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Interactive Comment

Interactive comment on "Development of a meandering channel caused by the plane shape of the river bank" *by* T. Nagata et al.

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I am grateful that you spared your precious time to review this article. Please accept our sincerest thanks for your useful feedback. Responses to each point made by the reviewers are given below.

0. Previous studies by the Parker and Jhohannesson group, the Lanzoni and Seminara group, Shimizu and othershave provided a wealth of knowledge on highly developed meandering watercourses. Studies by the above researchers have shown that highly developed meandering watercourses result from bank erosion and the backfilling of point bars at the bank side of river bends, and that such watercourses increase the degree of meandering while a constant river width is maintained. The present study was based on these results. However, its most distinctive feature is that it addresses

the developmental process of the alternating bars that are produced when the river width changes longitudinally over time due to bank erosion. In most previous studies, however, the analyses of bed morphology characteristics and of sandbar stability were conducted for straight channels with fixed banks. Very few studies were conducted under conditions that produce bank erosion. Fig. 15 in the present paperis based on the results of an experiment using a straight channel. However, the applicability of those results has been confirmed in many rivers in Japan. Therefore, the figure is presented in this paper in order to roughly indicate the bed morphology that can be expected to be produced. Meandering channel geometries that form under natural conditions have various configurations. Therefore, the definition of a meander can vary depending on the river or the basin that is studied. However, in this paper, the definition of a meander given in Fig. 7 is used only to approximate the configuration of the normal line in an artificially produced low-water channel. In addition, the actual normal line in the low-water channel was fully explained by this definition. Therefore, supplemental examinations are not made here.

1. In the 1970s, large-scale river improvements were made on almost the entire section that was examined in this study (KP17.0 - 20.0). Aerial photos taken before and after the improvements (1972 - 1978) are shown in the upper part of Fig. 1. In the improvements, a levee was constructed on the right bank immediately downstream of KP19.2, and low-water-channel drilling was done to shift the watercourse toward the center of the river channel. At that time, bank protection was not constructed on the riverbank of the low-water channel. Therefore, the entire river channel became prone to bank erosion. From immediately upstream of KP.19.2, the right bank of the river took the form of a terrace cliff and the watercourse originally ran along the right-bank side. For flood control, the erosion of the terrace cliff was inevitable; therefore, at the river improvement site, the watercourse was allowed to keep running along the right bank side, and as a result, the low-water channel came to have a planar shape with a meander angle of 13°. According to the river channel cross-sections for 1978 (before the 1981 flood), the average width of the low-water channel was approximately 80m and the riverbank

height was approximately 2m, although these varied by location (Fig. 2). However, the aerial photo taken a few years afterward, at the time of the 1981 flood, shows that flood flow with a width of 100m ran through the entire section, and meandering flows that had amplitudes as wide as the river width were produced at M-1, M-2 and M-3 (Fig. 3). This indicates that submerged alternating bars were produced during the flood; accordingly, it was considered that the river width observed during the recession of the 1981 flood (i.e., slightly greater than the width after river improvements; B = 80-100 m) had a dominant effect on river channel formation during the flood. Accordingly, in the analysis for Section-1, the following were given as the initial conditions of the river channel: a curved planar shape with a meander angle of 13°, a 100-m-wide low-water channel and a rectangular cross-section with 2-m riverbank height.

With regard to Section-2, the point bar at M-1 that formed in Section-1 developed a wave height that was as high as the crest of the riverbank over the course of about 30 years. Thus, the low-water channel that largely bent toward the right bank formed before the flood. As shown in this paper, this was confirmed by onsite observation results from aerial photography, laser profiler (LP) measurement data and cross-sectional survey data. In the analysis for Section-2, the initial riverbed was given a sharp meandering angle immediately upstream of the section, under the assumption that such a planar shape of river bank had a dominant effect on the large-scale development of meandering flow brought about by the 2011 flood. Numerical analyses on both sections under the above-mentioned initial river channel conditionsfound that the development of meander channels that occurred in Section-1, which is on the upstream side of Section-2, was brought about by the gentle curvature of the river channel in the process of point bars development immediately downstream of the bend during the flood. In contrast, the development of meander channels that occurred in Section-2, which is downstream of Section-1, was found to be brought about by a process whereby the highly developed point bar promoted the development of meandering flows and such development propagated downstream during the flood. That is to say, as the referee has presumed, it is understood that in Section-2, a high-angle meander at the up-

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stream end of Section-2 gradually propagated downstream, and as a result, the entire river channel became a large meander.

2. As you point out, in this analysis model, braided channels will form if steady flow runs through the channel for a prolonged time. As an example, Fig. 4 shows the results of the analysis in which 400m3/s of steady flow (approximately 2.5 times the maximum yearly discharge of the Otofuke River) ran through the straight channel for ten days. Additionally, in all the simulations in this study, uniform flow depth was given as a boundary condition at the downstream edge of the analysis section and sediment budget at the upstream edge of the analysis section was assumed to maintain a state of equilibrium. As shown in Run 1 in the figure, in the initial stages of water flow (0 - 72h), characteristics of alternate bars temporarily appeared. However, once the meandering had increased beyond a certain degree, new watercourses taking short cuts across the watercourses appeared on the sandbars. After that, the new watercourses repeated irregular watercourse changes while meeting and diverging from the existing watercourses, and with time, braiding streams developed in the channel. Additionally, in Run 2, in which the initial riverbed was given regular disturbance (alternating bars), the development period of alternate bars became even shorter (0 - 48 h), and in Run 3, whose channel width was twice those of Runs 1 and 2, double-row bars developed without the formation of alternate bars, which resulted in the development of braided streams. However,this study was conducted for the purpose of reproducing the phenomena of the development of a single-low meandering channel that occurred in the field and analyzing the dominant factors that led to the phenomena, thus focusing attention on the channel migration that takes place under the specific discharge conditions for the duration of one flood (72 h). In other words, Fig. 4 in the present study, for example, only addresses the development process of alternating bars from 0 to 72 h in Runs 1 and 2. Studying the development process of braided streams that takes place under conditions in which the river width can freely change by means of bank erosion is a very interesting research theme, and it is regarded as a promising avenue of research.

In the development of meandering flow, how the cross-sectional profile of a sandbar changes with time is an extremely important point. Here, the cross-sectional profile of an alternating bar is expressed with wave height HB and river width B, and time series variation of sandbar profile for representative cross-sections of Section-1 and Section-2 are shown in Fig.6. The upper part of the figure shows the following: the results from the experiment on the equilibrium wave height of alternating bars that was conducted using a straight channel and the region where the equilibrium wave height could be found, which was indicated by dimensional analysis (Ikeda, 1983) and onto which the results obtained from this analysis were overwritten. In addition, the lower part of the figure shows the time series variation of the cross slopes (HB / B). The two sections can be said to have the following two points in common. The first is that the sandbar wave height increases with time; however, after the sandbar wave height reaches the equilibrium wave height, the sandbar moves while maintaining the same state. The second is that the time-series variation of the sandbar cross-slope reaches the maximum value when the sandbar wave height reaches equilibrium. Thus, both sections show a convex-shaped variation that has the maximum value as its peak value. This result can be roughly interpreted as follows (Fig. 7). A. Before the wave height has fully develop, the change in the vertical direction predominates (sandbar development process). B. When the sandbar wave height reaches the equilibrium state, the cross-slope also reaches its peak (HB / B = 0.020 - 0.025). C. After that, the change in the transverse direction predominates, while the equilibrium height is maintained (bank erosion process). In other words, what the sections have in common is that the planar shape of the meandering flow develops after the cross-sectional profile of sandbars has developed. The largest difference between the two section lies in time at which the sandbar wave height reaches equilibrium (B). It is possible to interpret it as follows. In Section-2, where the sandbar wave height reaches equilibrium at an early stage of the flood, bank erosion continues for a prolonged time, which leads to the development of meandering flows that is more remarkable than that in Section-1. Additionally, the difference in the timing of when the sandbar wave height reaches the equilibrium wave height is brought about by the presence or absence of the remaining traces in the watercourse or sandbars that were produced during previous floods. Therefore, different planar shapes of river bank were given to Section-1 and Section-2 as the initial riverbeds for analysis. If a highly developed sandbar like M-1 exists in a low-water channel, it will cause strong meandering flow during a flood. It is assumed that such meandering flow increases the development rate of sandbars to a great degree (peak arrival time of HB/B).

3. I will review the overall structure of the paper, when I revise it in the light of your comment.

Interactive comment on Earth Surf. Dynam. Discuss., 1, 1019, 2013.

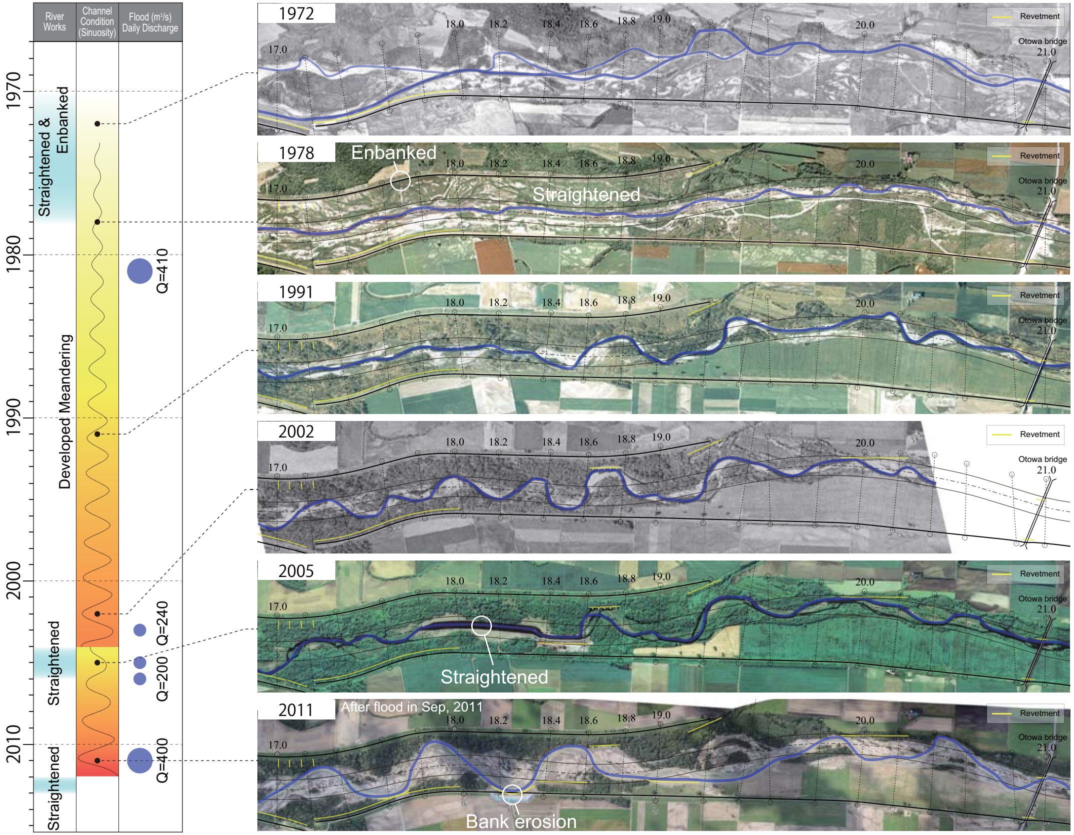

Fig. 1. Migration history of the river channel (Otofuke River, KP17.0-KP21.0)

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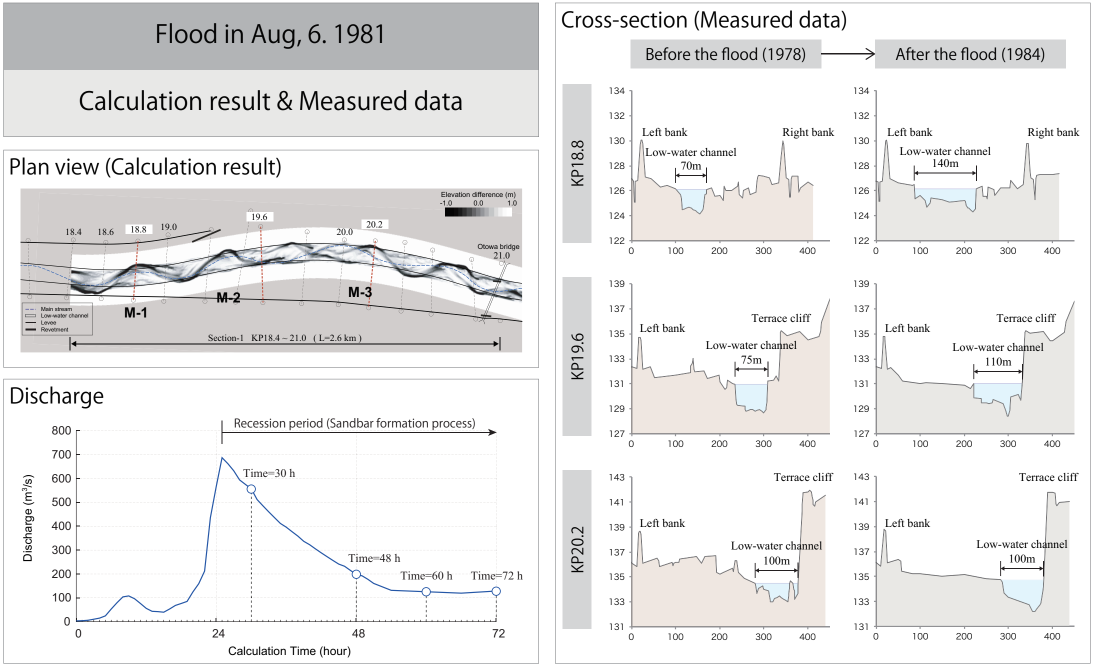

Fig. 2. Cross-section in 1978 and 1984 (Section-1)

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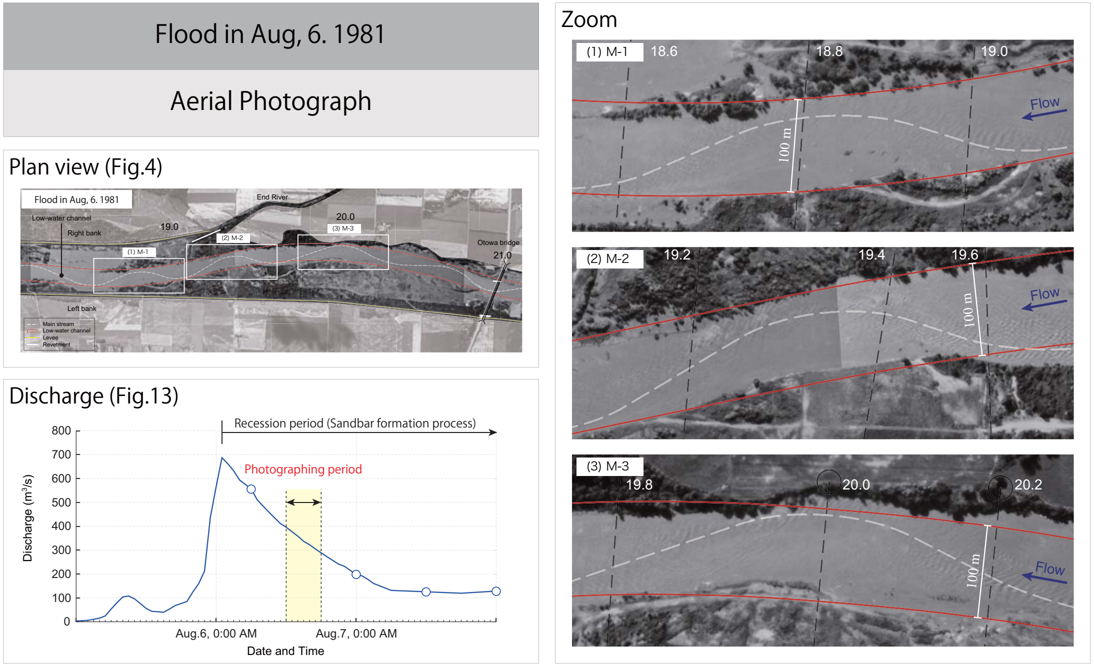

Fig. 3. Aerial photograph (Flood in Aug, 6. 1981)

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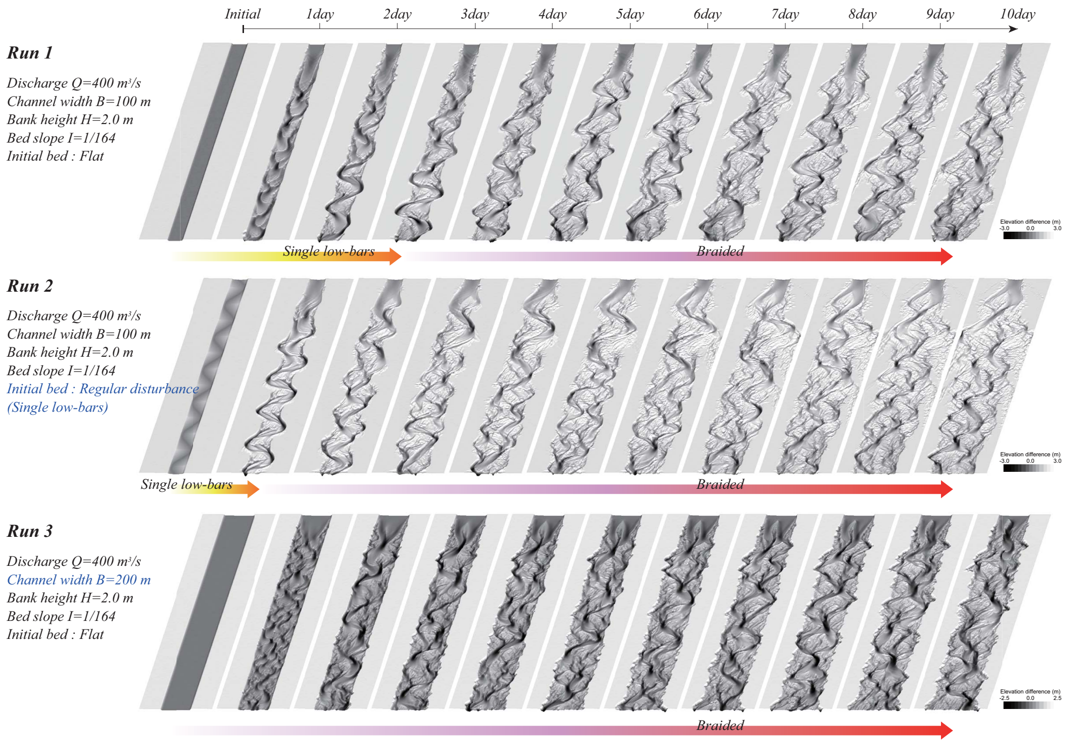

Fig. 4. Calculation ï¡Šesults in different calculation condition

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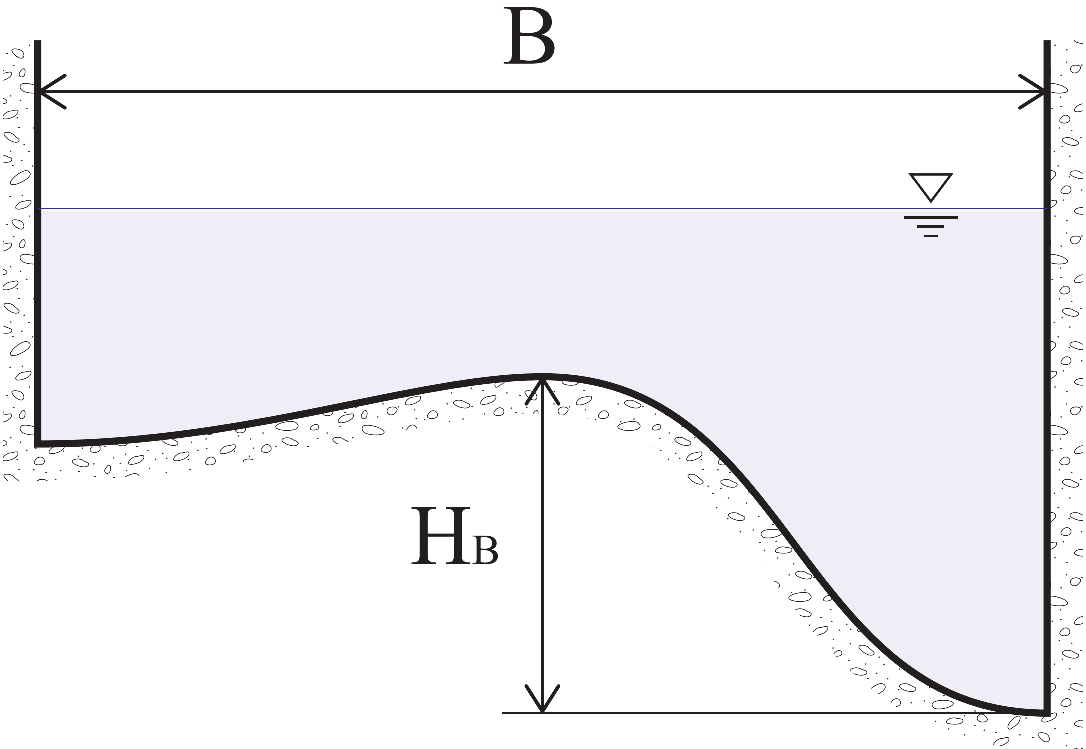

Fig. 5. Schematic diagram of cross-section profile

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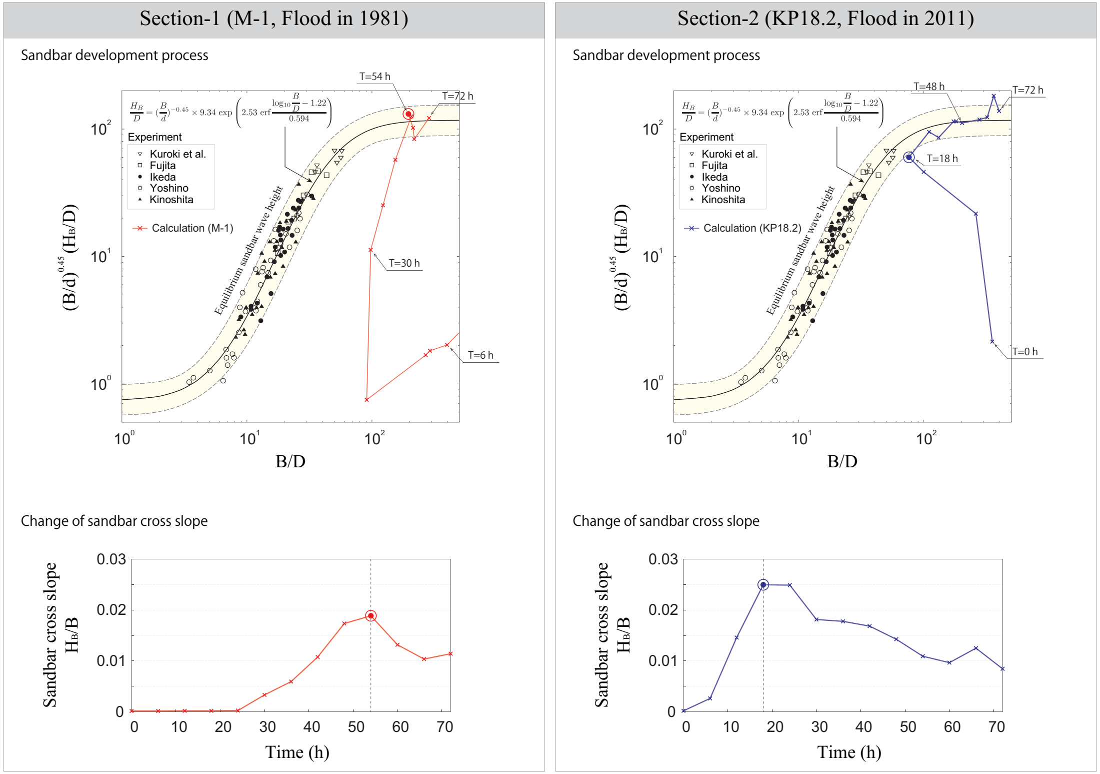

Fig. 6. Sandbar development process and change of sandbar cross slope

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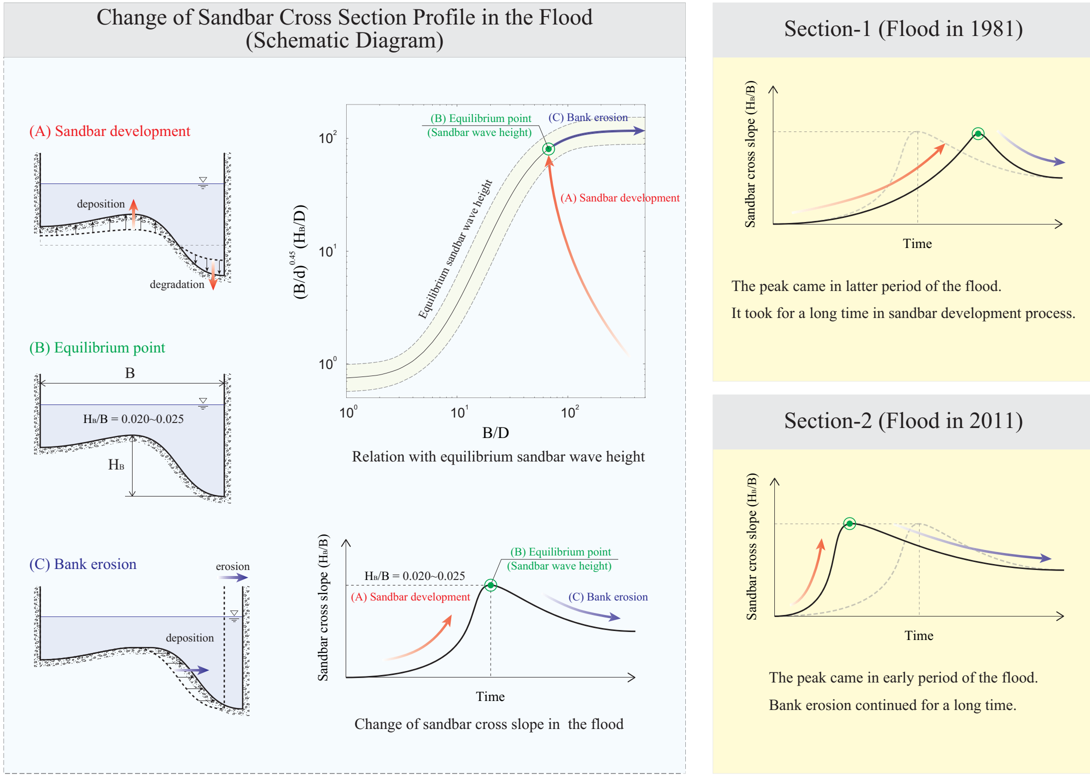

Fig. 7. Change of sandbar cross section profile in the flood

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