博士論文(要約)

論文題目 Development of a Method of Forest Road Network Planning Using GIS that Discriminates and Avoids Dip Slopes

（流れ盤斜面の判別と回避を組み込んだ GIS による森林路網計画手法の開発）

氏名　孫　芝　英(ソンジヨン)

Chapter 1
Introduction

1-1 Background

The forest management is very important in terms of maintaining public function such as conservation of national land, watershed conservation function, prevention function for global warming, etc. in addition to taking out resources such as timber from forests and supplying timbers stably and effectively. The forest road network is indispensable to practice forest works such as reforestation, logging and transportation, and to realize sustainable forestry management. Moreover, the forest road network contributes to the improvement of forestry working conditions through making easy access to the operation sites. It is important to keep forest road network maintenance. However, as for Japan, the forest road network density is only approximately 17m/ha because of steep terrain and various of geological features. As for in overseas, Germany has achieved intensive forest road network from 1960s to 1970s; thereby, the forest road network density has reached approximately 118m/ha. Austria has also done intensive forest road network from mid-1990s; thereby, the forest road network density has reached approximately 90m/ha.

In the forest and forestry basic plan in 2011 (the Forestry Agency2011) in Japan stated that it was necessary to have an integrated business or an improvement of profitability through the establishment of forest road networks in order to achieve a sustainable forestry by an efficient and stable forestry management. The government has defined the forest road that was a driveway allowing for the passage of trucks, forest operation road that was used for the passage of truck and skidding road that was used for the forestry machines.

However, a simple and durable forest operation road or skidding road must be constructed by opening technology. The Forestry Agency drafted the guidance of opening a skidding road in order to summarize the construction methods and techniques of such roads and promoted their construction, and each prefecture drafted 「the standard for construction a forest operation road」 based on it. Each of them has a different awareness as to a simple and durable road. However, there have been actually different images as to forest road network for each region or business or party who is in charge of the maintenance of a forest road network respectively (the Forestry Agency 2010a). The forest and forestry revitalization plan has emphasized the need for the road network maintenance for the introduction of machinery (Table1-1, Table1-2).

According to the Forestry Agency (the Forestry Agency 2010b), the total length of forest road at the end of 2007 was 131,000 km, and the total length of forest operation road by the classification at the time was 98,000 km. And the forest road density including public roads, etc. was 12.9 m/ha and the density of forest operation road was 3.9 m/ha. However, the actual density does not reach at the criterion of Table-1.1. It would be necessary to proceed particularly construction of a forest road network. In order to realize this it would be required to establish an opening plan of forest road network (Figure1-1). As it is first to determine a work system and next set such standards as forest road network density that is suitable for the machinery, width of road, etc. After then, it will be advanced to select a place that can be opened from the topographic map and review the placement of forest road network. Lastly, routes can be determined by on-site survey.

First, as for the determination for work system, it would be necessary to determine appropriate forestry machinery according to the forestry management direction. So far, appropriate work system and forestry machinery have been proposed by geographical slope, annual production, full tree logging, forest conditions, etc. (a, the National Forestry Improvement and Diffusion Association 2001). Next, it would be required to determine the standards as to the forest road network density, width of road, etc. by the machinery in use or geographical conditions. As for the forest road network density, the criterion can be determined through the forest road network represented in Table1-1 with work systems. As for the standard of forest road network, the criterion is stated in the guideline of opening a forest operation road. The guideline of opening a forest operation road contains the criterion on the minimum requirements that have to be considered. For instance, the criteria as to the size of road width in accordance with the slope, longitudinal slope and cutting slope surface of embankment of excavation. As for the review of the placement of a forest road network, it the route must be selected by on-site survey after considering the placement on the map. Forest road network must be open at a minimum cost while preventing it from being collapsed. As for the opening place of forest road network, it must be a point where the geographical features of the ground is stable, therefore the work for the placement of a forest road network is important. At the same time, the forest road network must be appropriate for the type and performance of the forestry machinery. It is difficult at present to apply the guideline of opening a forest road network uniformly to all over the places through detailed database. Simple and durable forest road network based on the scientific evidences, must be practiced by determining where and which placement of forest road network should be opened. The placement of a forest road network varies significantly for each technician, and in some cases, there occurs a collapse of forest operation road (the Forestry Agency 2010) due to misjudgment of selecting a planning place.

It is not clear where and which type of forest road network should be opened at the phase of reviewing the plan. As for setting the placement of a forest road network to open, planning for the placement of forest road network is not doable except skilled technicians. To become a skilled technician, it would be required to have relevant knowledge based on long experience; however, such functions are sensible so that they are transferred through vague expressions. Thus, it would be difficult for technicians with limited experience to learn them. However, it would be required to create a guideline even for technicians with limited experience to make a plan for opening forest road network with high degree of work efficiency that is safe and not easily collapsed for the promotion of a system that integrates forest road network and forestry machinery in the future.

Table 1-1 Standard of road net maintenance level corresponding to terrain slope

(Forestry Agency2010 a) Unit(m/ha)

Classification	Operation system	Maximum Travel Distance(m)		Example of operation system			
		Main Road Network	Sub Road Network	Felling	Yarding Skidding	Branching Bucking	Transport
Gentle slope (0～15°)	Vehicle -type	150～200	30～75	Harvester	Grapple	Processor	Forwarder Truck
slope (15～30°)	Vehicle -type	200～300	40～100	Harvester Chain saw	Grapple Winch	Processor	Forwarder Truck
	Cable-type		100～300	Chain saw	Swing yarder	Processor	Forwarder Truck
Seep slope (30～35°)	Vehicle -type	300～500	50～125	Chain saw	Grapple Winch	Processor	Forwarder Truck
	Cable-type		150～500	Chain saw	Swing yarder Tower yarder	Processor	Forwarder
(35° ～)	Cable-type	500～1500	500～1500	Chain saw	Tower yarder	Processor	Truck

Table 1-2 One example of work system corresponding to terrain slope

(Forestry Agency2010 b)

Classification	Operation System	Main Road Network			Sub Road Network	Forest Road Densty
		Forest Road	Forestry Exclusive Road	Total	Yarding Road	
Gentle slope (0 ~ 15°)	Vehicle -type	15～20	20～30	35～50	65～200	100～250
slope (15 ~ 30°)	Vehicle -type	15～20	10～20	25～40	50～160	75～200
	Cable-type				0～35	25～75
Seep slope (30～35°)	Vehicle -type	15～20	0～5	15～25	45～125	60～150
	Cable-type				0～25	15～50
(35° ～)	Cable-type	5～15	-	5～15	-	5～15

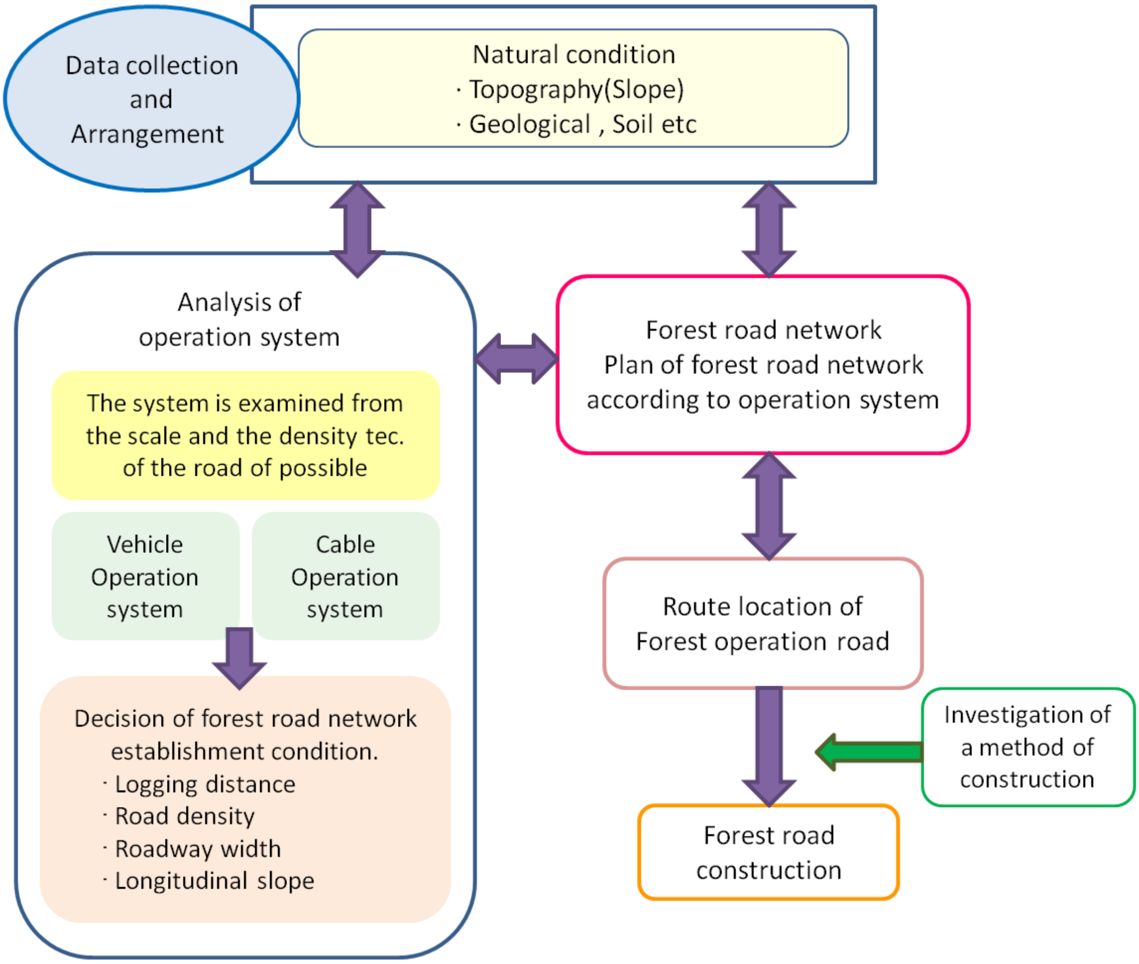


Figure 1-1 Steps to the construction based on the road network plan

1-2 Previous study

This chapter describes the construction of infrastructure forest road network and the planning of forest road network using GIS.

First, the numeric values, which could become the index for each step, or the support methods have been researched in consideration with various of conditions in order to perform the infrastructure of forest road network appropriately. The density of forest road network, which could become an index for the amount of route openings and the evaluation in of work or productivity have been the basis of the studies. The theoretical flow of the density of forest road network was started by the Matthews theory (Matthews 1942) that minimizes the sum of the opening cost and the log skidding cost, and has been studied by Kato (1967) who examined it through applying to Japanese steep terrain. And it was developed to the density theory of complex forest road network (Minamikata 1967) in consideration of forest road density including walking cost and low standard forest road as advocating the limit forest road density (Minamikata 1985). Since then, the aptitude density of forest road network for each condition, such as the saturation density observed from timber transportation and the determination method of forest road network density (Sakai 1987) with the output of working machinery as parameter. Later, it became possible to determine the index of forest road network density in consideration of employing a high-performance forestry machinery (Tasaka 2002).

These studies have mainly assumed forestland as monotype model; however, such forestland does not actually exist and the detour of log skidding of forest road network is issued by topography in mountain forest. In addition, the numeric value of approximately 1.5 to 2.0 in general has been reported while the density correction coefficient (V-corr) and the detour correction coefficient (T-corr) being examined by Segebaden (1964) since the shape of the subject forest is an irregular shape. The opening of forest road network should be reviewed with the objective of the density of forest road network the method to evaluate the distribution of range in forestry by (Hori et al., 1971, 1987), the method to estimate the range by the lattice point method by Sakai(1990) and the method to evaluate forest road network using the geographically optimal method such as (Ishikawa et al., 1995) have been suggested as the index to determine of forest road network. In recent years, the studies to evaluate route network as the basis of a region rather than evaluating only an effect of the work in the forest (Yoshimura 1997, Matumura 2000, Nakazawa 2007). As for the studies to optimize the forest road network planning and to determine the priority of route openings, the complex forest road network including low standard forest road (Kobayashi 1991, Sakai 1987, Sawaguchi 1996) was examined for mountain forest, and particularly, the forest road network of tractor log skidding (Inoue1989) including low standard spur road was also examined.

GIS generates highly valuable spatial information through a process to analyze the information increasing the utilization of geographic information to solve the complex problems spaces.

As for the usability of DTM and GIS, B has defined the organic body of computer hardware, software, documents and inputting in order to input, save, renew, manipulate, analyze and output of all forms of geographically relevant information effectively as GIS. It is possible to manage and search a large amount of documents rapidly and cost-effectively since documents are processed in a form of numerical value, and it has the advantage of generating new information through integrating and modeling documents with a variety of methods and perspectives. With the development of performance of personal computer, the development of the remote search technology, the introduction of graphic user interface and multimedia and the technological development of computer hardware and software in the 1990s, the technologies of GIS have become matured and its application areas have been diversified.

As for the GIS study in the field of forest, Maclean (1992) has estimated the amount of changes of forest resources using GID, and Morgan and Hohmann (1992) were able to present a reasonable measure as to various conditions and circumstances for forestry workers. Hickman(1995) and Reute(1988) have evaluated the opening of forest road network depending on the function of forest road using GIS. And Bormann and Likens(1997) suggested that GIS has been regarded as an effective measure to predict the input and harvest of capitals for forestry workers. In the US, the potential of forest function is being evaluated through FLESA (Forestland Evaluation and Site Assessment) based on GIS, which is the model to predict mountains. In particular, it has being utilized in real practices since it is developed as an extension of GIS software (Richard, 2001). In addition, Do Song Cha and Jun Woo Lee (1992) have researched the optimal route planning using the assessing factor depending on the purpose of forest road opening as to design forest road route using GIS in Korea. And Gwon

Seok Jun and Ho Sub Ma (2000) have researched the establishment of D/B and route selection of the plan of forest road network, and Joo Sang Jeong and Bung Do Lee (2005)have developed the eco-friendly forest road route and the evaluation program. And Ock Ha Sea (2000) and the others have developed the prediction expert system of collapse risk of forest road, and Jun Woo Lee and Myung Jun Kim (2003) have researched the development of the vehicle prediction model using GPS and GIS.

Thus, various GIS studies have been conducted from the view point of functional evaluation, but prediction dangerous area for forest road network planning by GIS and Prediction of the lack of research are.

In this study, the method is applied to determine the dip slope are presented.

1-3 Objectives of this study

It is required to create a guideline that allows for forest road planning, which satisfies safety and highly operation efficiency, and not collapsed even for engineers with little experience in order to implement forestry system forestry. According to the previous studies, the construction methods are well summarized and the criteria are stated in the guideline for establishing forest road. However, as for the placement of forest road network, a lot of experiences are still required. Thus, there are still no clear definitions as to which location of forest road network would be highly efficient for operation and where the terrain is safe and not collapsed in terms of using forest road network and also where the terrain is in danger of collapse.

According to Sakai (2004), it is pointed out that it is difficult to establish forest road network in the regions where the cutting slope surface increases particularly when the slope reaches to more than 30 degrees. Therefore, the purpose of this study is to establish an optimal forest road network by clarifying the location of forest road network that is highly efficient for operation and avoiding danger areas of collapse. The working system in which the operational efficiency is significantly changed by the placement of a forest road network is the working system of yarding. Before establishing a high-dense forest road, the yarding becomes a pivotal by a cable system. Therefore, the location of forest road network that increases the operation efficiency of yarding, is to be uniformly placed with high efficiency of operation (Kamiizaka et al., 1971).

The location of forest road network with high efficiency of forestry operation is to place forest road network in a uniform way. The extraction work is to reduce the average distance of moving logs to the landing (average extraction distance) by forest road network. It is possible to evaluate how uniformly target forest road networks are placed by the forest road network location index (Hori et al., 1971); thus, utilizing this index clarifies the relationship between the work efficiency of pre-yarding and the location of forest road network and consequently it becomes a placement of a forest road network with high efficiency of operation (Inoue 1989).

However, it would be required to establish a future plan by determining the status of basic maintenance for more strategic forest road network location plan. Therefore, the analysis was conducted as follows in order to determine the selection of regions in which the maintenance of a forest road network should be conducted as a target district of forestry management and future in advance using GIS.

The configuration of this study is as follows.

The first chapter investigated and states the background of needs for the maintenance of forest road network and the purpose of the study.

The forest road is in a situation to be opened from background investigation; however, it is not clear what form and where it has to be established the study stated the need of a guideline, which even engineers with limited experience could make a plan of forest road that was safe and not collapsed and also highly efficient for operation by selecting appropriate places.

The second chapter developed a GIS system to open forest road network that is simple, safe and not collapsed.

In forest road network planning, road sections on dip slopes are difficult to fill, and collapse of the cutting slope raises the maintenance cost. It is important to distinguish dip slopes in advance to build more stable and economical road network location that can be used for a long time. By applying the theory of distinguishing the dip slope in advance using the combination of slope and the apparent dip (relative dip) of stratum, it was tried to avoid dip slopes on GIS with DEM and geological map. Prior areas larger than 1 ha plantation forests and with a gentle slope under 35 degrees were extracted, and the forest road network planning system which connected such areas with the shortest pass by Dijktra method avoiding dip slopes was established. The possibility of predicting dip slopes in advance from DEM and geological map was recognized, and it became possible to save much man-power of reconnaissance. Construction cost and section length of each section in a planning area were also estimated simultaneously by using GIS. These results should be useful for deciding the construction order and avoiding unnecessary routes according to the condition of the forest resources.

The third chapter analyzed based on the technique developed in the second chapter by applying it to Takayama-city of Gifu prefecture. First of all, a rough placement plan of a forest road network that avoided dip slope was conducted. And there was a need to establish a future plan by determining the status of basic maintenance for more strategic placement plan of a forest road network; therefore, areas that had to conduct the maintenance of forest road networks as a target district of forestry management were selected by overlapping the status of geographical conditions and forest resources after calculating the average yarding distance using

GIS and determining the current maintenance status of forest road networks. And the range of yarding by the work system was reviewed by reducing the average yarding distance through the implementation of basic maintenance. In addition, as a result of overlapping the average slope, the study analyzed by the geographical conditions the areas where a basic maintenance has to be conducted in the future such as an area where the placement of high density forest road network is advantageous, an area where the placement of high density forest road network above the level of the current status is not feasible and an area where the placement of high density forest road network is not feasible due to steep slope. And Takayama-city is the target area for research area with the forest rate of 90 percent; thus, the study reviewed a case of converting the annual growth rate of forest trees into forest biomass resource amount and energy by identifying the current status of forest resources.

The fourth chapter contemplated the information based on the review of the analysis results found from the chapter 1 to 3.

Chapter 2

Forest Road Network Planning by Using GIS Incorporative Discrimination of the Dip Slope

1. Introduction

Efficient and reasonable layout of the forest road network based on construction and maintenance cost and efficient timber production is important in forest management. At the same time, places prone to collapse must be avoided and geographical and geological stability must be secured for long term use of the road especially when road density increases.

Japan Islands are fundamentally composed of accretionary wedges (SAKAHI, 2009). Except for igneous rock areas and colluvial slope, terrains are classified into either dip or opposite slope especially in accretionary wedges. A dip slope is a slope in the same direction of the inclined stratum, which generally makes filling difficult. Indeed the dip slope on a mountain side is generally gentle having long and smooth river systems (SUZUKI, 2000), and it is not difficult to construct roads. However, landslides and collapse of the cutting slope frequently occur, so that roads on a dip slope require higher construction and maintenance costs (SAKAI, 2012). Road planning must consider not only efficiency and construction cost but also safety factors and maintenance cost. A dip slope is often covered with thick colluvial soil, and such accumulated soil is prone to slide after a heavy rain. On the contrary, a road planned on the opposite slope which is steep, with a short and parallel waterfall and, winding in short sections (SUZUKI, 2000), takes much time to construct, but is stable once constructed (SAKAI, 2012). Therefore, it is important to distinguish a dip slope from the opposite slope to locate a stout and stable road network in advance to road network planning.

It is impossible to distinguish a dip slope on a contour map alone, but it is possible to distinguish a dip slope with the help of published digital geological maps. If the method of distinguishing a dip slope from such digital data could be established, it will save much man-power for reconnaissance and risky areas can be avoided in road construction. It was tried to distinguish the dip slope using both contour map and digital geological map.

It was also conducted a study to develop an efficient road network design applying geographical information system (GIS). For example, Yoshimura and Kanzaki predicted zones with a high risk of collapsing by using the fuzzy theory and considered the influence of soil erosion (YOSHIMURA and KANZAKI 1998). Saito used a high resolution digital terrain model (DTM) by light detection and ranging (LiDAR) for topographical information, and calculated the earth-volume and cost, and judged the risk of collapsing by a dynamic model of slope stability (SAITO, 2012). He also developed an automatic method for designing a forest road avoiding dangerous areas. However, they did not consider geological factors. It was developed a method of route location using GIS considering the geological structure, dip or opposite slope. GIS helps to simulate the route location, and stout roads considering the dip slope will help decrease road maintenance cost on the long term.

2.Materials and methods

2-1 Geological structure of the Japanese Islands

The geology of Japan is located on top of the orogenic belt in which the oceanic plate and the continental plate collide. It forms the subsidence of oceanic plate, the division of continental plate and the complex topography and geology due to active magmatic activity.

As for the plan of forest road network, it is important to have a holistic and comprehensive opening as well as the selection of construction method. It is necessary to respond through examining the conditions of local nature such as topography and geology to open forest road network. It is imperative to determine the dangerous local terrain and select a secure and cost-effective route when selecting a route. When opening a road, it is required to research precisely the quality of soil such for appropriate road construction. Figure 2-1 shows the geological structure of the Japanese Islands.

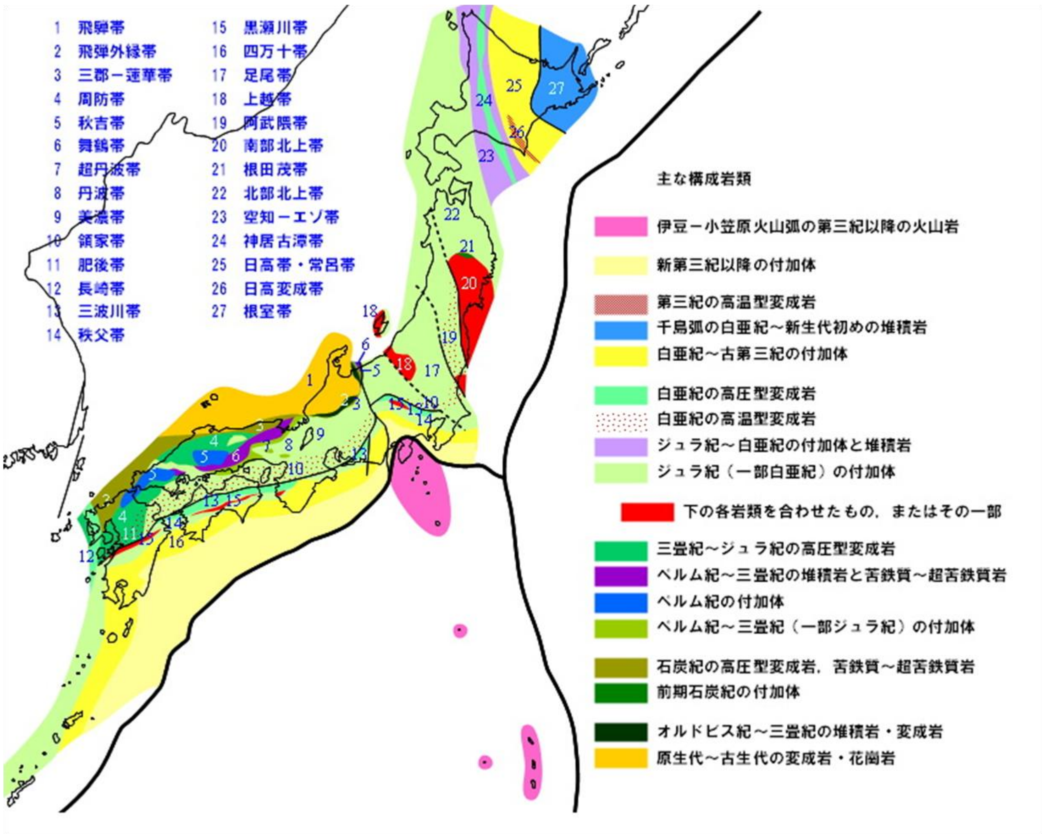


Figure 2-1 Geological structure of the Japanese Islands (In Japanese)

Data :Geological survey of Japan

2-2 Definition of Dip slope and Opposite slope

When establishing forest road network, it is recommended to distinguish the region of opposite slope and dip slope. The dip slope and opposite slope are divided because of the relation of the direction of the slope of the stratum and the slope. The dip slope is a direction where the slope of the stratum and the slope are the same. On the other hand, the opposite slope is a direction where slope of the stratum has intersected with the slope (Figure 2-2). Therefore, in the case of heavy rain, the ground pressure of the dip slope has high risk of collapse (Figure 2-3). When decoding with the topographic map, it is important to learn the fact that dip slope is prone to collapse with landslides, slope failure and outflow of groundwater. When looking in the form of a water system on dip slope, the side with more gradual slope of stratum is substantially parallel to the direction of the tilt, and long water system is visible. And in opposite slope the water system is parallel to the direction of an increase of slope, and narrow and often curved (Figure 2-4). The division of dip slope and opposite slope was read from the present condition of the water system by using the topographic map. For example, to prove it by using water system, dip slope at can be extracted. As shown in Figure 2-5, dip slope has mild slope and long curved pattern. At the opposite slope, water flows are short and parallel, and has steep slope. However, when reading from topographic map is impossible, for more precise finding of dip slope, the data of stratum plane's slope and aspect made by Institute of Advanced Industrial Science and Technology can be used.

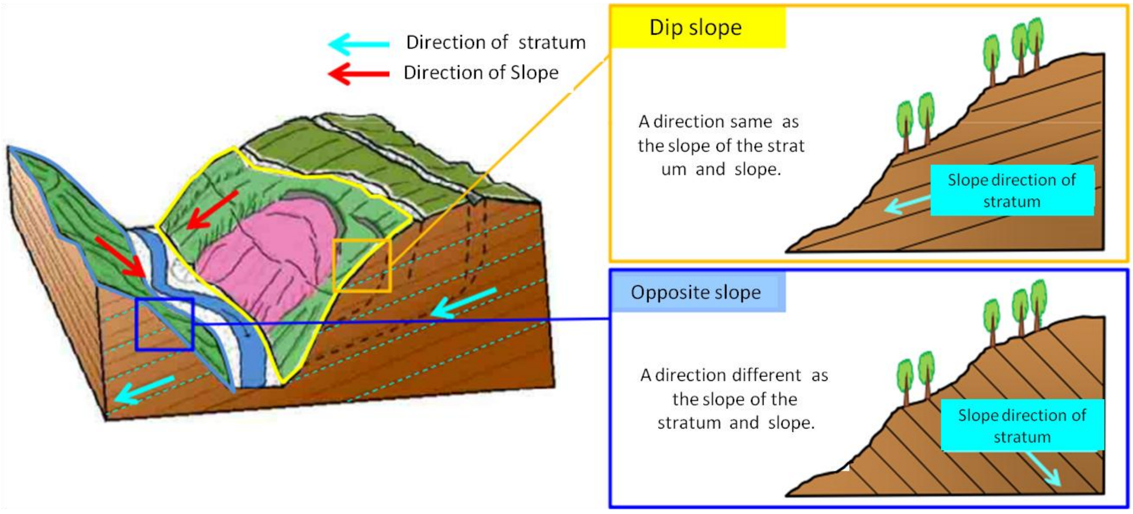


Figure 2-2 Definition of Dip slope and Opposite slope

Data : Nara prefecture

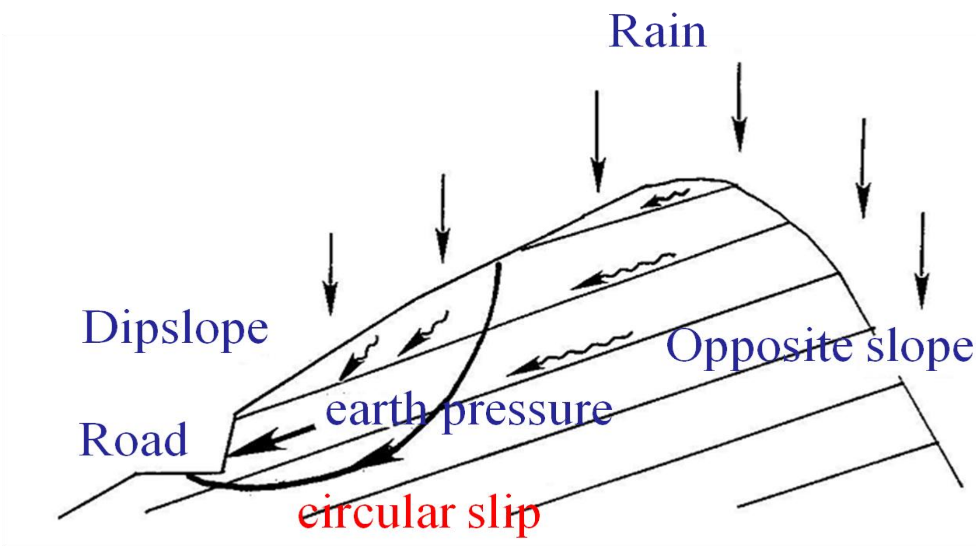


Figure 2-3 Pattern diagrams of dip slope collapse

Data :Sakai(2009)

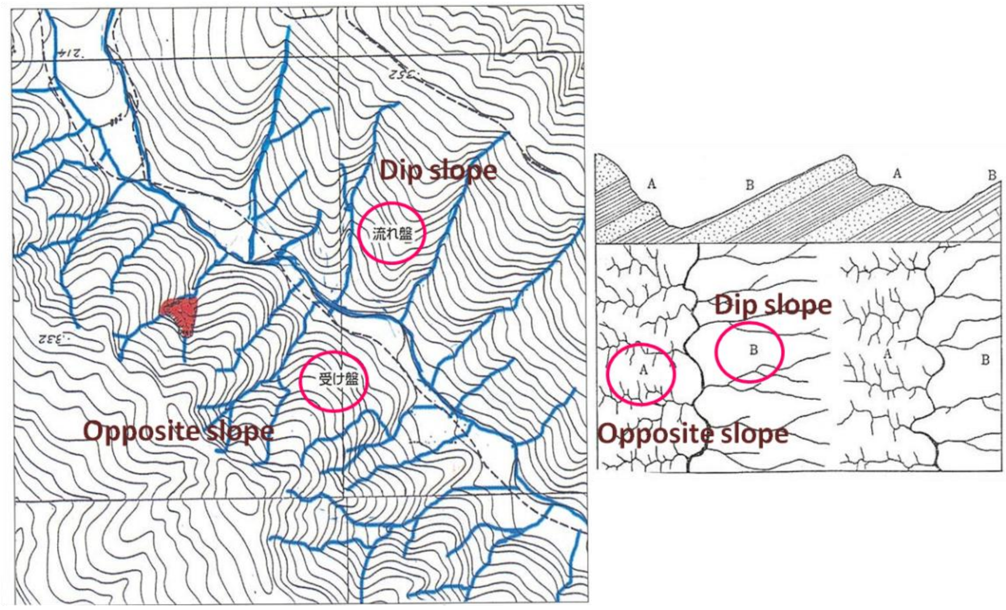


Figure 2-4 Pattern diagrams in section and water system form of dip slope and opposite slop

Data : Oohshi (2001)

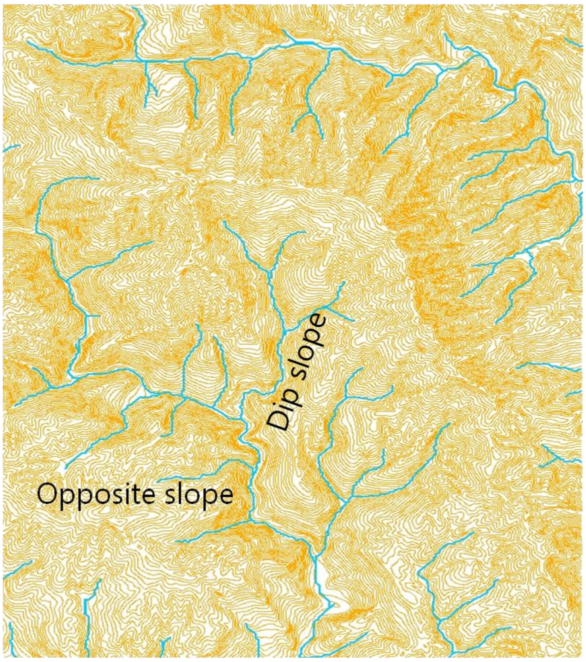


Figure 2- 5 Sample of dip slope and Strum of opposite slope at Atera in Sizuoka prefecture

(The original DEM : Geospatial Information Authority of Japan)

2-3 Study Site

The method was applied at The University of Tokyo Chiba Forest (UTCBF) located in the southeastern part of the Boso Peninsula. It lies from 140º 5′ 33″ to 10′ 10″E and from 35º 8′ 25″to 12′ 51″N. Most of the forest exists at altitudes of 50 – 370 m. The geographical structure consists of marine deposits from the Neogene period, partly covered with nonmarine deposits from the Quaternary period; slopes are generally very steep, about 26degrees, and the contour lines are complicated (THE TOKYO UNIVERSITY FORESTS, 2007). The planned area was 2,226ha consisting of 1~23 compartments among 47 compartments (Figure 2-6).

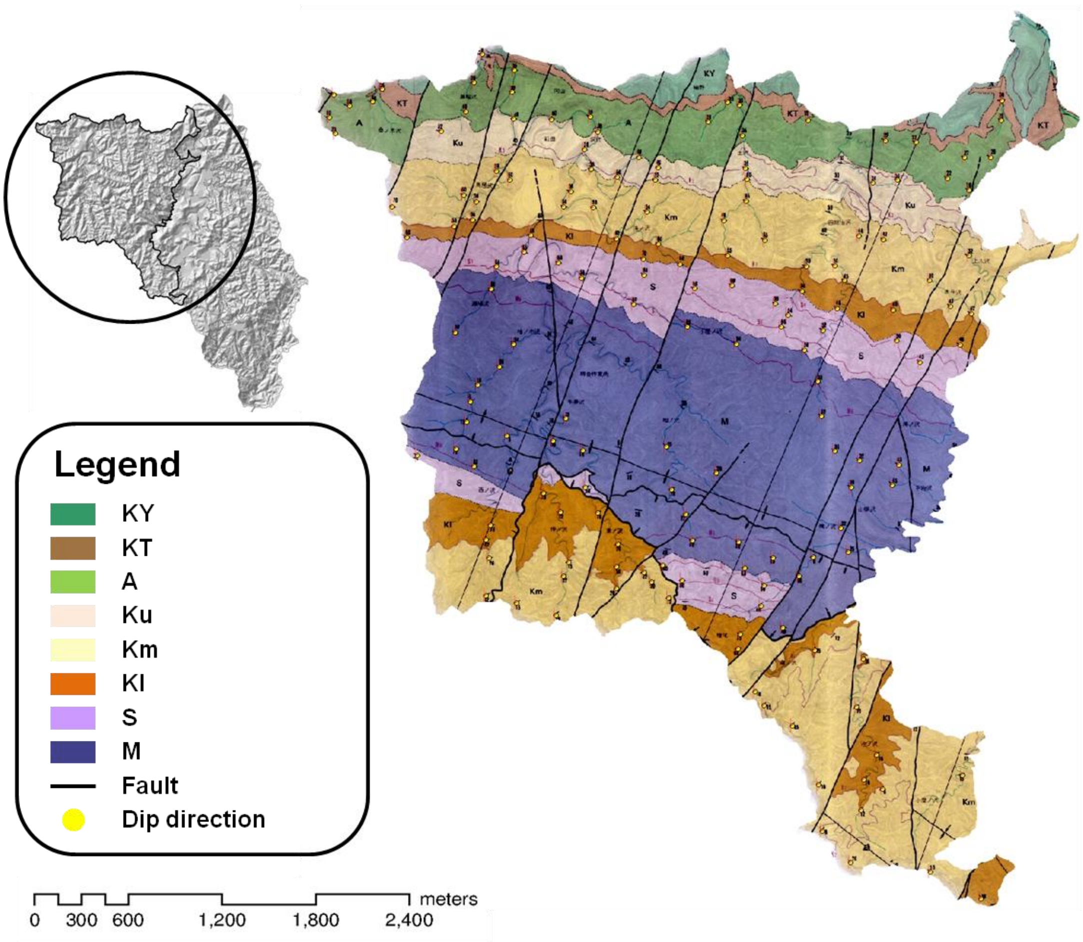


Figure 2-6 Study area and information of dip direction of stratum

by 1/10,000 geological map from UTCBF

Note : **KY** : Massive mudstone interbedded with tuffs and sandstones

KT : Andesitic breccias, sandstone, tuff and calcarenite

A : Mudstone with interbeds of sandstone

KU : Sandstone interbedded with tuffs and mudstones

KM : Sandstone with interbeds of mudstone

KI : Sandstone and granule conglomerate

S : Mudstone with interbeds of tuff

M : Mudstone with interbeds of tuff and sandstone

2-4 Theory of distinguishing dip slope area

The procedure for planning the forest road network consisted mainly of three parts; 1) identifying the dip slope area from geological data and terrain data, 2) finding in advance the area for forest road network from forest resource data and terrain data, and 3) connecting these areas with a forest road considering the dip slope (Figure 2-7).

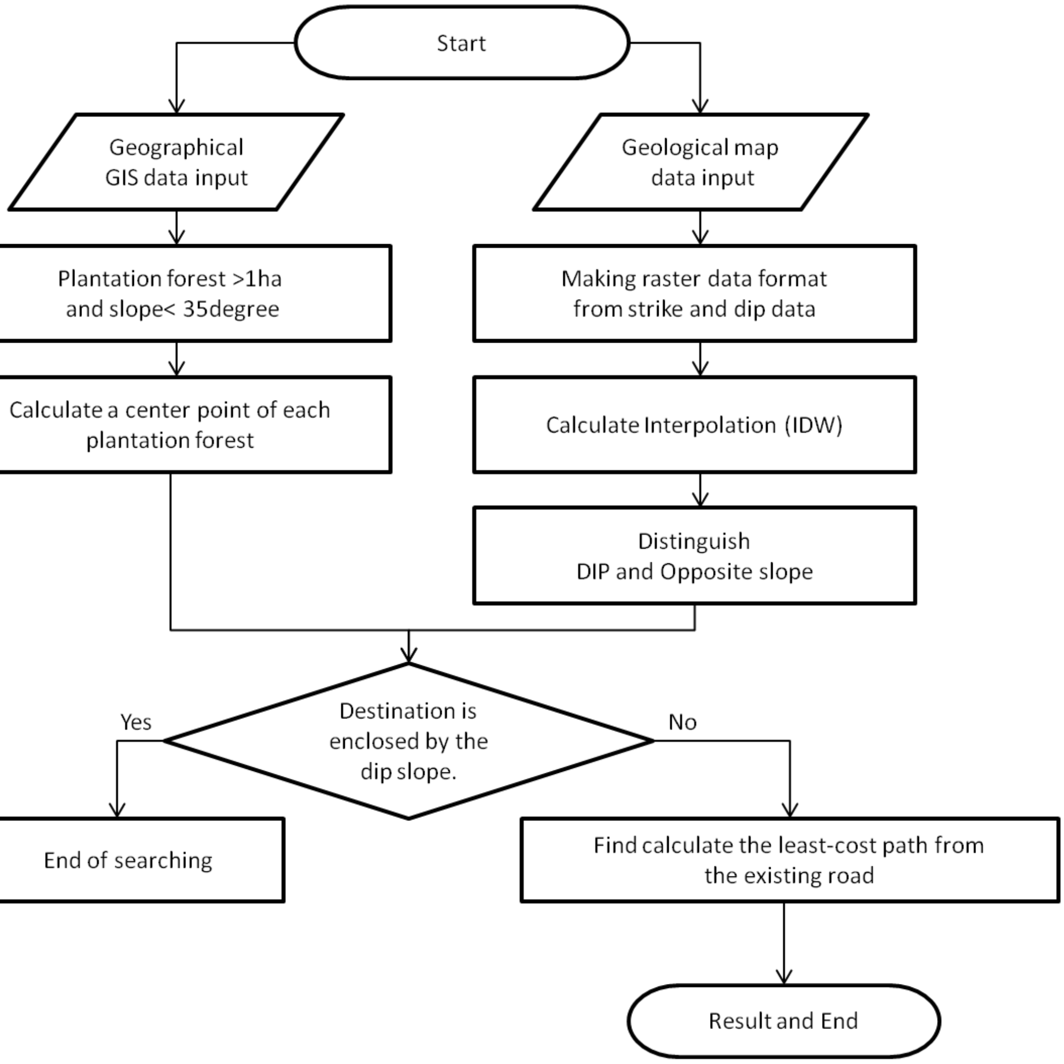


Figure 2-7 Flowchart of procedure for planning the road network

The dip slope has been mainly studied in the field of land-slide as a risky area. Suzuki classified the patterns of combination between slope (θ) and relative dip, that is, apparent dip (β) explained later into six types (horizontal dip, daylighting dip, parallel dip, hangnail dip, vertical dip, and infacing dip) and evaluated each stability (SUZUKI, 2000), although horizontal, vertical and infacing dips were not quite dip slope, and his daylighting and hangnail dips were problem slopes in this study (Figure 2-8). Iwahashi *et al*. also classified dip slope and opposite slope of the area, and examined the number of collapse (IWAHASHI et al., 2001). In this study, Suzuki’s classification was summarized into three patterns for the practical purpose of distinguishing dip slope from the view point of road construction as shown in Figure 2-8.

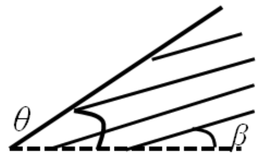
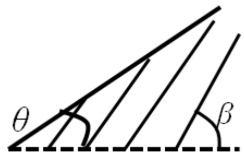
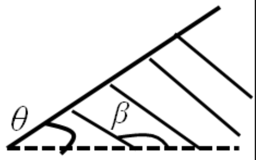
Structure			
Type of slope	Dip slope	Dip slope	Opposite slope
Define	$0^o \leq \beta < \theta$	$\theta < \beta \leq 90^o$	$90^o < \beta < 180^o$
Stability of Road construction	Not stable	Not stable	Stable
Modify from the Suzuki(2000)[10]			

Figure 2-8 Classification of slope by combination between slope (θ) and apparent dip (β)

First, the 10m digital elevation model (DEM) data was utilized as terrain data to calculate slope and aspect. Geological data was analyzed using the digital geological maps of Japan 1:200,000, Kanto-Koshin′ etsu and Izu-Ogasawara Islands published by National Institute of Advanced Industrial Science and Technology and the 1:10,000 geological map provided by the investigated site, UTCBF. It is necerrary to obtain the data of slope (θ) and apparent dip of stratum (β) to classify the slopes, and this geological information of stratum has not yet been digitized in the 1:200,000 digital geological map. Most of the existing studies obtained and analyzed the data by utilizing the 1:50,000 geological map. As the 1:50,000 geological map has not been prepared by UTCBF, the above 1:10,000 geological map was arranged to analyze at GIS through creating the point data that had dip direction of stratum by scanning and rasterization. The information of dip direction of each point was digitized by reading in clockwise 360 degrees. This point data was interpolated to a 10 m grid using the IDW (Inverse Distance Weighted) technique (Figure 2-10 and 2-11).

Here Figure 2-8 explains the relationship between steepest angle of stratum direction (α), that is, true dip and apparent dip (β) of stratum, where Point A in Figure 2-18 is the point in calculation whether dip or opposite slope. The apparent dip here is the same as the relative dip which Suzuki used (SUZUKI, 2000) (Figures 2-12, 2-13 and 2-14).

The following formula can be derived,

$$\tan\beta = \tan\alpha \cos\eta, \qquad (1)$$

where η is the direction from the dip direction.

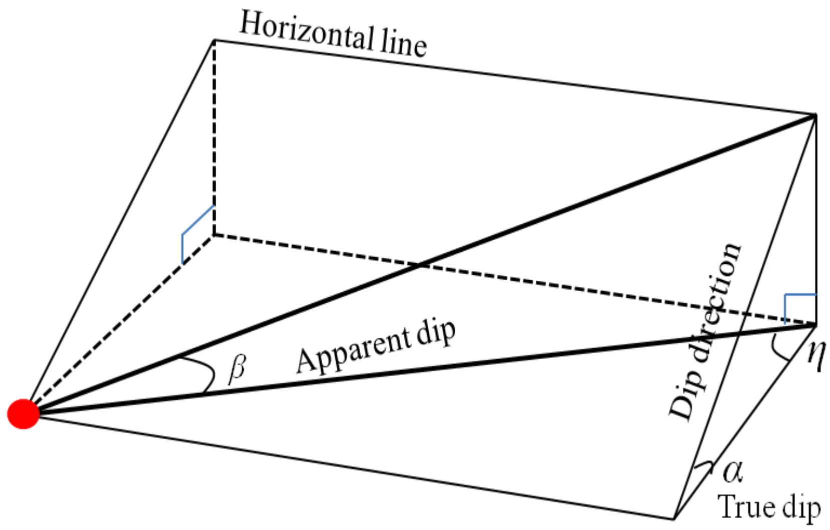


Figure 2-9 Relationship between true dip and apparent dip of stratum

Note : The slope expressed the stratum. Ponit A is the investigating point whether dip or opposite slope

Then, the slope could be distinguished as dip slope if η is 0－90°, and opposite slope if η is 90－180° (Figure2-15).

In order to validate the results of calculation, some sample points which were in extracted area as dip slope were picked up, and the actual geological layer was investigated by the naked eye at these points, and the correctness of this method was analyzed.

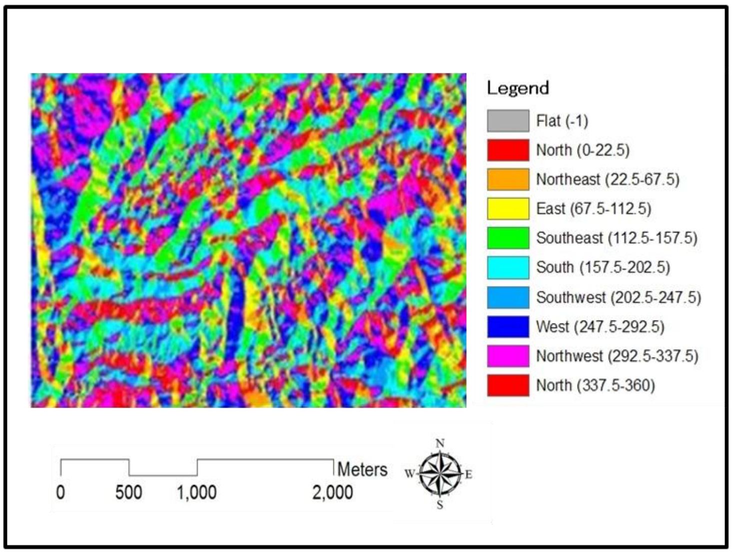


Figure 2-10 Aspect map [Aspect]

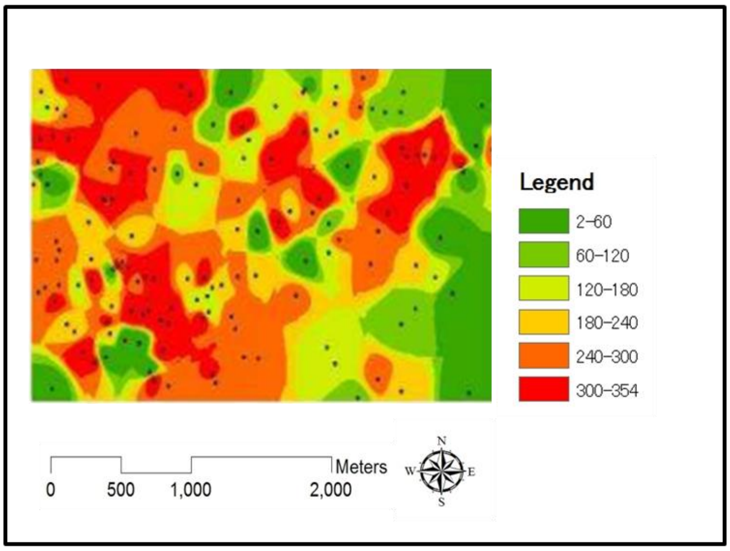


Figure 2-11 IDW interpolated surface of dip direction layer with used location points [DipDir]

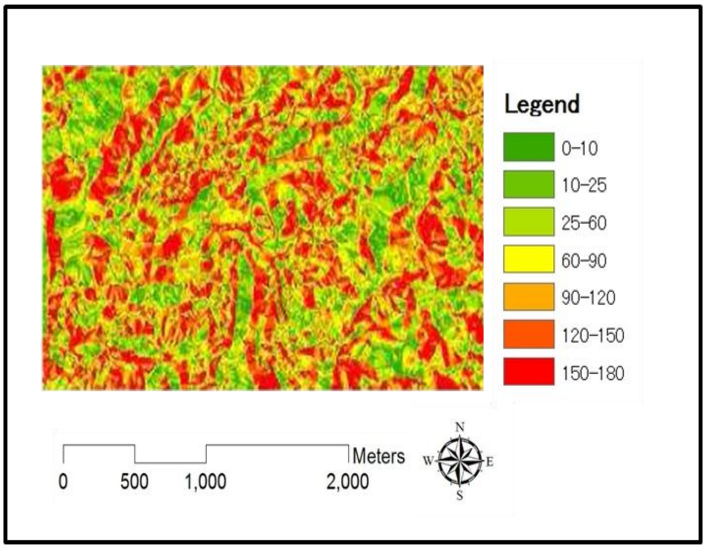


Figure 2-12 Layer of deviation angle η

Con(abs([Aspect] - [DipDir]) < 180, abs([Aspect] - [DipDir),

360 - abs([Aspect] - [DipDir]))

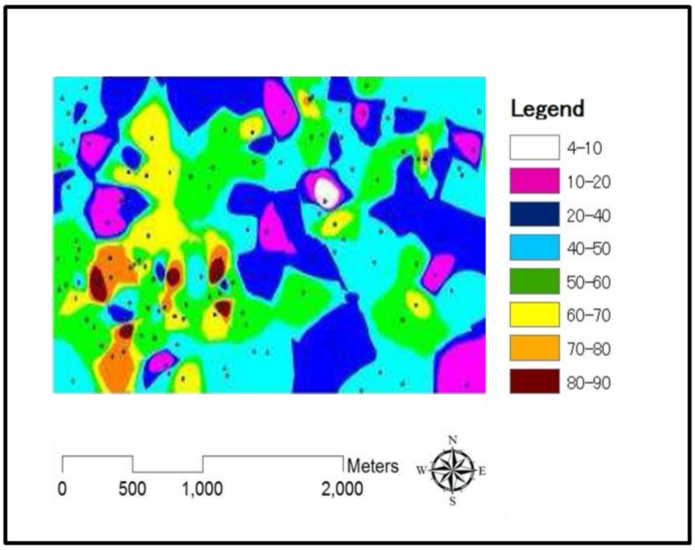


Figure 2-13 Dip angle IDW

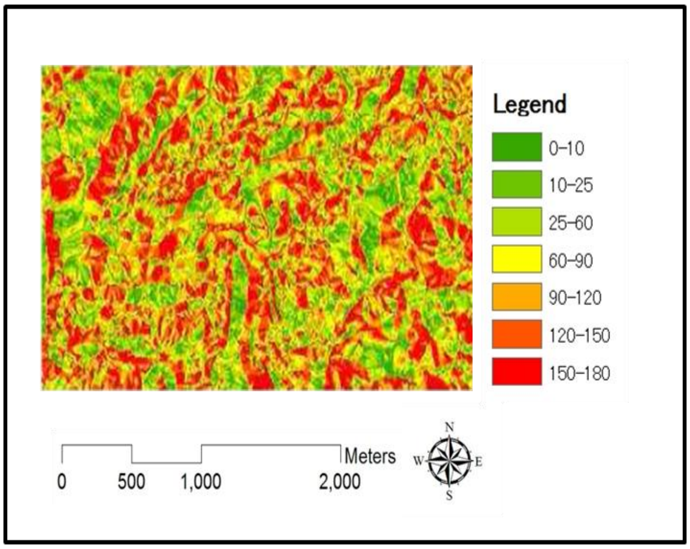


Figure 2-14 Layer of deviation angle η

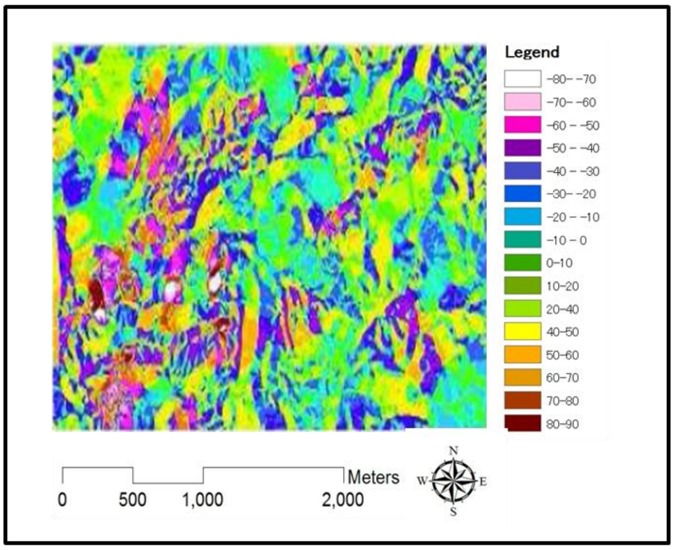


Figure 2-15 Apparent dip angle

β = tan-{(tanα) * (cosθ)}

2-5 Applying GIS to forest road planning

Esri ArcInfo GIS 9.3 software was used for route planning. Inclination and direction of slopes were analyzed by using 10 m x 10 m DEM, which was prepared from the data of UTCBF as mentioned above.

In this study, forest areas which had priority for harvesting were picked up first. The forest areas which had high priority were defined as covered by plantation forest larger than 1 ha on a slope less than 35 degrees, When the slope exceeds 35 degrees, it is difficult to construct road without walls, and the cost increases drastically, so that it is said that high density road networks cannot be realized on such steep terrain (SAKAI, 2009). The areas with a slope less than 35 degrees were extracted using the DEM data. Indeed harvesting should be carried out in a plantation forest, but was inappropriate in a forest smaller than 1 ha taking into consideration the cost-benefit balance of constructing or efficient maintenance of forest road. This factor lead the qualification; plantation forests larger than 1 ha. The area of plantation forests was selected from the forest resource map and data of UTCBF. When some plantation forests were adjoined with each other, the area was added up. Road network could be located at the preferential area, which satisfied these factors.

Next, the forest road network that connected each prior area was calculated. For calculation, the grid of DEM was used as the base unit, as reported by Kobayashi (KOBAYASHI, 1983) and Sakurai *et al.* (SAKURAI *et al.*, 2004). Furthermore, in this study, a dip slope was considered.

The gravity center of each extracted priority area was determined as the destination of road network, and its position was expressed by the coordinate of the DEM. When the destination was on a dip slope, it was not considered in road planning. Then the constructing costs for each destination and between destinations and existing roads were calculated.

The Dijkstra method (DIJKSTRA, 1959) was used to form the forest road network. When calculating cost for each section, the DEM grids were treated as nodes in the Dijkstra method, and edge path costs between each node were given as road construction cost per unit length. When the dip slope was considered, the algorithm was arranged to avoid the dip slope area.

After this process of calculating every road section, the minimum network was computed by Prim's algorithm (PRIM, 1957). In the algorithm, the initial node was existing road. This algorithm gave the cost-minimum forest road network from the cost table prepared in advance.

The road construction cost on slopes below 35 degrees without walls was estimated based on standard unit price for civil engineering works (CONSTRUCTION RESEARCH INSTITUTE, 2006) assuming that the construction by 0.28㎥ class excavator and 3 m in road width, and obtained the regression line of unit price of construction as follows (Figure 2-16).

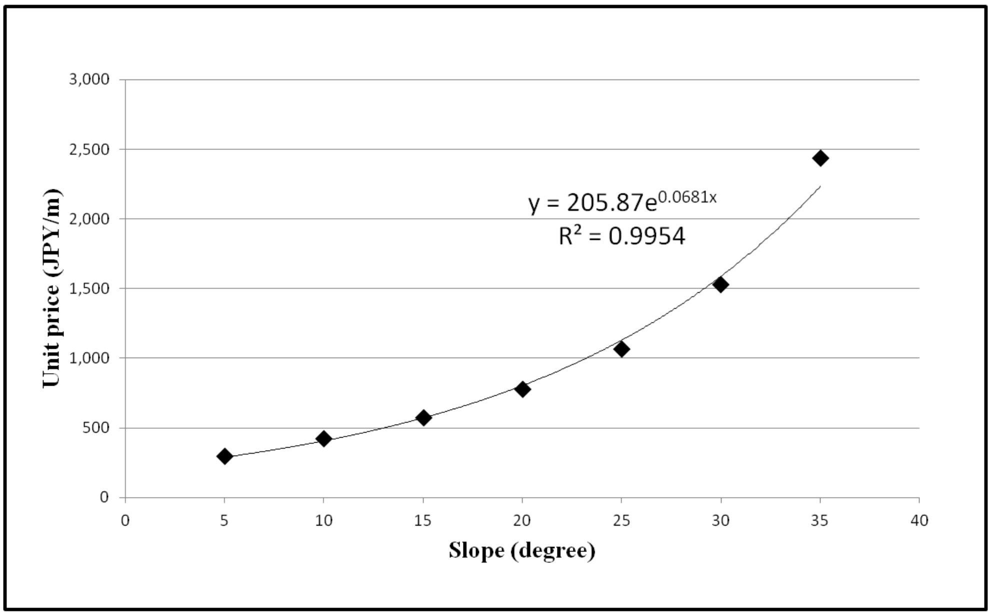


Figure2-16 Unit price of road construction

$$y = 205.9 \exp(0.068x), \qquad (2)$$

Where y is unit price of road construction (JPY / m), and x is degrees of slope.

3. Results and discussion

The assumed dip slope area from the apparent dip (β) and surface slope (θ) are shown in Figure2-17. The extracted dip slope area was accounted for 8 percent of the total area with an area of 201ha. The dip slope was found in a bundle on the slope in the north direction and more than 76 percent was distributed on gentle slope areas with a slope angle of less than 35 degrees (Figure 2-18 and Figure 2-19). To validate this assumption, 11 points in the extracted dip slopes were investigated by the naked eye. As a result, all points were actually on the dip slop.

Figure2-20 shows the extracted priority areas for harvesting area and numbered destination and the results of outline of forest road network not considering dip slopes. Roads were divided into sections between destinations and existing roads. Road density reached 14.0 m/ha. This network and result will be called ‘Not considering dip slope (ND)’, hereafter. On the other hand, a road network covering the planning area considering dip slopes was allocated as shown in Figure2-21. This result will be called ‘Considering dip slope (CD)’ hereafter. The total length of the network in CD was 13,251 m which is slightly shorter than that in ND with 13,381m. The total construction cost and average construction cost of unit length in CD was 20,242,578 JPY and 1,528 JPY/m, which were higher than those of ND, that was 16,228,603 JPY and 1,213 JPY/m, respectively. The average degrees of mountain slope where roads were located could be estimated as 29 degrees at CD and 26 degrees at ND from Figure 2-16. The route locations of both situations were similar to those from the topological network because; (1) these results depended mainly on the location of the plantation area, (2) the same unit cost for road construction was used for dip and opposite slopes, and (3) there were some sections already constructed on dip slopes, which eliminated the clear difference.

Roads were divided into sections between destinations and existing roads. Divided road sections were numbered the same number as destination number farther from existing road. For example, the section No. 3 means the section between destination No. 3 and 4, and similarly, section No. 15 was road between destination No. 15 and existing road. At the investigated site, there was a slight difference in road section between CD and ND as mentioned above. Construction length and cost from each section can be shown in Figures 2-22 and 2-23 together with CD and ND. Since destinations No. 2, 10, 13, 16, 18, 32-34, 36 and 40 were in the dip slope area, they were not used for road network planning at CD.

In Figure 2-22, detours caused by consideration of the dip slope increased the length of road, for example, sections No. 25, 28, and some other sections. However, the constructing cost was not affected by considering a dip slope, because the road detouring the dip slope might pass a mild slope area, and the construction cost would not be increased. For example, in sections No. 3, 5, 6, 8, 12, 14, 17, 31, 35, and 38, the cost was decreased after considering the dip slope.

The locations in Figure 2-21 successfully avoided dip slopes, e.g. sections No. 25 or 28. However the difference in construction unit cost between the dip slope and opposite slope was not clear due to lack of precise information, and the results would be improved if more precise data for road construction and maintenance cost on the dip slope and opposite slope could be obtained. However, when the road construction cost on the dip slope was assumed to be twice that in formula (2), the results of road network was the same as in Figure 2-23 because the increase of cost in the dip slope areas was avoided by making a detouring route. And useful figures, maps, such as the bird's eye view map shown in Figure 2-24 could be drawn easily with a computer by this method using GIS. These resources will enable further discussion on the harvesting system, e.g., cable logging, terrain, yarding distance, and forest road.

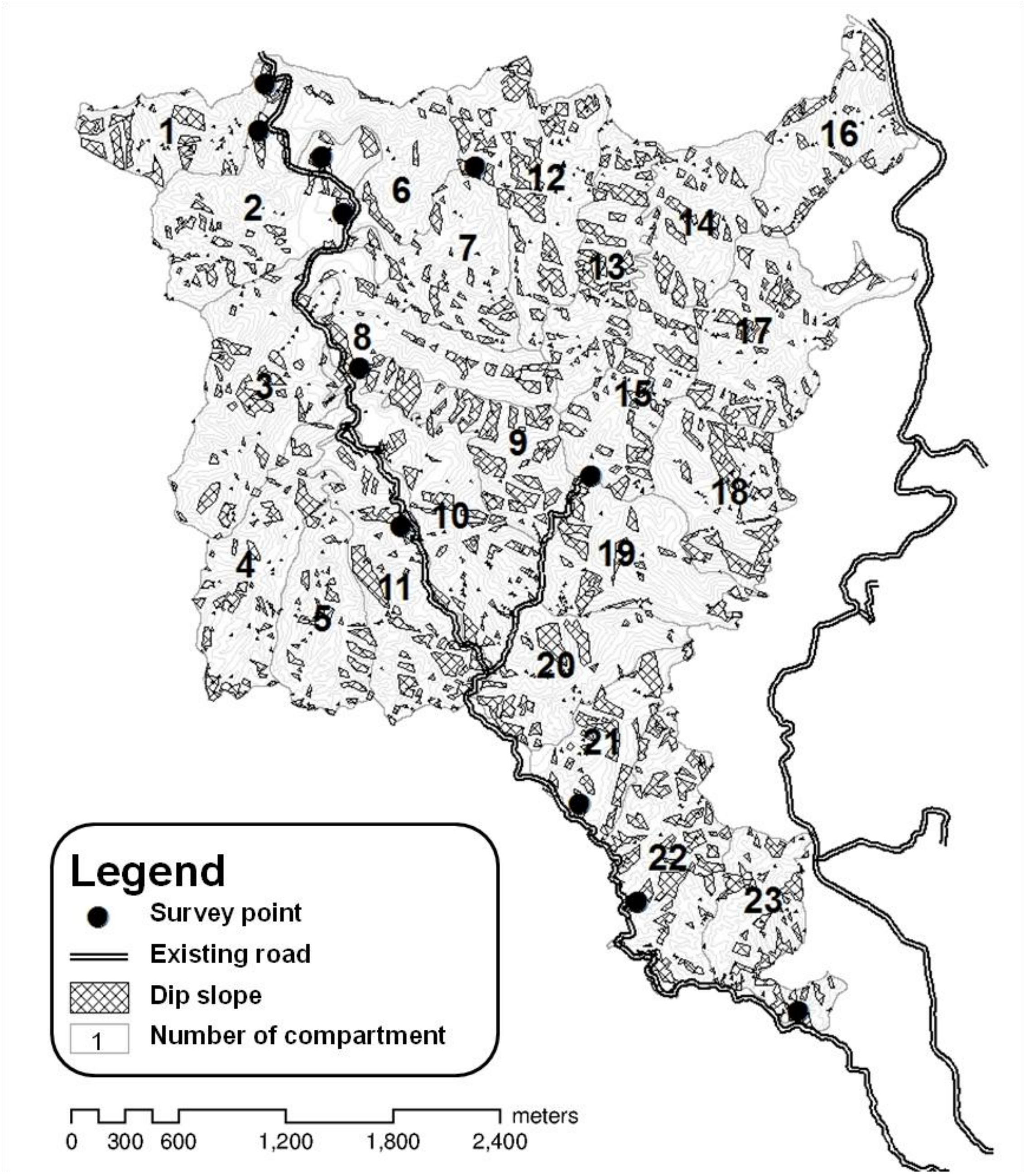
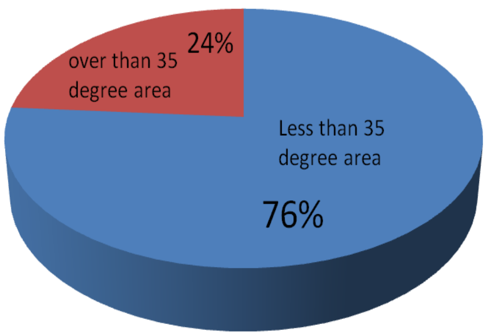


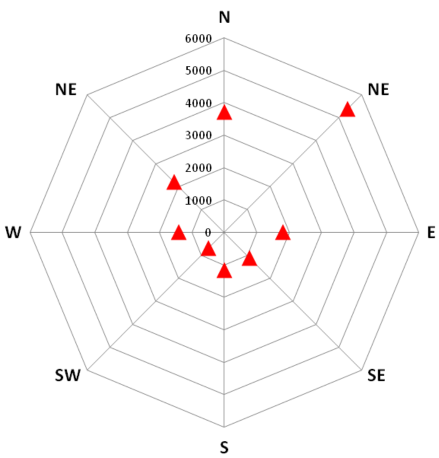
Figure2-17 Extracted dip slope area and confirmation survey area

Figure 2-18 The field photo in Chiba experimental forest of

the University of Tokyo on dip slope.

Note:→ Direction of stratum





Direction of dip slope

Slope distribution of the dip slope

Figure 2-19 Features of the dip slope

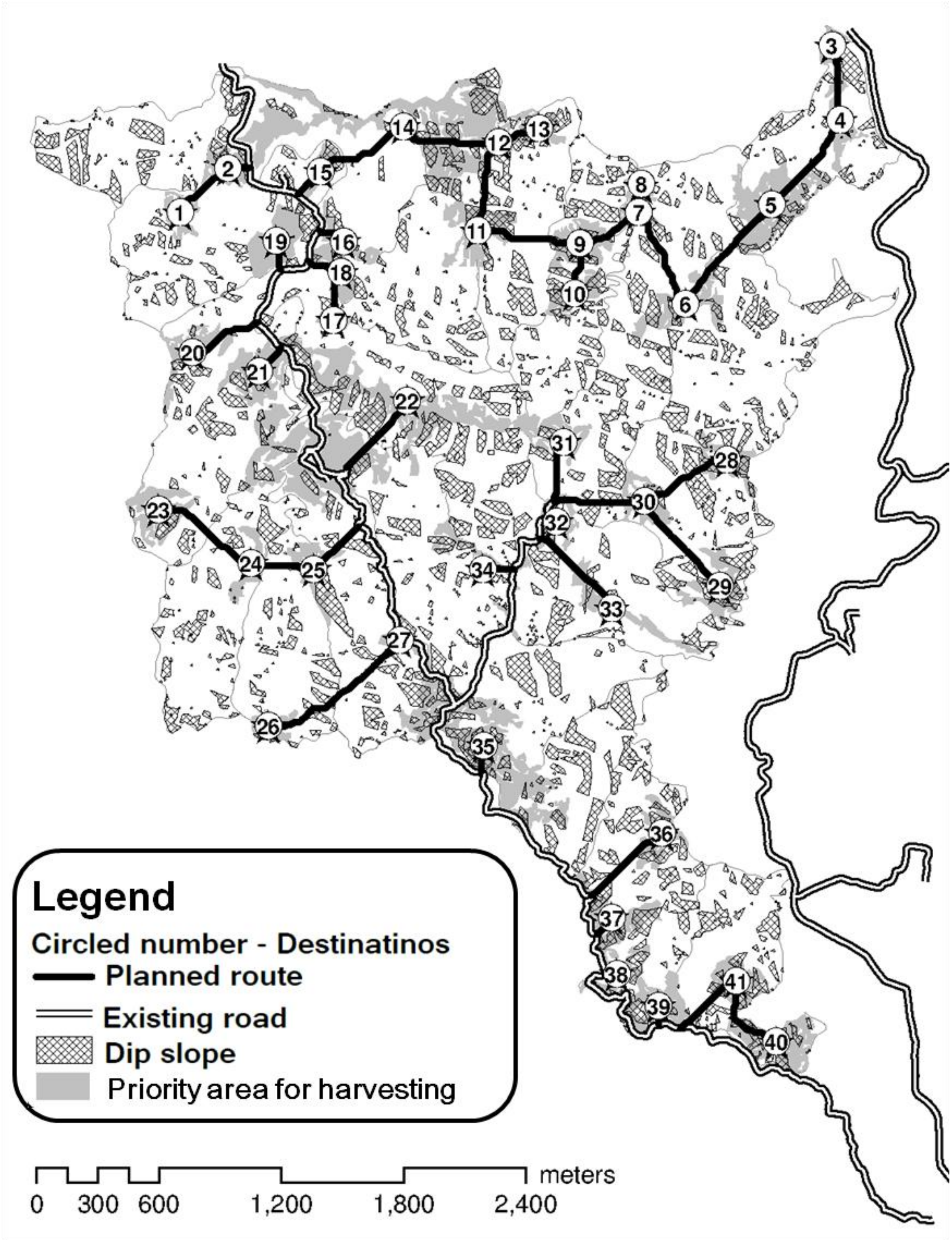


Figure 2-20 Results of forest road network not considering dip slope

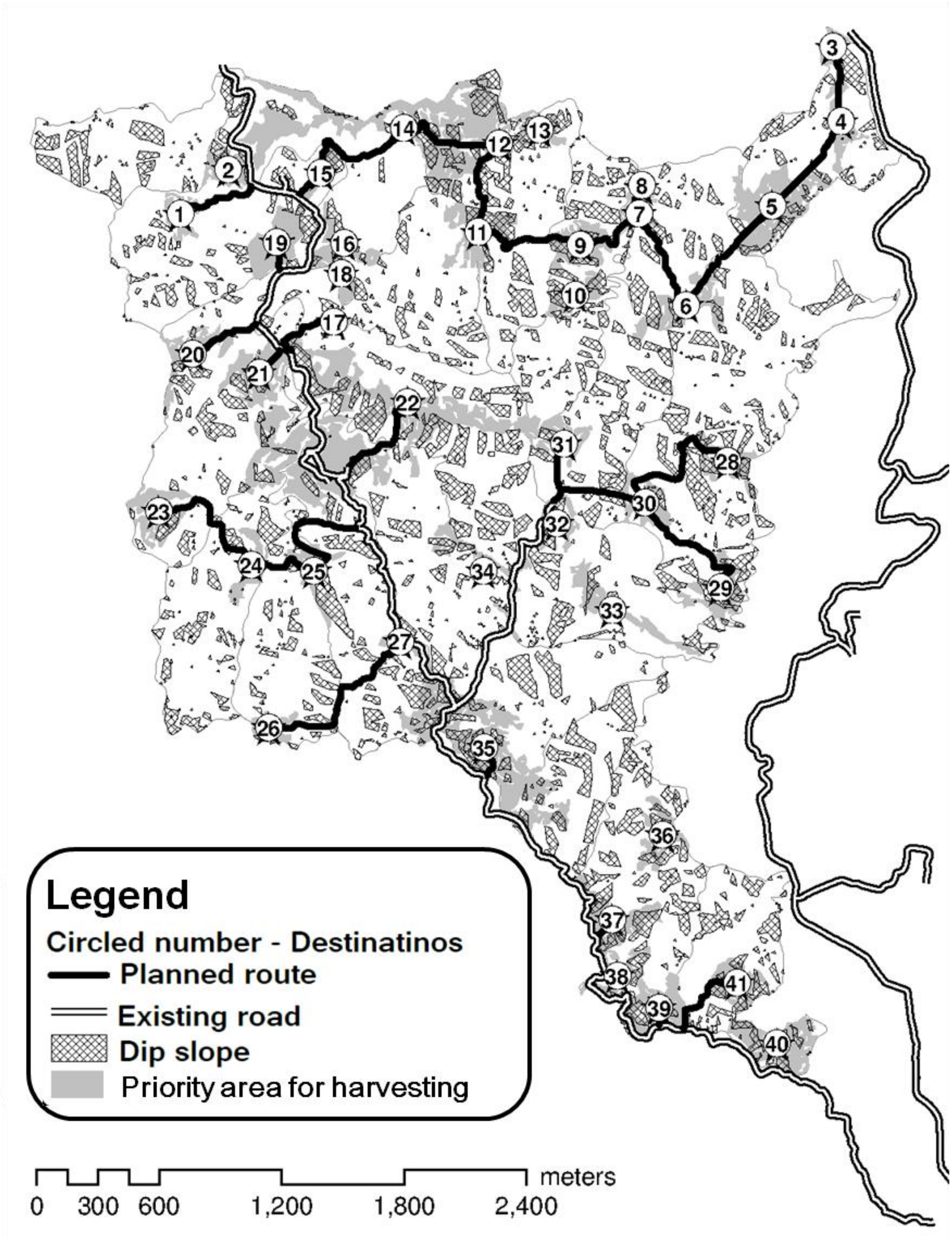


Figure 2-21 Results of forest road network considering dip slope

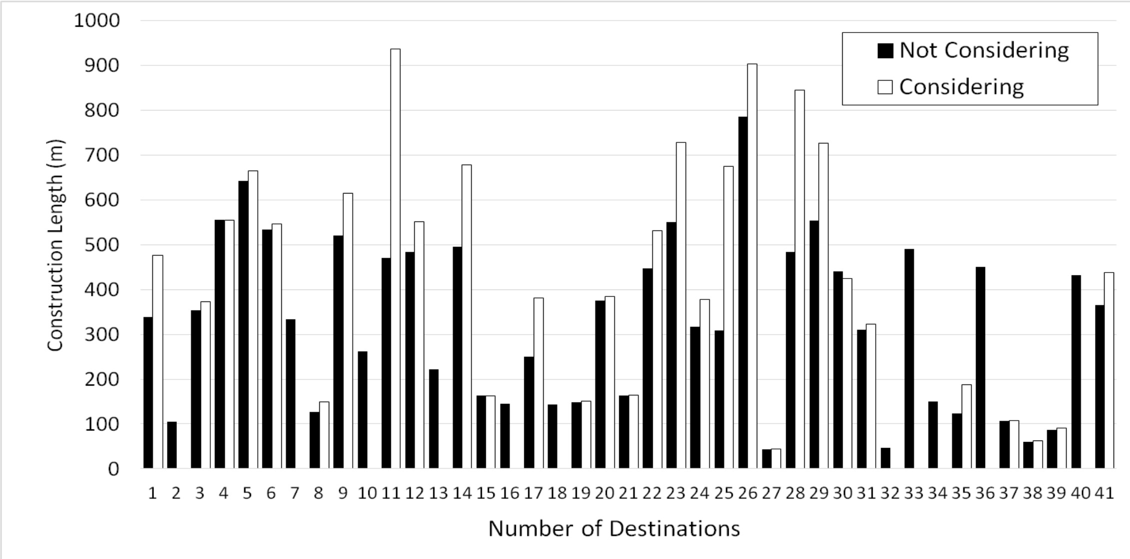


Figure 2-22 Construction length of each sections

Note : Numbers are named route section

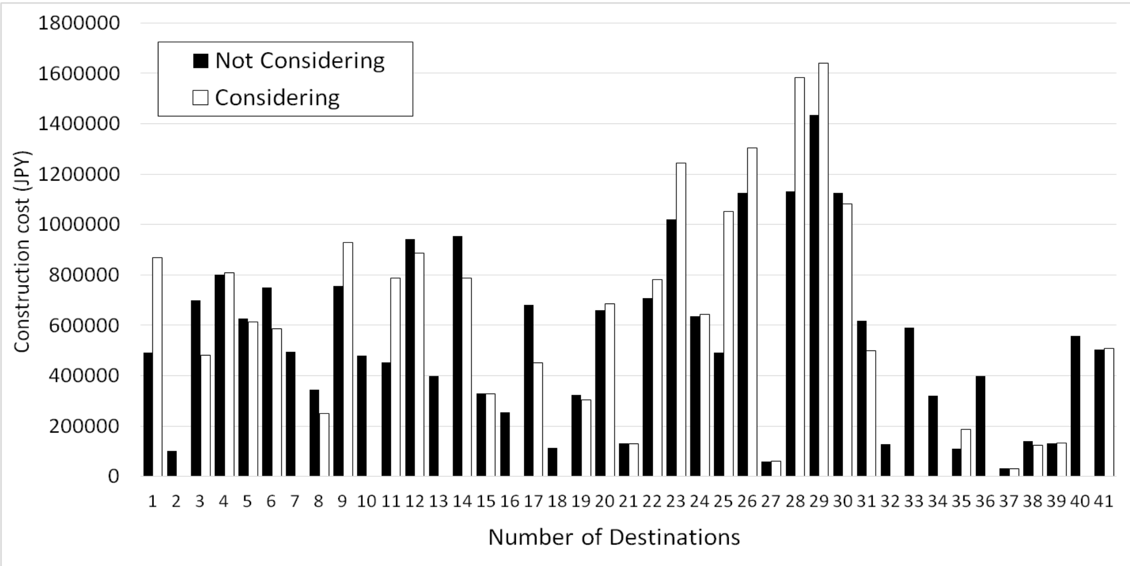


Figure 2-23 Constructing cost of each sections

Note : Numbers are named route section

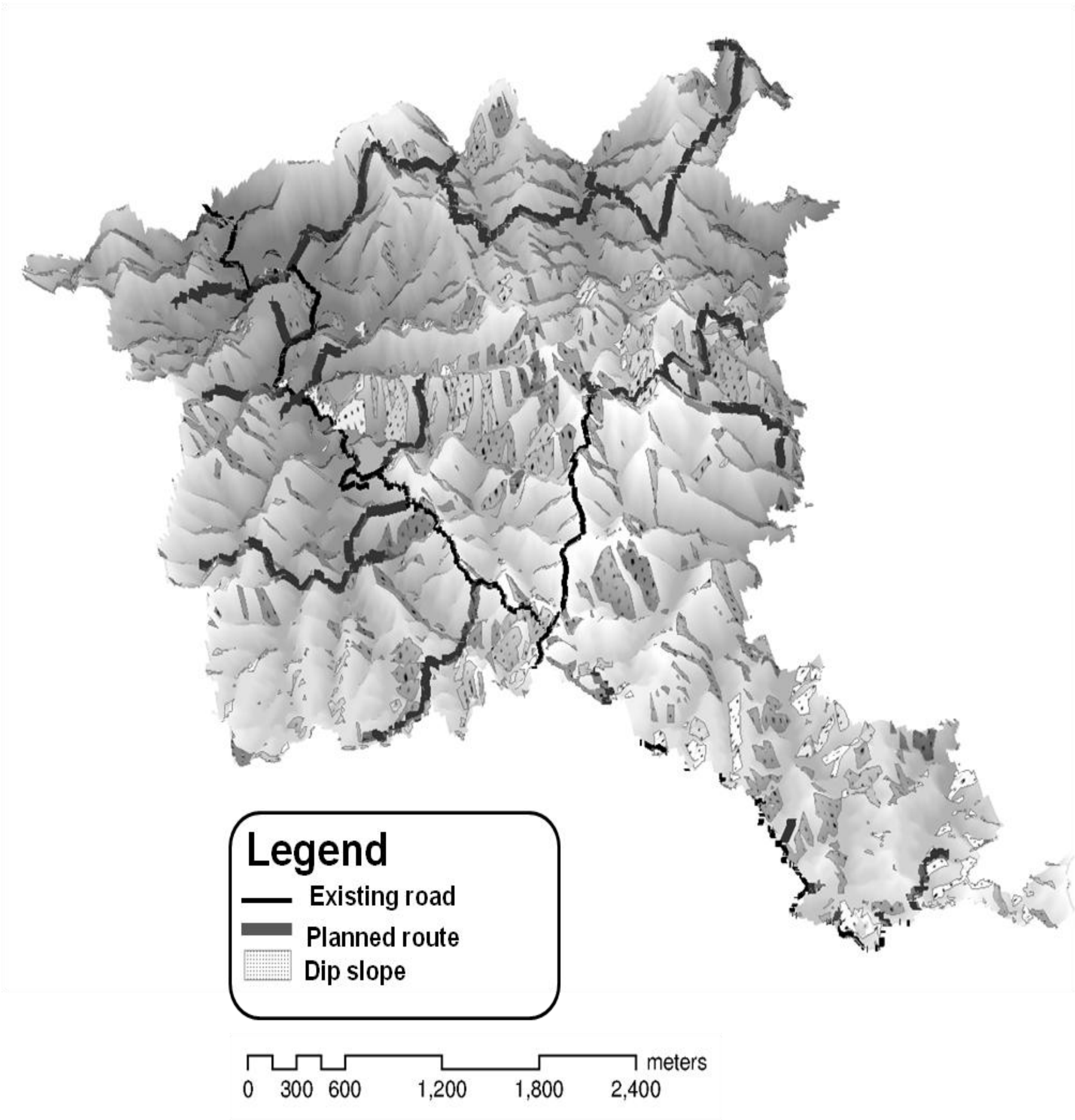


Figure 2-24 Bird’s eye view of tested site with given forest road (With considering dip slope)

4. Conclusion

A new method for planning a rational forest road network by determining the dip slope areas was developed in advance automatically to build a stable forest road that would not collapse after construction and be cost-efficient in the long-term. The method was designed to obtain a forest road network with the minimum cost taking into consideration the zones with a high risk of collapsing after construction.

The study verified that the extracted dip slope was actually a dip slope, and the method proposed in this study could be applied as basic data for planning of forest roads. One network which took into consideration the dip slope, and other method which did not, were compared and reviewed to verify the effectiveness of the proposed method through the simulation. However, it must be noted that the routes are roughly located because they must have windings to mitigate longitudinal slope of roads, and the actual road length will be longer, which is the limitation of applying the Dijkstra method in this study and more precise investigation will be required when making roads based on the results. Nevertheless, the results will be useful for efficient planning. Further research on the dip slope estimation method through more precise field investigation and application to more cases will improve the reliability and effectiveness of the proposed method.

Not all of the routes obtained in this study may be necessary in the management term. Then it would be useful to add the information of forest resources such as forest age and stock volume to estimate the construction cost and decide the order of route construction.

Actually, plantation areas on dip slopes must be thinned or harvested. In such cases, cable logging will be needed, and the forest road must be constructed with minimum earth volume in a narrow width and drainage, or deep base excavation should be adopted.

Actually, the UTCBF once failed in construction of a forest road on a dip slope and caused collapse of the cut slope in the marked area in Figure 2-17. The method to distinguish a dip slope showed in this study will be available for planning a stout forest road network with less maintenance. Repeated comparison of route selections and reviewing the plan with a rough estimated construction cost as in Figures 2-22 and 2-23 using GIS can also lead to cost reduction of road construction.

Although the volcanic terrain of a granite area appearing among accretionary wedges has no distinct inclined stratum and the geological structure, the analyzed area was more complicated than other areas such as Shimanto metamorphic belt. The distinguishing dip slope method presented in this study could be a useful tool. Finally, before constructing a forest road, reconnaissance is indispensable, and the prediction of dip slope area in advance will help save time and man power.

Chapter 4

General Discussion

This study described the forest road construction and improvement, which is required for not only harvesting the resources as lumber, etc. from forest but also retaining the public interest functions such as conservation of national land, watershed conservation prevention for global warming, etc. through the stable and efficient forestry management. It would be required even for engineers with low level of experience to have a support system that allows for the implementation of forest road network planning with high degree of security and operational efficiency. The construction method has been more or less organized by the existing studies. The forest road network, particularly the route selection or location of forest road network has been relied on the experiences of engineers, and the trial and error have been repeated. Various factors should be taken into consideration when construction forest road network; however, the confirmation of low risk geographical features would be particularly important in terms of the collapse of cutting slope and the construction of dip slope. Therefore, discerning in advance the difficult dip slope in terms of construction or maintaining forest road network would enhance the work efficiency and clarify the forest road network planning. And discerning dip slope and developing a planning method for forest road network to avoid the area were attempted by utilizing GIS for the purpose of clarifying the construction of optimal forest road network that will not be easily collapsed.

The main result of from this study is brought as follows.

The first chapter described the background, the need and the overview of this study.

The second chapter developed the method to plan the stable construction of forest road network by avoiding places with high risk of collapse. Several factors should be taken into consideration when construction forest road network. In particular, the banking is difficult in the dip slope section. As for cutting the ground, it increases the maintenance cost due to frequent collapse on dip slope. Discerning dip slope in advance is useful when planning strong and stable forest road network in the long term. Dip slope could be discerned in advance on GIS by utilizing DEM and the geological map. The theory of classifying the inclined plane based on the relative relationship between the slope of inclined plane of Suzuki and the slope of geological stratum was utilized in order to discern dip slope.

It was applied to the University of Tokyo Chiba Forest (UTCBF), and the possibility of prior estimation of dip slope was confirmed. Furthermore, it was possible to find out that dip slope of the University of Tokyo Chiba Forest (UTCBF) was distributed northward and 76 percent of them were distributed in the areas of less than 35 degrees. And then, the results were applied to the forest road network. Planning by avoiding dip slope with Dijkstra method after extracting the regions with slope of less than 35 degrees and the artificial forest of less than 1ha requiring the thinning. As a result of comparing the case of plan that took dip slope into consideration and the case that did not take it into consideration, the total distance and the total construction cost of the target area for the planning that considered dip slope were found to be higher than those of not considering dip slope. It is believed to be due to the need for detour. However, it is believed to be a reasonable result when considering the future costs for maintenance. Utilizing the method presented in this study allowed for the substantial reduction of labor for future field survey, and convenient for the estimation of the distance of planned routes or the cost of opening. Furthermore, it became possible to determine the opening order of forest road networks from the ecology of forest resources and the unnecessary sections for opening.

The third chapter applied the planning method of forest road network that avoided dip slope developed in the second chapter for the part of Takayama city in Gifu prefecture, which has high potential for the use of woody biomass in the future. The Takayama city in Gifu prefecture area is with the forest rate of 90 percent; thus, it has high expectation for the use of biomass going forward. The forest biomass energy of the target regions and the available amount for use were examined. The energy reserves of accumulated stock base and the annual growth base were calculated by multiplying the caloric value by the weight estimated by calculating the growth amount through LYCS as a continuing available amount for use. Moreover, the available amount for use was calculated by estimating the generation amount of residues generated from the thinning materials for beauty and the material production. It became possible to select the regions in which the construction of forest road network has to be conducted based on the forest biomass energy resources.

The approach to the forest land by calculating the mean skidding distance on GIS under the assumption of the forest road network was obtained it became possible to review the area in which the construction and improvement of forest road network should be primarily implemented and the choices of operation systems for the skidding distance.

This study has developed the method for planning forest road network by GIS, which leveraged the discrimination and avoidance of dip slope and attempted to the application of the harvesting system for forest biomass it is believed that this will make it possible even for engineers with low level of experience to plan a safe and efficient forest road network by the utilization of GIS by unveiling the inclined planes with the risk of collapse.

論 文 の 内 容 の 要 旨

森林科学　専　攻

平成 21 年度博士課程　進学

氏　　　名　孫芝英

指導教員名　酒井秀夫

論文題目

Development of a method of forest road network planning using GIS

that discriminates and avoids dip slopes

(流れ盤斜面の判別と回避を組み込んだGISによる

森林路網計画手法の開発)

森林から木材等の資源を搬出し、安定的で効率的な木材生産を行い、国土保全や水源涵養機能、地球温暖化防止機能等の公益的機能を維持する観点から、森林路網整備が必要である。路網整備を進めていくためには、経験の浅い技術者でも安全かつ作業効率の高い配置計画を行うことができる支援体制が必要である。既往の研究により、施工方法はある程度整理されてきた。しかし、路網配置に関しては、経験が必要とされ、とくに路網の作設および維持管理にとって困難を伴う流れ盤の事前判別が必要とされている。本研究は、DEMと地質図から流れ盤斜面を判別し、地形、地質から最適な路網開設場所

を明らかにするとともに、作業効率の高い路網配置を行うことを目的とし、流れ盤斜面の判別と回避を組み込んだGISによる森林路網計画手法の開発を試みたものである。

第１章では本研究の背景および目的を論じた。森林路網整備は、森林から木材等の資源を搬出し、安定的で効率的な木材生産を行うだけでなく、国土保全や水源涵養機能、地球温暖化防止機能等の公益的機能を維持する観点からも必要である。また、木材の生産コストの低減、労働安全衛生向上のためには路網整備と一体となった林業機械化が不可欠である。しかし、路網整備、とくに路網のルート選定、配置に関しては、いまだに経験に頼る部分が多く、さらに作業効率の高い配置を求めて、試行錯誤が繰り返されている。また、切土のり面の崩落、盛土のり面の施工において、危険性の少ない地形、地質の見極めが重要である。安全かつ効率的な路網配置や路線の具体的な選定は、高度な経験が求められるが、このような技能、技術を科学的に解明し、経験の浅い技術者にも短期間で習得させていくことが望まれている。今後路網と林業機械を組み合わせたシステムを推進していくために、経験の浅い技術者でも路網整備に携わることができる支援システムの必要性について論じた。

第２章では、簡易な路体構造で、崩壊危険性があるところを回避して安全な路網開設を計画するための手法の開発について検討した。路網を開設する際には様々な因子を考慮しなければならないが、とくに流れ盤の区間は盛土がしにくく、切土は崩落の頻発等により維持管理費がかさむことから、流れ盤を事前に判別することが丈夫な路網を配置する上で有用であり、長期的には安定して経済的な路網配置になる。そのため、DEM と地質図により GIS 上で流れ盤の事前判別に取り組むことにした。流れ盤を GIS 上で判別するためには、鈴木の斜面の傾斜と地層のみかけの傾斜（相対傾斜）の組み合わせ理論を用いた。東京大学千葉演習林に本手法を適用し、DEM と地質図により流れ盤を事前予測して現地で照合した結果、流れ盤の事前予測の可能性を確かめることができた。さらに、流れ盤は北向き斜面に分布し、その 76%が傾斜 35 度以下であることが明らかになった。次に、森林施業の集約化のために、傾斜 35 度以下で、かつ間伐を必要とする１ha 以上のまとまりを有した人工林を抽出して路網配置林分とし、ダイクストラ法を用いて流れ盤を回避しながら最短経路で結ぶ路網配置計画の手法を作成した。流れ盤を考慮した場合の路網配置計画と、考慮しない場合の路網配置計画を比較した結果、流れ盤

を考慮した計画対象地における路網配置計画では、総延長 13,251m、総開設費用 20,242,578 円となり、流れ盤を考慮しない路網配置計画では、総延長 13,381m、総開設費用 16,228,603 円となった。流れ盤を考慮した方が総延長、総開設費用ともに大きくなったが、迂回が必要となったためである。しかし、将来の維持管理費用を考えれば、合理的な結果と考察された。本研究で提示した手法を用いることにより、今後現地踏査の大幅な省力化と、計画路線の距離や開設費用の容易な見積もりが可能になり、さらには森林の資源状態から路網の開設順序、開設不要区間の決定を行うことが可能となった。

第３章では、将来木質バイオマス利用のポテンシャルが高い岐阜県高山市旧高山地区に第２章で開発した流れ盤を回避して路網を配置する手法を適用して路網配置を行った。第２章では路網配置の際に考慮しなかった縦断勾配も考慮して、対象地に流れ盤を回避した路網を配置した結果、路網密度 12m/ha、開設した路線の平均縦断勾配が 19 度の路網配置を得ることができた。また、本手法で得られた路網配置を仮定して GIS を用いて平均集材距離を算出し、林地へのアクセスを検討した。その結果、今後路網整備を重点的に進めるべき地域と、集材範囲を拡大することが可能な作業システムの選択肢を検討することができた。

対象地の森林バイオマスエネルギーの賦存量（森林蓄積）と利用可能量の算定を行なった。持続的に利用可能な量として成長量を LYCS を用いて推定した。これに発熱量を乗じることにより、蓄積ベースと成長量ベースのエネルギー賦存量をそれぞれ算出した結果、蓄積ベースの賦存量に対して発電量は 2,862,090 千 kwh/年で、熱利用量は 10,363,533 千 MJ/年になった。成長量ベースの賦存量の発電量は 7,820 千 kwh/年となり、熱利用量は 2,8152 千 MJ/年になった。また、バイオマス収穫が容易な林地として、路網の片側 50m の領域を作成し、その賦存量を算出した結果、重量換算で 414,072ton/年、発電量は 1,269,820 千 kwh/年、熱利用量は 4,571,354 千 MJ/年になった。

このように、森林バイオマスエネルギー賦存量と路網配置結果を重ね合わせることにより、林業経営の重点地区として路網整備を推進すべき地域の選定が容易になった。

第４章では、２～３章で明らかになった分析内容と知見をまとめて総括した。

以上のように本研究では、流れ盤斜面の判別と回避を組み込んだGISによる森林路網計画手法を開発し、東京大学千葉演習林でその実用性を確認するとともに、森林バイオマス収集システムへの応用を試みた。これにより、経験の浅い技術者でも崩壊の危険性のある斜面を明らかにしながら、GISの活用により、安全で効率的な路網計画に資することが可能となった。

References

Aruga K., Saito M., Tasaka, T., and Yoshioka T,(2007) Long-term feasibility of forest biomass resources at an intermediate and mountainous area : Reducing harvesting costs by constructing forest roads. The Japan institute of energy 142-143

Aruga, K., Sessions, J., Miyata, E.S. (2005) Forest road design with soil sediment evaluation using a highresolution DEM. J.For.Res.10:471-479

Aruga K., Yoshioka T., and Sakurai, R (2006) Long-term feasibility of forest biomass resources at an intermediate and mountainous area [in Japanese] The Japan institute of energy (1), 24-25

Bormann, F. H. and Likens, G. E. 1997. Patterns and processes in a forested ecosystem. Springer- verplag, New York. 253

ESRI. 2010. ARC/INFO User's Guide

Christopher, S. (2006) Forest Road Decommissioning:Modeling the Effect on Hydrological Connectivity.University of Southern Queensland 69pp

Chung, W., Sessions, J. (2001) Designing a forest road network heuristic optimization echniques. In Proceedings of the 24th Meeting of the Council of Forest Engineering, July 15-19, Snowshoes, WV

Clark, M.M., Meller,R.D., McDonald,T.P. (2000) Athree-stage heuristic for harvest scheduling with accessroad network development. For.Sci 6:204-218

Construction research institute (2006) Standard Unit Price for Civil Engineering Works.93, Tokyo (In Japanese)

Coulter, E., Chung, W., Akay, A., Sessions, J. (2001) Forest road layout using a high resolution digital terrain model generated from LIDAR data. In Proceedings of the First International Precision Forestry Symposium, June2001,University of Washington, Seattle, WA.

Dijkstra, E. W. (1959) A note on two problems in connection with graphs. 269-271. Numerische Mathematik.

Forest maintenance management technology society 2010 Surveillance study on road net maintenance and forest management (especially, thinning) systematized techniques Report

General incorporated Association Operator survey. (2010) Forest road network construction training project Forest road making planning. 12-13, Tokyo, (In Japanese)

General corporation National Forestry Extension Association. 2011 Forest White Paper on Forestry

Gerasimove, Y., Sokolove, A and Karjalainen, T (2008) GIS-base decision- support program for planning and analysis short-wood transport in Russia. Croatian J. of Forest Eng. 28 (2), 163-175.

Hasmadi, M. and J.C. Taylor, 2008. Sensitivity analysisof an optimal access road location in hilly forest area: A GIS approach. Am. J. Applied Sci.,5: 1686-1692.

Hayati E, Majnounian B, Abdi E, Sessions J, Makhdoum M.(2012)An expert-based approach to forest road network planning by combining Delphi and spatial multi-criteria evaluation

Hickman, C. E. 1995. Feature-based data models and linear referencing systems aids to avoiding excessive segmentation of network links. GIS-T Symposium.

Hiroshi Kobayashi and Toshio Nitami (1991) Forest- road network planning in small scaleforestry 1-10 Bulletin of the university of Tokyo forests No. 85

I. Mohd Hasmadi, H.Z. Pakhriazad and F.S. Mohamad (2010) Geographic Information System-Allocation Model for Forest Path: A Case Study in Ayer Hitam Forest Reserve, Malaysia. American Journal of Applied Sciences 7 (3): 376-380.

Iwahashi, J., WatanabeA, S., Furua,T.(2001) Landform analysis of slope movements using DEM in Higashikubiki area, Japan. 27:851-865. Computers & Geosciences.

Ito, K., Murakami, A., Saito, M., Aruga K., Tasaka, T (2011) A study on the planning method for circular forest road networks considering geographic features in a private forest in Kanuma city, Tochigi prefecture [in Japanese] Journal of the Japan Forest Engineering Society 26(3), 157-162,

Kato, S.(1976)Studies on forest road system –Preliminary report on the road density. Bull. Tokyo Univ. For

Kamaruzaman, J. and S. Shamsul,(1999) Geographicalinformation system for forest road planning: A casestudy of Balah Forest Reserve, Ulu Kelantan. Proceeding of the Tropical

Forest Harvesting: New Technology Examined, Nov. 22-24, Published by FRIM, Terengganu, Malaysia, pp: 76-90.

Kamiizaka, M. (1963) Studies on optimum density of forest roads (I). J.Jph.For.Soc. 45,289-292

Kamiizaka, M.(1966)Studies on optimum density of forest roads (II). J.Jph.For.Soc. 48,48-54

Kazuhiro A., Ayami M., Chikara N., Reiko Y., Takuyuki Y. (2011) Discussion on Economic and Energy Balances of Forest Biomass Utilization for Small-Scale Power Generation in Kanuma, Tochigi Prefecture, Japan. 571-586. Croat. J. for. Eng. 32

Kazuhiro ARUGA, Takuyuki YOSHIOKA and Rin SAKURAI Long-term feasibility of timber and forest biomass resources at an intermediate and mountainous area-Balance of harvesting volumes using random serch. J. Jpn. For. Eng. Soc. 21(1):49~59, 2006

Kazuhiro Aruga, Masashi Saito, Toshiaki Tasaka, Takuyuki Yoshioka Long-term feasibility of forest biomass resources at an intermediate and mountainous area(2) – Reducing harvesting costs by constructing forest roads- japan institute of energy 142-143

Kazuhiro Aruga, Masashi Saito, Toshiaki Tasaka Long-term feasibility of forest biomass esources at an intermediate and mountainous area(3) – Discussion on energy balance- 251-256 The Japan Forest Engineering Society Vol. 21, No. 4 2007

KOBAYASHI, H. (1983) Studies on the forest-road network planning system in mountaion forests. Special Bulletin of the College of Agriculture Utsunomiya University. 38:1-101 (In Japanese with English summary)

Maclean, A, L. D. R David., D. M, Glenn., W. L. Gary., and E. Thomas. 1992. Using GIS estimate forest resource changes. Journal of Forestry. 90(12); 22-25

Majnounian, B., Abdi, E and Darvishsefat, A.A. (2007) Planning and technical evaluating of forest road networks from accessibility point of view using GIS (Case study: Namkhane district, Kheyroud forest). Iranian J. of Nat. Res. [In Farsi]. 60 (3), 907-919.

Masshi SAITO Development of forest road design and strip road networks arrangement support techniques using LiDAR data. Bull.Utsunomiya Univ.For. No. 48 71-110

Matumoto, T, Furukawa, k (2007) Development of support tool for strip road network planning(<SPECIAL ISSUE>FOREST ROADS NETWORK) 22(3), 181-186,

Matthews, D.M. (1942) Cost control in the logging industry. 374pp Mc Graw-hill Book Co. Ins.

Minamikata, Y. (1967) Studies on the planning of forest road network. J. Jph. For. Soc. 49, 53-55

Morgan, G. and M. Hohmaann. 1992. Social Forestry and GIS. Journal of Forestry. 90(12); 10-15

Murakami, A., Ito, K., Saito, M., Aruga, K. and Tasaka, T. Extraction of production forests for sustainable forest management based on economic balances in the Kanuma Area of Tochigi Prefecture.　J. For. Plan. 10：245 ～ 254.

Murakami, A., Yamaguchi, R., Nakahata, C., Aruga, K., and Tasaka, T(2012) Feasibility of forest biomass harvesting under sustainable forest manegement - Case study of Nasushiobara city and Kanuma area in Tochigi prefecture - [in Japanese] Bulletin of the Utsunomiya University Forests 48, 123-138

Nakazawa, M., Matumoto, T., Yamada,Y.(2008) Comparison of local forestry operations in the Higashimikawa Forest Planning Area of Aichi Prefecture. Journal of the Japan Forest Engineering Society 23(3), 189-200

Nakazawa, M, Matsumoto, T, Oka, M and Yoshida, C (2009) Characteristics of a correction factor for road density in mountainous area : The effect of scale on a correction factor. J. Jpn. For. Eng. Soc. 24(1)

Nationwide forestry improvement spread society Management of mechanization. How to efficient forestry machine made the best use of for the management ability improvement of the region.

Oohshi, K.(2001) Everything on forest road making planning.78-79, National Forestry Extension　Association in Japan, Tokyo. (In Japanese)

PRIM, R. C. (1957) Shortest connection networks and some generalizations. Bell System Technical Journal 36: 1389～1401.

Reiko YAMAGUCHI, Kazuhio ARUGA, Auami MURAKAMI, Masashi SAITO, and Kaname ITO Development of the Model to Estimate the Harvesting Volumes and Costs Of Logging Residues Considering Economic Balances of Timber and Logging Residue Harvesting in Sano city, Tochigi Prefecture. Journal of the Japan Institute of Energy, 89, 982-995 (2010)

Reute, S. E. 1988. ROUTES : A Computer Program for Preliminary Route location. USDA For. Ser. PNW-GTR-216

Richard, D. 2001. FLESA-Tools ArcView software Extension User Guide. North Country and Southern New Hampshire Resource Conservation and Development Area Councils.

Rin SAKURAI, Yutaka TATE, Takuyuki YOSHIOKA, Toshio NITAMI, Teruhisa OHNO and Hiroshi KOBAYASHI Possibility of energy use of forest biomass and effect of forest road network in mountainous area. The Japan Forest Engineering Society Vol. 21, No. 3 December, 2006

Saito, M.(2012) Development of forest road design and strip road networks arrangement support techniques using LiDAR data.71-110, No.48, Bulletin of the utsunomiya university forests.

Sakai, H. (2009) Logging road seminar. 288pp, National Forestry Extension Association in Japan, Tokyo. (In Japanese)

Sakai, H. Forestry production technology seminar. From the carrying out road net to the supply chain Nationwide forestry improvement spread society

Sakai, H., Aruga, K., and Watanabe, S.:Environmental Conservation Effects of Forest Strip Roads and Promotion of Infrastructure. J. Jpn. For. Soc. 84:125~129, 2002

Sakurai, R., Nitami, T., and Kpbayashi, H. (2004) Construction of planning system for forest roads with ability of yarding. Journal of the Japan Forest Engineering. 19:119-126 (In Japanese with English abstract)

Sawaguchi, I.(2010) A fair chance to be given and some problems to be solved, for building forest spur-road network with super-high route density [in Japanese] Journal of the Forestry Mechanization Society (676), 1-8

Segebaden, G. (1964) Studies of cross-country transport distances and road net extension. Stud. For. Suec. 18,

Sessions, J., 1992. Using network analysis for road and harvest planning. Proceedings of the Workshop on Computer Supported Planning of Roads and Harvesting, Aug, 26-28, Published by Oregon State University, Feldafing, Germanym pp: 26-35.

Seyed Ataollah Hosseini , Mohammad Reza Mazrae , Majid Lotfalian, Aidin Parsakhoo (2012) Designing an optimal forest road network by consideration of environmental impacts in GIS. Joural of environmentl engineering and landscape management. Volume 20(1): 58–66

Shirasawa, H.,Hasegawa, H., and Umegaki, H.(2013) Cost-reducing effectiveness of selecting the type of transportation vehicle in a roundwood supply chain : a case study in Hyogo prefecture(<SPECIAL ISSUE>Effective and efficient utilization of local forest resources) [in Japanese] Japan Forest Engineering Society 28(1), 7-15

Stuckelberger, JA, Heinimann, H. R, Chung, W (2004) Improving the effectiveness of automatic grid cell based road route location procedures. In proceedings of the 12 International Mountain logging Conference 13-16 June 2004, Vancouver, B.C Edited by M Clark University of British Columbia. Vancouver B.C CD-ROM

Suzuki, R. (2000) Introduction to map reading for civil engineers. 942 pp. Terrace Hills and Mountainous, Tokyo. (In Japanese)

Suzuki, Y., Gotou, J., and Yamauchi, J (2010) A case study on operational efficiency of downward felling, direct logging and winching operation on Hinoki plantation forest with dense road network and prospected effect of upward felling [in Japanese] Journal of the Japan Forest Engineering Society 25(2), 91-96

The Tokyo University Forests. (2007) Miscellaneous Information the Tokyo University Forest. 46:163-165. Tokyo. (In Japanese)

Yamaguchi, R., Aruga, K., Murakami, Saito, M., and Ito, K(2010) Development of the model to estimate the harvesting volumes and costs of logging residues considering Economic Balances of Timber and Logging Residue Harvesting in Sano city, Tochigi Prefecture Journal of the Japan Institute of Energy, 89, 982-995.

Yoshimura, T., Kanzaki, (1998) Fuzzy export system laying out forest roads based on the risk assessment. 144-150. Proceedings of the seminar on environmentally sound forest roads and wood transport.

Yoshimura, T., Kokutani, S., Kanzaki, K., and Uchida, O. (1996) A study to evaluate forest-road plans using landscape simulation [in Japanese] ournal of the Japan forest Engineering Society 11(1), 21-28,

Yoshioka, T. and Sakai, H.（2005）Amount and availability of forest biomass as an energy resource in a mountainous region in Japan:a GIS-based analysis. Cro. J. For. Eng. 26：59 ～70.

Kana K., Hirofumi K., Koichi Y. Estimating wood biomass supply using efficiency of transport cost 24-24. The Japan Institute of Energy.

Kilian, W., Möller, F., Starlinger, F.: Forestal Growth Zones of Austria. Natural Regions According to Forest Ecological Criteria. Forstliche Bundesversuchsanstalt, Wien, p. 60.

K. Mohammadi Samani*, S. A. Hosseiny, M. Lotfalian and A.Najafi (2010) Planning road network in mountain forests using GIS and Analytic Hierarchical Process (AHP) Caspian J. Env. Sci., Vol. 8 No.2 pp. 151~162

Kunwoo, C (1990) Studies on forest road construction in mountain forest. Kangwoon national university. Research bulletin of the experimental forest. 16, 109-131.

Kyu-Sang Kim, Hyuck-Jin Park, Saro Lee, Ik Woo (2004) Geographic Information System (GIS) based stability analysis of rock cut slopes. Geosciences Journal Volume 8, Issue 4, pp 391-400.

Acknowledgements

I wish to express my hearty gratitude to my supervisor, Professor Sakai Hideo at Laboratory of Forest Utilization, Graduate school of Agricultural and Life Sciences, The University of Tokyo, for his excellent guidance, constant suggestion and hearty encouragement during my study. I am also very grateful to him for his invaluable discussion, helpful comments and teaching in order to perform this study.

I would like to express my gratitude to Professor Nitami Toshio for his excellent teaching and warm encouragement during my study. I am grateful to assistant Professor Sakura Rin for his excellent teaching and warm encouragement during my study. And I am also very grateful to our laboratory member for they invaluable discussion, helpful comments and teaching in order to perform this study. And support while I was a graduate student.

The graduate students of the Laboratory of Forest Utilization showed great friendship and encouragement while I was at University of Tokyo; especially Mrs. Ichikawa and Mr. Osawa, for their attention and support while I conducted experiments.

I would like to express my thanks to Dr. Koo-Hyun Cho and Dr. Gwang-Su Lee at Korea Forest Research Institute, and Professor Jung-Soo Lee at Gangwon National University, for the faith they showed in my capability and who showed their kind support and warm concerns. I am also very grateful to Dr. Su-Il Suk for his patience in instructing me experimental techniques and sharing in the discussion of my study.

I would like to thank Professor Oh-Kyu Kwon, my former supervisor, Laboratory of Forest Policy, Department of Agricultural and Life Sciences, Kyung book National University, for giving me the invaluable chance to study in Japan and encouraging me. And I am also very grateful to our laboratory member for they support while I was a graduate student.

Appreciation to my parents Tae-Bong Son and Sun-Nam An, my lovely sisters Ji-Suk, Ji-hea, Eun-Hea, Eun-Ju, I thank you from the bottom of my heart for your continued love and support. This dissertation would not have been possible without their support.

And finally, I would like to dedicate this dissertation work to my lover Jung Yun Kim for his love and sacrifice who have great power of wearing a smile that gave encouragement when I troubled. I thank you from the bottom of my heart for your continued love and support.

I'd like to attribute this glory to everyone who helped me.

I heartily thank you.