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Study on the Securement of Smooth Traffic Flow on Roundabouts in Cold, Snowy Regions

By

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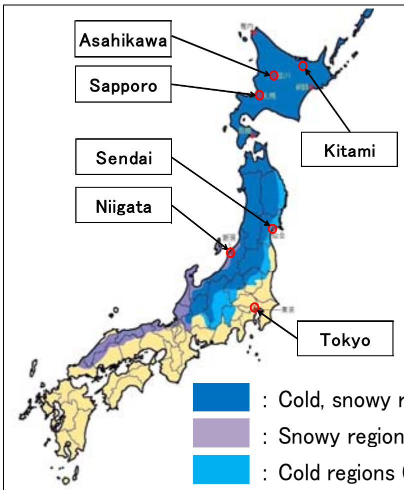
1. Introduction

Roundabouts have been actively introduced in many countries due to the higher levels of safety, traffic flow and economic efficiency they offer compared to general intersections. Japan is no exception to this trend. Guideline development and other steps are being taken in an effort to introduce roundabouts. In addition, demonstration data on test roads are being collected. However, the introduction of roundabouts in Japan has so far been limited, and methods for roundabout winter management have not yet been developed.

In this context, the authors examined an efficient snow removal method for roundabouts by performing a wide range of tests on a simulated roundabout with the aim of enhancing road transportation safety in winter.

2. Cold, snowy regions in Japan

Approximately 60% of Japan's land area is made up of cold, snowy regions, in which as many as 28 million people live. This is a situation found in few other places worldwide. The city of Sapporo in Hokkaido (Japan's northernmost island) is the only urban area in the world that has a population of over one million combined with annual snowfall totaling as much as five meters.



		Sapporo	Asahikawa	Niigata	Sendai
Temperature (°C)	Highest	36.2	36.0	39.1	36.8
	Lowest	−23.9	−41.0	−13.0	−11.7
	Annual average	8.5	6.7	13.5	12.1
Total precipitation (mm)		1,128	1,074	1,776	1,242
Cumulative snowfall (cm)		496	647	165	70
Max. snow depth (cm)		98	90	30	13
No. of snowy days		132	148	58	36.6

: Cold, snowy regions
: Snowy regions (the max. snow depth in Feb. is at least 50 cm)
: Cold regions (average temperature in Jan. is below freezing)

Cold, snowy regions in Japan

Sidewalk side

Roadway side

Snow piled up between a sidewalk and roadway (Kitami, Hokkaido)

3. Study principles

①For efficient snow removal at roundabouts

Vehicular swept paths for different types of snowplow were measured to investigate their suitability for a roundabout and **allow the proposal of a snowplow selection method.**

②For enhancement of roundabout safety in winter

Changes in actual visibility and driver influence resulting from different snow pile locations and heights were surveyed to **allow the proposal of appropriate snow locations and heights.**

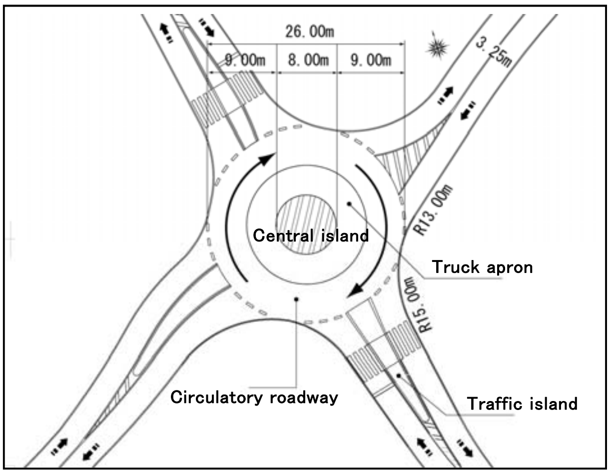
4. Vehicular swept path test

A vehicular swept path test was conducted to determine the effectiveness of each type of snowplow in removing snow (traveling) at roundabouts.

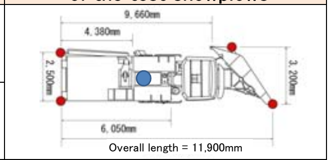
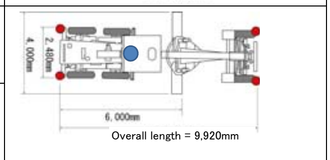
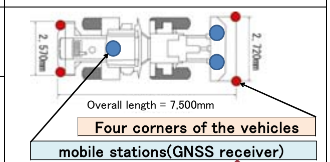
In the test, snowplows were driven on a simulated full-scale roundabout to obtain RTK-GNSS measurement data. For measurement, a fixed station was set up at the test track and mobile stations were mounted on top of the test vehicles. Based on the measurement results, vehicle locations and travel directions were ascertained. Continuous vehicular swept paths and the positions of the four corners of the traveling vehicles were also surveyed by superimposing them onto pre-registered map data (using road configurations and vehicular external dimensions).

4.1 Test conditions

・Test vehicles : snow-removing truck, snow-removing motor grader, snow-removing wheel-type loader
・Travel patterns : loop, right turn, straight line, left turn
・Travel speed : speed expected in snow removal operations, minimum speed
・Measurement and analysis interval : 1 sec.

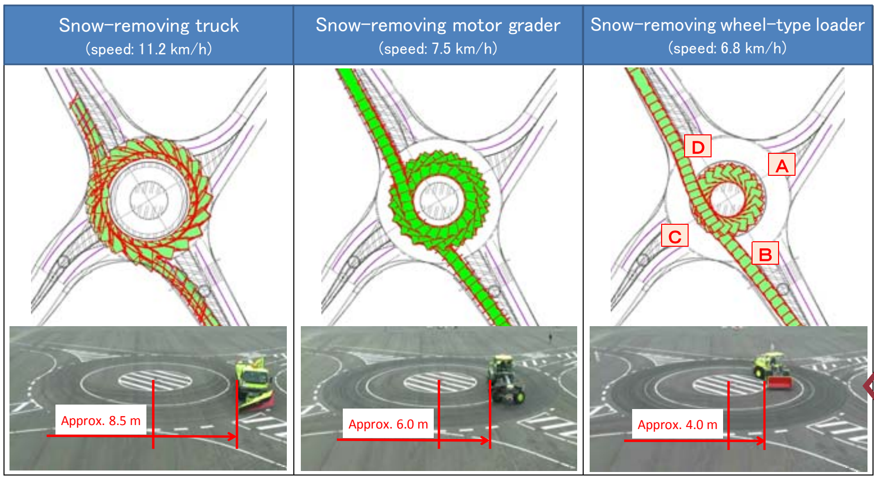


Simulated roundabout configuration

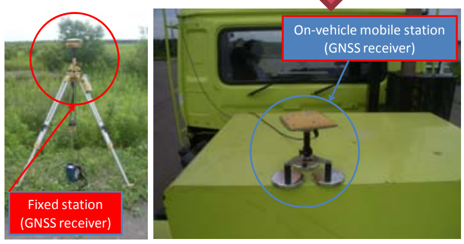
Snowplow/Features	Schematic diagram of the test snowplows
Snow-removing truck (10-ton class) ・Superior mobility and comfort ・Positioned mainly in suburbs	
Snow-removing motor grader (4.0-m class) ・Superior workability and ability to remove compacted snow ・Positioned mainly in urban areas	
Snow-removing wheel-type loader (13-ton class) ・Superior maneuverability ・Positioned usually for specific uses such as community roads and intersections	

Features of typical snowplows

4.2 Test results



Results of vehicular swept path test (Travel patterns : loop)



Installation of GNSS instruments

Example : snow-removing wheel-type loader

Measurement point	Vehicle passage point (In m)			
	Front right-side tip	Rear right-side tip	Front left-side tip	Rear left-side tip
A	4.84	5.68	7.16	7.67
B	4.79	5.82	7.07	7.69
C	4.81	5.93	7.24	7.92
D	4.80	5.70	7.09	7.68

5. Proposal of a snowplow selection method

・The vehicular swept path test revealed that the snow-removing wheel-type loader was capable of traveling along the edge of the central island and the outer circumference of the circulatory roadway, which the snow-removing truck and snow-removing motor grader could not do. Accordingly, the snow-removing wheel-type loader was deemed to be best suited for the simulated roundabout (circulatory roadway outer diameter: 26 m; central island diameter: 8 m).
・On roundabouts with larger central island diameters, snow-removing trucks and snow-removing motor graders, which have better mobility and workability than snow-removing wheel-type loaders, can be used.
・It is also necessary to adequately consider the conditions of roundabout approach roads and the types of snowplows already positioned there.

The snowplow types to be used must be selected in consideration of field conditions in addition to the results of vehicular swept path testing.

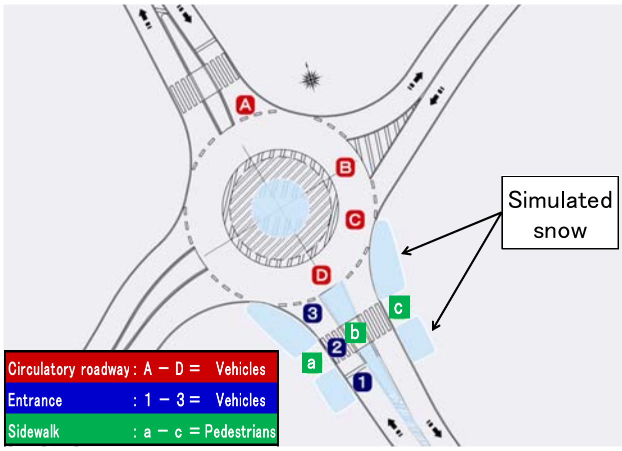
6. Visibility confirmation test

A test concerning the visibility of drivers and pedestrians at a roundabout in snowy conditions was conducted. In the test, simulated snow piles and objects (moving vehicles and pedestrians) were positioned at the simulated roundabout, and pictures were taken from the eye heights of drivers and pedestrians using digital cameras to show how they saw each other. By comparing images with varying shooting conditions (objects, snow heights, etc.), changes in visibility were determined. The number of pixels in the visible area of the objects was also counted for quantitative assessment of the visible area.

6.1 Test conditions

- Objects : passenger cars, snow-removing motor graders, pedestrians (dummies)
- Simulated snow piles : at 7 locations (central island and entrance/exit)
- Simulated snow pile height : 0 m, 1.2 m, 1.5 m
- Camera: digital single-lens reflex (with fixed 50 mm lens)

Shooting condition (at eye height from snow-removing motor grader)



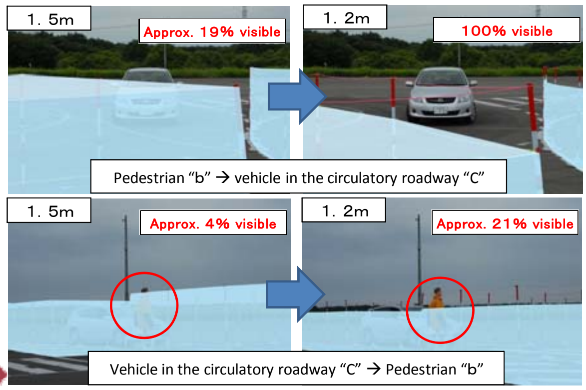
Positions of vehicles and other objects

6.2 Test results

- The results of the visibility test confirmed that actual visibility for a snow height of 1.5 m differed significantly from that for a height of 1.2 m.
- As a specific example, a survey was carried out in which a car was located at "Position C" on the circulatory roadway and a pedestrian was located at "Position b" on the sidewalk to allow examination of vision from each point. The results for a snow height of 1.5 m showed that only the head of the pedestrian (approx. 4% of the total body area) was visible from the car, and only the top of the vehicle (approx. 19% of its total area) was visible from the pedestrian's point of view. In contrast, when the snow was 1.2 m high, the entire vehicle (100%) was visible, and the pedestrian was visible from the chest up (approx. 21%).
- The lower part of objects used in these tests (dummies and vehicles) tended to have a larger visible area. In some cases, it increased more than fivefold when the snow height decreased from 1.5 m to 1.2 m, quantitatively confirming that differences in visibility exceed differences in snow height.

Visual object / Shot from	Pedestrian "b"					
	No snow		Snow height 1.2 m		Snow height 1.5 m	
	No. of pixels	%	No. of pixels	%	No. of pixels	%
Snow-removing motor grader on circulatory roadway A	5,135	100%	1,838	35.8%	678	13.2%
Snow-removing motor grader on circulatory roadway B	12,102	100%	4,614	38.1%	244	15.0%
Snow-removing motor grader on circulatory roadway C	19,580	100%	9,271	47.3%	3,628	18.5%
Passenger car on circulatory roadway A	6,730	100%	501	7.4%	0	0.0%
Passenger car on circulatory roadway B	15,064	100%	3,470	23.0%	619	4.1%
Passenger car on circulatory roadway C	31,602	100%	6,698	21.2%	1,249	4.0%

Comparison of visible area (example)



Comparison of visibility varied by different snow heights

7. Subjective assessment test

A subjective assessment test was conducted to determine the degree of hindrance caused by each snow pile to driving performance. In the test, 17 subjects drove on the simulated roundabout where simulated snow piles were positioned, and assessment was made using a questionnaire (with answers indicated on a scale of 1 to 7). The snow piles were simulated by attaching white netting to survey poles.

7.1 Test conditions

- Simulated snow piles : at 7 locations (two different profiles for Traffic Island A)
- Simulated snow pile heights : 1.2 m and 1.5 m
- No. of snow piles evaluated : 16
- Test vehicle : passenger car (Toyota Cardina)
- Travel route : Entrance→ Circulatory roadway (loop) → Exit

Simulated snow piles and Test vehicle

Q : Check the most appropriate severity of hindrance caused by each snow pile when you were driving.

【First driving test】 Name :

Central island	1.2m	1	2	3	4	5	6	7
Entrance A	1.2m	1	2	3	4	5	6	7
Entrance B	1.2m	1	2	3	4	5	6	7
Exit A	1.2m	1	2	3	4	5	6	7
Exit B	1.2m	1	2	3	4	5	6	7
Traffic Island A	1.2m	1	2	3	4	5	6	7
Traffic Island B	1.2m	1	2	3	4	5	6	7
		No hindrance						Hindrance

Driving course and questionnaire of subjective assessment test

7.2 Test results

The results of the questionnaire answered on a scale of one to seven were standardized for each subject to give standard values in order to facilitate comparison for each snow pile. A subjective assessment score for each pile was found by averaging all the subjects' standard values.

In this case, higher scores mean a greater hindrance to driving performance.

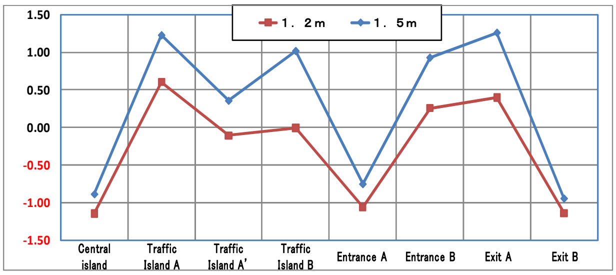
・Standard value (a) = (Individual assessment score – Average score) / Standard deviation

・Subjective assessment score = $1 / n \sum_{j=1}^{n} a_j$

※Focus of attention ： Pedestrians > Traveling vehicles
※Snow height ： 1.5 m > 1.2 m
※Snow location vs. snow height ： Location > Height
※Comparison of snow profile : influenced by the range of vision

Location of simulated snow	Driving condition		
	On circulatory roadway	Entering the roundabout	Exiting the roundabout
Central island	Traveling vehicles	Traveling vehicles	–
Entrance A	–	Traveling vehicles	–
Entrance B	–	Pedestrians	–
Exit A	–	–	Pedestrians
Exit B	–	–	Traveling vehicles
Traffic Island A	–	Traveling vehicles	Pedestrians
Traffic Island A'	–	Traveling vehicles	Pedestrians
Traffic Island B	–	Pedestrians	Traveling vehicles

Objects to which attention is supposedly directed



Subjective assessment results

8. Proposal for snow pile locations and heights

【Snow pile locations】

The results of the subjective assessment test indicated that it was best to pile removed snow on the "Central island", "Entrance A", "Exit B".

However, the amount of snow piled at "Entrance A" may increase due to daily snow removal operations. In such cases, snow will need to be piled at "Exit A" on the adjacent approach road to the roundabout. Thus, it is considered optimal to pile snow removed from the roundabout at the "Central island" and "Exit B".

【Snow pile heights】

The results of the subjective assessment test indicated that variations in subjective assessment scores (indicating the degree of hindrance) were smaller for snow heights than those for snow pile locations. However, in the visibility confirmation test, actual visibility varied significantly. Accordingly, a snow height of 1.2 m was considered preferable.

・Snow pile locations＝「Central island」 and 「Exit B」
・Snow pile heights ＝「1.2 m」
are the most preferable

9. Summary

【Results】

・This study enabled identification of a snowplow selection method and the proposal of snow pile locations and heights in consideration of visibility.

【Future tasks】

・Tests involving vehicular swept paths on winter road surfaces will be conducted.
・Snow removal operation procedures and the costs associated with removing and piling snow will be examined.