu, X.D., and Zhang, X.P.: Morpho-sedimentary and stratigraphic characteristics of the 2000 Yigong River landslide dam outburst flood deposits, eastern Tibetan Plateau, Geomorphology, 107293, https://doi.org/10.1016/j.geomorph.2020.107293, 2020. Turzewski, M.D., Huntington, K.W., and Leveque, R.J.: The Geomorphic Impact of Outburst Floods: Integrating Observations and Numerical Simulations of the 2000 Yigong Flood, Eastern Himalaya, Journal of Geophysical Research: Earth Surface, 124, 5, https://doi.org/10.1029/2018JF004778, 2019.

2. The authors do not provide a clear basis and justification for the experiments. Neither a hypothesis nor scientific question are presented in the introductory material as a basis for the experiments. Instead, the justification appears to be that 'sandbars are important'. Because the authors appear to have confused sandbars in low-slope, low Froude number rivers with gravel bars from outburst floods, this justification is moot. In line 52 of the Introduction, the author's state "Sandbars are one typical landform formed during the outburst flood evolution (Turzewski et al., 2019; Jiang and Wei, 2020; Wu et al., 2020)." Neither the T urzewski nor Wu papers describe sandbars at all, they de-

scribe gravel bars from outburst floods. Only the paper written by Dr. Jiang, which also appears to have confused sandbars with gravel bars, uses the term 'sandbars'. The authors should revisit their results and the literature to provide the reader with a clear justification for the experiments by clearly stating a hypothesis or scientific question addressed

Thank the reviewer very much for the comments. We fully agree with the reviewer's opinion. We have corrected "sandbar" to "boulder bar" in the revision. It was noticed that most researchers focused on distribution characteristics and consisted material characteristics of boulder bars triggered by landslide dam overtopped failure after the dam failure based on field investigations (Wu et al., 2020; Turzewski et al., 2019). However, the boulder bar' formation process and development characteristic during the process of dam failure are still not clear. Therefore, we have proved the formation and development of the boulder bar during the failure process of the landslide dam through the flume experiment. We have pointed out the scientific question and rewritten the introduction section in the revision.

Reference: Wu C.H., Hu, K.H., Liu, W.M., Wang, H., Hu, X.D., and Zhang, X.P.: Morpho-sedimentary and stratigraphic characteristics of the 2000 Yigong River landslide dam outburst flood deposits, eastern Tibetan Plateau, Geomorphology, 107293, https://doi.org/10.1016/j.geomorph.2020.107293, 2020. Turzewski, M.D., Huntington, K.W., and Leveque, R.J.: The Geomorphic Impact of Outburst Floods: Integrating Observations and Numerical Simulations of the 2000 Yigong Flood, Eastern Himalaya, Journal of Geophysical Research: Earth Surface, 124, 5, https://doi.org/10.1029/2018JF004778, 2019.

3. The manuscript lacks a clear description or discussion of the scientific contribution. The Results contain very long, detailed descriptions of the spatial-temporal dynamics of bar formation, geometries, and migration processes in the experiments. These descriptions could be shortened, and the scientific community would be better served with a discussion detailing how the results add to our understanding of bar formation

from landslide outburst floods. For example, are the final geometries and along-stream scaling of the bars helpful in geologic interpretation of ancient bar deposits? Can they be used to improve interpretation of return frequency of certain outburst floods over recent geologic history? This manuscript simply does not contain any discussion linking the experimental results to the broader scientific literature, nor does it effectively relay the importance of the results to interpretation or prediction of landslide-dam outburst events.

Thanks a lot for the reviewer's comments. We have simplified the description of the position and size characteristics of the boulder bar in the experiment according to the reviewer's suggestions. The simplified description is as followsïijŽ "3. Experimental results 3.1 Formation processes of boulder bars The formation processes of boulder bars are almost similar for all the tests. Therefore, it takes the T7 test as an example to analyze below in this section, as shown in Fig. 3. When the flow overtopped the dam crest, the outburst flood carried the dam materials to the dam downstream slope (T=5 s) and then to the channel bed (T=19 s) with outburst flow discharge increasing. It should be noted that although a large number of sediments were transported on the channel bed before the peak discharge, no boulder bar formed on the downstream channel bed. After the moment of peak discharge, the flow discharge gradually weakened, and dam materials were transported to the position near the dam toe. The flow could not transport all the sediments away, and some sediments gradually silted down, then the first boulder bar occurred near the dam toe (T=30 s, the boulder bar in the figure is marked with a blue dotted line). After the first boulder bar was formed, the flow direction was changed when water flow bypassed the boulder bar. And the moving sediments still moved along the original direction due to inertia, which causes sediments piled up to form the second boulder bar on the opposite side of the first boulder bar (T=33s). Similarly, the first and second boulder bars affected the formation of the boulder bar downstream. Eventually, boulder bars were scattered on both sides of the channel, forming a meandering channel downstream (T=40 and 47 s). This phenomenon is in good agreement with the field boulder bars along the Yigong river (Wu

et al., 2020).

Figure. 3 The riverbed morphology at six different moments during the boulder bars' formations and growths process for the T7 experiment. The boulder bars in the figure are marked with blue dotted lines. 3.2 Characteristics of the boulder bars' positions Figure. 4 shows boulder bars' locations on the channel bed during the dam failure process. The red lines in the figure represent the boulder bars' outlines, and the orange rectangles represent the channels. It clearly shows the formation sequences of boulder bars at different locations. That is, boulder bars were formed first near the dams (upstream reaches of riverbed), and the farther from the dam toe, the later the boulder bar was formed, which is consistent with the content of Sect. 3.1. Boulder bars near the downstream dam toes are all located on the dam breach side across the river. This characteristic has also been found in Chen et al. (2015). According to the boulder bars' formation sequences, the channel bed's boulder bars were divided into three types: âĚă. the boulder bar near the upstream reaches, that is, the boulder bar near the dam toe; âĚą. the boulder bar at the middle reaches; and âĚć. the boulder bar near the downstream reaches. Figure 4 shows that the upstream edges of the boulder bars of type I for all the tests basically moved toward the dams with time development. The movement directions of the downstream edges of boulder bars of type I showed a little different: for T1, T2 and T5, the boulder bars' downstream edges moved toward the dam toes, from a distance from the downstream toe of 3.6 to 2.55 m, 3.3 to 2.9 m and 3.7 to 3.4 m, respectively, as shown in Fig.4 (a), (b) and (e); for T6, T7, and T8, the boulder bars' downstream edges first moved away from the dam toes and then moved toward the dam toes, and the downstream edges move forward compared to the original location. However, the distance they moved is 0.1 to 0.2 m, as shown in Fig.4 (f), (g), and (h); for T3 and T4, the boulder bars' downstream edges positions remained almost unchanged, see Fig. 4(c) and (d). No matter how the downstream edge positions of the boulder bars type I changed, there is a common feature: compared with the initial positions of the boulder bars, the downstream edges almost remained original locations, and the movement distances were much smaller than those of boulder bars' upstream edges. The lengths of the boulder bars of type I increased with the failure time. It can be seen that the sediments on the boulder bars' upstream edges played a great role in the length developments of type I boulder bars.

(a)

(b)

(c)

(d)

(e)

(f)

(g)

(h) Figure. 4 The boulder bars' locations during the dam failure process. Notation: (a) to (h) represent the boulder bars' locations for T1-T8 tests, respectively. The red lines in the figure represent the boulder bars, and the orange rectangles represent the channels. The numbers at both ends of the red lines represent the distances between the upstream and downstream edges of boulder bars and the dam toe. The positions of the upstream edges of type II and III boulder bar moved toward the dam toe during dam failure, but the downstream edges' positions could move toward or away from the dam. The distances of movement of the downstream edge positions were smaller than that of upstream edge positions. Compared with the boulder bars of type I, the movements of type II and III boulder bars were smaller. The distance between the boulder bars in the middle and downstream reaches is smaller than the distance between boulder bars near the upstream reaches and adjacent boulder bars. 3.3 Characteristics of the boulder bars' geometric sizes It is corresponding to Sect. 3.2, Fig. 5 shows that the lengths of the boulder bars of type I were longer than other types of boulder bars' lengths due to the sufficient incoming materials from the upstream dam. For all the boulder bars, their lengths along the channel were largest, followed

by widths, and lastly the heights. Boulder bars' lengths had a growing trend, and their growth rates were larger than widths and heights. The boulder bars' shapes were irregular during the entire dam failure process, similar to the field boulder bars (Wu et al., 2020). The average values of the widths and heights of the boulder bars along the channel were selected as the parameters reflecting the characteristics of boulder bars' widths and heights (Fig. 5). The figure shows that boulder bars' heights changed less drastically than widths, which because boulder bars' heights were significantly affected by outburst flow depth. In most cases, flow depth was less than the heights of boulder bars. The sediments mainly accumulated at the boulder bars' edges and waists and could not "climb up" boulder bars' tops. Besides, the reduction of flow depth was not large enough, so the boulder bars' heights did not change seriously. The boulder bars' widths were significantly affected by the discharge of the outburst flow. When the discharge was enough, the sediments around the boulder bars were taken away by the flow, and the widths decreased. The variations of widths and heights both increase slowly with time and then tended to be stable values.

Figure. 5 The lengths, widths, and heights of the boulder bars: (a) sizes of the boulder bars near the upstream reaches; (b) sizes of the boulder bars near the middle reaches; (c) sizes of the boulder bars near the downstream reaches. Notation: L, W, and H represent the length, width, and height of the boulder bar, respectively. i represents the Ti experiment. For example, MUL6 indicates the length of the boulder bar near the middle-upstream reaches for the T1 test. When the amounts of sediments deposited on boulder bars were larger than the quantities of eroded sediments, boulder bars' volumes became larger. Otherwise, boulder bars' volumes would decrease or remain at a stable level. Figure. 6 reveals boulder bars' volume characteristic during the dam failure. Most of the 25 boulder bars gradually increased in volume, indicating that the amounts of outburst flow erosions in the boulder bars' vicinities were less than the amounts of siltation during the entire outburst process. Referred to Figs. 5 and 6, the boulder bars' volume characteristics were consistent with the boulder bars' length characteristics. And because the widths and heights developed slightly, boulder bars' volumes were mainly controlled by boulder bars' lengths.

Figure. 6 Volumes of boulder bars. Notation: UVi, MVi, DVi, MUVi, MDVi represent the volume of the boulder bar near the upstream reachesïijŇthe boulder bar near the middle reaches, the boulder bar near the downstream reaches, the boulder bar near the middle-upstream reaches, and the boulder bar near the middle-downstream reaches, respectively. For example, UV1 means the volume of the boulder bar near the upstream reaches of the T1 test." We study the formation process and growth characteristic of the boulder bar during the landslide dam overtopping failure process. The boulder bar's position and the change characteristics of geometric dimensions in the process of dam failure were carefully discussed. In addition, we have added a new discussion section to compare the experimental results with a field case (Wu et al., 2020; Turzewski et al., 2019). The experimental results and field data are consistent, indicating that the experimental results can provide references for the study of the formation and growth of the boulder bar formed by the outburst flood. The Discussion section is as follows: " 5. Discussion The field data of the Yigong landslide dam are used to verify the reliability of the results in this paper. Turzewski et al. (2019) investigated the boulder bars in the Yigong River triggered by the Yigong landslide dam outburst flood in 2000. They found that the number of boulder bars is about 0.69 to 0.77 times the ratio of river bed length to dam length for the boulder bar frequent region. In this study, boulder bars were distributed in the 8 m length of the channel, which is 4 to 7 times of dam length. It reflected the number of boulder bars was 0.4 to 1.0 times the ratio of river bed length to dam length. By comparing the experimental data and the field data of Turzewski et al. (2019), it can be found that field data falls within the range of experimental data. Experimental models took more influence factors into account in this paper, while the field data of Turzewski et al. (2019) only focused on the Yigong landslide dam case. This may be why the field data range is smaller than the experimental data in this paper. Wu et al. (2020) classified the boulder bars in the downstream reaches of the Yigong River into three types according to their shapes and used the length to width ratio as the indicator of a bar shape. The 16 boulder bars in the downstream reaches of the

Yigong River have a length to width ratio of 2.5-15. As can be seen from Fig. 9, the length to width ratio of the boulder bar formed in this experiment is in the range of 7 to 16, which indicates the field data could prove the experimental results.

Figure. 9 The ratio of boulder bar length to width Turzewski et al. (2019) measured the sizes of boulder bars. They found that grain sizes of boulder bars decrease downstream. In this experiment, boulder bar materials from different river bed sections were collected. And after screening and analysis, it was found that as the distance between the boulder bar and the dam increases, the particle diameter in the bars shows a decreasing trend, as shown in Fig. 10. This feature is consistent with the description of Turzewski et al. (2019).

Figure. 10 Gradation curve of the boulder bar materials. Notation: U, M, D, MU, and MD, represent the boulder bar near the upstream reaches, the boulder bar near the middle reaches, the boulder bar near the downstream reaches, the boulder bar near the middle-upstream reaches, and the boulder bar near the middle-downstream reaches, respectively. Based on the above points, it can be seen that the experimental results in this paper are consistent with the actual boulder bars in the field. Therefore, the experimental results can provide guidance for the field study of the boulder bar formed by the outburst flood."

Reference: Wu C.H., Hu, K.H., Liu, W.M., Wang, H., Hu, X.D., and Zhang, X.P.: Morpho-sedimentary and stratigraphic characteristics of the 2000 Yigong River landslide dam outburst flood deposits, eastern Tibetan Plateau, Geomorphology, 107293, https://doi.org/10.1016/j.geomorph.2020.107293, 2020. Turzewski, M.D., Huntington, K.W., and Leveque, R.J.: The Geomorphic Impact of Outburst Floods: Integrating Observations and Numerical Simulations of the 2000 Yigong Flood, Eastern Himalaya, Journal of Geophysical Research: Earth Surface, 124, 5, https://doi.org/10.1029/2018JF004778, 2019.

Please also note the supplement to this comment:

https://esurf.copernicus.org/preprints/esurf-2020-92/esurf-2020-92-AC1-supplement.pdf

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Interactive comment on Earth Surf. Dynam. Discuss., https://doi.org/10.5194/esurf-2020-92, 2020.

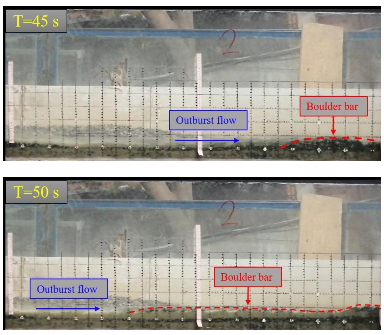

Figure 1. boulder bar obstructs the outburst flow to the river bed lower reaches

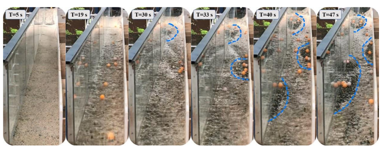

Figure. 3 The riverbed morphology at six different moments during the boulder bars' formations and growths process for the T7 experiment. The boulder bars in the figure are marked with blue dotted lines.

Fig. 1.

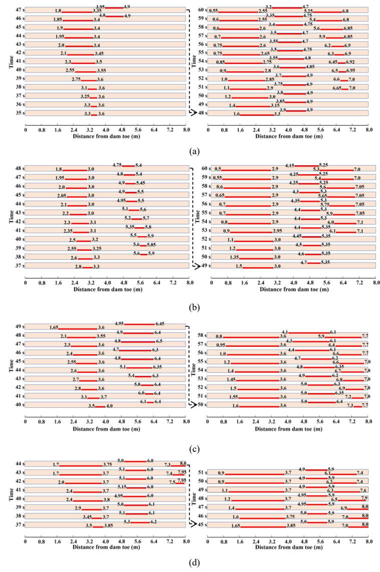

Fig. 2.

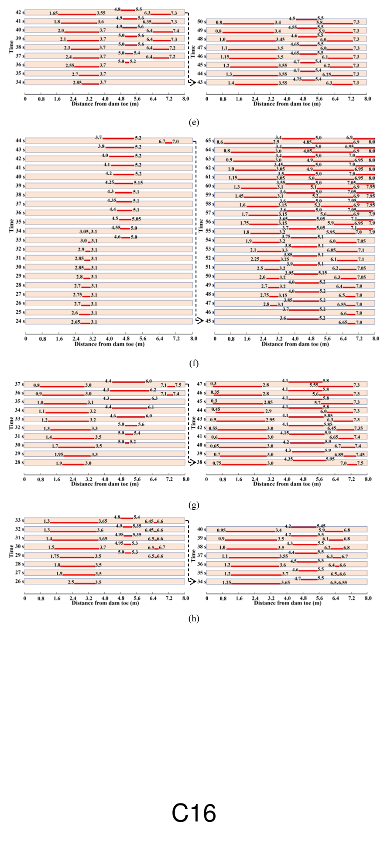

Fig. 3.

Figure. 4 The boulder bars' locations during the dam failure process. Notation: (a) to (h) represent the boulder bars' locations for T1-T8 tests, respectively. The red lines in the figure represent the boulder bars, and the orange rectangles represent the channels. The numbers at both ends of the red lines represent the distances between the upstream and downstream edges of boulder bars and the dam toe.

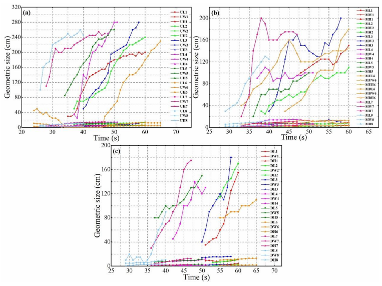

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Fig. 4.

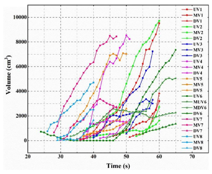

Figure. 6 Volumes of boulder bars. Notation: UVi, MVi, DVi, MUVi, MDVi represent the volume of the boulder bar near the upstream reaches, the boulder bar near the middle reaches, the boulder bar near the downstream reaches, the boulder bar near the middle-upstream reaches, and the boulder bar near the middle-downstream reaches, respectively. For example, UV1 means the volume of the boulder bar near the upstream reaches of the T1 test.

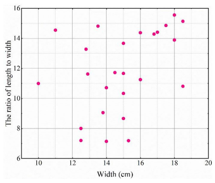

Figure. 9 The ratio of boulder bar length to width

Fig. 5.