GIS ANALYSES OF SHALLOW AND DEEP-SEATED LANDSLIDES IN JAPAN

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Abstract:

GIS is a useful technology for visualization and analyses of landslides. In this paper, we are describing preliminary results of analyzing shallow landslides triggered by heavy rainfalls and deep-seated landslides existing already in Japan.

1. Introduction

GIS is one of useful technology for analyses of variable landslides. Recently, in a search engine of "Google Scholar" by Key words "GIS and landslides", more than 20000 articles have been hit in May 10 , 2010 at present. Therefore, on February25 2010, "GIS Landslide Research Group" was established at National Research Institute for Earth Sciences and Natural Disasters (NIED), Tsukuba, Japan.

In Japanese, the term "Landslides" imply not only failures (hokai) due to heavy rainfalls and earthquakes, but also deep-seated large-scale landslides (jisuberi). The former "hokai" is difficult to predict where and when occurring, but the latter "jisuberi" which is inventoried by aerial photographs, it is difficult to predict exact place and the time of occurrence, but the inventory maps of the existing deep-seated landslides can be improved to at least susceptibility maps.

While, in order to know the danger of temples and associated cultural heritages, we have done GIS analyses of relationship between the deep-seated landslides and the cultural factors. In this paper, we are describing the examples of the GIS analyses of recent shallow landslides (failures) triggered by heavy rainfalls and deep-seated ones which were published already in Japan.

3. Recent Heavy rainfall induced failures in Japan

Japanese Islands are composed mostly of fragile rocks because

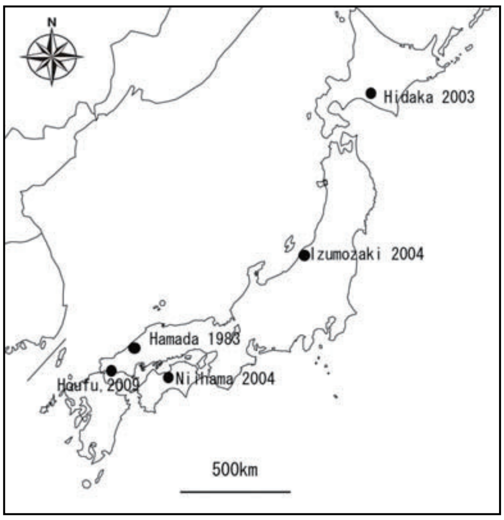

Fig.1 Locality map of the recent heavy rainfall-induced failures in Japan

of young ages and fracturing due to tectonic deformation and faulting. Therefore, Japanese Islands are prone to landsliding caused by earthquakes due to active faulting and heavy rainfalls because of Monsoon zone climate. Actually, recent heavy rainfalls triggered many failures (hokai) and also intensive earthquakes triggered many hokai and deep-seated landslides (jisuberi) as shown by Yamagishi and Iwahashi (2007). In this paper, at first we are describing GIS analyses of heavy rainfall induced failures at several places; Hamada Shimane in 1983, Hidaka Hokkaido in 2003, Izumozaki Niigata in 2004, and Houfu Yamaguchi in 2009（Fig. 1）.

2.1 Heavy rainfall-induced failures in 1983 in Hamada area, Shimane

Hamada area (Fig.2) is a coastal area of hills and plains with elevations up to 400m. The bedrocks of the area mainly consist of Paleozoic to Mesozoic pelitic and psammitic schists, granitic rocks, and Paleogene volcanic rocks. An intensive rainfall occurred between July 20th and 23rd, 1983 and triggered

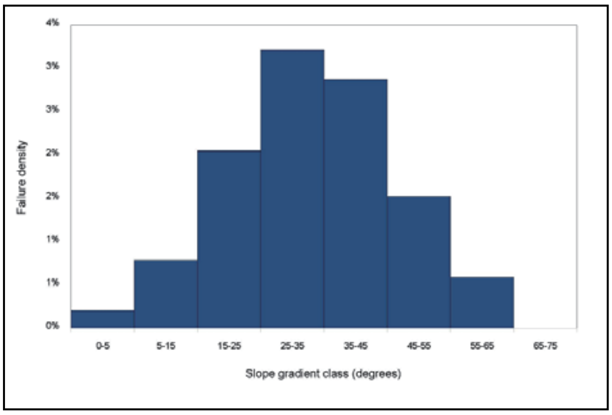

Fig. 2. Frequency distribution of percentage of failure density in relation to slope gradient classes (Hamada, Shimane Pref.). It indicates that the peak within the concentrated area is 25-35 degree.

numerous failures and caused flooding in western Shimane. The total precipitation was recorded at 742 mm and the maximum daily precipitation reached 372 mm/day. Most failures were shallow, from colluvium and residual soil, and were related to topographic and geologic conditions in addition to precipitation intensity. The highest frequency of failures occurred on 30º to 40º slopes, and the largest slope failures occurred in granitic rock regions.

The slope failure distribution was obtained from the stereoscopic interpretation of 1:8,000 scale black-and-white aerial photographs that were taken just after the rainfalls. The slope failure distribution map (Pimiento and Yokota, 2006) was compared to slope gradient and elevation. The elevation data is the 10m DEM downloaded from the Website of Geographical Survey Institute of Japan (2009). In relation to elevation, failure density on the total area was higher than the general density between 100 and 350 m. The number of failures gradually increased to 459 events for the 150-200 m class, and then the frequency decreased gradually for higher elevation classes. In relation to slope gradient, in the total area, the failure density increases up to around 35-45^{O} with slope degrees. While, in the highly concentrated area, the peak (3.2%) of the highest failure density corresponds to 25 to 35 degree slope class (Fig. 2).

2.2 Rainfall-induced shallow failures from 1961 to 2004 in the Izumozaki , Niigata

On July 13, 2004, heavy rainfalls due to the strong activities of rain front occurred in the Mid Niigata Region, Japan. They

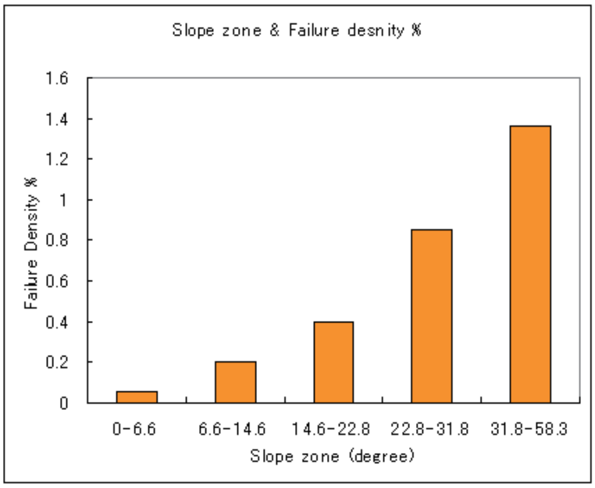

Fig. 3 Graph showing the relationship between the failure area ratio (density) (2004) and slope gradient zones (Izumozaki, Niigata)

are as much as 400 mm in 24 hours, bringing about serious flooding by breaking the river banks in the Mid Niigata area. The heavy rainfalls also triggered more than 3359 failures which were inventoried by air-photographs by Asia Air Survey Co. Ltd. The air-photograph interpretation and field research revealed that two types of landslides were inventoried; one is shallow failure and the other is deep failure which is associated with mudflows. We are focusing the shallow failures in the Izumozaki area. Because the area was affected mostly by numberless shallow failures due to 2004 July rainfalls, and was also damaged by the same type of failures in 1961 August, and 1976, 1978. Therefore, we have interpreted the air-photographs of Izumozaki area of 1962 (one year later of the heavy rainfalls in 1961), 1980 (1976-1978 rainfalls) and 2004 (just after the July 13 rainfalls) (Yamagishi et al., 2008)

However, in this paper, using GIS, we have analyzed the failures on July 13, 2004 in order to make clear the relationship between the failures and slope degrees in the polygonal area We have made slope distribution map derived from 10 m grid DEM and divided into 5 zones in gradient zones with intervals of 8^{o} degree. As the results, we have revealed that the shallow failure highest density is corresponding to 31.8-58.3 zone (Fig. 3). The fact suggests that failure density mostly depends on the slope degrees.

2.3 Heavy rainfall-induced failures in 2004 in Niihama, Ehime

In 2004, total ten typhoons were landing on Japanese Islands, and many places were affected by heavy winds and rains

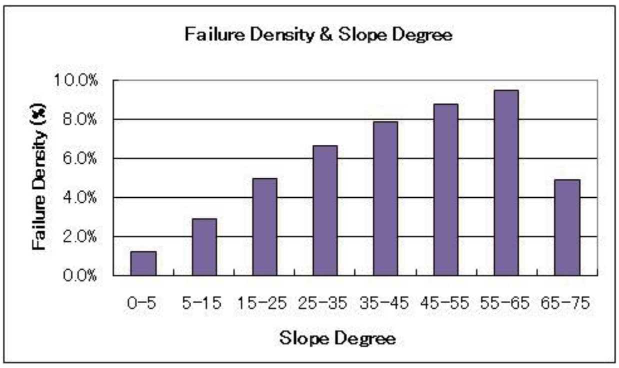

Fig. 4 Graph showing the relationship between the landslide density (%) and slope degree zones (Takihama area, Niihama).

Sep 27, 2004, and passed Shikoku on Septermber 29- 30th , where totally more than 400 mm precipitation was recorded. By the precipitation, Niihama, Ehime Prefecture, was damaged by numberless shallow failures which were inventoried as 1300 failures by Aero Asahi Corporation .

In the highly affected area (Takihama), east of Niihama City, the total number of the failures was 900 sites. Using GIS, we have obtained the results related to slopes by 10m_DEM. Slope gradients were reclassified into 10-degree classes and the highest failure densitiy increased gradually to 9.5% for the 55-65 degree slope class; then it decreased drastically for up to more than 65^{o} degree (Fig. 4).

2.4 Heavy rainfall-induced landslides in 2003 in Hidaka, Hokkaido

In August 9th to 10th, 2003, in Hidaka area, Hokkaido, typhoon No.10 was closing to Hidaka Mountains. The typhoon brought about total more than 400mm precipitation within two days. At

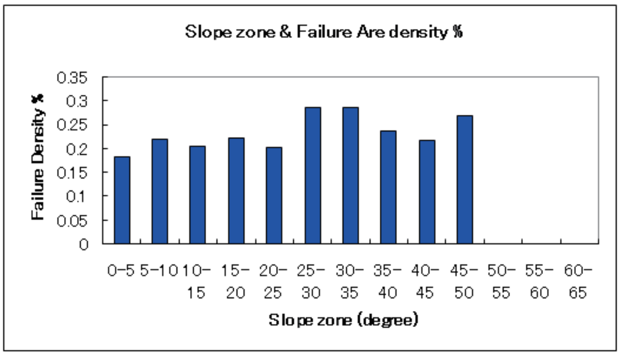

Fig.5 Bar graph showing the relationship between the failure density and slope-class (Hidaka, Hokkaido).

maximum, 50mm/hour was recorded. As the results, total 20,000 failures were inventoried along the Sarugawa and Appetsugawa tributaries, Hidaka, Hokkaido. In this section we are focusing the concentrated failure area along the Appetsugawa. We are analyzing the failures using GIS and 10m_DEM for clarify the relationship to slope gradient. As the results, we have obtained the graph (Fig.5). It shows different patterns from the failures of the other areas; the bars of the landslide densities show variable degrees, although the highest peaks are 25 to 35^o degrees.

2.4 Heavy rainfall-induced landslides in 2009 in Houfu, Yamaguchi On July 21 to 22, 2009, heavy rainfall attacked the Houfu Area, Yamaguchi Prefecture. In particular, on 21th,

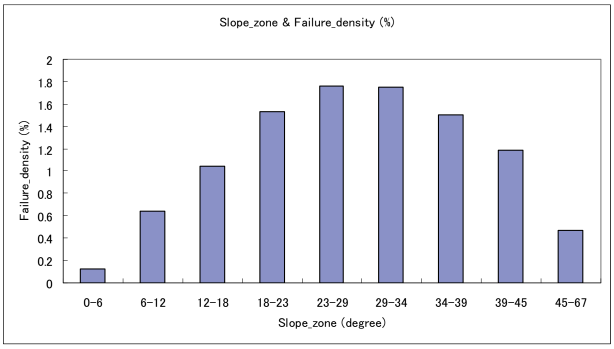

Fig. 6 Graph showing the relationship between the slope zone and failure density (failure cell count/ total area count) related to the slope zone(Tsurugigawa, Houfu, Yamaguchi)

total daily precipitation reached 275 mm and maximum hour precipitation was documented at 72.5mm (Japan Meteological Agency). As the results, many failures and debris flows took place along the Sabagawa Tributaries. These events killed 14 peoples and destroyed many houses and facilities. These areas are composed of mostly deep-weathering granites. We have analyesed the slope failures along the Tsurugigawa tributary by 10m_DEM provided from Geographical Survey Institute of Japan (GSI). As the results, the highest failure density shows the 23 to 29 degree zones (Fig.6) .

3. GIS analyses of the heavy rainfall failures

As mentioned above, we have analyzed using GIS the recent heavy rainfall landslides at 2003 Hidaka Hokkaido, 1983 Hamada, Shimane, 2004 Izumozaki Niigata, 2004 Niihama, Ehime, and 2009 Houfu, Yamaguchi in Japan. For all of the failures, we have analyzed the failure distributions and their relationship to slope degrees using 10_DEM.

As the results, the relationship to slope degrees, at Izumozaki and Niihama, highest failure densities are up to 58^o-65^o degree, while at Hidaka, Hamada and Houfu, those are up to 23^o-35^o degree. The bedrock geology of former two are composed of sedimentary rocks, while that of the latter three are of granites and metamorphic rock, excepting for Hidaka area. Namely, Hidaka area shows different patterns from the two although the bedrocks are similar to the two. However, Hidaka mountainous areas are covered by Quaternary pumice deposits up to 1 meter. Namely, the mentioned facts may be due

Disaster name	2003 Hidaka failures	2004 Izumozaki failures	1983 Hamada failures	2004 Niihama failures	2009 Houfu failures
Slope zone of the highest failure numbers	25°-30°	23°-32°	25°-30°	25°-30°	23°-29°
Slope zone of the highest failure density	25°-35°	31°-58°	25°-35°	28°-65°	23°-29°
Bedrock Geology	Tertiary mudstone and sandstone	Neogene mudstone and sandstone	Granite and Serpentine, metamorphic rocks (including schists)	Cretaceous sandstone and mudstone	Granite
Surficial Geology	Quaternary ash and pumice fall	Weathered sandstone and mudstone	Weathered granite (Masa) and weathering soils	Weathere sandstone and mudstone	Weathered granite (Masa)

Table 1: Summary of the relationship between the failures failure number/density and slope gradients, and bedrock geology and surfacial geology

to the difference in surface materials rather than bedrock geology. However, the slope zones of the highest failure numbers range from 23 and 32^o , in common within all of the dealt areas in this paper (Table 1).

4. Deep-seated landslide maps in Japan

Japan, deep-seated landslide maps have been completed in Hokkaido b **I**n y H. Yamagishi (1993) and in Honshu, Shikou and Kyushu by National Research Institute for Earth Science and Disaster Prevention (NIED; http://lsweb1.ess.bosai.go.jp/en/index.html). Recently, NIED has also begun to provide the landslide maps of Hokkaido from the southern part.

4.1 GIS analyses of deep-seated landslides in Hokkaido

H. Yamagishi has published the database of the landslides of Hokkaido in 1996, based on the landslide distribution maps (Yamagishi et al., 1996) with CD (Fig. 7). The database is providing the attributes of each landslides by EXCEL data which is composed of landslide number, provincial division, height, length, width and areas, movement direction, forestry etc. These data can be added to ARCMap as attributes because that each landslide has location of the central point of each polygon of the landslide area. Using the GIS map of the

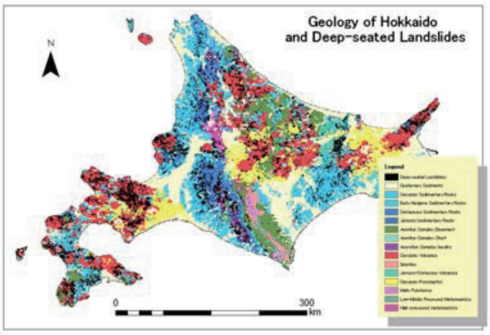

Fig.7 Geologic map of Hokkaido derived from Geo_DB (Default legend 200 was reclassified into 17

landslide of Hokkaido, we have done analyzing several statistics of scales, relationship to geology etc. Fig. 8 show the relationship between landslide percent and the geology division reclassified from default of Geo_DB (200 legend) to 13 legend.

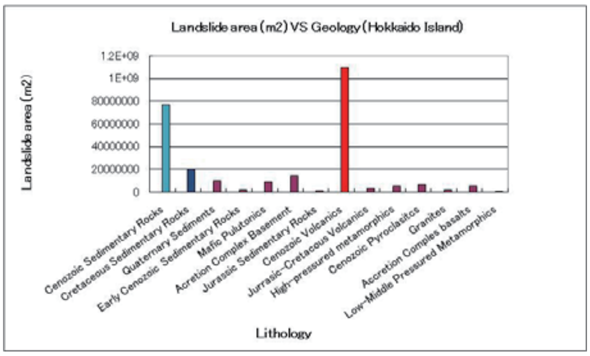

Fig. 8 Graph showing the landslide area from NIED in each lithology of Hokkaido Island from Geo_DB (200 legend reclassified into 17 legend)

(Geological Survey of Japan; http://iggis1.muse.aist.go.jp/en/top.htm)

Using GIS, we have revealed the relationship between the simple geologic map and landslide data base; as the results, we have got the graph of Fig. 8. It shows that the most of the landslides are located on the Cenozoic sedimentary rocks and Cenozoic volcanic rocks.

4.2 Deep-seated landslide distribution in Shikoku island

Shikoku island is one the regions of the deep-seated landslide concentration as shown in Fig. 9. The Shikoku Island is geologically composed of Izumi Group, Sanbagawa Group, Mikabu Group and Shimanto Group (Suyari et al., 1991) . In particular, they are mostly concentrated into the Sanbagawa

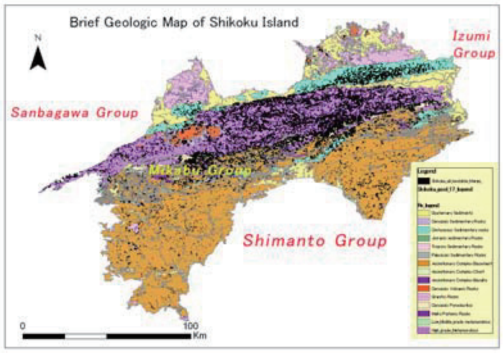

Fig. 9 Landslide distribution derived from NIED underlain by geologic map of Shikoku Island from Geo_DB (reclassified from 200 legend into 17 legend)

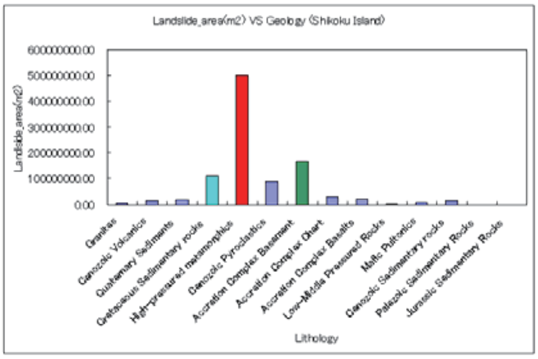

Fig. 10 Graph showing the landslide area from NIED in each lithology of Shikoku Island from Geo_DB (200 legend reclassified into 17 legend)

Group (Geologic zone) which are composed of muddy schists, sandy schists, mafic schists and other crystalline schists (Fig. 10) . They are classified as high-pressured mmetamorphic rocks. In order to check the dangers of the cultural heritages in Shikoku Island, we are examining using GIS how relationship of the Ohenro Temples (total 88) http://www.karasu.net/gmap/ohenro/) to active faults and landslides .

We have checked how far are the temples are from the landslides inventoried by NIED. The results are that only three temples are within the landslide movement blocks, and that within 100m from the slides are also only three temples. Therefore, most of the temples are safe from the landslides. While, we are checking these temples related to active faults which are called Median tectonic Line. This is the longest active fault running along The Shikoku to Kii Peninsula from EW direction. This is classified as lateral slip fault and consists of three main segments (Nakata and Imaizumi, 2002). Using GIS, we have revealed how far from the Ohenro temples in Shikoku Island. As the results, in Shikoku, only five temples are located within 100 m from the fault line.

5. Conclusion and discussion

Recently, many digital data are providing for GIS analyes of the landslides, such as 10m_Dem from GSI, Geolgoical maps from Geological Survey of Japan (Geo_DB) and deep-seated landslide maps from National Research Institute for Earth Science and Disaster prevention (NIED) Therefore, using the above digital data and GIS, we have done the statistical analyses of the failures of several areas due to recent heavy rainfalls in Japan and of the deep-seated landslides in Hokkaido and Shikoku. As the results the GIS analyses of the heavy rainfall-induced failures suggest that the failures depends on the slope degrees rather than bedrock geology, while the deep-seated landslides depends on bedrock geology as shown in Hokkaido.

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