WINTER ROAD RESEARCH PROGRAMS OF THE PUBLIC WORKS RESEARCH INSTITUTE OF JAPAN UNDER THE CIRCUMSTANCES OF CLIMATE CHANGE AND FINANCIAL CONSTRAINTS

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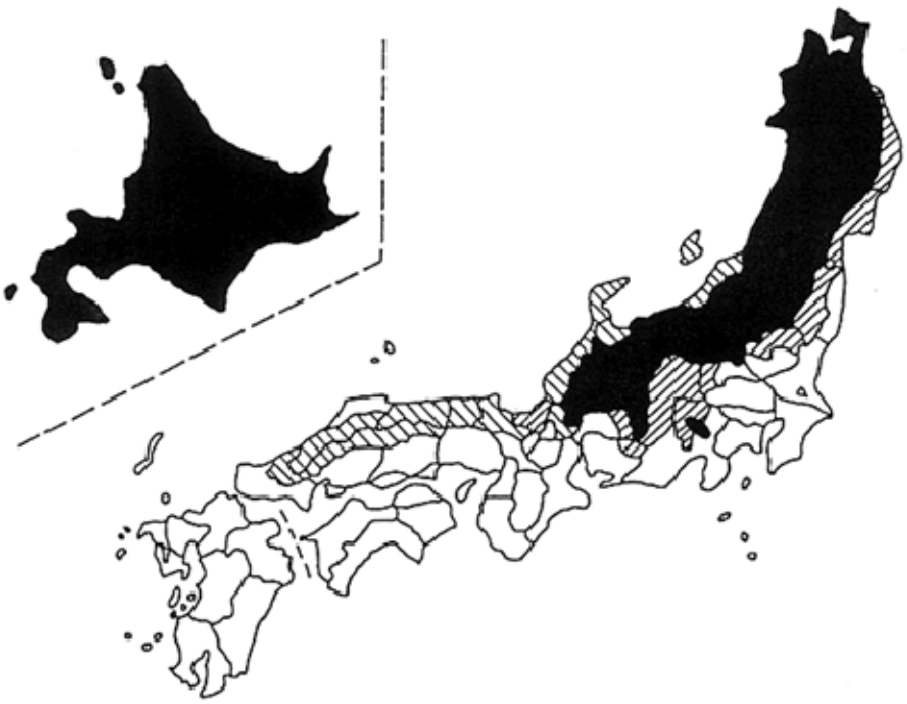
ABSTRACT

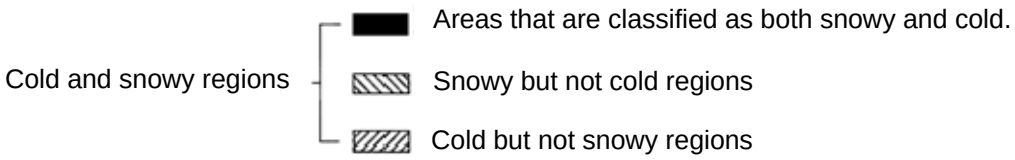
Parts of Japan have experienced severe climate-related disasters caused by localized heavy snowfall due to high temperatures in winter. The occurrence patterns of these disasters have been changing. Under severe economic circumstances, the provision of economically efficient and effective winter road services has been called for. The Public Works Research Institute has two research projects that address these problems. The first project involves studies to develop technologies to address such disasters. The four individual themes of the studies being implemented are as follows: the relationship between climate change and changes in the snow and ice environment; the development of technologies for forecasting snowstorm-induced visibility hindrance; technologies that allow snowstorm risk to be assessed; and risk-assessment technologies to address avalanches that accompany winter rainfall. The second project aims at improving winter road services. The five individual themes of the studies being implemented are as follows: technologies that support efficient estimation of the road surface conditions for winter road management; composite road surface treatment technologies; snow removal technologies that utilize ICT; sidewalk surface management in the snowy season; and technologies for preventing vehicles from deviating from their lane. This paper discusses the details of these studies.

1. THE PRESENT STATE OF JAPAN

About 20% of Japan's population live in areas designated by the government as cold snowy special areas, and these areas accounts for about 60% of the nation's land area (Fig. 1). Snowfall and low temperatures in winter greatly affect the lives of Japanese. The long-term trends in snowfall and average temperatures in winter in Japan show that the annual average snowfall decreased from 391 cm in the Showa era (data is available from 1953 to 1988) to 324 cm in Heisei era (data are from 1989, the first year of the Heisei era, to 2011). The monthly average temperature for January rose by about 1 °C, from -1.2 1 °C in the Showa era to -0.2 1 °C in the first three years of the Heisei era. The overall tendency shows that winters have become warmer and less snowy (Fig. 2). In contrast to the overall tendency, aberrant climatic phenomena have gained attention. These include heavy snowfall in areas that have historically tended to have moderate snowfall, localized heavy snowfall, and snowstorms during periods other than midwinter. Snowfall events in recent years, for example, have tended to be short and intense. The annual number of days with snowfall has decreased, and the amount of snow that falls in one day has increased (Fig. 3). Snow tends to fall in large amounts in short periods of time. Winter climatic

phenomena have tended to be more intensified in recent years. For example, at some locations, a single day's snowfall exceeded the largest annual snowfall of the previous several years. The influence of winter climatic phenomena on socioeconomic activities, which had been a handicap for snowy cold regions, has intensified to a serious degree.





Snowy regions: areas whose cumulative annual average of maximum snowfall (the average of the values for the most recent five years or more) in February exceeds 50 cm
Cold regions: areas whose cumulative annual average of monthly average temperature for January is 0 °C or lower.

Figure 1 - The cold, snowy regions of Japan

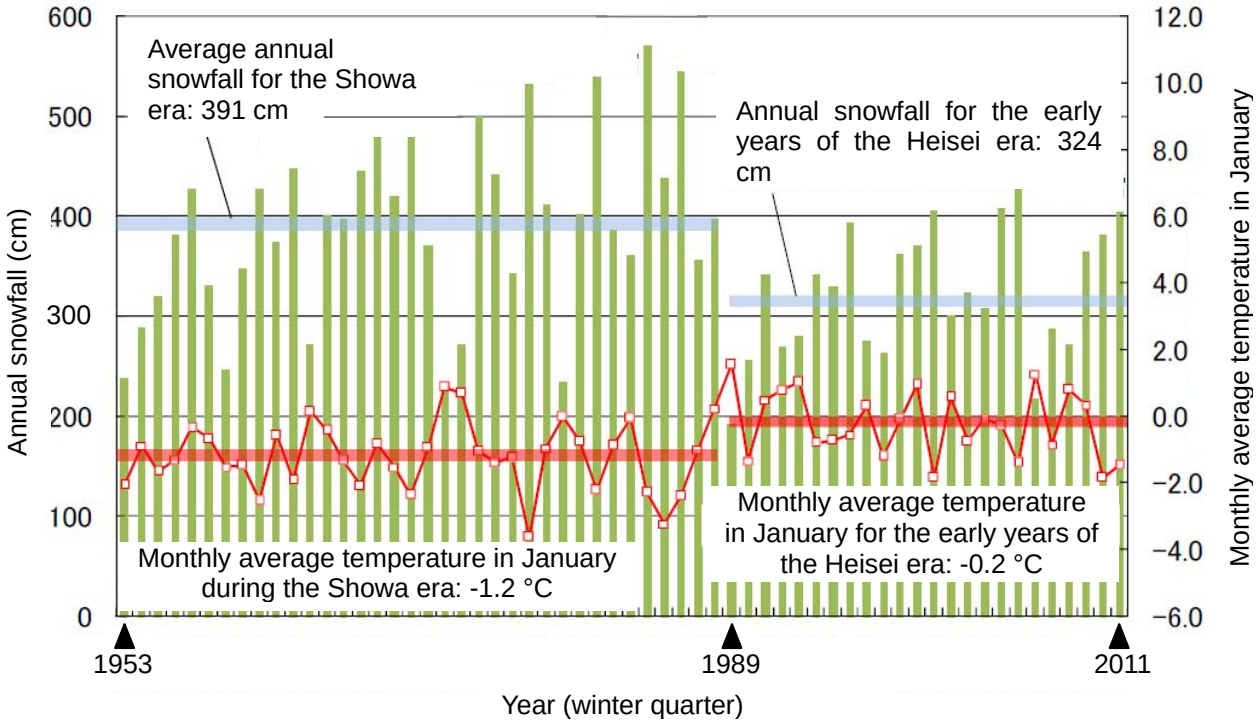


Figure 2 - Annual snowfall and monthly average temperature in January

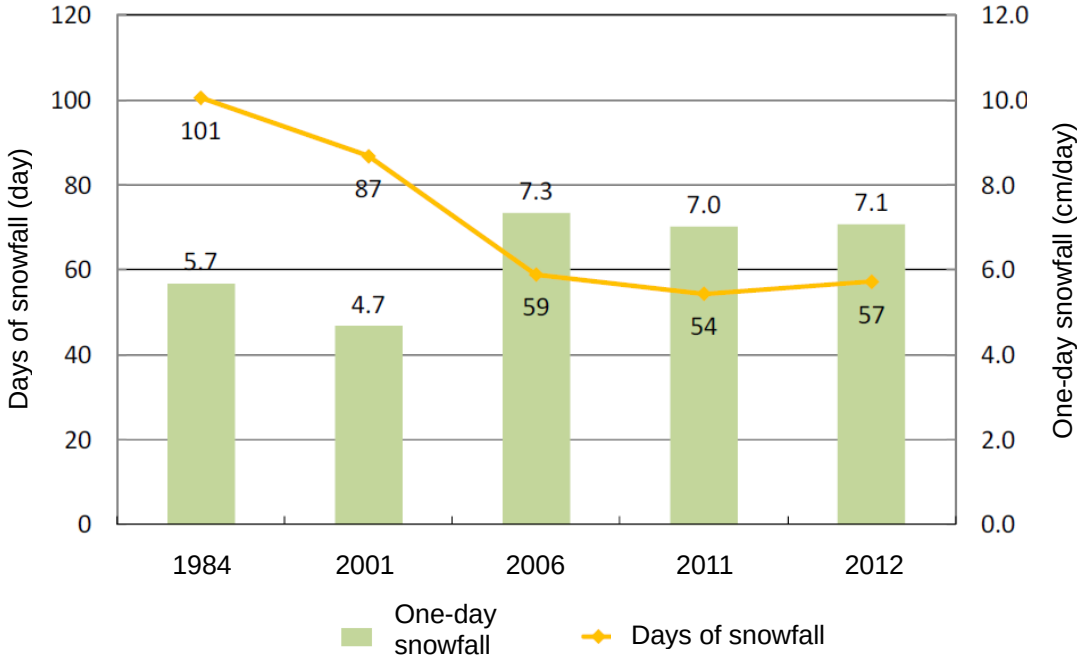


Figure 3 - Changes in the annual number of days of snowfall and the one-day snowfall

To overcome the innate vulnerabilities of Japan's land and to maintain the nation's vigorous, dynamic and affluent society, safe and smooth winter traffic must be secured in the snowy cold regions, which have large areas and populations. Despite this requirement, the financial circumstances of the central and local governments have been deteriorating, particularly in snowy cold regions. The financial capability index of the snowy cold regions is 0.39, which is low compared to the national average of 0.49. It is difficult to fully satisfy the residents' strong requests for winter road management.

Under such circumstances, the Public Works Research Institute formulated mid-term plans to achieve the mid-term goals that were established by the Minister of Land, Infrastructure, Transport, and Tourism. With the help of assessments by outside experts, the institute has

been implementing its tasks based on the mid-term plans. The studies at the institute have been done based on the two 5-year mid-term plans during the ten years since it was established in 2001. The Third Five-year Mid-term Plan was formulated in 2011.

2. OUTLINE OF THE THIRD MID-TERM PLAN

Four mid-term goals were identified as those highly required by society: the realization of a safe and secure society; the realization of a sustainable society based on green innovations; strategic management of social infrastructure so that it is long-lasting; and international contributions to civil engineering. In the mid-term plan, the following six important research themes are set up to achieve the four goals.

- The realization of a safe and secure society
(1) Prevention and mitigation of natural disasters, which have become more severe, and quick recovery from such disasters
- The realization of a sustainable society based on green innovations
(2) The development of innovative technologies for making infrastructure "greener"
(3) The development of technologies for managing catchments and social infrastructure, to realize a society that coexists with nature
- Strategic management of social infrastructure so that it is long-lasting
(4) The development of technologies for strategic management of the social capital stock
(5) Improvements in the functions of social capital toward making it long-lasting
- International contributions to civil engineering
(6) Support for Asian countries based on Japan's advanced civil engineering technologies

To realize these six important research themes, 16 research projects have been intensively implemented.
- The development of technologies for preventing or mitigating water-related disasters that have been intensified by climate change.
- The development of technologies for mitigating large-scale landslide disasters and ensuring early recovery from them
- Securing of the functionality of various structures based on improvements in aseismic performance
- The development of technologies for mitigating snow- and ice-related disasters
- The development of technologies for efficient use of disaster prevention information and other disaster-related information
- The utilization of renewable energy and waste-derived biomass fertilizers produced from waste materials, and the development of technologies for introducing renewable energy and waste-derived biomass fertilizers into local communities
- The development of low-carbon-emitting, environmentally friendly construction materials and of technologies that use such materials
- The development of technologies for effective river channel design and management to conserve and restore river ecosystems
- Elucidation of the characteristics of sediment movement in rivers, the influence of sediment movement on the river environment, and the development of technologies to conserve the river environment
- Elucidation of the movement of materials on a catchment-wide scale, and the development of technologies for water quality management
- The development of technologies to conserve the ecosystem of each local area

- The improvement of food production capabilities toward making the subject area better adapted to environmental changes, and the construction of sustainable systems necessary for a food production base.
- The development and systematization of technologies for management and maintenance of social capital stock so that they may be used for as long as possible
- The development of technologies for maintaining the functionality of structures under cold natural conditions
- The development of technologies for improving the functionality and durability of social capital
- The development of technologies for improving performance of roads in winter in cold regions

Of the above themes, two study themes relate closely to winter road management: study on technologies for mitigating snow and ice-related disasters, and study on technologies for improving the performance of roads in winter in cold regions

3. PROJECT STUDY: STUDY ON TECHNOLOGIES FOR MITIGATING SNOW- AND ICE-RELATED DISASTERS

Snow- and ice-related disasters, including heavy snowfall, snowstorms and wet snow avalanches caused by abnormally high temperatures in winter, have become severe because of climate change in recent years. To address these disasters, the studies in this project include elucidation of the environmental changes that are involved in such disasters. Other areas of studies included in this project are prediction and risk assessment technologies for blowing-snow-induced visibility hindrance, which is the most common cause of road closures in cold, snowy regions; and technologies to mitigate wet snow avalanches at rainfalls during winter.

Four individual themes for the studies have been selected, and research on them has been implemented. They are the study on the changes in the snow and ice environment under climate change; study on the development of technologies for predicting snowstorm-induced visibility hindrance; study on technologies for risk assessment for blowing-snow throughout the route; and study on risk assessment technologies for avalanches that occur with rainfall in winter. The following is an outline of each study and the tentative result.

3.1. Study on changes in the snow and ice environment caused by climate change

In this study the following items were set as targets.
(1) Elucidation of trends in the changes in the snow and ice environment in recent years- Analyzing the existing meteorological data (e.g., temperatures, precipitation, etc.) and clarify the trends in changes in recent years
(2) Elucidation of relationship between the indicators for the snow and ice climate and the basic meteorological data.
- Clarifying the relationship between the indicators for the snow and ice climate (snow drift transport rate, frequency of snowstorm-induced visibility hindrance) and the basic meteorological data (temperature, precipitation), which is necessary in considering measures against snow- and ice-related disasters.
(3) The creation of a distribution map for indicators of the snow and ice climate in recent years
- Creating distribution maps of indicators for the snow and ice climate (e.g., snow drift transport rate, frequency of visibility hindrance, and freezing index) that reflect the climate changes in recent years, and providing the maps to be used as reference materials for planning and designing snow control facilities.

(4) Proposal for technologies to estimate snow- and ice-related climatic conditions by using predicted climatic values
- Proposing technologies to estimate snow- and ice-related climatic conditions by using predicted meteorological data, such as RCM20, based on the relationship between the indicators for snow and ice climate and the basic meteorological data.
(5) The creation of a distribution map of predicted indicators for the snow and ice climate
- Creating distribution maps for estimated values of the indicators for the snow and ice climate of the future (snow drift transport rate, frequency of visibility hindrances, freezing index, etc.) The result of these studies will be reflected in various manuals.

A distribution map for the indicators of the snow and ice climate of the future was created based on an examination of the two types of techniques for estimating the snow and ice climate (i.e., a technique based on the calibration of basic meteorological data, and a technique based on the calibration of data for the indicators for the snow and ice climate). As the result of examinations in creating the distribution map, it was found that the predicted average values of the indicators for the snow and ice climate tended to decrease; however, they tended to increase for areas including the inland areas of Honshu and Hokkaido and the eastern part of Hokkaido. The results will be useful in the planning and designing of measures against snow- and ice-related disasters.

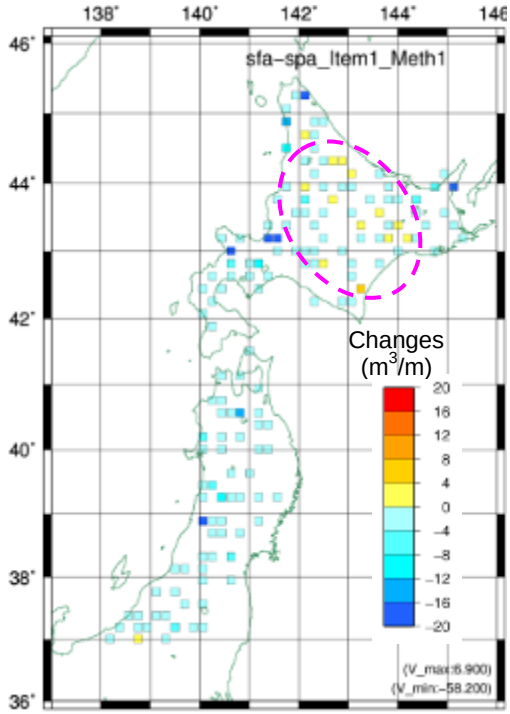


Figure 4 - Prediction results for changes in snow drift transport rate

3.2. Study on the development of prediction technologies for snowstorm-induced visibility hindrance

In this study the following items were set as targets.
(1) Clarification of conditions for the occurrence of blowing-snow by considering historical data, including meteorological data
- Clarifying the occurrence conditions of blowing-snow by considering the differences in wind velocity and temperature

(2) The development of technologies for predicting blowing-snow-induced visibility hindrance

- Developing technologies for predicting blowing-snow-induced visibility hindrance based on the occurrence conditions for blowing-snow obtained by considering the historical meteorological data and the predicted meteorological data.

(3) The development of information provision technologies related to blowing-snow induced visibility hindrance
- Developing a system that can provide real time information on predicted blowing-snow-induced visibility hindrance to road users and the road administrator.

It was clarified that it was possible to improve the accuracy of the prediction for visibility distance under blowing snow conditions by considering historical data on meteorology, and that it was possible to further improve the accuracy of prediction by improving the computation flow. Provision of information on the Internet on 24-hour predicted visibility hindrance was started, and the area divisions for provision of predicted information was improved from 46 areas to 203 areas based on the unit of municipalities.

Figure 5 - Snowstorms-induced Poor Visibility

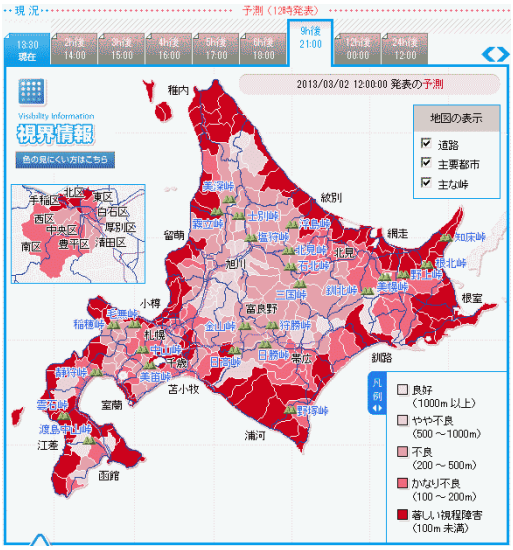


Figure 6. - Information on predicted visibility hindrance

3.3. Study on technologies for spatially continuous risk assessment of blowing snow for an entire route

In this study, the following items were set as targets.
(1) Quantification of the extent to which each risk factor contributes to blowing-snow risk
- The risk factors necessary for assessing the risk of blowing snow will be extracted and the influence of blowing snow on driving will be quantified by conducting patrol vehicle observations during blowing-snow conditions.
(2) Assessment of the blowing-snow risk by taking wind direction into consideration
- Proposing assessment technologies for risks of blowing snow that take wind direction into consideration by analyzing data collected under various wind directions during patrol vehicle observation.
(3) Proposal for technologies for spatially continuous risk assessment of blowing snow for an entire route
- Proposing spatially continuous risk assessment technologies for an entire route based on quantitative clarification of the levels of influence of the risk factors on driving and by taking wind direction into consideration

Visibility, wind direction and velocity, temperature, traveling speed, driving behavior and road images were observed by using patrol observation vehicles. It was clarified that when the visibility distance is 50 m or shorter, driving becomes very difficult. Fixed-point weather observations found that two wind directions tended to predominate at the time of visibility hindrance, and it was concluded that measures against visibility hindrance that consider both of these wind directions were necessary. The results of comparison between the risk assessment method for blowing snow based on the existing Highway Snowstorm Countermeasure Manual and the results of observation by patrol vehicles clarified that assessment by the existing method was not sufficient for determining locations with high frequencies of visibility hindrance.

Figure 7 - Traveling observation vehicle

3.4. Study on technologies for risk assessment of avalanche disasters that accompany rainfall in winter

In this study, the following items were set as targets.
(1) Elucidation of the occurrence conditions of wet snow avalanches
- Clarifying weather conditions, including rises in temperature, sunlight and rainfall, that contribute to the occurrence of wet snow avalanches
- Clarifying snowpack conditions when wet snow avalanches occur, including the formation of water bearing layers in the snowpack, and the characteristics of shear strength of wet snow.
(2) Proposal for risk assessment technologies for wet snow avalanches
- Developing a snowpack model for simulating various thicknesses and locations of water bearing layers by utilizing meteorological data
- Proposing risk assessment technologies for wet snow avalanches by using precipitation data collected by radar

Difference in the amounts of water supply at the time of occurrences of wet snow avalanches and the trends in occurrences of wet snow avalanches in the extreme cold period and the snow melting period were clarified; at the same time, the differences between water infiltration, snow quality and the structure of the snowpack on the flat area versus on the slope were clarified. The stability of the snowpack, which can be assessed by considering failures at the top and bottom parts of the snowpack on the slope, was incorporated as an index for risk assessment of wet snow avalanche.

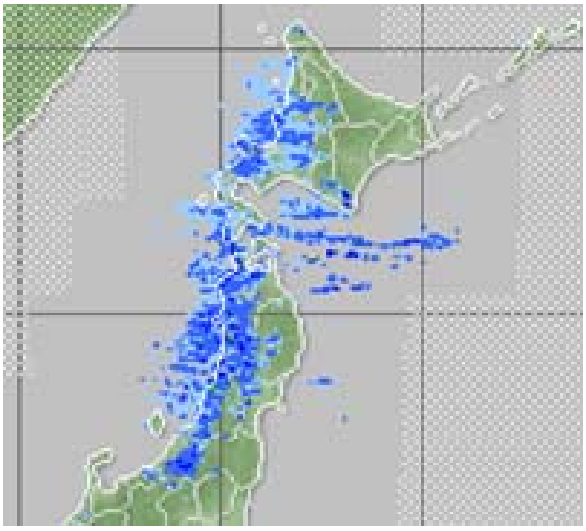


Figure 8 - Radar precipitation data

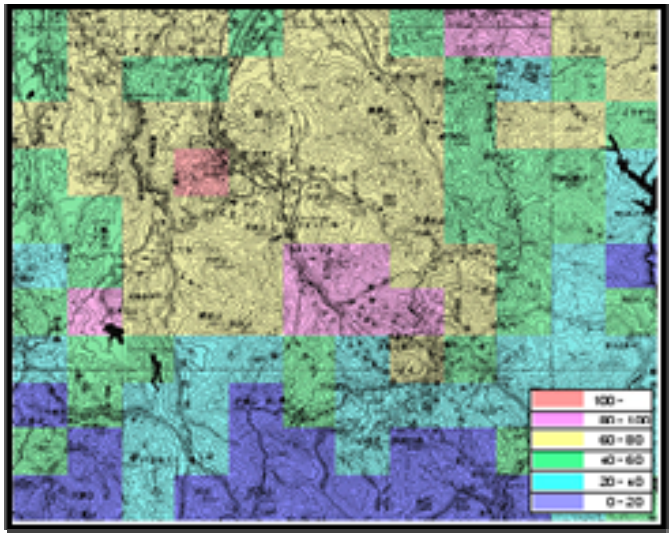


Figure 9 - Evaluated risk image of wet-snow avalanches

4. PROJECT STUDY: STUDY ON TECHNOLOGIES FOR PERFORMANCE IMPROVEMENT OF ROADS IN WINTER IN COLD REGIONS

In this study, to maintain and improve the performance of winter roads, including the smoothness, safety and reliability of the traffic in cold regions, four areas of technologies are being developed: technologies used in supporting the evaluation of the levels of road surface and in maintenance for winter roads; technologies for evaluating and maintaining winter road surfaces most strongly related to the performance of winter roads; technologies for improving the efficiency of snow removal throughout an entire route or area; technologies for improving the safety and reliability of winter sidewalks; and technologies for mitigating winter traffic accidents.

To achieve the above-mentioned basic study themes, the following five studies have been conducted: studies on technologies for supporting decision-making in winter road surface maintenance; studies on multiple technologies for surface treatment for effective winter road maintenance; studies on efficient and effective snow removal management technology by using ICT; studies on surface management technologies for safe and comfortable sidewalks in the snowfall season; and studies on technologies for preventing vehicles from deviating from their lanes in suburban areas. The outline and results of each study area are described below.

4.1. Study on technologies for supporting decision-making in winter road surface management

In this study research will be conducted to develop technologies for supporting decision-making in winter road surface management

(1) Examination of the appropriateness of winter road surface management

- Accumulating data for evaluating the effectiveness of the work and for examining the appropriateness of the works and management by measuring the skid resistance before and after the maintenance work

(2) Establishment of technologies for clarification and diagnosing of the skid resistance along the entire route

- Establishing technologies for diagnosing the tendency of the winter road surface condition (slipperiness) to occur along an entire route, and for determining locations and

conditions that require special attention based on the skid resistance of the road surface, weather conditions and road structures
(3) Establishment of technologies for supporting decision-making in winter road surface management based on road weather data and diagnostic technologies
- Establishing and proposing technologies for supporting decision-making in starting road surface management works based on the weather conditions, locations and timing for starting works, by accumulating data on road weather and skid resistance

Basic characteristics of the influences of road structure, elevation of the location and weather conditions, and other environmental factors along the road on the skid resistance were clarified by measuring the skid resistance of roads in service, matching the data on measured skid resistance to those on winter road surface management works, and improving the database. It was verified that the skid resistance characteristics for the entire route are reproducible under the same weather conditions.

Figure 10 - Continuous Friction Tester

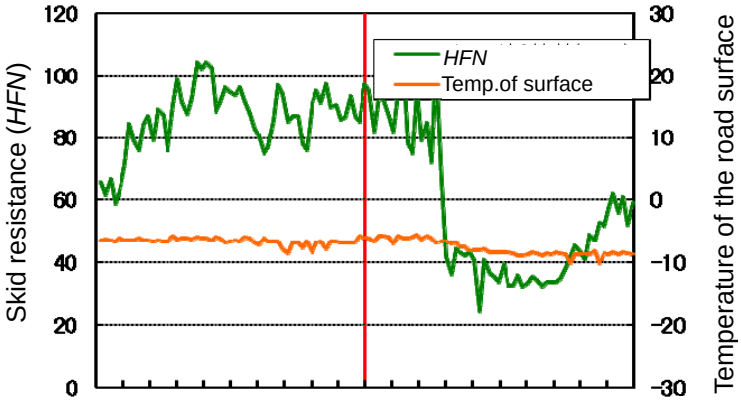


Figure 11 - Sudden changes in skid resistance at the tunnel mouth

4.2. Study on multiple road surface treatment technologies for efficient winter road surface management

In this study, the following items were set as targets.
(1) Proposal for effective and efficient technologies for spreading anti freezing agents corresponding to the type of pavement
- Examining effective and efficient spreading technologies for anti-freezing agents that suit the type of pavement, by clarifying the current conditions of anti-freezing agent spreading for each type of pavement, and measuring the resulting effects of the spread agent.
(2) Proposal for technologies for icy road surface treatment that include improvements in the anti-freezing agents and the technologies for spreading them, and improvements in the spreading machines.
- Improving anti-freezing agents other than chlorides, the technologies for spreading them and the spreading machines. Examining the effectiveness and efficiency of icy road surface treatment technologies by clarifying the effects of developed technologies in experiments on test roads and roads in service.

The skid resistance for various amounts of anti-freezing agent spread on rough-surface pavement sections and dense-graded asphalt pavement sections of roads in service were measured, and the tendency in the resulting skid resistance was clarified. To develop spreading techniques that are appropriate for each pavement type, the rate of road surface exposure and the residual salt concentration on the road surface were measured in laboratory tests, and the mechanism of road surface freezing and the relationship between

the spreading anti-freezing agent and the effect of spreading were clarified. The effect of non-chloride liquid that works as a fixative agent was examined by conducting spreading tests using a test model for heated water mixed spreading.

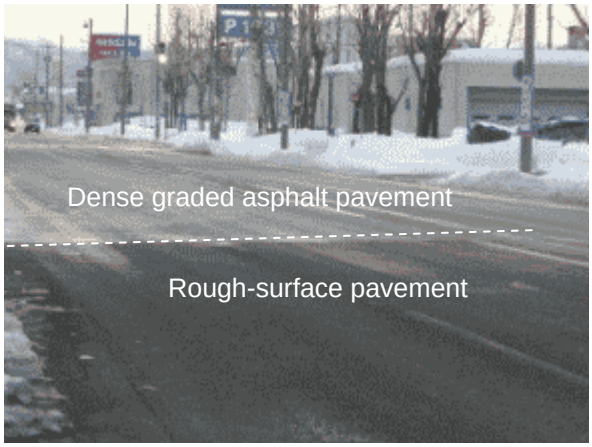


Figure 12 - Difference of the road surface


Figure 13 - Laboratory test equipment

4.3. Study on efficient and effective snow removal management technology using ICT

In this study, to develop technologies for supporting decision-making in snow removal operations, particularly in selecting the optimal timing for mobilizing snow removal units, the following items were set as targets.

(1) Proposal for technologies for analyses and evaluation of the efficiency of snow removal operations by visualizing the information on weather and the operating conditions of snow removal machines.

- Investigating the changes in work speed of snow removal operation, conditions of the fleets and the timing of snow removal in relation to that of the neighboring work area. The information on weather and on snow removal machinery (e.g., locations of machinery and other information on operation) that is accumulated in the snow removal machinery management system is visualized on a table and a map that is able to indicate the changes in snow removal operations with time.
- Extracting inefficiencies and waste factors, which are unseen in conventional examinations of snow removal operations, by analyzing in detail the efficiency of routine operations, the appropriateness of the timing of mobilization and modifications of work operations at the time of heavy snowfall, and the relationship between the snowfall data and snow removal operation data.

(2) Proposal for technologies that support decision-making in mobilization of snow removal units and management of snow removal based on the analysis of the weather information and the information on operation of snow removal machinery and information-sharing that uses ICT technologies.

- Examining technologies for efficiently and effectively conducting snow removal operations by analyzing, evaluating and simulating the information on operation of snow removal machinery and weather information
- Examinations for developing technologies that support decision-making in optimal mobilization of the snow removal units by collecting, managing and sharing information on the snowfall and road surface conditions of the subject area, and by analyzing the information on snowfall forecast, icy road surface forecast and work operation.

(3) Proposal for a method of applying management technology towards the efficient operation of snow removal machinery by utilizing the information on the locations and work progress of such machinery

- Examining the development of a technology that supports timely snow removal operations at heavy snowfall by analyzing snowfall information and real-time information on the operation of snow removal machinery.

The effectiveness of the method for visualizing the analysis was verified by analyzing the snow removal operations, including the locations and speed of snow removal machinery and the changes in the work formation of the fleets, which changed with time and were visualized on the map. The changes in the work formation of fleets and the routes for the operation were readily understood.

Figure 14 Data on the locations and operations of snow removal machinery

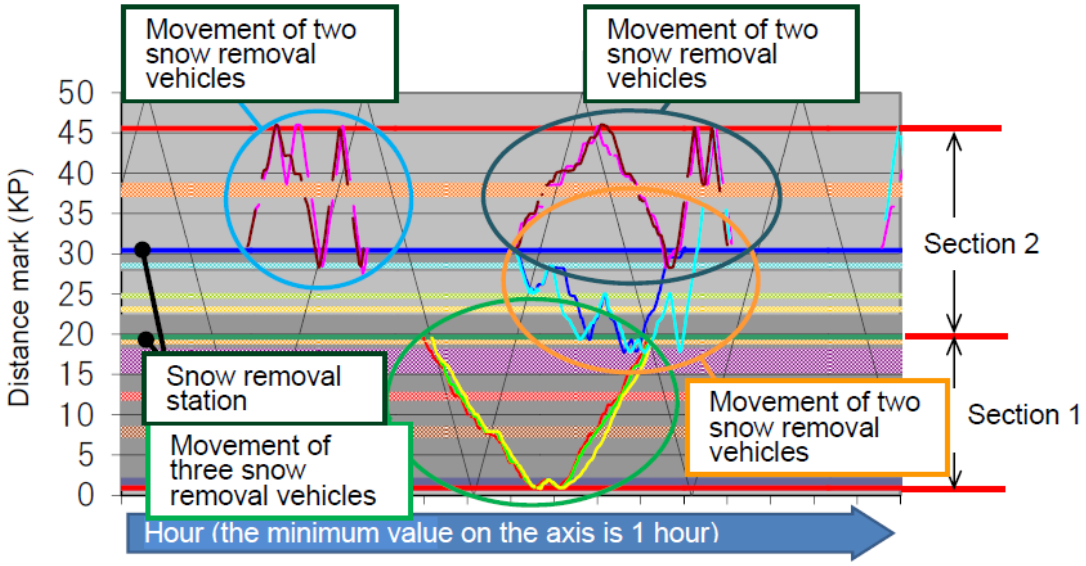


Figure 15 Visualization image

4.4. Study on surface management technologies for safe and secure sidewalks in the snowfall season

In this study, to develop road surface management technologies for providing a safe and secure sidewalk environment, the following items were set as targets.
(1) Elucidation of the performance of sidewalks in cold regions in order to address needs arising from demographic aging
- Clarifying the sidewalk surface performance that is required for safe and comfortable sidewalks in snowy season (e.g., flatness, gradient, texture of the snow surface) by surveying the current conditions of sidewalks in winter and performing walking tests.

(2) Proposal for sidewalk design technologies in snowy areas and those that take snow removal into consideration
- Designing sidewalks that are suited to snowy regions and to snow removal, and developing management techniques for such sidewalks. Conducting demonstration experiments by constructing sidewalks using the developed design.
(3) The development of winter road surface treatment machinery for newly developed sidewalks
- Developing technologies for machine-treating sidewalks with compacted snow covered with ice sheet by conducting ice and snow treatment experiments.
(4) Proposal for optimal road surface management technologies for winter sidewalks
- Examining the development of surface management technologies for sidewalks that appropriately combine, based on cost and functional performance, snow removal and surface treatment by machinery and the spreading of anti-skidding agents

The effect of spreading anti-freezing agents on icy and snowy sidewalk surfaces on the sense of ease for walkers was investigated by objective and subjective evaluations. The influence of the longitudinal gradient of the sidewalk on the sense of ease of walkers was clarified. A surface treatment machine for winter sidewalks was experimentally built, and performance verification for the machine was conducted.

Figure 16 - Walking experiment using subjects simulating the elderly

Figure 17 - Surface treatment machine for sidewalks

4.5. Study on technologies for preventing vehicles from deviating from their lanes in suburban areas

- Developing technologies for preventing vehicles from deviating from their lanes in suburban areas, including wire rope guardrails.
To verify the effect of guardrail installation on expressways, measurements were taken at a section with guardrails that had been experimentally introduced. Techniques for construction and maintenance were examined: The subject techniques include that for the application of guardrails to specific sections with dips or crests, that for driving in tube sleeves, that for management of the tension of wire ropes and that for snow removal. Toward developing guardrails for ordinary highways, preparations for full-scale car crash experiments were done using CG simulations.

Figure 18 - Wire-rope guardrail systems

Figure 19 - Plowing test

5. CONCLUSION

This report discussed the study themes related to winter roads in the Third Five-year Mid-term Plan that started in FY 2011. While the five-year plan was in the process of being finalized, the Great East Japan Earthquake occurred, on March 11, 2011. After that earthquake, the mid-term plan was slightly modified to further enforce research on earthquake disasters.

It is possible for the mid-term plan to be modified whenever necessary. The necessity for developing indexes for evaluating the performance of winter roads and studies that address localized and extremely heavy snowfall have been called for by external experts. We are considering launching studies with such themes in the future.