2. DEVELOPING AND APPLYING THE SYSTEM TO SET AREAS AUTOMATICALLY, WHERE NEED TO TAKE WARNING AGAINST SEDIMENT-RELATED DISASTERS

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ABSTRACT

Since the latter half of the 19th century, Japan has imported its sediment control and related disaster prevention technology primarily from Austria. These technologies were then combined with Japan's indigenous technologies to develop new disaster prevention measures, mainly by constructing facilities such as sediment control dams.

However, following the economic boom of the 1960's land development advanced rapidly throughout Japan. Particularly, a remarkable number of sediment-related disasters occurred in newly constructed housing areas developed at the foot of mountainous areas. In recent years, these kinds of disasters have been increasing, which, in turn, have led to a steep rise in the construction of welfare facilities for senile citizens.

For all these reasons, the importance of improved warning and evacuation systems and measures to control construction development in risky areas has increased considerably. In May 2000, the "Sediment-Related Disaster Prevention Law" was enacted to cover areas where sediment disaster risk was judged to be high. These areas were designated at dangerous and strictly regulated.

In relation to these new regulations, the authors have developed a new system as mentioned below in detail.

In this system, it is possible to calculate the peak flow of a debris flow, as well as its fluid dynamic force and sedimentation height etc. based on factors such as the amount of discharged sediment from the torrent. The districts facing a disaster affected by debris flows are expressed on a three-dimensional disital maps and on an orthogonal photographs.

Keywords: Debris flow, software measures, three-dimensional numerical map

1. Introduction

In Japan 70% of its national land consists of mountain ranges and hills, and in the remaining narrow livable space a population of one hundred plus some dozens of million resides. Even in recent years after the high-growth period, the concentration of population into urban areas is still going on, and many people reside in dangerous areas like the foot of a cliff, the downstream basin of a torrent, or the surrounding areas of a landslide area. According to the result of nationwide investigations in March 2003, the number of sediment-related disaster hazard areas that are prone to the failure of land with steep slopes, debris flows or landslide is as many as 525,307, and about 900 cases/year of sediment-related disasters occurred on average in the past 10 years, and in this year as well, sediment-related disasters occurred in the Kyushu District where debris flows and slope failures hit a great number of houses and at the same time they claimed 22 irreplaceable human lives.

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Under the circumstances, the Japanese Government enforced in 2001 a law to promote software measures such as the establishment of warning and evacuation systems (Sediment-related Disaster Prevention Law).

In this law, dangerous land such as the foot of a cliff, the downstream basin of a torrent, and the surrounding areas of a landslide area can be designated as sediment-related disaster hazard areas, etc., thereby establishing warning and evacuation systems, and at the same time the law enables regulations including the limitation of private rights to be enforced such as the regulations on the structures of buildings and the limitation of development. Also, the setting of zones stipulated by laws, etc. requires accuracy and efficiency, and in particular, upon establishing special sediment-related disaster hazard areas, the hydrodynamic force of debris flow according to the topography, geology and the amount of sediment is supposed to be calculated, and such work is complicated and requires a lot of time and effort.

The present authors have been working on the development of a zone-setting system whereby the work for setting sediment-related disaster hazard areas, etc. can be made accurately and efficiently as well as the study of techniques to put the system into operation. This system utilizes the state-of-the-art GIS (Geographic Information System) technologies by means of the three-dimensional topographic information and orthophotos.

2. Introduction of modern sabo technologies

In Japan, sabo incorporating modern sciences/technologies started in 1904 when Amerigo Hofmann was invited from Austria to Tokyo Imperial University as the first professor of sabo.

At the time Japan has already its inherent sabo technologies, but they were intended mainly to protect mountain forests such as measures against bald land, and measures by planting works such as terracing with seeding and simple terracing works were taken in the main.

Meanwhile, sabo in Austria was the "torrential sabo" in which civil engineering techniques were adopted to prevent severe horizontal and vertical erosion in torrents in mountain ranges, and for the purpose of introducing such technologies Kitaro Moroto and Masao Akagi went to study there, and thus sabo in Japan was systematized by using sabo in Austria as a model.

——— In Japan, the construction of castles was carried out in the whole country in the early days of the Edo period (in the 1600s), and the sand retaining works that are functional, albeit on a small scale, in which construction technologies acquired through the construction of rock walls for such castles were exploited, were built mainly in areas having remarkable sediment runoff (granite areas) in western Japan, and it is worthy of special note that a lot of such works still exist in the form of being merged into the natural scenery in the surrounding areas of the Dodo River in Kannabe Town, Hiroshima Prefecture (the former Fukuyama clan in the Bigo region). ———

3. Promotion of comprehensive measures against sediment-related disasters

Right after the World War II, several large typhoons mercilessly hit the national land that had been devastated by the war, claiming a large number of human lives and properties, and while the importance of erosion control/flood control was being emphasized, the Law on Urgent Actions for Mountain and River Control was enacted in 1960.

With the enactment of the law, erosion control/flood control projects were now implemented systematically, which led to the gradual diminishing of damages caused by flood.

In the meantime, in association with the economic development in the 1960s and thereafter, the development of national land was carried out rapidly, and the concentration of population toward the urban areas was accelerated, with the result that hills around city areas were developed for use for residential land in all parts of Japan.

Sediment-related disasters now came to be repeated almost every year in geologically vulnerable areas, and the Nagasaki disaster in July 1982 sacrificed 299 lives.

In September 1982, the administrative vice-minister of the Ministry of Construction gave an official notice entitled "On the Promotion of Comprehensive Measures against Debris Flows", thereby setting off "software measures" such as seeking an enhancement of the establishment of warning and evacuation systems in addition to the conventional "hardware measures".

4. Advantages of the zone-setting system

4.1 Increased efficiency of work and reduced cost

As stated above, a huge amount of time and cost is required to set the sediment-related disaster hazard area, etc. Hence, the zone-setting support system enabled the time for work to be shortened and the cost to be reduced, by increasing the efficiency of work and automating the complicated work that requires time and effort, and at the same time by visualizing information on the portion requiring the evaluation of topographical and geological conditions to provide support for the judgment made by technical personnel.

4.2 Improved accuracy and fairness of work processes and the securing of reproductivity

Once the sediment-related disaster hazard areas, etc. that have been specified in the law are designated, the limitation of private rights is to be enforced such as the regulations on the structures of buildings and the limitation of land development in such zones. And therefore, it is important in the designation of the zones, that the work processes are accurate and fair, not only in terms of disaster prevention, but also with reference to the rights of the parties concerned and the relations in local communities. Also, obligations arise to be accountable for reproducing the work processes (making them traceable) and for their legitimacy in response to doubtful points raised by the parties concerned such as local residents. Hence, upon developing the zone-setting system, a mechanism has been devised by which the accuracy and fairness of work processes can be improved and the reproductivity of such processes can be secured.

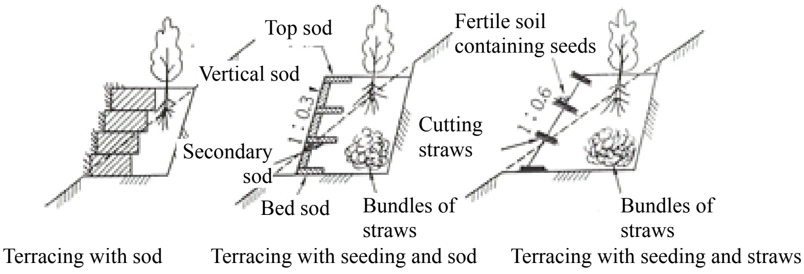


Fig-1 Terracing with seeding

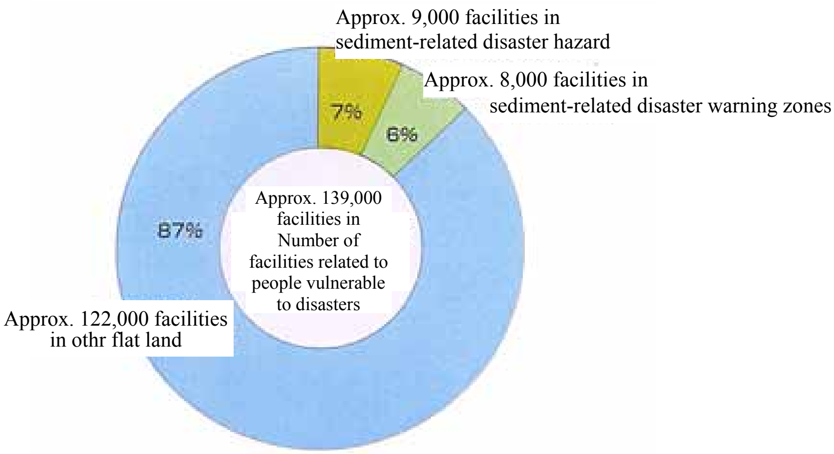


Fig-2 Locational conditions of facilities related to people vulnerable to disasters
(Joint investigations conducted by the Ministry of Construction, Ministry of Health and Welfare, Ministry of Education, etc., September 1998

Photo-1 Fukami sand retaining works – This dam was constructed by stone masonry in Dodo River in 1854 (Hisoshima Prefecture)

Photo-2 A debris flow that occurred at a hill behind a social welfare facility directly hit the facility, claiming 5 lives (Fukushima Prefecture). (August 27, 1998)

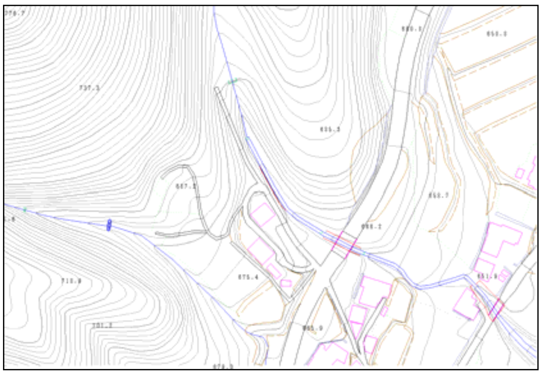
5. Development of a system for setting sediment-related disaster hazard areas, etc.

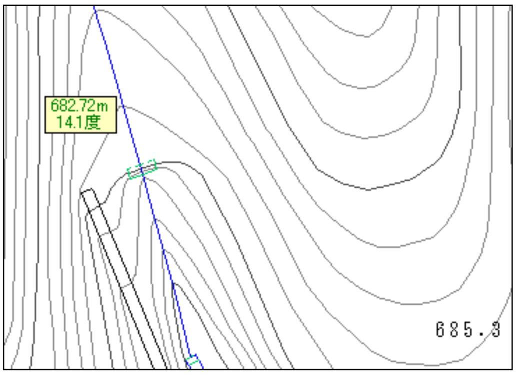
The system for setting sediment-related disaster hazard areas, etc. was developed in terms of the 3 phenomena: failures of land with steep slopes, debris flows and landslide. Of these phenomena, this description reports debris flows that required the most complicated and high-grade technologies.

5.1 Spatial information used in the zone-setting system

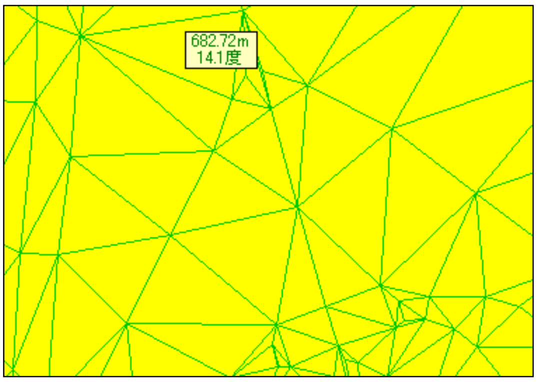
The following 3 types of spatial information are required for zone-setting.

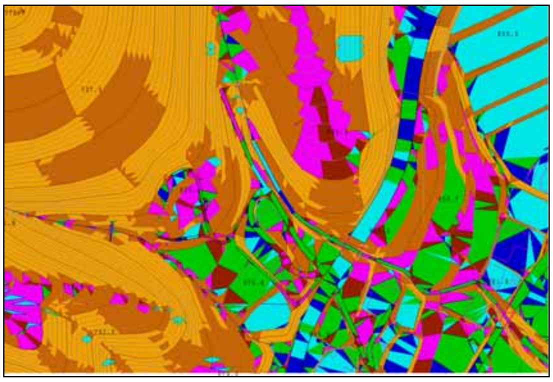
1) Numerical map: DM (Digital Mapping)



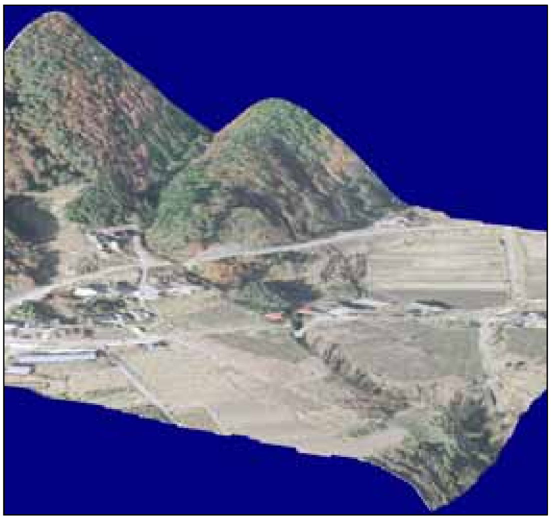


2) Three-dimensional topographical model: TIN (Triangulated Irregular Network)





3) Orthophoto



5.2 Settings of the watercourse of debris flow and the starting point of inundation

The watercourse of debris flow is indicated on a screen by designating a point 200 m upstream of the starting point of inundation that is estimated on a map and an orthophoto, whereupon the system automatically searches the route of flow from a three-dimensional topographical model. By adopting this technique, the difference in the result of route setting according to the person who made the setting was eliminated, thus securing reproductivity. And regarding the overflow in the bend of a debris flow as well, the system has been made to be able to handle it by incorporating a tool that enables the set watercourse to be corrected and changed.

Since the setting of the starting point of inundation needs to be determined by making comprehensive judgment based on the topographical situation of the whole basin, locational conditions such as houses, the result of site investigations, etc., a function has been developed in which the setting of the starting point of inundation is made by displaying a longitudinal profile and a plan of the set watercourse in contrast with each other and designating a point gradient changing point on the longitudinal profile. Fig-3 shows a longitudinal profile of a watercourse in which each gradient section is indicated by a different color. (In the figure, the vertical red line marked with 0 denotes the starting point of inundation.)

Fig-3 A longitudinal profile of a watercourse

5.3 Setting of a "land with a danger of harm"

A "land with a danger of harm" (Yellow Zone) means the land that is recognized as having a danger that any harm will be done to the lives or bodies of residents, etc. in the case of an occurrence of a debris flow, which is defined as, of the zones of which land in the lower reach of the starting point of inundation has a gradient of 2 degrees or more in the basin of a torrent of which catchment area is 5 km^2 or less, the zones excluding such zones, as are recognized evidently, that a debris flow will not reach by topographical conditions.

In this system, a mechanism has been made in which, as shown in Fig-4, by designating the points on both sides having a relative height of 10 m in the cross-section at the starting point of inundation, the zones of which gradient in the lower reach is 2 degrees or more are automatically surrounded. In its algorithm, the steepest gradient vector of which land gradient is 2° or more is drawn from the starting point of calculation toward the direction of a circle of 40 m (horizontal distance) in radius. Next, a 30° open angle vector is drawn, which is 30° open toward the outer angle from the starting point of this steepest gradient vector. At the time, if the difference in relative height between the ground height pointed by the steepest gradient vector and the ground height pointed by the 30° open angle vector is 5 m or more, the degree of the open angle of the 30° open angle vector will be reduced so that the difference in relative height with the outer angle will become 5 m. This calculation is repeated until the gradient of the land pointed by the steepest gradient vector becomes less than 2°. Note that the steepest gradient vector is basically drawn with the radius being set to 40 m, but it has been made possible to use the radius of 20 m or 60 m as well according to the relief of topography.

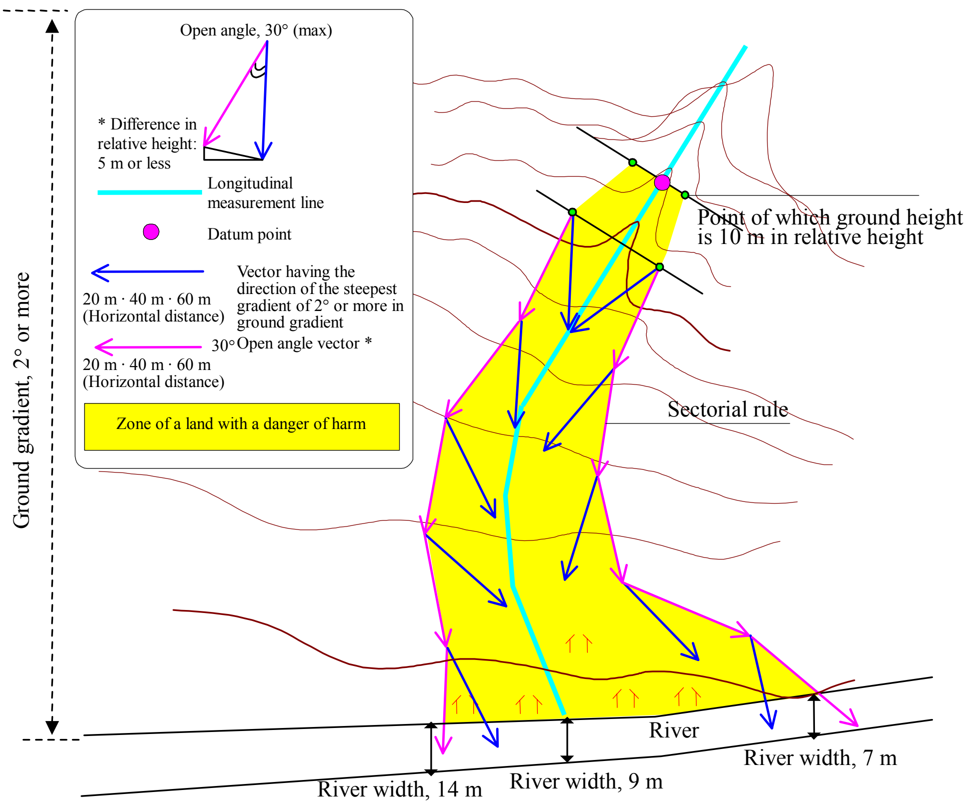


Fig-4 Method of the setting of a "land with a danger of harm"

5.4 Setting of a "land with a considerable danger of harm"

A "land with a considerable danger of harm" (Red Zone) is a zone of land in which the magnitude of a force that is estimated to be applied to a building as a result of a debris flow surpasses the magnitude of a force that an ordinary building (wooden structure) can withstand without receiving such damage as to cause considerable harm to the lives or bodies of residents, etc. (which is called the "limit strength of an ordinary building") The method of setting a zone of a "land with a considerable danger of harm" is described below.

1) Grasping the transversal shape and sectional gradient

Set transversal measurement lines that intersect at right angles with the flowing direction of a debris flow, and grasp the transversal shape and sectional gradient there.

The transversal measurement lines are set at 20 m intervals from the starting point of inundation, to draw a cross-sectional view for grasping each of the various transversal shapes (Fig-5). Each sectional gradient shall be the average gradient in a section 200 m upstream of the transversal measurement line.

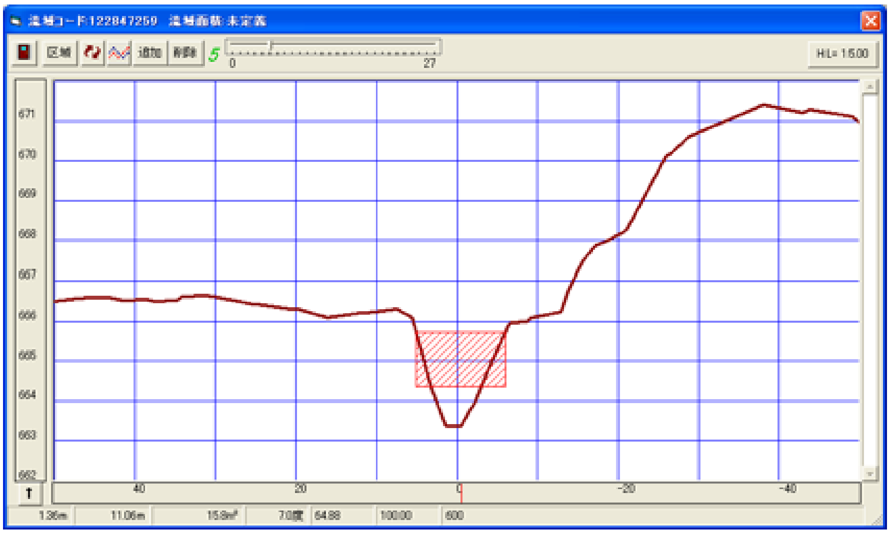


Fig-5 Cross-sectional view (of a part 100 m downstream of the starting point of inundation)

2) Setting of the peak flow rate of a debris flow

In each of the transversal measurement lines of the present channel through which a debris flow runs down, the peak flow rate of a debris flow is calculated by using Equation (1).

Equation (1) is an expression of the relation between the volume sediment concentration of a debris flow moving and the peak flow rate of the debris flow at each calculation point. Assuming that the peak flow rate of debris at an arbitrary calculation point is Qsp_i, the volume sediment concentration of the moving debris flow is Cd_i, the gradient of the land is θ_i, the peak flow rate of the debris flow at the starting point of inundation is Qsp_0, the volume sediment concentration of the moving debris flow there is Cd_0, and the sediment discharge running down is V_0, the peak flow rate of debris at an arbitrary calculation point Qsp_i can be obtained by Equation (1). C_* is the volume concentration of deposited debris, etc.

$$Qsp_i = \frac{C_* - Cd_0}{C_* - Cd_i} Qsp_0 \quad , Qsp_0 = \frac{0.01 \cdot C_*}{Cd_0} \cdot V_0 \quad \cdots\cdots\cdots \text{Equation (1)}$$

where Cd_i and Cd_0 are given by Equation (2). If the calculated values, Cd_i and Cd_0, are greater than $0.9C_*$, then they will be set to be $0.9C_*$, but the lower limit will not be set. However, if the gradient of the land at each calculation point forms an adverse slope ($\theta_i > \theta_{i-1}$), then Cd_i will be set to $Cd_i = Cd_{i-1}$ on condition that the amount of debris, etc. will not increase in the lower reach of the datum point.

$$Cd_i = \frac{\rho \cdot \tan\theta_i}{(\sigma - \rho)(\tan\phi - \tan\theta_i)} \quad \cdots\cdots\cdots \text{Equation (2)}$$

In this equation, each of σ, ρ, ϕ, and θ stands for the following numerical value.

σ: Density of pebbles contained in the debris flow (unit: ton per 1 cubic meter)

ρ: Density of flowing water contained in the debris flow (unit: ton per 1 cubic meter)

ϕ: Internal friction angle of debris, etc. contained in the debris flow (unit: degree)

θ: Gradient of the land on which the debris flow runs down (unit: degree)

3) Setting of the width and height of the debris flow running down

The width of the debris flow running down is set by using Equation (3) of a type of Manning's formula if its cross-section can be recognized clearly, or otherwise by using Equation (4) of a Regime type.

$$U_i = \frac{Q_i}{A_i} = \frac{1}{n} R_i^{\frac{2}{3}} I_{bi}^{\frac{1}{2}} \quad \text{Equation (3)}$$

where U_i: Average cross-sectional velocity

Q_i: Flow rate

A_i: Cross-sectional area of the flow

n: Roughness coefficient

R_i: Hydraulic radius, R=A/S (S is the length of the wetted perimeter)

I_b: Longitudinal gradient of the waterway

$$B_i = \alpha \cdot Q_{spi}^{\beta} \quad \text{Equation (4)}$$

where B_i: Flow width (m)

α, β: Coefficient (set to α=4.0; β=0.5)

* α=4.0; β=0.5 are the values set from the flow width that roughly contains a house that was completely destroyed based on the previous results of debris flow disasters.

The height of the debris flow at the starting point of inundation and each of the transversal measurement lines are calculated with Equation (5) by means of the flow width, the peak flow rate of the debris flow and the gradient of the land.

$$h_i = \left(\frac{n \times Qsp_i}{B \cdot (sin\theta_i)^{0.5}} \right)^{\frac{3}{5}} \quad \text{Equation (5)}$$

4) Setting of a "land with a considerable danger of harm"

The setting of a "land with a considerable danger of harm" is done by obtaining a force (F_d) that is estimated to be applied to a building by the debris flow at the starting point of inundation and each calculation point by using Equation (6), calculating the proof stress of the building at ordinary times (Pi) by using Equation (7), and by comparing these two values.

$$F_{di} = \rho_{di} \cdot U_i^2 \quad \text{Equation (6)}$$

$$P_i = \frac{35.3}{H_i \cdot (5.6 - H_i)} \quad \text{Equation (7)}$$

If the condition of $F_d > Pi$ is satisfied at the starting point of inundation, the zone from this point up to the calculation point at which the condition of $F_d \leq P_i$ has been met for the first time will be set as the "land with a considerable danger of harm". Note that this system employs a method in which the end of the "land with a considerable danger of harm" is obtained by means of repeated calculations carried out for each of the sections of 1 m.

It has been decided to clearly indicate the case in which there is such a zone in the set zone that the height of the debris flow exceeds 1 m and the force estimated to be applied to a building by the debris flow exceeds 50 kN/m^2, as well as the zone where the height of the debris flow exceeds 1 m and the force estimated to be applied to a building by the debris flow is 50 kN/m^2 or less.
Fig-6 shows the result of setting zones for the "land with a danger of harm" (Yellow Zone) and the "land with a considerable danger of harm" (Red Zone), by overlapping it with orthophotos.

Fig-6 Result of setting zones by means of the system

In this system, visual verification has been made easier to be performed by displaying the result of setting zones on the three-dimensional space as shown in Fig-7, and at the same time it has been made possible to provide such result for residents, etc. as explanatory materials that are easy to understand.

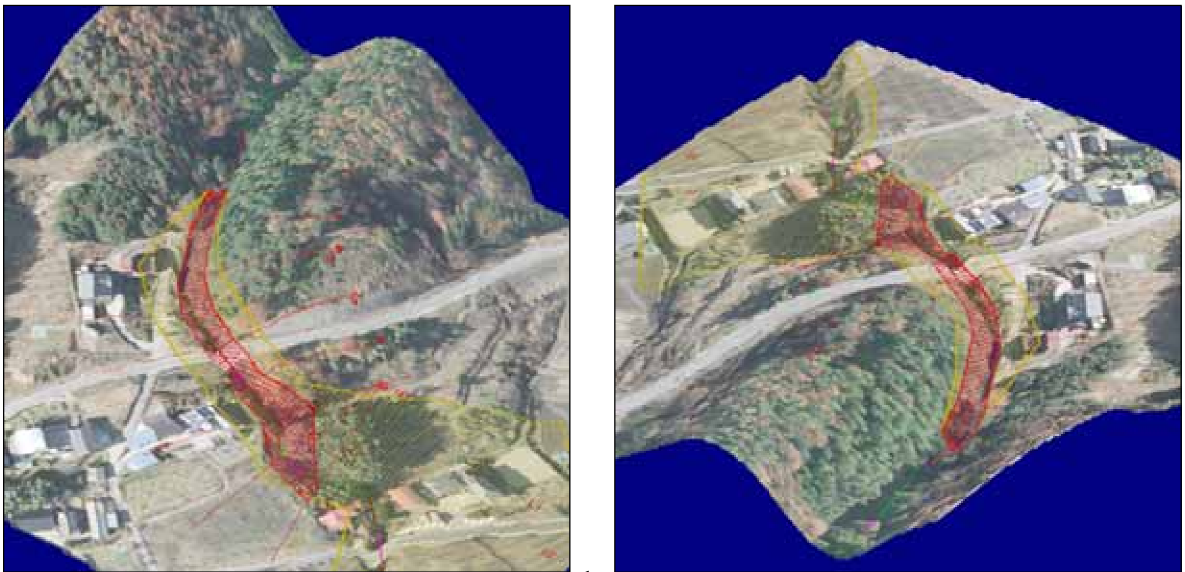


Fig-7 Result of setting zones on the three-dimensional space

6. Operation of the system for setting sediment-related disaster hazard areas, etc.

Since the system for setting sediment-related disaster hazard areas, etc. stores information on each zone as GIS data for the 3 phenomena: failures of land with steep slopes, debris flows, and landslide, it can be used not only for the sediment-related disaster hazard areas, etc., but for other work as well, such as city planning, together with the other information on zones subject to regulations by laws that is related to disaster prevention and land use.

Also, since a mechanism has been developed to store in a database the three-dimensional topographical information that have been used for calculation, various types of parameters, the result of setting zones, etc., they can be referred to at any time, and at the same time it has also been made possible to output their data in the xml format externally. Therefore, even when they have been made available to the public, they can be fully utilized as explanatory materials when making a response to residents and rightful claimant to the land.

As an evaluation of the operation of the developed zone-setting system, a comparison of the accuracy of work and working time has been made with the case in which the same work has been done by manual work, and as a result of this, with the system, mistakes made by humans have been eliminated and the working time has been shortened to about 1/10. Also, since this system operates on a PC of the standard specifications (Pentium III 800 Mhz, Memory 256 MB) without any stress, a large number of zone-setting work can be performed simultaneously with accuracy and efficiency.

7. Conclusion

In this study it has been tried to implement the work for setting sediment-related disaster hazard areas, etc. with greater accuracy and efficiency by developing a system that makes use of three-dimensional topographical information and GIS technologies.

As a result of evaluation of the developed system, it has been verified that, with the system, the efficiency of work increases, and the effectiveness of the accuracy and fairness of work processes as well as reproductivity, etc. can be secured.

Note that the work for improving this system is still underway, with efforts being made to reproduce actual phenomena of sediment-related disasters. And while the function for managing work processes and information on the result of zone-setting has also been developed, it is thought that a mechanism needs to be established hereafter that is related to the disclosure of information for promoting residents' familiarization with information.

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