ISSUES IN THE PLANNING AND MANAGEMENT OF ROUNDABOUTS IN COLD, SNOWY REGIONS: Traffic capacity reduction at a roundabout with a compacted-snow road surface, and truck apron design that considers snow removal

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ABSTRACT

Two-thirds of Japan is classified as cold and snowy. When roundabouts are planned and managed, snow must be considered. In this study, first the reduction in traffic capacity was determined for a roundabout with a snow-covered surface on a test track. Vehicle gap parameters were measured at a roundabout. These parameters were critical gap time ($t_c$), follow-up time ($t_f$) and minimum headway time for vehicles on the roundabout’s circulatory roadway ($\tau$). When the roundabout had a compacted-snow surface, the entry capacity was about 300 vehicles/hour less than when it had a dry surface. However, when the surface was compacted snow spread with non-slip abrasives, the entry capacity was reduced by only about 150 vehicles/hour from that for the dry road surface.

Next, tests were conducted on damage to the truck apron structure from snow removal operations. Three types of apron with various height and angle conditions were tested in terms of damage to the apron from contact by snow removal machinery. The types were four conventional stepped aprons, one step-and-gradient apron, and four gradient aprons (i.e., a total of nine aprons). The tested snow removal vehicles were a wheel loader and a motor grader. The gradient aprons were found to be damaged less than the other types of aprons.

This paper discusses issues to be addressed in the planning and operation of roundabouts in cold, snowy regions, specifically their decreased flow rate when covered with compacted snow and designs for their aprons that resist damage from snow removal machinery.

<Key words: snow condition, gap parameter, snow plowing, truck apron>
INTRODUCTION

About two-thirds of Japan is classified as cold and snowy. Hokkaido, Japan’s northernmost prefecture, accounts for a quarter of the area of Japan, and there is snow here for the 5 months from November to March. Hokkaido receives about 5m of annual snowfall, although there is some variation by region. In Asahikawa, which is near the geographical center of Hokkaido Island, the maximum temperature in January is -4 to -5 °C, the minimum temperature is -15 to -20 °C, and the average temperature is about -7 to -8 °C. To ensure smooth winter traffic in such a cold, snowy region, daily snow removal and other road management work is important.

Japan is also prone to natural disasters, such as earthquakes, tsunamis, typhoons and extreme snowfall. Large-scale traffic congestion and traffic accidents caused by power outages at times of natural disaster have been major social problems. Roundabouts excel in safety, environmental impact mitigation, and resistance to natural disasters.

In Japan, practical studies on roundabouts have been in full swing since 2009 (1). Based on social experiments and the like, the Road Bureau Division of the Ministry of Land, Infrastructure, Transport and Tourism issued the notification, Desirable Roundabout Structure (2) on August 8, 2014, which specifies criteria for roundabout planning and design. The revised Road Traffic Law includes a new traffic rule that gives vehicles on the circulatory roadway of a roundabout priority over entering vehicles, and this revision took effect on September 1, 2014 (3).

In May 2016, The Roundabout Manual for Japan (4) was published by the Japan Society of Traffic Engineers. Roundabout planning, design and basic operation methods have been defined toward the introduction of roundabouts to Japan. Currently, 51 intersections in 16 prefectures around Japan are operated as roundabouts.

However, issues in the planning and design of roundabouts in cold, snowy regions have not been identified because of insufficient data on the use of roundabouts in Japan’s cold, snowy regions. Therefore, the research group that includes the authors installed a roundabout at the Tomakomai Test Track (211, Aza Kashiwabara, Tomakomai City, Hokkaido, Japan). Our research has addressed how snow affects the roundabout. We focused on differences in road surface between snowy and dry conditions, and we made tests on the behaviors of vehicles and their traveling positions on roundabouts whose circulatory roadway was covered with compacted snow. Based on the results, we proposed a desirable structure for roundabouts in snowy regions (5),(6), and we clarified how the locations and heights of snowbanks resulting from snow removal operations on the circulatory roadway affect the traffic flow (7).

Report 672 of the TRB’s National Cooperative Highway Research Program (NCHRP) includes recommended roundabout maintenance methods, such as snow removal methods for roundabouts, and notes the need to secure snow banking space at roundabouts (8).
K. Munehiro

noted the difficulty of snow removal work at the truck apron of a roundabout. She recommended that snow removal be done only at the circulatory roadway (9). Snow removal and anti-freezing techniques are included in the Roundabout Maintenance Manual of Perdue University (10). However, few preceding studies have addressed the snowfall-related reduction of traffic capacity at roundabouts.

Therefore, as considerations for the planning and management of roundabouts in a cold, snowy region, this study addresses the following.

1) The traffic capacity reduction at roundabouts that results from the emergence of the compacted-snow surface
2) Damage to the truck apron resulting from snow removal work

**EXPERIMENT 1: TRAFFIC CAPACITY REDUCTION ON A COMPACTED-SNOW ROAD SURFACE**

**Traffic capacity of the roundabout**

A formula based on the gap acceptance probability of an entering vehicle has been adopted in roundabout design guidelines in Germany (10).

\[
Ci = s \cdot \left[ 3600 \left( 1 - \frac{Q_{ci}}{3600} \right) \cdot \exp \left\{ - \frac{Q_{ci}}{3600} \cdot \left( tc - \frac{tf}{2} - \tau \right) \right\} \right]
\]

(1)

Where,

- \( Ci \): flow rate at the entry i (vehicles/h)
- \( Q_{ci} \): traffic volume on the circulatory roadway upstream of entry i (vehicles/h)
- \( tc \): critical gap time for an entering vehicle (sec) (4.1 sec)
- \( tf \): headway time of traffic flow for an entered vehicle (sec) (2.9 sec)
- \( \tau \): minimum headway time of traffic flow on the circulatory roadway (sec) (2.1 sec)
- \( s \): safety factor (0.8)

The traffic capacity of a roundabout is defined as the maximum flow rate (vehicles/h) at one of the entries. The maximum flow rate is calculated for each entry (11). The German guidelines use \( tc = 4.1 \) seconds, \( tf = 2.9 \) seconds, \( \tau = 2.1 \) seconds as the vehicle parameters. In Japan, the decision on whether to introduce a roundabout is determined by using the flow rate calculated by multiplying the safety factor of 0.8 and the flow rate given by a calculation formula (1).

Usually, the flow rate of the roundabout is calculated under the dry road surface condition. It is assumed that fewer vehicles will enter a roundabout with a compacted-snow road surface than will enter one with a dry road surface. However, there are no data available to test this assumption. In this study, by measuring the gap acceptance behavior at the time of vehicle entry,
we tried to estimate the flow rate of the roundabout under the compacted-snow condition.

**Test installation of the roundabout**

A single-lane roundabout was installed at the Tomakomai Test Track. The design specifications and the size of each component are listed below and are based on the German design guidelines (*Merkblatt für die Anlage von Kreisverkehren*) (11).

- Type of site: the intersection of ordinary roads in cold, snowy rural area
- Daily traffic volume: up to 10,000 vehicles
- Outer diameter of the circulatory roadway: 26.0m (27.0 m including the shoulder)
- Road width: 5.0 m (the circulatory roadway only), plus the truck apron
- Entry radius: 13.0m
- Exit radius: 15.0m
- Length of deflection island: 30.0m

Temporary pavement markers were used for carriageway markings. Simple banks made of sand bags and covered with artificial turf were substituted for the central island and the splitter islands. Substitute curbs were arranged around the central island and the splitter islands. A guide sign was installed at each entry.

**Experiment cases**

The test targeted a single-lane roundabout. A driving experiment was made with test subjects. The three experimental cases for the roundabout surface were 1) compacted snow, 2) compacted snow spread with crushed stone (abrasive), and 3) dry pavement (*Table 1*). Crushed stone No. 7 (JIS A5001-1995), with a particle size of 2.5~5mm, was applied as the abrasive in Case 2. The compacted-snow road surface was formed by natural snow. The coefficient of sliding friction for the road surface at the time of each experiment case was measured 6 times by accelerometer (manufactured by Coralba). The maximum and minimum values were excluded, and the remaining four measurements were averaged. The air temperature at the time of the experiment was below freezing. The road surface for Case 1 was very slippery compacted snow. The road surface for Case 2 was very slippery compacted snow spread with crushed stone as an abrasive. The coefficient of sliding friction of the road surface was increased by such spreading. On high-grade national highways in Japan, anti-freezing agents such as calcium chloride are generally spread. For low-grade municipal roads, crushed stone and burnt sand are frequently used as anti-skidding agents. This experiment assumed a low-grade municipal road with a low maintenance level, so we spread crushed stone. Case 3 is the dry surface condition. Under these road surface conditions, the entering traffic and circulatory roadway traffic flow for 12 to 16
vehicles was reproduced. The present experiment did not address pedestrians and cyclists.

**Table 1 Experimental Cases**

<table>
<thead>
<tr>
<th>Experimental Case</th>
<th>Date</th>
<th>Start time</th>
<th>Ending Time</th>
<th>Road Surface Condition</th>
<th>Non-slip Material</th>
<th>f</th>
<th>Temp. (℃)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case 1</td>
<td>Feb. 9th, 2015</td>
<td>AM 9:00</td>
<td>AM11:50</td>
<td>Compacted-Snow</td>
<td>No</td>
<td>0.18</td>
<td>-4.6</td>
</tr>
<tr>
<td>Case 2</td>
<td>Feb. 10th, 2015</td>
<td>AM12:30</td>
<td>PM 2:50</td>
<td>Compacted-Snow</td>
<td>Yes</td>
<td>0.55</td>
<td>-1.4</td>
</tr>
<tr>
<td>Case 3</td>
<td>Sep. 16th, 2009</td>
<td>AM10:00</td>
<td>PM 4:00</td>
<td>Dry</td>
<td>–</td>
<td>–</td>
<td>21.6</td>
</tr>
</tbody>
</table>

**Reading of the image data**

A video camera installed in the observation scaffolding (at a height of about 5.4m) recorded the driving test. From the recorded images, the gap time between the circulatory roadway traffic and the entering vehicle, and the follow-up headway time (follow-up time) at the time of entering traffic were determined. The data were analyzed by image-analysis software that can record data at a 0.01-sec interval.

Traffic capacity estimation is based on gap acceptance theory (Fig.1). For a roundabout entry taken as a T-junction, it is estimated based on three assumptions given below. Three vehicle parameters were acquired: critical gap time \((tc)\), follow-up headway time \((tf)\), and minimum headway time of vehicles on the circulatory roadway \((τ)\).

Assumption 1: A vehicle trying to enter the circulatory roadway can enter if the gap is greater than or equal to the minimum gap (critical gap time \((tc)\) (sec)) of the vehicles travelling on the circulatory roadway. The acceptance gap (headway interval) is shown in Fig. 1 (1). The rejection gap is shown in Fig. 1 (2). We set a conflict point on the software-generated image of the roundabout and traffic flow, and measured the gap time from the transit times of the vehicles passing through the conflict point.

Assumption 2: When a vehicle enters the circulatory roadway following a vehicle driving
in the roundabout, the headway time \((t_f)\) (in seconds) is the headway time between the preceding vehicle and following vehicle in the circulatory roadway traffic flow (Fig. 1 (3)).

Assumption 3: The minimum gap in the circulatory roadway traffic flow is the minimum headway time of the circulatory roadway traffic flow \((\tau)\) (seconds).

Fig. 1  Acquisition of Gap Parameters
RESULTS OF EXPERIMENT 1: TRAFFIC CAPACITY REDUCTION ON THE COMPACTED-SNOW ROAD SURFACE

Measured vehicle gap parameters
The cumulative probabilities of a rejection gap and an acceptance gap at entry 1 of the roundabout are shown in Fig. 2. Case 1 is compacted snow, Case 2 is compacted snow + crushed stone (non-slip abrasive), and Case 3 is dry pavement. Following the method adopted in the NCHRP Report (12), we plotted the cumulative probabilities of rejection gaps and acceptance gaps and set the intersection between these plotted density functions of rejection gaps and acceptance gaps as the critical entering gap ($t_c$) for the critical gap time ($t_c$).

From the results of Figure 2 (1), the critical gap time ($t_c$) is 6.7 (sec) at the time of compacted snow. When the crushed stone was spread on the compacted-snow, that time was reduced to 6.4 (sec). The critical gap time ($t_c$) on the dry road surface was 5.1 sec. For the compacted snow, when the gap time ($t_c$) is 7 (sec), the acceptance probability is about 0.2, and when the gap time is 8 (sec), the acceptance probability is increased to about 0.5. For the compacted snow on which crushed stone was spread, when the gap time ($t_c$) is 7 (sec), the acceptance probability is about 0.3, and when the gap time is 8 (sec), the acceptance probability is increased to about 0.8. Consequently, it was proved that spreading crushed stone on compacted snow is effective in increasing the acceptance probability of a vehicle entering the circulatory roadway.

Next, the follow-up headway time ($t_f$) at entry 1 is shown in Figure 2 (2). The cases are compacted snow, compacted snow + crushed stone, and dry road.

From the results, the follow-up headway time ($t_f$) was 5.0 (sec) on compacted snow was reduced to 4.0 sec on the compacted snow spread with crushed stone. Incidentally, the following headway time on the dry road ($t_f$) was 3.5 sec.

The cumulative probabilities of a vehicle entering the traffic flow at the circulatory roadway for the observed headway times of traffic flow on the circulatory roadway are shown in Figure 2 (3). The minimum headway time of traffic flow on the circulatory roadway $\tau$, which is 3.5 (sec) under compacted-snow conditions, is reduced to 3.0 (sec) under the condition of compacted snow spread with crushed stone. It is 2.5 (sec) on the dry road.
K. Munehiro

Relationship between the flow rate of traffic entering the circulatory roadway and the flow rate of traffic on the circulatory roadway

From the above-mentioned Figure 2, the critical gap time \((t_c)\), follow-up time \((t_f)\), and minimum headway time of traffic flow on the circulatory roadway \((\tau)\) are as follows.
K. Munehiro

1) Case 1
   \( t_c \): 6.7 sec, \( t_f \): 5.0 sec, \( \tau \): 3.5sec

2) Case 2
   \( t_c \): 6.4 sec, \( t_f \): 4.0 sec, \( \tau \): 3.0sec

3) Case 3
   \( t_c \): 5.1 sec, \( t_f \): 3.5 sec, \( \tau \): 2.5sec

The vehicle parameters of each case were introduced into Equation (1). The flow rate of the roundabout is estimated in Figure 3.

When the flow rate of the circulatory roadway is 100 vehicles/hour, the flow rate of entering traffic is about 630 vehicles/hour for compacted snow (Case 1), about 790 vehicles/hour for compacted snow + crushed stone (Case 2) and about 930 vehicles/hour for dry pavement (Case 3).

When the flow rate of the circulatory roadway is 500 vehicles/hour, the flow rate of entering traffic is about 330 vehicles/hour for compacted snow (Case 1), about 430 vehicles/hour for compacted snow + crushed stone (Case 2) and about 600 vehicles/hour for dry pavement (Case 3).

For the compacted-snow road surface, the flow rate of traffic entering the roundabout is reduced by about 300 vehicles/hour from the flow rate of traffic entering the roundabout for dry pavement.

It was proved that spreading abrasives on compacted snow can be an effective measure against very slippery snow-covered roads, because the flow rates of entering traffic with and without the spreading of abrasives on slippery compacted snow differed by about 150 vehicles/hour.

When the results of Case 3 and the German formula are compared, the flow rate of traffic on the circulatory roadway for the German formula is shown to be 200 vehicles/h higher than that of Case 3 at all ranges of flow rate. In this experiment, which used a roundabout on an experiment road section, data on the vehicle gap parameters were collected by using drivers who were not accustomed to driving through roundabouts. It is thought that the vehicle gaps were great because these test subjects, who were inexperienced in driving on roundabouts, may have been cautious about keeping their distance from the vehicle ahead.
EXPERIMENT 2: TRUCK APRON DESIGN THAT CONSIDERS SNOW REMOVAL

Test on the resistance of the truck apron to snow removal damage

The truck apron is installed inside the circulatory roadway. It allows the passage of large vehicles, tow vehicles, etc. For speed suppression, the apron is usually stepped. The design heights of truck aprons are about 1.5~7.5cm in various countries (13). To prevent small vehicles from taking shortcuts, *The Roundabout Manual for Japan* (4) recommends a step of approx. 5cm in height. However, in areas of extreme snowfall such as Hokkaido, Japan, this step is expected to interfere with snow removal. Specific problems are snow being left behind, damage to the step portion from snowplow contact and damage to the snowplow from apron contact. The amount of snow left behind and the severity of damage were tested by using a snowplow.

Test summary

To reproduce snow removal operations at the truck apron, three types of apron were placed at the Tomakomai Test Track. In the test, the following were carried out.
(1) Measurement of the height of snow remaining at the truck apron after snow plowing
1) In the absence of snow, the grader blade or wheel loader bucket is placed on the truck apron for measurement of the area where mechanized snow removal is not possible due to the height of the truck apron.
2) After snow is placed on the truck apron, the snow is removed by using snow removal machinery to find the locations and volume of snow not removed from the apron.

(2) Measurement of the severity of damage to the truck apron edge from snow plowing
1) Acceleration is measured by a contact accelerometer attached to the grader blade or wheel loader bucket. In the absence of snow, the blade of the snow removal machinery is lowered until it makes contact with the apron, and the damage is determined.

Tested types of truck apron
A total of nine truck aprons of three types were tested (Fig. 4).

<table>
<thead>
<tr>
<th>Normal Step (H=2cm, 4cm, 5cm, 6cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Circulatory Roadway</td>
</tr>
<tr>
<td>Height of truck apron</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Step-and-gradient (H=2 to 5cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Circulatory Roadway</td>
</tr>
<tr>
<td>Height of truck apron</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Gradient-type (Slope Angle= 7deg, 9deg, 11deg, 13deg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Circulatory Roadway</td>
</tr>
<tr>
<td>Angle</td>
</tr>
<tr>
<td>Height of truck apron</td>
</tr>
</tbody>
</table>

Fig. 4 Truck Apron Types
1) Four conventional stepped aprons (step heights: 2cm, 4cm, 5cm, 6cm)
2) One step-and-gradient apron (2cm high at the edge adjoining the circulatory roadway and 5cm high at the opposite edge)
3) Four gradient aprons (7-degree angle, i.e., 0cm high at the edge adjoining the circulatory...
roadway and 3cm high at the opposite edge; 9-degree angle, i.e., 0cm high at the edge adjoining the circulatory roadway and 4cm high at the opposite edge; 11-degree angle, i.e., 0cm high at the edge adjoining the circulatory roadway and 5cm high at the opposite edge; and 13-degree angle, i.e., 0cm high at the edge adjoining the circulatory roadway and 6cm high at the opposite edge).

**Snowplow**

The snow removal vehicles listed below were used for the test. These are typical snow removal machines used on rural municipal roads in snowy areas of Japan.

(1) **Wheel loader (7t class)**

The heights of the left and right sides of the snow removal device (the bucket) cannot be adjusted independently.

(2) **Motor Grader (3.1m class)**

The width, height and angle of the motor grader’s snow-removing assembly can be adjusted.

![Photo 1](types_of_snow Removal_Vehicles.jpg)

**Photo 1** Types of Snow Removal Vehicles
EXPERIMENT 2 RESULTS: TRUCK APRON DESIGN THAT CONSIDERS SNOW REMOVAL

Measurements for the height of snow remaining at the truck apron after snowplowing

In the absence of snow, the right tire of a wheel loader is driven onto the truck apron and the grader blade or bucket is lowered until it makes contact with the apron surface. The height difference between the apron surface and the right end of bucket is measured 5 times (Fig. 5) and the measurements are averaged.

After snow removal by the wheel loader, the heights of remaining snow are measured along 5 to 13 measurement lines (Photo 2). This is repeated three times for each tested truck apron.

These measurements found the maximum space height to be 63mm in the absence of snow and 47mm after snow removal by wheel loader. These were both for aprons of 6cm in height (Table 2).

<table>
<thead>
<tr>
<th>Shape</th>
<th>No Snow Trial</th>
<th>After Snow Removal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal Step 2</td>
<td>17</td>
<td>–</td>
</tr>
<tr>
<td>Normal Step 4</td>
<td>32</td>
<td>17</td>
</tr>
<tr>
<td>Normal Step 5</td>
<td>46</td>
<td>–</td>
</tr>
<tr>
<td>Normal Step 6</td>
<td>64</td>
<td>45</td>
</tr>
<tr>
<td>Step-and-gradient</td>
<td>43</td>
<td>47</td>
</tr>
<tr>
<td>Normal Step 2</td>
<td>0</td>
<td>–</td>
</tr>
<tr>
<td>Normal Step 4</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>Normal Step 5</td>
<td>0</td>
<td>–</td>
</tr>
<tr>
<td>Normal Step 6</td>
<td>0</td>
<td>15</td>
</tr>
<tr>
<td>Step-and-gradient</td>
<td>0</td>
<td>11</td>
</tr>
</tbody>
</table>

Note) 「－」 indicates no experimentation.
Fig. 5 Measuring the Height of Remaining Snow
Next, in the absence of snow, the right tire of the motor grader is driven onto the truck apron, the blade angle is set at 90 degrees, the blade is lowered until it makes contact with the apron (Photo 2 (3)), and the height of the space between the blade and the apron is measured.

Then snow is placed on the roundabout to a height of 8 to 17cm. After the snow is removed by using the motor grader, the height of remaining snow is measured along 7 to 10 survey lines. This was repeated three times for each tested truck apron.

The measurements found that there was no space between the blade and the truck apron in the absence of snow. The height of snow remaining at the 6cm-high truck apron after snow removal was 15mm (Table 2).

In terms of reducing the snow remaining at the apron, motor graders were found to be advantageous. In addition, the snow height in the case of using a wheel loader was 47mm.

**Measurements of damage severity at the truck apron edge**

The snow removal vehicles were installed with accelerometers (Slick, manufactured by G-MEN DR20) (Photo 3). Damage severity and acceleration were measured at the snow
removal equipment’s contact with the truck apron.

Whereas the inclination angle of the bucket of the wheel loader is fixed at 90 degrees, the angle of the motor grader blade is adjustable. We set the angle of that blade at 90 degrees.

The driving speed of snow removal was set at about 5km/h. With the contact angle between the bucket or blade and the curb of the apron set at 30 degrees, the edge of the bucket or blade is put into contact with the apron 6 to 8 times for the apron configurations listed in Table 3.

The measurements show that every time the bucket of the wheel loader (Photo 4) came in contact with the apron, the cobblestones were damaged and were partly lost at the bottom where the curbstone meets the circulatory roadway surface. The damaged portion of the curbstone averaged 23cm along the curbstone (length) by 7cm transverse to the curbstone (width) (Table 3). No damage occurred to the 13-degree gradient apron (Photo 4).
### Table 3 Measured Damage to the Truck Apron

<table>
<thead>
<tr>
<th>Type of Snow Removal Vehicles</th>
<th>Truck Apron</th>
<th>Damage of Truck Apron</th>
<th>Edge contact during Acceleration (G)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Shape</td>
<td>Height (cm)</td>
<td>Length (cm)</td>
</tr>
<tr>
<td>Wheel Loader</td>
<td>Normal Step</td>
<td>2</td>
<td>14.9</td>
</tr>
<tr>
<td></td>
<td>Normal Step</td>
<td>4</td>
<td>23.3</td>
</tr>
<tr>
<td></td>
<td>Normal Step</td>
<td>5</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td>Normal Step</td>
<td>6</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td>Step-and-gradient</td>
<td>2 - 5</td>
<td>18.5</td>
</tr>
<tr>
<td></td>
<td>Gradient-type</td>
<td>0 - 3 (7deg)</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td>Gradient-type</td>
<td>0 - 4 (9deg)</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td>Gradient-type</td>
<td>0 - 5 (11deg)</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td>Gradient-type</td>
<td>0 - 6 (13deg)</td>
<td>0</td>
</tr>
<tr>
<td>Motor Grader</td>
<td>Normal Step</td>
<td>2</td>
<td>13.0</td>
</tr>
<tr>
<td></td>
<td>Normal Step</td>
<td>4</td>
<td>25.1</td>
</tr>
<tr>
<td></td>
<td>Normal Step</td>
<td>5</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td>Normal Step</td>
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<td>Step-and-gradient</td>
<td>2 - 5</td>
<td>16.0</td>
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<tr>
<td></td>
<td>Gradient-type</td>
<td>0 - 3 (7deg)</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Gradient-type</td>
<td>0 - 4 (9deg)</td>
<td>10.6</td>
</tr>
<tr>
<td></td>
<td>Gradient-type</td>
<td>0 - 5 (11deg)</td>
<td>11.2</td>
</tr>
<tr>
<td></td>
<td>Gradient-type</td>
<td>0 - 6 (13deg)</td>
<td>39.0</td>
</tr>
</tbody>
</table>

Note) 「－」 indicates no experimentation.
Measured damage to the truck apron caused by snow removal vehicles is shown in Table 3. When the wheel loader was used, the damage to the 4 cm-high stepped apron was greater than that to the 2 cm-high stepped apron and that to the 13-degree tapered-gradient apron. When the motor grader was used, the damage to the apron ranked from more to less as follows: 1) the 4 cm-high stepped apron, 2) the 2 cm-high stepped apron, 3) the step-and-gradient apron and 4) the 7-, 9- and 11-degree gradient aprons.

When geometric design and winter maintenance are planned for roundabouts in cold, snow regions, one should consider the combinations of snow removal machinery and truck aprons.
CONCLUSIONS

(1) Flow rate of traffic entering the circulatory roadway and flow rate of traffic on the circulatory roadway under snowy conditions

On the single-lane roundabout at the Tomakomai Test Track, in order to calculate the traffic capacity under snowy conditions, vehicle gap parameters were measured. The experimental conditions were the compacted-snow road surface, the road surface of compacted snow spread with crushed stone as abrasives, and dry pavement. Three vehicle gap parameters were measured: critical time gap $t_c$, follow-up headway time $t_f$ and minimum headway time of traffic flow on the circulatory roadway $\tau$. The time for each of these three parameters decreased when the roadway condition changed from compacted snow to compacted snow spread with abrasives, and from compacted snow spread with abrasives to dry pavement.

The values of vehicle gap parameters for each case obtained by this experiment were introduced into Equation (1). The flow rate of traffic entering the circulatory roadway of the roundabout was estimated. The flow rate at the entry at the time of compacted snow was found to decrease by about 300 vehicles/h compared with the dry road condition. Applying abrasives to the compacted snow road surface was shown to mitigate that decrease to only 150 vehicles/h. The flow rate in Japan is calculated by multiplying the flow rate of traffic entering the roundabout (determined by Equation 1) by the safety factor of 0.8. Equation one gives the German parameters.

The graphs of the flow rate of traffic entering the circulatory roadway and the flow rate of traffic on the circulatory roadway with dry pavement (Case 3) are very similar to those graphs obtained by the Japanese equation. In this experiment, the vehicle gap parameters were collected by using experiment subject drivers who were new to driving on a roundabout. Therefore, the vehicle gaps are thought to be slightly large. For all the ranges of flow rate, the flow rate of traffic entering the circulatory roadway estimated by using our data was about 200 vehicles/h lower than that estimated using the German formula. It is thought that, in future surveys, vehicle gaps on the roundabout will be measured by using test subjects who are used to driving on roundabouts, the vehicle gaps on the roundabout will be smaller, and the estimate of traffic flow rate on the circulatory roadway will be close to that obtained by the German formula.

This experimental result shows that, under snowy conditions, the flow rate of traffic entering the roundabout decreases by between 1% and 30% as compared to the dry road surface.

The results of this experiment were based on measurements on the roundabout of the experimental road section. Snow removal and road surface management (i.e., the use of anti-freezing and anti-skidding agents) will be indispensable for minimizing the impact of snowfall.
and for appropriately operating roundabouts in winter on roads in service.

(2) Impact of snow removal operations on truck apron structure
Tests were made on three types of truck apron structures at roundabouts: 1) the conventional step apron with heights of 2 to 6 cm; 2) the step-and-gradient apron and 3) the gradient apron with inclination angles of 7 to 13 degrees. The snow removal vehicles were a wheel loader and a motor grader. Through experimental snow removal, the height of remaining snow and the severity of damage to the truck apron were measured.

The step-and-gradient apron and the gradient apron had less snow remaining after mechanized snow removal than the normal stepped apron had. This study suggests that a motor grader that is able to adjust the horizontal angle of its blade is able to maintain good contact between the blade and the apron surface during snow removal.

In areas of extreme snowfall, snow removal operations need to include the apron portion and the circulatory roadway. Considering this fact, it is necessary to plan the snow removal work program such that it considers the following special conditions: the width of the snow removal machinery (the blade), the type of snow removal machinery, and the roundabout geometry (the circulatory road width and the truck apron width and height).

In a region of heavy snowfall, there is a high risk of damage to the truck apron edge. To reduce such damage, it is considered possible to select the step-and-gradient apron or gradient apron.

(3) Planning and management of roundabouts in cold, snowy regions
In planning roundabouts in cold, snowy regions, one must fully understand the winter weather conditions, such as snowfall and low temperature. Due to slippery winter road conditions, such as compacted snow, the traffic capacity of the roundabout is reduced.

To mitigate the adverse effects of winter road conditions on roundabouts in cold, snowy regions, it is essential to plan and design roundabouts whose structure makes them suited to snow removal, and to keep appropriate management and snow removal operations. More specifically, it is important to maintain the roadway such that is it less slippery, such as by spreading abrasives. Snow removal operations also damage the truck apron edge. To reduce such damage, the apron structure needs to have some integrity, such as that of a stepped-gradient apron or a gradient apron that is less prone to damage from snow removal machinery.

At CERI, we are working to test research on snow and road structure. In the future, we intend to continue to engage actively in research in order to solve problems caused by snow.
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