Sediment Related Disasters Generated by Typhoons in 2004

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ABSTRACT: In 2004, ten typhoons have attacked Japan islands of which 6 typhoons have generated severe damages onto Shikoku Island. This paper will feature the condition of the occurrences of sediment related disasters together with rainfall conditions. The disaster is divided into two types from the view point of mechanism; "Valley-off type debris flow" and "Gigantic slope failure which is controlled by the geological condition such as fault system or weathering of bed rocks during long time". The former occurred in the area of rainfall less than 1,500mm/year, while the latter occurred in the area of rainfall more than 2,500mm/year.

1 TYPHOONS AND THE RAINFALL IN 2004

1.1 *Rainfall condition of Shikoku Island*

From figure 1, it can be recognized that for the upper one-third of Shikoku Island(northern part of Ehime Prefecture and Kagawa Prefecture), rainfall does not exceed 1500mm/year and on the contrary the lower two-third of island(Kochi Prefecture and Tokushima Prefecture), rainfall exceeds 2000mm/year. The difference comes from the existence of Shikoku ridge which goes from east to west in the middle of island.

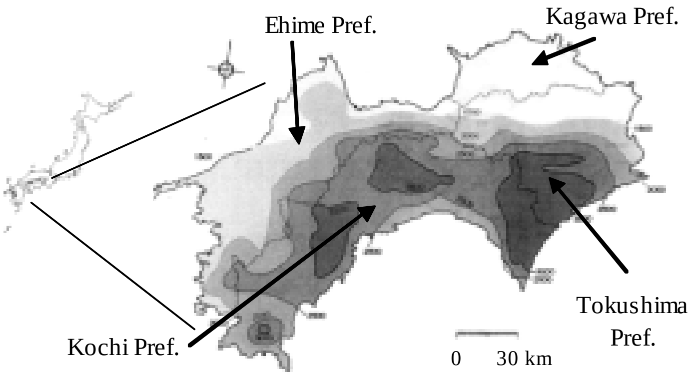


Figure 1 Iso-precipitation curves of Shikoku Island in use of mean annual rainfall during 1981-2000

Thus, the climate of northern part of island is the inland type climate like Mediterranean region and subsequently have few rainfall. The southern part of island faces to the Pacific Ocean and in the rainy season sometimes attacked by Typhoons and by the heavy rainfall of frontal storms, thus much rainfall is brought, though the area of latter has much experiences of heavy rainfall.

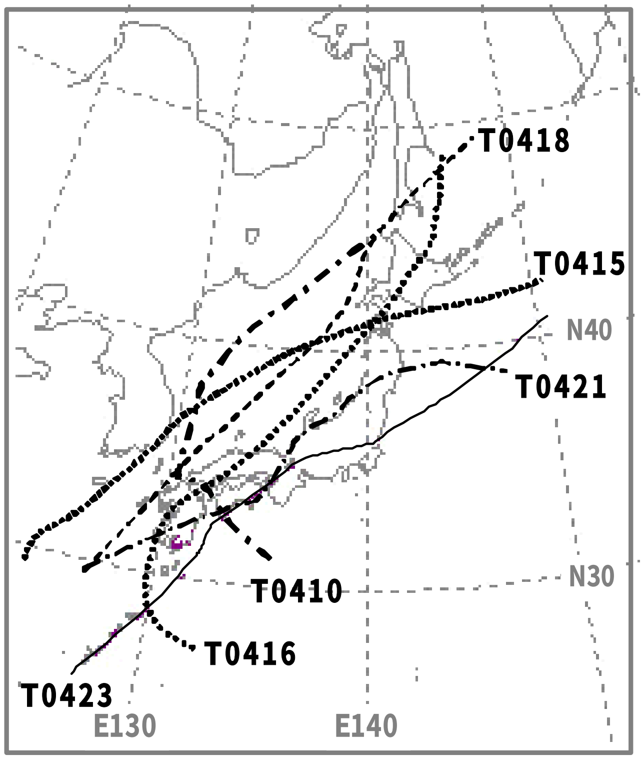
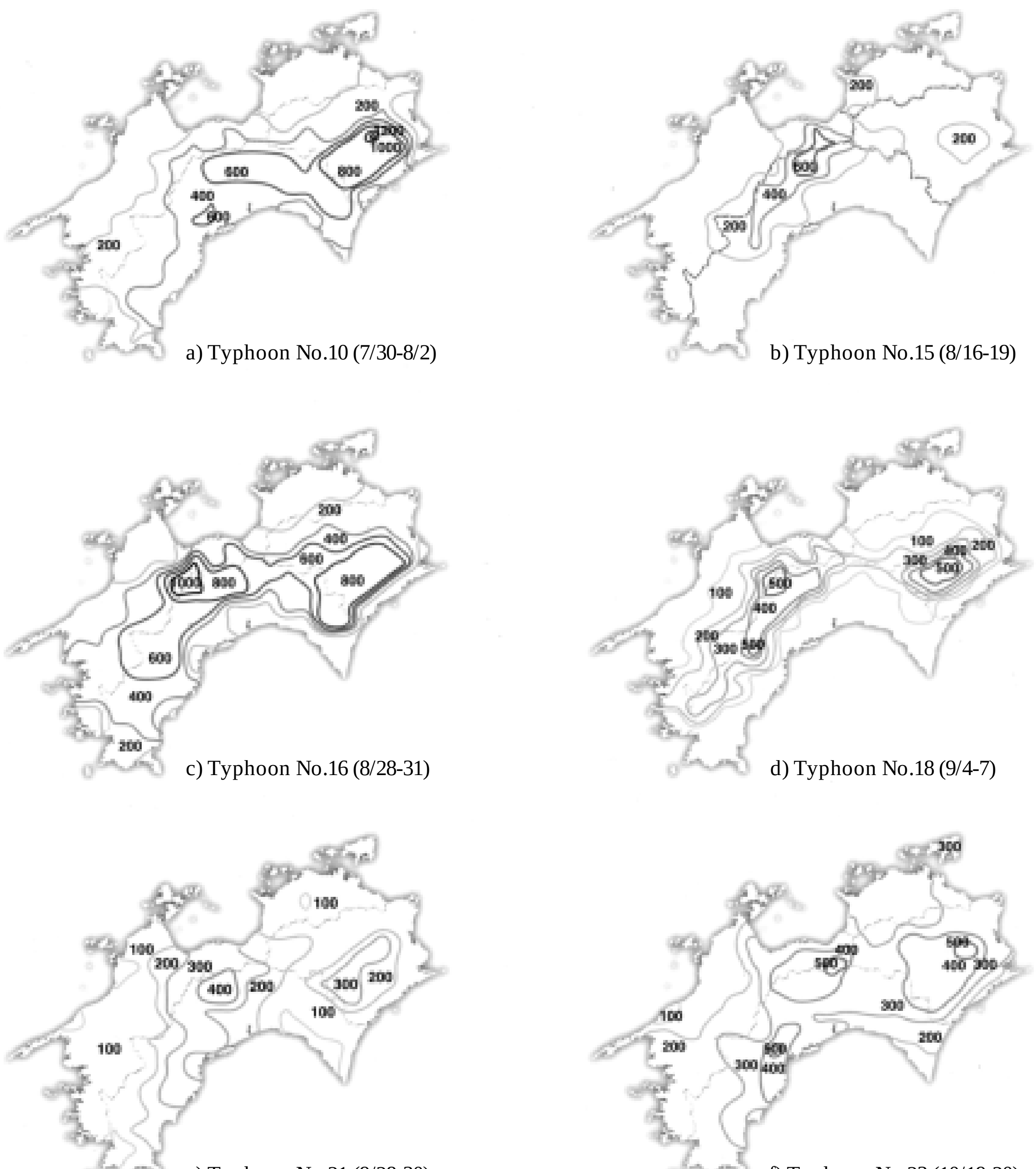


Figure 2 Tropical cyclone (Typhoon) tracks that affected Shikoku Island in 2004

1.2 *Sediment related disasters occurrences due to Typhoons in 2004*

Figure 2 shows the courses of 6 Typhoons which attacked Shikoku Island and figures in Figure 3 are the iso-precipitation curves of 6 Typhoons respectively. As mentioned above, because of the



a) Typhoon No.10 (7/30-8/2) b) Typhoon No.15 (8/16-19)

c) Typhoon No.16 (8/28-31) d) Typhoon No.18 (9/4-7)

e) Typhoon No.21 (9/28-30) f) Typhoon No.23 (10/19-20)

Figure 3 Iso-precipitation curves of Typhoons that attacked Shikoku Island in 2004 (rainfalls are the cumulated values of the days indicated in parenthesis)
(＊Documents proposed by the Japan Weather Association(JWA))

morphological condition, much rain is brought onto the mountainous region of Shikoku Island(Fig.2 a),b) and d)), and further more, the areas usually have less rainfall were attacked by heavy rainfall(Fig.2 c),e) and f)). In consequence, by the un-experienced rainfall for both areas, the great number of sediment related disasters have occurred. Table 1 and Figure 4 show the documents of the number of disasters together with those of all Japan.

Figure 5 and Figure 6 are the records of rainfall at typical places in Tokushima Prefecture and in Ehime Prefecture respectively as mentioned above, in which bars are hourly rainfall and curves are the cumulated rainfall. As indicated on the figures, disasters occur round at time when rain intensity becomes gentle after the peak value, and this fact is statistically recognized widely in Japan due to the analysis of past rainfall data.

Table 1 Number of Sediment Related Disasters in 2004

	Debris flows	Landslides	
		Deep slides	Shallow slides
Shikoku Isl.	214	42	326
Whole Japan	564	461	1535

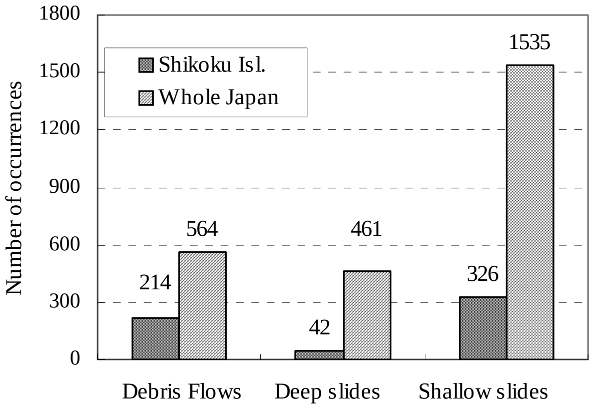


Figure 4 Number of Sediment Related Disaster in 2004

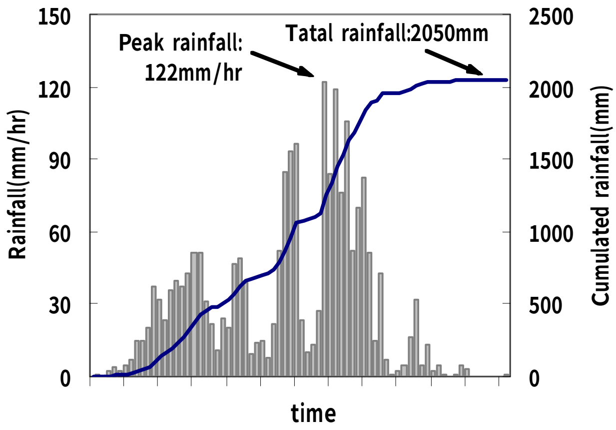


Figure 5 Rainfall of Typhoon 10 at Kaikawa, Tokushima Prefecture (Data by Shikoku Electric Com.) July 30.22:00-Aug.2.24:00

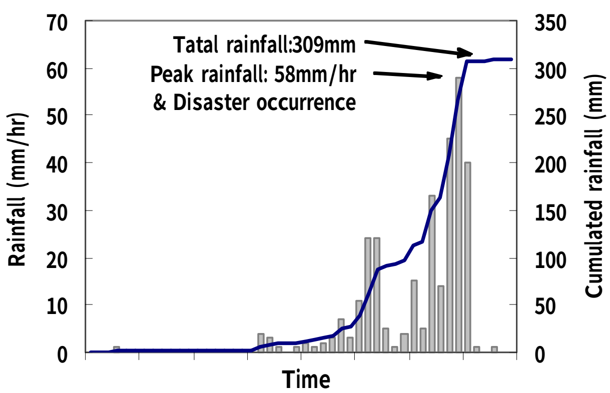


Figure 6 Rainfall of Typhoon 21 at Niihama, Ehime Prefecture (AMeDAS data)
Sep.28.18:00-30.24:00

1.3 *Half life of rainfall, effective rainfall, critical line and snake line*

In Japan, sediment related disasters due to yearly attack of Typhoon and/or frontal storms are of the main interest of many researchers, especially predicting the place of the occurrence and the dimension of it still remain an important problem. Deciding the threshold of certain rainfall indexes is the proper way for the prediction of the occurrences, though we don't have definitive ways for it yet. Among rainfall indexes, "effective rainfall" is often used, which is defined as the summation of rainfall until the occurrence of break out of the event. Yano(1990) has proposed to use hourly rainfall as the fundamental unit of rainfall to discuss about the disaster occurrences. Furthermore, he has introduced another index of 'half life of rainfall', which means that an hourly rainfall at an arbitrary time will reduce the energy exponentially to be one half of initial height. There will be a complicated situation that the duration of rainfall is different in spite of the summation of rainfall from the beginning to the occurrence of the event is same. If the duration of rainfall is enough long, then the rainfall will be harmless and the disaster will never occur. On the contrary, usually when the duration is short, we had the experiences of the occurrences of disasters. In use of half life of rainfall, the short and high intensity rainfall and long harmless rainfall will be distinguished. The below equation shows the concept of this relation;

$$h=h_0\times e^{(\alpha t)}$$

here, h_0 is the initial value of rainfall at an arbitrary time, α is reduction coefficient and t is the value of half life. Figure 7 indicates how the initial rainfall will decrease under the condition of different half life. In case of the half life is infinite, as there is no reduction of initial height of rainfall during the run of time, thus rainfall remains its initial value.

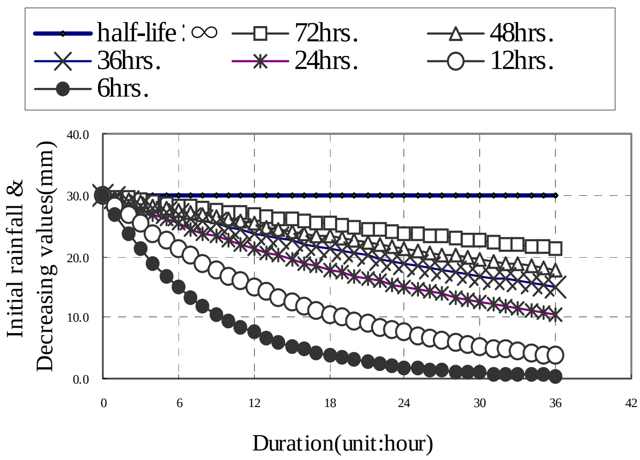


Figure 7 Initial rainfall and time dependent decrease of values according to the half life

Figure 8 indicates the relation of effective rainfall and hourly rainfall during 1972-2003 concerning the condition of the occurrences of sediment related disaster(Hiura, 1999). In case when disasters occurred, the abscissa indicates the cumulated effective rainfall of one hour before the occurrence of the event, while the ordinate indicates the triggering hourly rainfall. In case of non-occurrence rainfall case, the abscissa is the cumulated effective rainfall just one hour before the appearance of peak rainfall of a continuous rainfall.

As referred to in the preceding part of this paper, sediment related disasters often occur round the time when the intensity of rainfall becomes gentle, which is the time near the peak rainfall. The reason for the usage of effective rainfall of infinite half life is due to the convenience of treating and calculating rainfall data. The line drawn from upper left to the lower right on the figure is the critical line, and this line divides safety zone and dangerous zone from the occurrences of sediment related disasters. Thus, the upper right part of the line is dangerous and the lower left part is safe from the occurrences of the disasters.

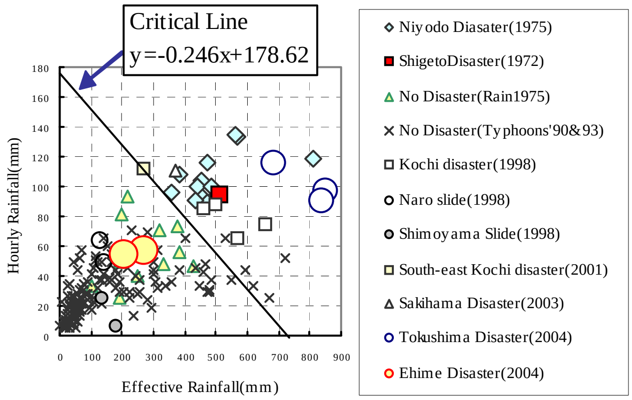


Figure 8 Critical line drawn according to the past rainfall data in Kochi during 1972-2003

The inclination of the critical line depend on the climate, topographical and geological conditions of the area and should be renewed by the occurrence of new disastrous event. On the figure, three point of Tokushima and two points of Ehime concerning the Typhoon disasters in 2004 are included. The points of Tokushima disasters are plotted at far right hand site on the figure 8, on the contrary points of Ehime are plotted to the lower left hand side in the safety zone together with points of Naro in 1998 and Shimoyama in 1998. Consequently, the area where the usual annual rainfall does not exceed 1500mm can not be discussed on the same diagram or same critical line. Though, for the case of Tokushima, points are plotted properly, though the magnitudes are far big.

The snake line is drawn as follows; the abscissa is effective rainfall at an arbitrary time and the ordinate is subsequent hourly rainfall, connecting each point as time goes by, then the line similar to the movement of a snake is drawn on the diagram. This method is applicable during the rain is continuing and if the snake line goes close to critical line in the near future(2 or 3 hours later) , then the warning can be given or the preparation for the evacuation can be started. Two snake lines on the Figure 9 represent when the half life is 6 hours and infinite respectively for the case of Tokushima disaster in 2004. As a result, due to the high intensities of rainfall, snake line has been crossed in the early stage of whole length of the rainfall (36 hrs. from the beginning of rain.

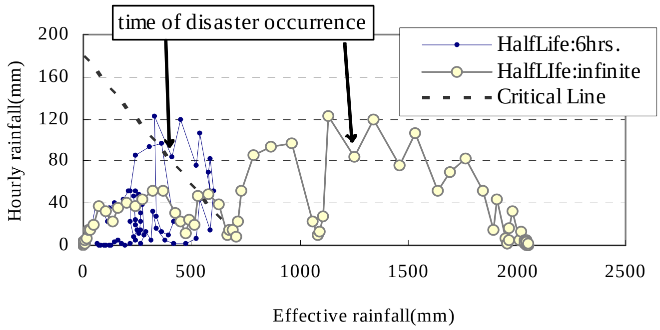


Figure 9 Snake lines of the Tokushima disaster in 2004

2 SEDIMENT RELATED DISASTERS CAUSED BY RAINFALL INDUCED LANDSLIDES IN 2004

Authors have identified two types of mass movement from the view point of mechanism. The first is “Valley-off type debris flow”, and the second is “Gigantic slope failure which is controlled by the geological condition such as fault system or weathering processes of bed rocks during long time”. The former type mass movements have occurred in the area of less rainfall(<1500mm/year) as northern part of Ehime Prefecture and Kagawa Prefecture and the latter has occurred in the area of much rainfall(>2000mm/year) as Tokushima Prefecture. Typical places of both type slope failures are indicated on the Figure 10 together with geological settings.

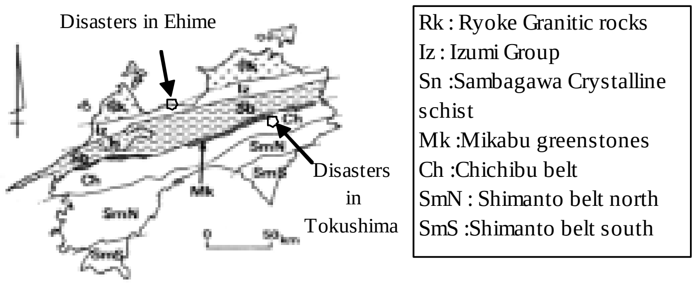
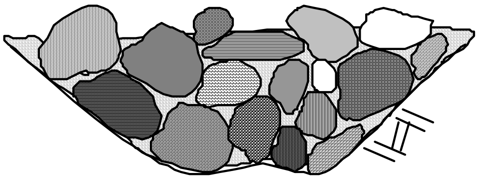


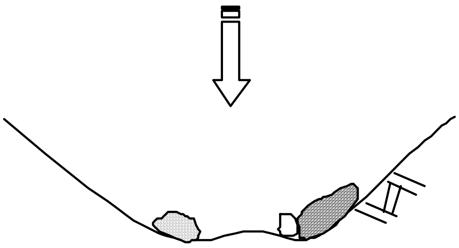
Figure 10 Geological settings of Shikoku Island and typical places of disasters

2.1 *Valley-off type debris flow*

Figure 11 shows the schematic view of the occurrence of the valley-off type debris flow of which the mechanism is commonly recognized as follows; if a large amount of rainfall is poured onto the sediments deposited for a long time on the floor of a torrent, loose structure of sediment will be broken by the rising water depth then transforms to debris flow state under the condition of an angle of repose of sediments in water. Except for the gigantic slope failures which will be discussed in the following part of this paper, this type of debris flows by the valley-off of deposited sediments occur very often in the recent time. Authors have recognized this type of debris flow not only in Ehime Prefecture and in Kagawa Prefecture, but also in Kochi and in Tokushima. There are two limiting conditions of breaking off, 1)the condition of the place where it takes place; torrents have fairly abundant sediments on their floor deposited at least more than 30 years or so, 2) the triggering condition of rainfall; short time intense rainfall having intense hourly triggering peak rainfall as well as total rainfall. Especially for the case of Ehime Prefecture and Kagawa Prefecture, where the mean annual rainfall does not exceed 1500mm, the rainfall events brought by Typhoons in 2004 were un-experienced ones for the area. Once the deposited torrents were scoured, the same torrents would be safe enough for the next few decades.



a) Cumulated debris on the torrent floor



b)After debris flow has flew away

Figure 11 Schematic view of the occurrence of Valley-off type debris flow

Photo 1 Upper reach of a valley-off torrent
（Niihama City, Ehime Prefecture）

Photo 2 Middle reach of a valley-off torrent. Sand stone and mud stone alternate, all deposited sediment was swept away as the debris flow.ca.2-3m. Kike a big snake has gone away. Width: ca.4-5m. Depth of deposited debris

2.2 *Gigantic slope failure and subsequent debris flow occurrence*

The magnitude of the slope failures which occurred in Tokushima Prefecture in 2004 were very big and seem to be controlled by the geological condition such as fault system or weathering of bed rocks during long time. Undoubtedly, the main triggering factor is rainfall, and the maximum daily rainfall was recorded to be 1,317mm/day at Kaminaka town which located in the middle of disaster affected area and this is the value of the highest record in Japan. Despite the experiences of long time heavy rainfall, the area was peace from the sediment related disasters and subsequently, thick weathered superficial layer or thick deposit on the torrent floor may have been formed.

Here, two events will be introduced, the first is Kamagatani slope failure, and the second is Azue slope failure(Hiura *et al*,2004). In both cases, the excess amount of rainfall has crossed the threshold and generated slope failures. And as shown in following two photographs(Photos 3 & 4), small torrents are seen which seem to have been existed before failure, thus there is a possibility that the slope movement was begun by the valley-off movement of deposited debris on the torrent floor, then due to the excess water provided by the overland flow and the underground water paths, slope movement has developed to become big. In case of Kamagatani slope failure, the moving soil mass was first moved onto the slope of the opposite side breaking two small check dams constructed in the valley of tributary, then turned to the right to the main stream and formed landslide dam for a while and the landslide dam was broken sooner after that.

The second gigantic slope failure has occurred at Azue slope which is designated as deep slide area by the government. From the topographical point of view, the torrent flowing through the center of the fallen slope seems to have existed as well as the case of Kamagatani slope. Initially the slope was eroded at the foot by the River Sakashu-Kito and the unstable condition propagated retrogressively to the upper ward and at last whole slope has fallen. The maximum velocity of the moving soil mass was estimated to be 20m/sec according to the mark of splash of flowing debris. The liquidized water rich soil mass has run up on the opposite side of the River Sakashu-Kito from the present river water level to that of 20-30m above on the slope and dammed up for a while, and then the landslide dam was leached sooner by the increasing water level of main stream.

In the upper most area of Azue slope, the number of cracks was found which distribute to enclose the head scarp of the Azue failure. Among subsidence more than 2.5m within one month could be recognized. In Photo 4, cracks and subsidence found by the investigation in situ are indicated, thus the enlargement of these cracks and jointing each other to become continuous big cracks are worried to cause sever disaster in the near future.

Photo 3 Kamagatani slope failure. Length: 220m, Width: 200m, Mean thickness of superficial fallen layer: ca.5m, Mean inclination: 31degrees, Volume of fallen soil mass:ca.1.3×$10^5$$m^3$. Small torrent in the center of slope and spring point in the mid slope where the boundary of bed rock (weathered crashed muddy rock) and superficial thick layer

Photo 4 Aerial photograph of Azue area just after the occurrence of slope failure.
Length:ca.1km, Width:100-300m, Thickness of fallen soil layer: 10-15m(upper slope), 5-8m(lower slope),
Mean inclination: 20degrees, Volume of fallen soil mass:ca.1×$10^6$$m^3$. White dotted lines are cracks and/or subsidence recognized in situ.

3.References

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