Actual Condition of Sediment-Related Disaster in Nojiri Area, Totsukawa Village During Typhoon Talas, 2011

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Typhoon Talas hit Japan from Aug. 30 to Sep. 5, 2011 producing heavy rainfall. The rainfall caused a serious sediment-related disaster in the Nojiri Area, Totsukawa Village, southern Nara Prefecture on Sep. 3. The direct cause of this disaster was a hydraulic bore, but this bore was induced by a large-scale debris flow caused by a deep-seated landslide that occurred in Obara Valley, a left tributary (the opposite bank) of the Totsu (Kumano) River. Based on a close field investigation and aerial photograph analysis, it seems that the landslide soil turned to a debris flow continuously and rushed downstream running around alternately on the left and right banks of the valley with eroding and re-depositing sediment. The water level of the Totsu (Kumano) River increased by 10.8m from the normal level due to the outflow discharge from Kazeya Dam located upstream of the Nojiri Area became the cause of a hydraulic bore induced by a debris flow.

Key words: deep-seated landslide, debris flow, hydraulic bore, process of sediment-related disaster

1. INTRODUCTION

Typhoon Talas, a large-scale, slow-moving typhoon, hit Japan from Aug. 30 to Sep. 5, 2011 producing heavy rainfall. The rainfall caused a widespread serious sediment-related disaster in Nara, Wakayama and Mie prefectures, which are located on the Kii Peninsula, Western Japan. According to the Kamikitayama AMeDAS Station in southern Nara Prefecture, the cumulative rainfall was 1,812.5 mm (between Aug. 30 and Sep. 4), and the maximum 72 hour rainfall was 1,650.5 mm with maximum daily rainfall reaching 661 mm (on Sep. 3). The disaster was characterized by a deep-seated (catastrophic) landslide, landslide dam, debris flow and flood. The casualties were 41 people dead and 15 missing.

The rainfall also caused a serious sediment-related disaster in the Nojiri Area, Totsukawa Village, southern Nara Prefecture on Sep. 3, leaving 2 people dead and 6 missing. The Nojiri Area is located on the right bank along the Totsu (Kumano) River. The direct cause of the disaster was a hydraulic bore, but this bore was induced by a large-scale debris flow caused by a deep-seated landslide that occurred in Obara Valley, a left tributary (the opposite bank) of the Totsu (Kumano) River.

This study analyzes the actual condition and process of the sediment-related disaster that occurred in the Nojiri Area. To study and understand the process of the disaster, a close field investigation and aerial photograph analysis are used. The actual condition and the time of the disaster occurrence are examined by a fact-finding survey conducted on the inhabitants of the Nojiri Area.

2. SITE CONDITION

The Nojiri Area is located on the right bank along the Totsu (Kumano) River. The relative height is more than 22 m above the riverbed and the river width is approximately 100m. Route 168 runs along the area and along the river with a retaining wall. The confluence point of the Obara Valley is located 200 m upstream from the Nojiri Area. The Obara Valley has a steep V-shape, with a length of 1.04 km, average gradient of 1/3.8, and catchment area of 0.975 km^2. Kazeya Dam was located approximately 2.2km upstream from the confluence point of the

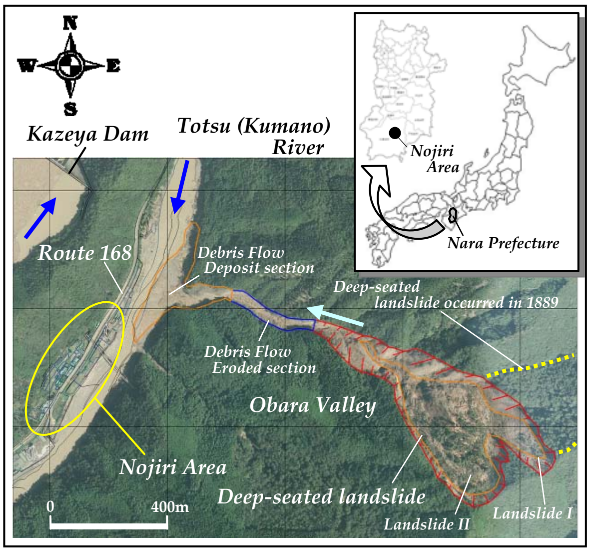

Fig. 1 Location and aerial photo image after the disaster in the Nojiri Area

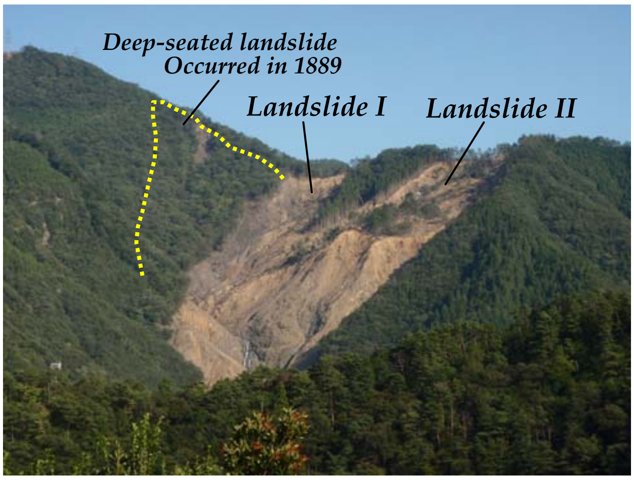

Fig. 2 View of deep-seated landslide at the Obara Valley

Obara Valley, and it was discharging water when the typhoon hit (**Fig. 1**, **Fig. 3**).

The deep-seated landslide occurred on the left slope at the middle reaches of the valley, where the maximum width and length is approximately 360 m and 590m, the area is 21.2 ha, the average depth is approximately 11m and the average slope gradient is 30°. The base rock is formed by shale with blocks of chert and greenstone, and alternation of sandstone as an accretionary wedge. At the upstream of the landslide, there is a former deep-seated landslide that occurred in the Meiji Era (1889) (**Fig. 2**).

3. ACTUAL CONDITION OF LANDSLIDE AND DEBRIS FLOW

The sediment-related disaster in the Nojiri Area occurred at approximately 18:38 on Sep. 3, estimated by a fact-finding survey of inhabitants at the area. According to the Kazeya AMeDAS Station, the nearest rainfall gauging station to the Nojiri Area, cumulative rainfall until the occurrence of the disaster was 967 mm (between 17:00 on Aug. 31 and 18:30 on Sep. 3), maximum hourly rainfall was 44.5 mm/hr and hourly rainfall at the occurrence was 30.0 mm/hr (**Fig.4**).

Based on a close field investigation and aerial photograph analysis at the Obara Valley, the process of the deep-seated landslide and debris flow occurrence are estimated to be as follows.

(1) Deep-seated landslide occurred at two sites (Landslide I : upstream side, Landslide II : downstream side) of the left bank's slope of the middle reaches in Obara Valley, and huge amount of landslide soil was generated and

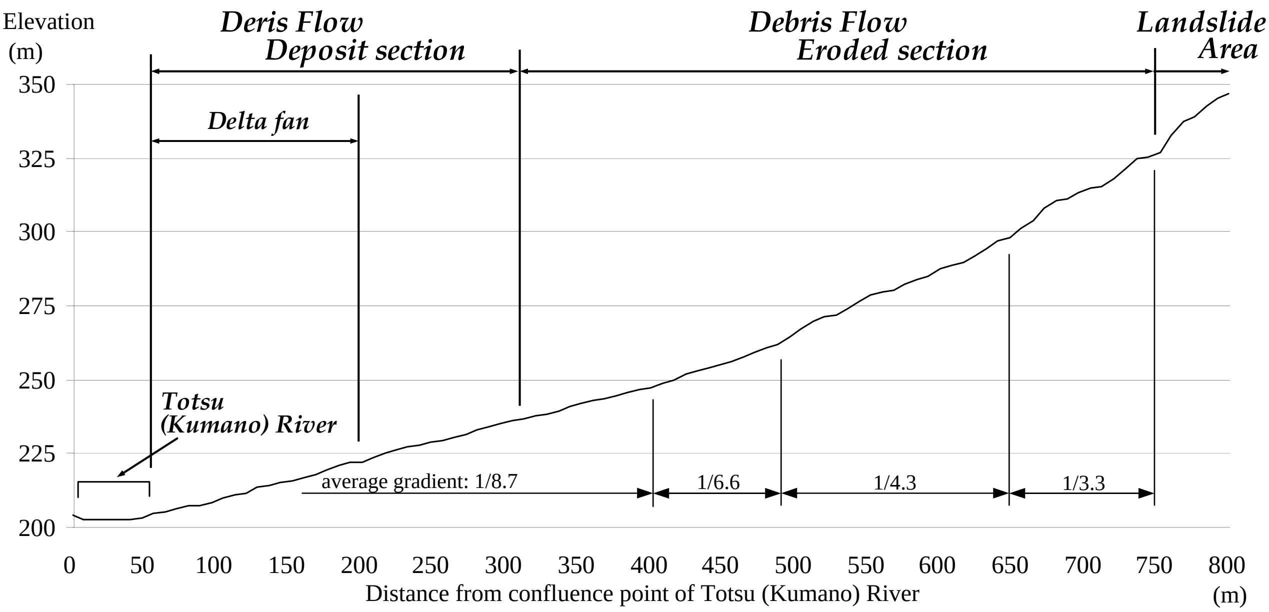

Fig. 3 Longitudinal profile of Obara Valley (after the debris flow, lower reaches)

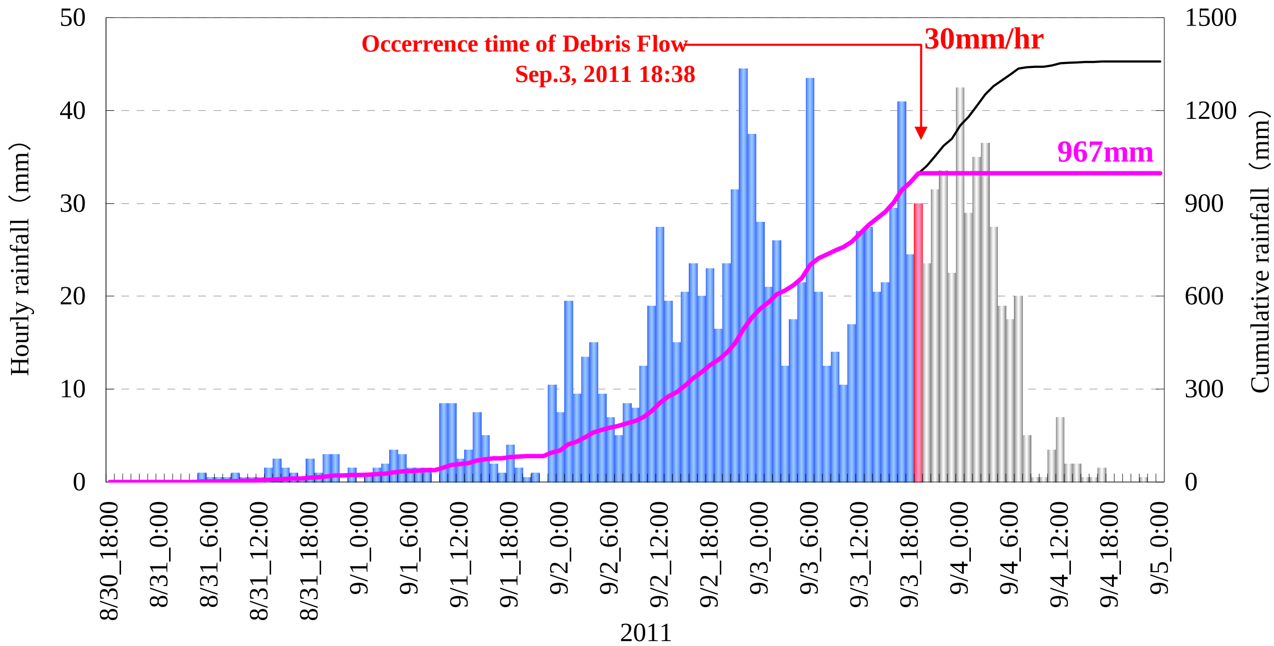

Fig. 4 Profile of hourly and cumulative rainfall between Aug. 30 and Sep. 4 at Kazeya AmeDAS station

remained at the foot of the landslides. The total volume of both landslide soil is estimated to be approximately 2,500,000m^3, while the sediment remained at the foot of landslide is estimated to be approximately 1,200,000m^3. As a result, approximately 1,300,000m^3 of landslide soil flowed down as debris flow (**Fig. 5**).

(2) Based on the fact that landslide soil did not remain at the foot of Landslide I, while a huge amount of landslide sediment remained at the foot of Landslide II, and the trace of the riverbed erosion, the process of the landslide occurrence

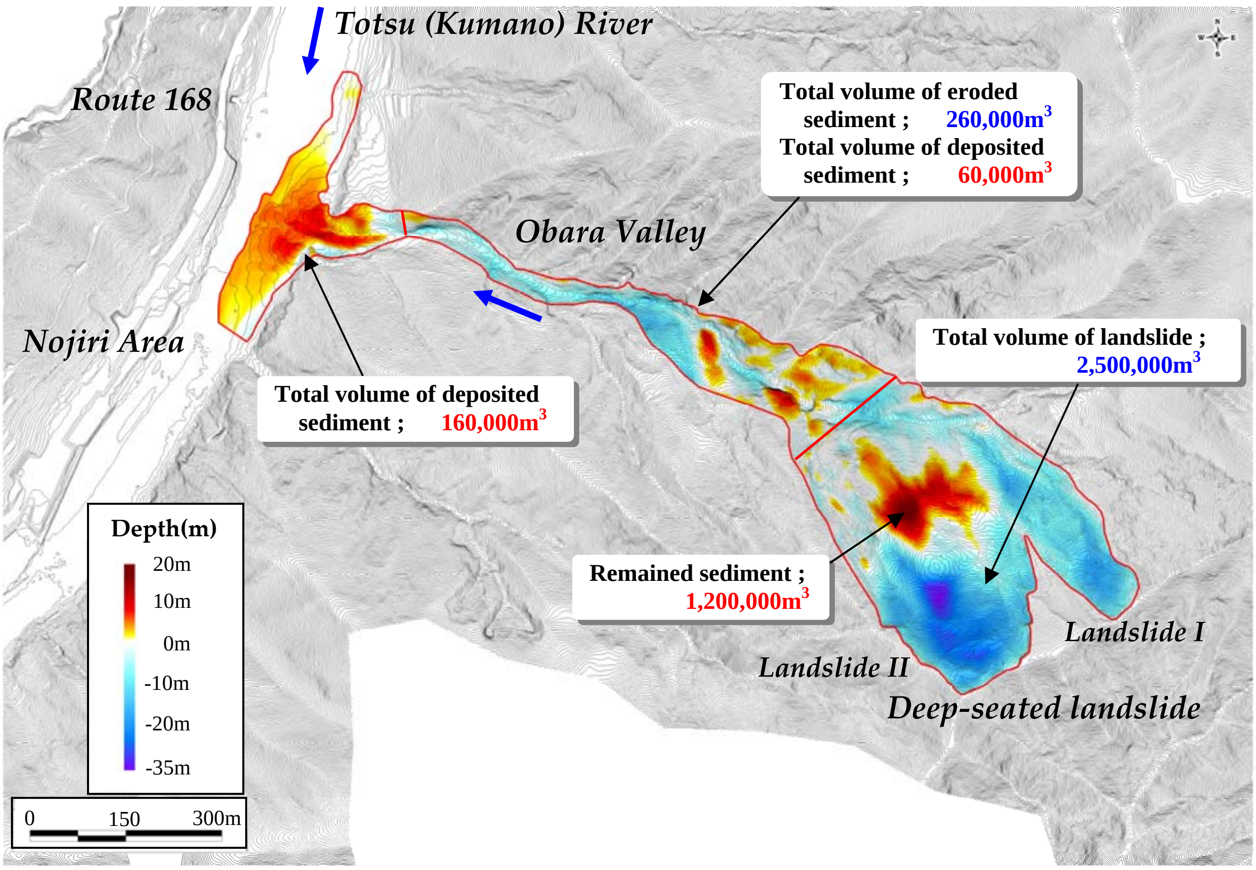

Fig. 5 Comparison of the terrain before and after the deep-seated landslide and debris flow

is estimated that 1) Landslide I collapsed, then, 2) the landslide soil of Landslide I fluidized and flowed down while eroding the foot of Landslide II, and 3) Landslide II collapsed. Although the occurrence time of each landslide is unknown, it is supposed that the two landslides occurred almost simultaneously.

(3) The fluidized soil of both landslides climbed up the slope of the opposite bank (right bank) and turned to debris flow continuously, because there was no trace of landslide dam left in the valley. The debris flow rushed downstream running aground alternately on the left and right banks of the valley as a superelevated flow with eroding and re-depositing sediment. The maximum height of the superelevated flow in the upstream was as high as 40.5m (left bank) and that of the downstream was as high as 42.2m (right bank) . The total volume of eroded sediment at the eroded section was approximately 260,000m^3 and that of deposited sediment was approximately 60,000m^3 (**Fig. 5**).

(4) The debris flow started to deposit rapidly at the upper reach of confluence point on the Totsu (Kumano) River while flowed into the Totsu (Kumano) River and spread there without being attenuated, then formed a delta fan and deposited there. The deposit gradient of the debris flow sediment was approximately 8°and the volume of the sediment was approximately 160,000m^3 (**Fig. 5**). Based on the downstream trace of superelevated flow on the right bank at the exit of the Obara Valley and riverbed gradient, the maximum flow velocity of the debris flow was estimated at 45.8m/s (164.9km/hr) and the peak discharge was 7,300m^3/s.

Fig. 6 Debris flow sediment at the exit of Obara Valley

4. PROCESS OF SEDIMENT-RELATED DISASTER

Based on a close field investigation in the Nojiri Area and around the confluence point of the Obara Valley, photographs collected from the Totsukawa Village Office immediately following the disaster, disaster research report including rainfall data, and the results of fact-finding survey of inhabitants, the processes that caused the sediment-related disaster are estimated to be as follow (**Fig. 7**).

(1) In the Nojiri Area, which was located on the opposite bank of the Obara Valley (right bank of the Totsu (Kumano) River), it was found that there were many cracks on the retaining wall right under Route 168, and that fences, grass and trees had been forced to fall, while the fine, black gravel sediment had been deposited on the road and the lower slopes.

(2) The area of these traces was confirmed sits on the extension of the downstream flow direction of the debris flow which had flowed out of the Obara Valley. It was supposed that the flow reached and ran up the Route 168 on the opposite bank, rebounded off the road's slope, and then flowed down as if returning to the main stream of the Totsu (Kumano) River while hitting the Nojiri Area along Route 168, causing the disaster that washed away 2 houses, leaving 2 people dead and 6 people missing.

(3) Although there were many cracks on the retaining wall right under Route 168, there was no damage and trace of collision caused by gravel on the surface, and although fences, grass and trees along Route 168 had been forced to fall, they stayed in their original positions. In addition, the fine, black gravel sediment deposited on the road and the slope under the road was similar to the debris flow deposit in the Obara Valley, the particle diameter was as small as approximately several centimeters. Therefore, it is estimated that the flow which hit the Nojiri Area was not the main flow of the debris flow containing gravel, but that the hydraulic bore was formed by the inflow of the debris flow on the Totsu (Kumano) River. Meanwhile, it is considered that this flow was mud water containing few sediment.

(4) The water level and discharge around the Nojiri Area, based on the floodmarks and the outflow discharge from Kazeya Dam, it is estimated that when the debris flow flowed down (it must have been around 18:38 on Sep. 3) was 10.8m, and that the discharge was approximately 4,400m^3/s.

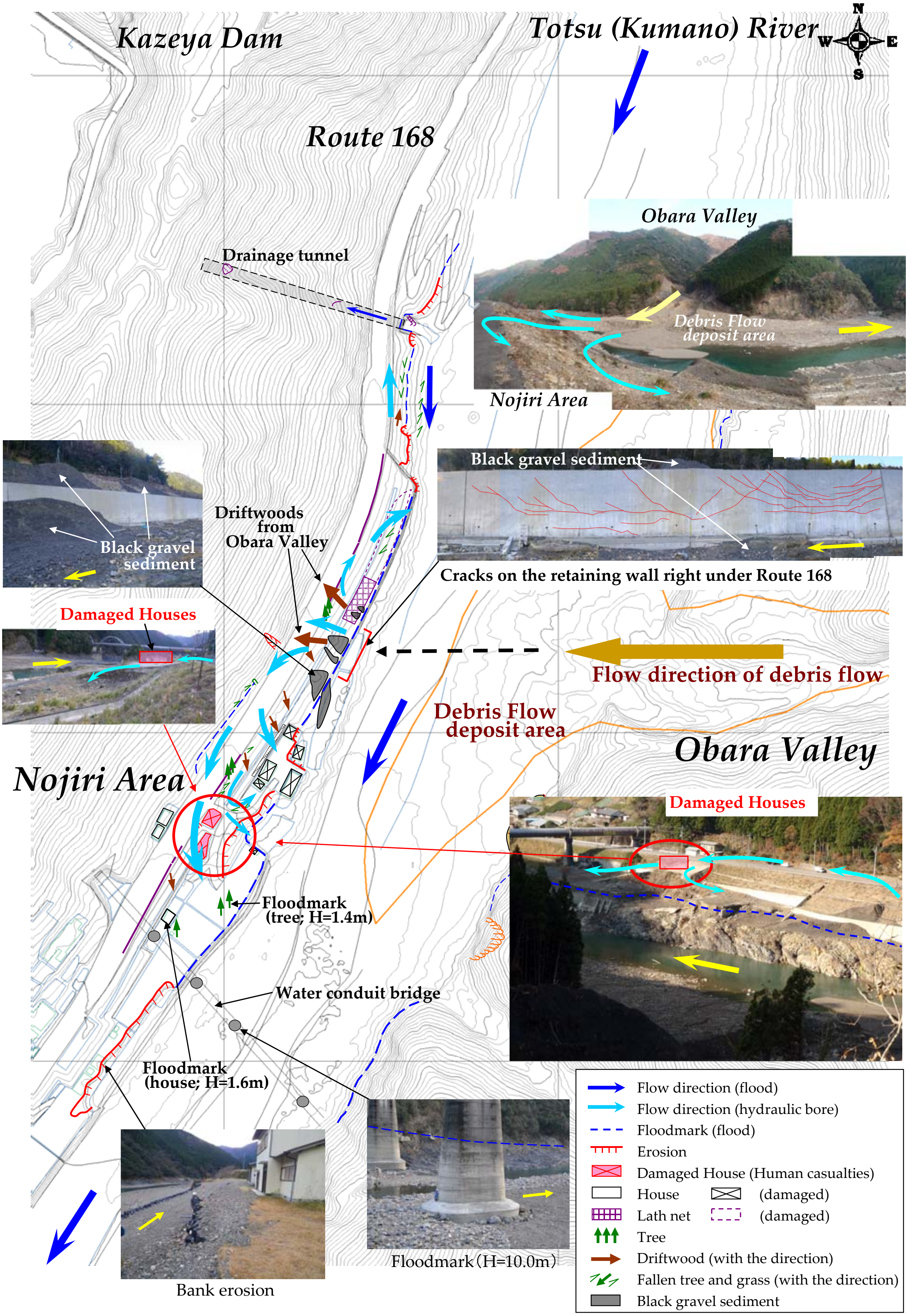

Fig. 7 Traces and floodmarks of the debirs flow and hydraulic bore at the Noijiri Area and the confluence point of Obara Valley and Totsu (Kumao) River

Since the relative height of the Nojii Area is more than 22m above the riverbed, it is estimated that the flow which hit the Nojiri Area ran up approximately 11m.

(5) Upstream right bank along the Totsu (Kumano) River in which the hydraulic bore reached by the inflow of debris flow, a trace of grass and trees that were forced to fall in the upstream direction of the river, which was in the opposite direction of the flood flow. This indicates the possibility of upswash had been caused by the inflow of the debris flow.

(6) According to the deposition shape of the debris flow delta fan, based on the site photographs and aerial photographs continuously shot after the occurrence of the debris flow, it is estimated that small-scale sediment flow or debris flow occurred at least twice (around 12:00 on September 4 and around 11:00 on September 6) after the occurrence of the debris flow on September 3.

5. CONCLUSION

The process of the serious sediment-related disaster that occurred in the Nojiri Area was considered to be caused by a continuous large-scale event of different sediment movements such as 1) deep-seated landslide, 2) debris flow, and 3) hydraulic bore.

In addition, generally, the impact of a mass movement of landslides and debris flows occurs along the relative wide rivers with relative height rarely reach the opposite bank. However, in the Nojiri Area although the river width is approximately 100m and the relative height is more than 22m above the riverbed, the hydraulic bore reached the opposite bank and ran up 11m caused a serious disaster (**Fig. 8**).

Thus, this disaster suggests that there is a high possibility of a hydraulic bore occurrence by the landslide and inflow of debris flow and cause an impact on the opposite bank from the source. The possibility of the occurrence estimated to depend on the scale of the landslide, debris flow and also the water level and discharge of the river.

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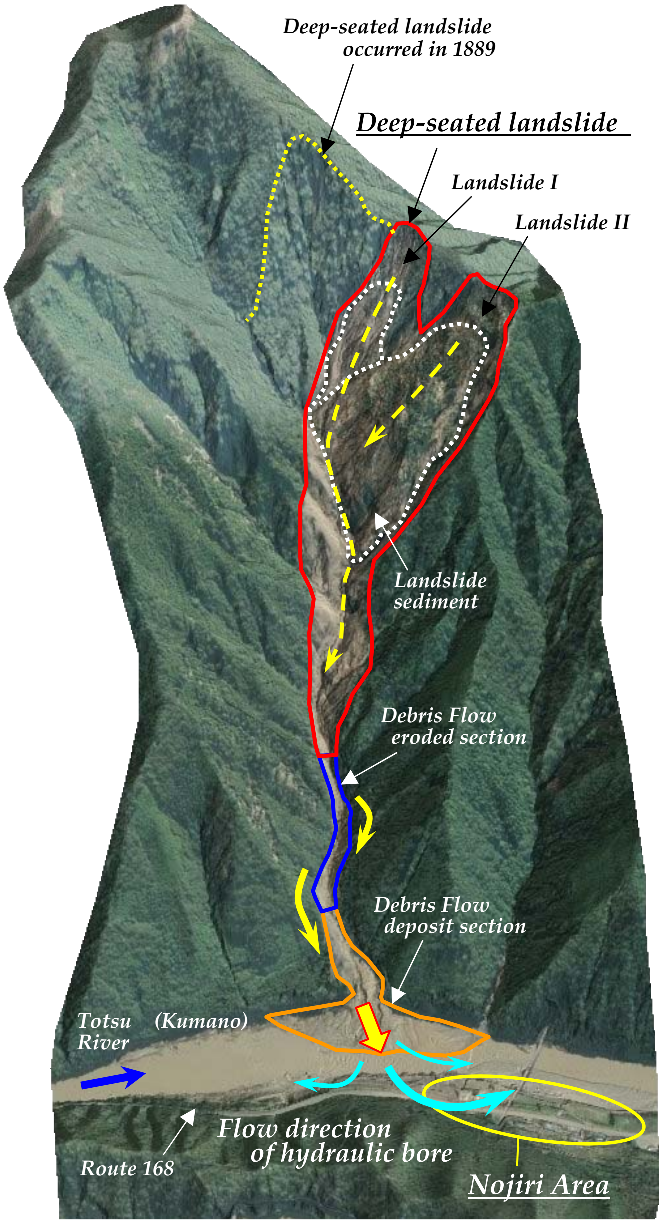

Fig. 8 Process of the sediment-related disaster in the Nojiri Area

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