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TRANSFORMATION OF BED SURFACE STRUCTURES AFTER DIFFERENT TIME LENGTH OF STEADY ANTECEDENT FLOW EXPOSURE

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ABSTRACT

Bimodal sediment beds were exposed to different duration of steady antecedent flow hydrographs. The works were intended to observe the changes in bed topography after certain duration of exposure by the flow. The changes in bed surface structure were observed by measuring the elevation of the bed surface at a large number of points organized on the orthogonal grid. Probability distributions of bed surface elevations were carried out to estimate the level of changes and the variations of bed surface level. The results suggest that the pattern of bed surface topography after steady flow hydrograph of 6 and 9 hours tended to form diagonal patches. Different bed surface formation than that in the original bed became apparent, particularly elongated valleys and peaks were established in the measurement area. Different patterns were produced by 12-hour steady flow hydrograph with the concentration of eroded bed in certain areas and the patches were more elongated in the streamwise direction. The level of stability formed by different duration of steady flow is also reflected by the distribution curves after stability test. The difference between the distribution curves was easily recognized in the shorter duration and decreased in the longer duration of hydrograph. Only bed surface elevation distribution around the mean level changed whilst the bed surface elevation at the higher values above and below the mean level did not deviate markedly.

Keywords: Bed surface stability, steady antecedent flow

1. INTRODUCTION

The erosion and sediment transport processes are believed to characterize the changes in bed topography. Some researchers (among others are Furbish, 1987 ; Nikora et al, 1998 ; Kirchner et al, 1990 ; Parker, 1996 ; Saadi and Tait, 2001), have claimed that the measurement of bed texture is necessary as well as a grain size distribution analysis in order to fully characterize a gravel bed surface. Although Furbish (1987) pointed out that it appears unlikely the grain size distribution of the bed surface can be linked directly to its surface topography as the bed topography of a surface will also be depending on the flow history, and the type and amount of sediment moved over it (e.g. Saadi, 2008), the grain size distribution of surfaces gives indirect indications of the relative proportions of sheltered to sheltering grains and topographical measurements will hopefully indicate the potential for nearbed flow adjustment and the degree of efficiency of the sheltering bed features.

The important of flow history on the behavior of bed material transport was investigated by Saadi and Tait (2001). It is found that in the steady flow test, duration was the main determinant of bed stability. It was believed that during the longer duration tests the increased length of time allowed the larger grains more time to attain more stable positions. Further study by Saadi (2009) suggested that during the initial exposure to the flow within a 3-hour antecedent flow hydrograph, grains sorting occurred simultaneously to characterize the development of the bed surface structure as indicated by the bed surface coarsening. However, how the bed stabilizes and how the period of destabilization affected in such short duration of flow exposure remained unclear. It has been recommended that the measurement should cover the intermediate and longer duration of antecedent flow hydrographs to identify the stabilization and destabilization processes and to obtain more information on the bed surface structure as the result of erosion and sediment transport behavior.

2. METHODOLOGY

In this experiment bimodal sediment was used as this type of grain size distribution has been found in many gravel bed rivers. The mixture has two modes with finer mode and coarse mode being at approximately 0.355 mm and 5.60 mm with d_{50} = 5.19 mm and the geometric standard deviation, σ_g = 3.42. Three different time length of steady flow hydrographs were applied in antecedent flow experiments with constant discharge of 0.0338 m^3/s. The time lengths were 6 hours for Experiment 6H, 9 hours for Experiment 9H and 12 hours for Experiment 12H respectively.

The stability of the beds was observed by the application of identical stability hydrograph after each antecedent flow test with one-hour increasing limb followed by another hour of declining flowrate with a maximum discharge of 0.0375 m^3/s. The selection of higher discharge for stability hydrograph was intended to obtain the impact of unsteadiness to the bed formed by different time length of steady flow. The existence of flow unsteadiness leading to variable bed shear stress and stream power that consequently affected bedload transport rate (Mrokowska et al., 2017). Size sorting process took place immediately in active layer, defined by Goshal et al (2010) as the current-affected top part of the bed surface. This process is expected to create a noticeable change in bed surface topography since it is generally recognized that the peak of bedload transport triggered by the peak of bed shear stress (Song and Graf, 1996).

The changes of bed surface structure were observed by measuring the elevation of the bed surface at a large number of points organized on an orthogonal grid. These measurements took place at the beginning and at the end of the initial part of each antecedent flow test. The laser displacement meter (LDM) used for this purpose was attached to a computer controlled motion frame. The displacement sensor traversed the sample area of 280 by 180 mm in a re-circulating glass sided tilting flume with 18.4 m long, 0.5 m wide and 0.5 m deep at 1.0 mm intervals both in streamwise and lateral directions in order to cover the close range of the bed surface variations.

3. RESULTS AND DISCUSSIONS

The application of different time length of antecedent flow changed the bed surface structure. Different bed surface formation than that in the original bed becomes apparent, particularly elongated valleys and peaks were established in the measurement area (Figure 1).

Figure 1. Elongated valleys and peaks in the measurement area

During the whole series of Experiment 6H the average bed surface elevation decreased from 2.032 mm to 2.054 mm below the zero datum. This indicates that there was a small amount of further degradation occurred during the experiment particularly after stability test with the increasing darker spots covering some areas (see top picture in Figure 2). However, some peaks with high exposure, e.g. at points (X30,Y70), (X50,Y15), (X60,Y100), (X135,Y90), (X210,Y90) and (X220,Y50), show permanent appearances in both stages. X and Y are the longitudinal and transverse coordinates. The similar levels of valley-formed structures in some areas before and after stability test are also found in this experiment.

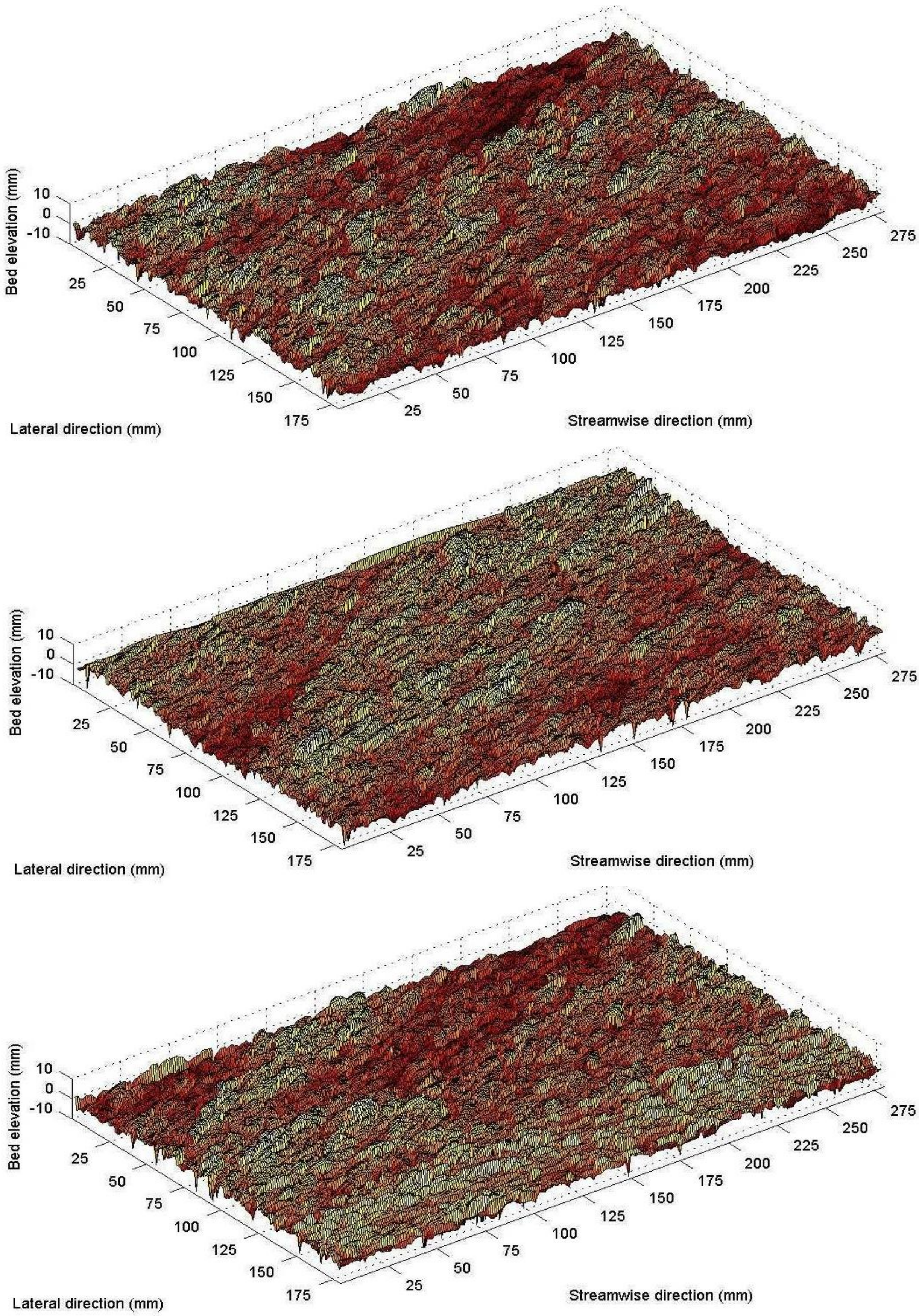

Figure 2. Bed surface topography of the measurement grid after stability test
(from top to bottom picture are experiments 6H, 9H and 12H)

An interesting feature was occurred during Experiment 9H where the bed formed by 9 hours of antecedent flow was stable and the patchiness was not destroyed by stability test (see middle picture in Figure 2). The patches moved upstream and more organized. The valley formed in the bed reduced the resistance of the grains at upstream edges and move forward during the stability test. The peak flowrates in the stability test was not able to entrain these grains and transport them far downstream because of the sufficient level of stability. The fluid forces only removed the grains in a rolling fashion over short distances to downstream either to fill the lower levels or to increase the level of bed surface. These movements made the patches (valleys) to move progressively upstream. The average bed surface level after stability test indicates almost no difference than the average bed surface before stability test. It changes to 0.111 mm below the zero datum, a decrease of only 0.031 mm.

Different bed surface formation found during the whole series of Experiment 12H. The level of decreased is more than that caused by steady antecedent flow experiments 6H and 9H. Points with high exposures before stability test were partially kept in existence after stability test (see bottom picture in Figure 2). Although the valley-formed area more spread, there are some indication that the stability test of Experiment 12H was only able to remove grains in similar fashion to those in stability test Experiment 9H. For instance, the low level in the area of point X100 to X125 and Y0 to Y25 was increased after stability test because of the movement of grains forward in rolling fashion. Further down to this area the level of the bed surfaces decreased, indicating the removal process took place.

As experienced in Saadi (2009) for shorter hydrograph of 3 hours of antecedent flow, visual examination to the figures of bed topography such those in Figure 2 give limited information so that further examinations were necessary. Probability distribution analysis of the bed surface elevations was then carried out to allow the estimation of grain exposure level and also to obtain more information on the bed surface level (Figure 3 and Figure 4).

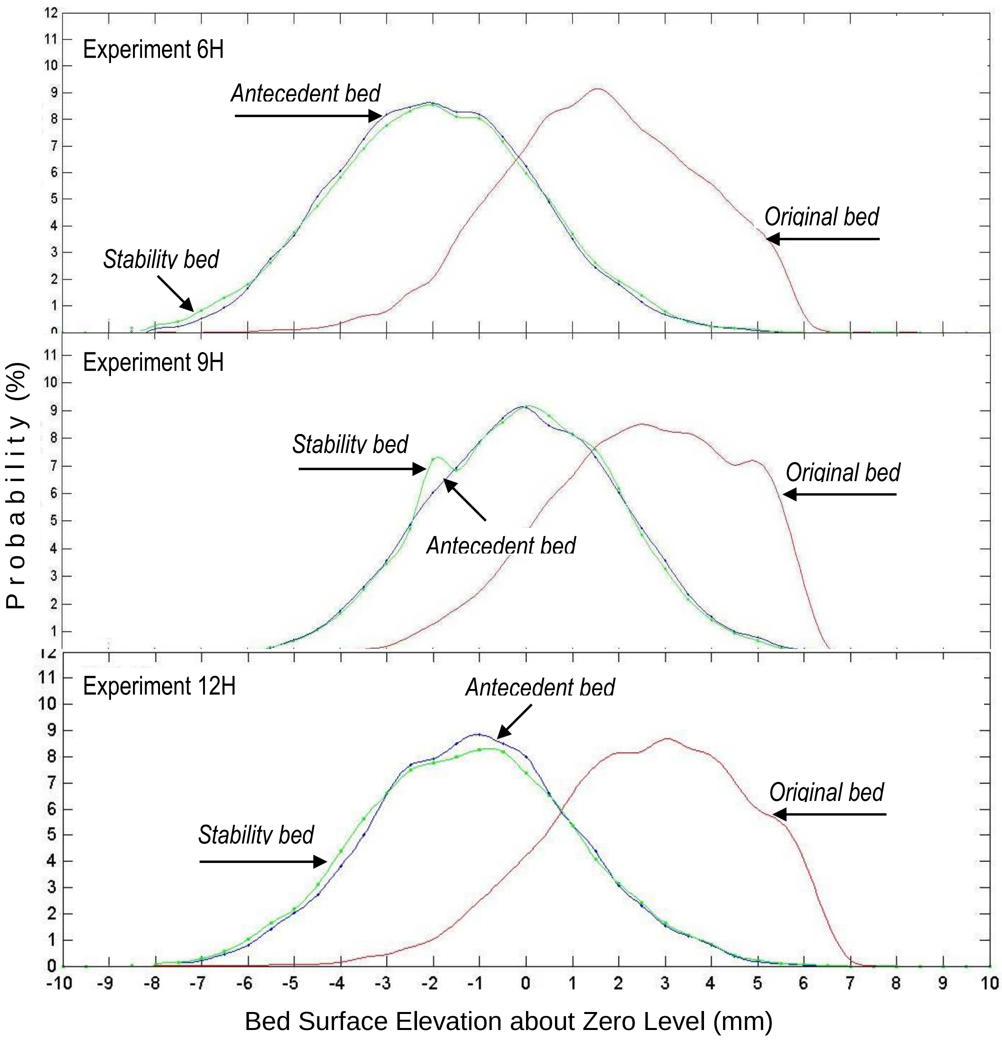

Figure 3. Probability distribution of bed surface elevation about zero level

The top picture in both Figure 3 and Figure 4 show that the level of exposure either about zero and mean level before and after stability test 6H produced almost identical curves. However it is not very difficult to distinguish between the curves. A small variation about the zero value describes the small range in the bed elevation. This coincides with a relatively similar pattern in relation to those appears in the bottom picture in Figure 2. The picture indicates that there is an increase in both negative and positive tail. More noticeable increase in negative tail indicates that to some extent the degradation phase was taking place during the stability test. A number of isolated grains also exist on the bed.

The middle picture in Figure 3 and Figure 4 show that the original bed elevation distribution of Experiment 9H has a different pattern than Experiment 6H. A high proportion of elevations above the zero datum appears. The unusual concentration of 5 mm elevation is thought to be due to the variability of the bed placing process. The curve of elevation distribution becomes more symmetrical. The bed surface elevations are relatively balanced in which the elevations below and above the average bed surface are quite similar. It is thought that the high proportion of 5 mm was not physically disappeared as the fluid forces of antecedent flow were only able to lower the level during the readjustment processes of the bed surface rather than transported them downstream.

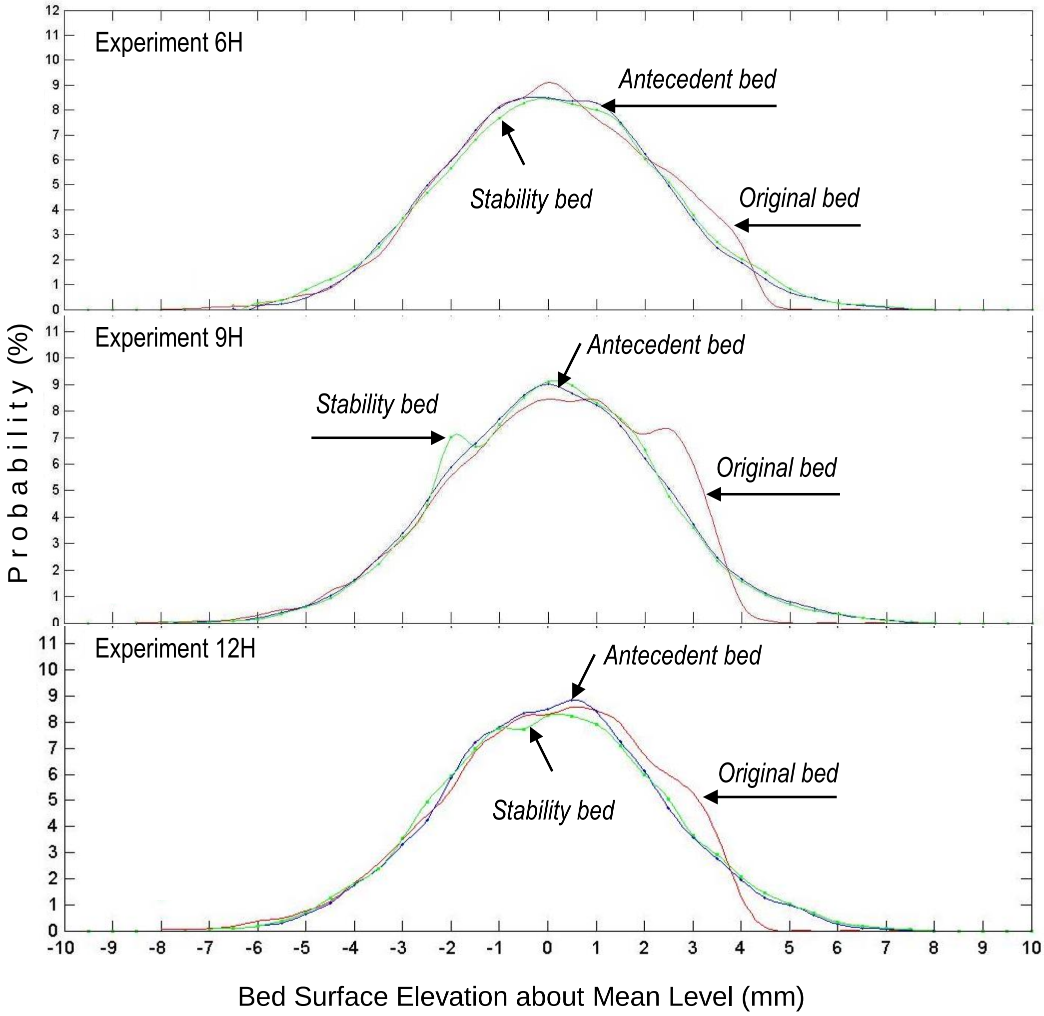

Figure 4. Probability distribution of bed surface elevation about mean level

The over proportion of elevation with 5 mm height from zero datum in the original bed surface distribution have significant impacts to the distribution curve of stability flow. The stronger fluid forces about the peak hydrograph of stability test are believed to completely remove the exposed grains, which was initially 5 mm height in the original bed but lowered after antecedent flow test. This transformation is evident in Figure 3 and Figure 4 (see middle pictures). The bed surface elevation distribution after stability tests shows the irregular form similar to the distribution curve of original bed surface. This time is in the left hand side of the peak distribution curve indicating the level of decrease of about -5 mm with similar proportion to + 5 mm height in the original bed. Apart from the considerable amount of 5 mm deep valley-formed, the changes of the elevation distribution shape after antecedent flow and the subsequent stability test are generally very small. It is very clear from the distribution of surface elevation that a generally very small degradation process took place during the stability test. This indicates a more stable bed is obtained in Experiment 9H than in Experiment 6H. The hump in the final distribution curve is created by the similar form in the original bed surface, which was temporarily hidden and adjusted by the available fluid forces during the antecedent flow test.

During the Experiment 12H the coarsening process caused variation in the bed surface, most notably in the positive side from the mean. The number of grains resting on the bed, with at least 4 mm exposure from the mean level increased (see bottom picture in Figure 4). It is also noticed that the proportion of bed surface level between 1 mm to about 4 mm height decreased suggesting the number of grains with moderate exposure has reduced. The tail of the distribution with negative excursions from the mean bed has little variation from the original bed. However, as the more stable bed condition was achieved after sufficient time of antecedent flow only bed surface elevation around the mean level was changing during the stability test 12H. In this test the bed surface elevation of higher values both above and below the average level did not deviate markedly from the mean. A stable bed configuration appears to be one in which there are few large negative and positive excursions from the mean bed. In a stable bed the number of moderate positive excursions is reduced and it appears a few well-sheltered and stable large grains exist.

The disruption caused by higher flowrates in the stability test is also believed to characterize the changes in the bed surface elevation. The bed surface distribution curves before and after stability test are relatively similar compare to the distribution of original bed surface. The more stable beds were characterized by a closer distribution of bed surface elevation before and after stability test. These identical bed surface distributions indicated that the variations of peaks and valleys are relatively balanced before and after stability test.

4. CONCLUSIONS

The experiments which observe the changes in bed surface topography through the examination of bed surface topography and the probability distribution of bed surface elevation enable some conclusions to be drawn as the following :

1. The applications of different time length of antecedent flow create different bed surface formation with the higher level of decreased were caused by the longer duration of 12 hours steady antecedent flow in comparison to those of 6 and 9 hours.
2. The distribution curves of the original bed surface for each test were not exactly similar but the antecedent flow tests produced almost identical distribution curves. The proportion of high exposed bed and the proportion of valleys are identical to each other although closer examination indicated that more stable bed of experiments 9H and 12H have more slightly large positive and negative excursions from the mean compare to Experiment 6H.
3. The level of stability formed by antecedent flow with different durations is also reflected by the distribution curves after stability test. The difference between the distribution curve before and after stability test was easily more recognized in Experiment 6H. The differences decreased as the time length of antecedent flow increased, with the least difference between curves found in Experiment 12H. The stability test 12H suggests only the distribution of bed surface elevation around the mean level changed whilst the bed surface elevation at the higher values above and below the mean level did not deviate markedly.
4. Although the pattern is subtle, it appears that the number of high positive and negative values is related to the bed strength.

5. RECOMMENDATIONS

In this experiment an extensive and detailed bed topography data collected using the LDM was solely used to calculate the distribution of bed surface elevation both from the arbitrary zero datum and the mean bed level. In this case only the general pattern of erosion can be recognized. Further research is necessary in order to obtain more detail information on how the particles on the surface are aligned and orientated over a range of scales.

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