Reducing Icy Conditions Over Bridges, Through Passive Means

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Abstract

Icy road conditions are a major cause for car crashes. 70% of all roads in the United States are located in icy regions, and winter and snow related maintenance account for 20% of the roads maintenance budgets (FHWA, 2017), Snow also reduces the average road speed by 30 to 40% on roads. More than 450 people are killed each year in the United States due to icy conditions on roads (icyroadsaftey.co, 2015) of which more than 10% of these deaths are caused by accidents over icy bridges. Due to this, many innovative systems have been designed and used to prevent bridge icing. Most of these systems either use heat sources to heat the bridges' surfaces or chemical spray to melt the ice that forms over bridges. Unfortunately, these systems are usually costly and require regular maintenance. Many researchers contributed bridge icing to the fact that bridges are suspended above ground resulting in bridge surfaces to freeze before adjacent roads, thus bridge decks lose heat from both the top and bottom surfaces while roads gain some heat from their contact with the ground. However, field monitoring and building simulation showed that the thermal properties of bridge surfaces are the true determining factor as to why bridges freeze before adjacent roads. Furthermore, icy bridge surfaces become dangerous when 1) the bridge's surface reaches freezing point before adjacent roads, and 2) the existence of water or

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snow over bridges when adjacent roads are dry (preferential icing). This research presents literature review related to bridge freezing. The research also used field observation of a 175-mile highway section during a snowstorm to investigate icing conditions over bridges. This research revealed that while bridges might freeze before roads during early night hours, dangerous icing formation over bridges occurs when snow is shoveled against the bridges' parapets after snowstorms. Thus, when air temperature rises above freezing, the snow melts and the water runs over the bridges' surfaces. When temperature drops again below freezing later at night, water can freeze over bridges and create dangerous icy conditions. This research suggests that a combination of applying paint with higher absorptive and lower emissive materials over bridges, along with better snow removal practices, will reduce the dangerous icy conditions over bridges significantly.

Keywords; Bridge Icing, Heat Transfer, traffic accidents, field mentoring, simulation

Introduction

Bridge freezing is a major cause of fatal traffic accidents. Traffic accidents related to icy conditions account for approximately 4% of the total accidents in some states (PenDoT, 2012). During major snowstorms, drivers are aware of the dangerous road conditions and drive cautiously; however, roads become dangerous when parts of them are dry and relatively safe to drive on while other parts, such as bridges, are icy (preferential icing). Bridges are usually more vulnerable to icing before roads, because some bridge surfaces freeze before the adjacent roads. The use of salt and sand is the prevailing method to prevent icing over bridges. However, salt has adverse effects on concrete bridges and also increase cars' body corrosion. In addition to the large cost of application, salt and sand are usually sprayed when the roads are still accessible and on anticipation of ice or snowstorms that might not happen. Another shortfall of using salt is when there is rain followed by freezing conditions is that the salt cannot be sprayed during the rain because it will be washed away before water starts to freeze over roads. Also, during major storms, snow is cleared from roads and bridges alike. However, sporadic ice patches on roads and bridges (black ice and preferential icing) are a major concern because it might not be practical to locate these spots and remove them using salt and sand.

The combination of water or snow accumulation and pavement freezing temperatures are what make icy roads hazardous. These conditions happen more frequently over bridges. Many methods were introduced to increase the bridge surface temperature above freezing. These methods include inserting heating elements inside the bridge deck structure. In a study of heated bridge deck surfaces in five states, Minsk indicated that although the systems were efficient in melting snow over bridges, several maintenance and cost factors are major concerns when using these systems (Minsk, 1999) , Another system is based on using ground source heat pipes to de-ice bridge surfaces. Lund used the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) design criteria to design a geothermal heat source to heat bridge decks. Polyethylene pipes, thermal heat exchangers and thermal storages where used to circulate water underneath bridge pavement. Although this system uses passive heating sources, it is a complex system, which requires periodic maintenance (Lund, 2009). Other systems include adding a porous asphalt layer to the bridge and circulating a heated fluid through it, or monitoring and applying antifreeze agent on bridge surfaces (Asfoura, 2016). Some systems use automated antifreeze spray over bridges at critical road areas (Zhirui, 2013).

Several bridge designs use rough bridge surfaces to improve friction and reduce accidents over them. However, a study by Dave on accidents for 9 years of records for bridges in Minnesota showed that rough surfaces did not reduce accidents related to icy conditions (Dave, 2016). The study suggested that when bridges freeze, rough bridge surfaces tends to trap more water and will freeze later when temperature drops below freezing.

Most of treatments for bridge icing focused on heating bridge surfaces or using chemicals to melt the ice over bridges. None of these treatments used a holistic approach that looks into the different factors that create dangerous icy conditions over bridges, and how to eliminate them using passive means with minimal cost. Several field studies and simulation models were developed to predict the freezing conditions of roads, and also predict the effect of adding anti-freezing agents (salt) to water and ice films over roads. These studies also investigated the effect of passing vehicles on dispersing water over roads: In his study, Fujimota, et al. developed a model to predict the thickness of water and ice films over pavements before and after applying anti-freeze agents (salt) to roads. The study showed a linear correlation between the thickness of the water film over roads and roads surfaces' roughness, and the traffic volume. This study showed that the thickness of a water film is less over roads on main tracks than in lighter traffic areas (Fujimotoa, 2014). Abaza and Connie investigated the effect of bridge surface properties on its surface temperature, and compared it to adjacent roads. The field tests and thermal simulation showed that regular concrete surfaces of bridges has a solar reflectancy of 0.72, with a transmittance of 0.9. After applying a special paint of 0.37 emissivity and 0.66 reflectancy on the bridge's surface, the bridge's surface froze less frequently than the adjacent road as shown in Figure 1-a and Figure 1-b (Abaza, 2006).

This study showed that before applying a low-emissivity coat over the bridge surface, the bridge surface reached the freezing temperature for 1509 hours for the entire year while the adjacent road reached the freezing temperature for only 1010 hours for the same period. This suggests that bridges' surfaces are reaching the freezing point for 499 hours more than the adjacent road. The researcher then applied a low-emissivity pant. The bridge surface temperature reached the freezing point for 940 hours only during the same period. This suggests that bridge surface temperature can be improved to match the adjacent roads and even reach the freezing temperature in less hours that the adjacent roads.

The simulation results also revealed that surface properties are the determining factor of the bridges and the road surface temperature. The researcher also found that the ground temperature under the road did not have a significant effect on the roads' surface temperature. These results are significantly deviating from the prevailing perception that bridges' surfaces freeze more often than roads because of the heat loss from the bottom surface of bridges.

In his paper about monitoring surface freezing of a bridge in Japan, Suzuki indicated that the field readings showed that a strong correlation between the bridge surface temperature and the solar radiation that hits the bridge surfaces, while the drop of the bridge's surface temperature was due to the long wave radiation heat loss. In this study, both bridge and adjacent roads have the same surface material (bituminous asphalt). The field temperature readings however showed small temperature variation on the bottom of the bridge. These results correlate with Abaza's previous results. The field results of this research also indicated that when the road and the bridge surface are covered with snow, both the road and the bridge surfaces have similar surface temperatures. Also, during cloudy days, the bridge surface and the bridge deck structure temperature are very close to that of the outside air temperature, but during a clear sky night with a higher wind speed, the bridge surface temperature was approximately 4 degree C below the outside air temperature. Another discovery provided by the study was that during freezing temperatures, higher wind speed reduce the bridge surface temperature during the day when solar radiation was strong and makes the bridge surface temperature less than that of the adjacent roads, However, during the night, higher wind speed over bridges, increasing the bridges' surface temperature to be close to the outside air temperature (which is higher than the bridge surface temperature). These results stressed the fact that bridge surface emissivity is the main factor in determining the bridge surface temperatures. This study also specifically indicated that the surface temperature at the bottom of the bridge was higher than the top of the bridge and also higher than that of the outside air temperature. The researcher indicated that heat loss from the bottom of the bridge was only 20% of that from the top of the bridge (Suzuki, 2007).

The above studies suggested that temperature differences between the bridge's surface and the adjacent roads are due to the bridge surface properties and weather exposure and not necessarily due to the heat loss from the bridge bottom structure compared to the road. Moreover, both studies showed that there are few hours after sunset and early in the morning where the bridge surface temperature is below freezing while adjacent road's surface temperature is above freezing. Thus, icy conditions can occur above bridges before adjacent roads. These times are the most critical for road hazard, when the low temperature is combined with wet surfaces.

Methodology

During a major snowstorm in North Carolina and the Northern part of Georgia, a 175 mile segment of the Intestate highway I-85 was surveyed. 660 pictures were taken along these roads at locations before bridges, on the middle of the bridges and at the end of the bridge. These pictures were taken during the late evening hours and the early morning hours after a major snowstorm. During the survey, air temperature reached 7C° during the day hours, and -5C° late at night. The pictures were tabulated into four categories related to road conditions; 1) snow accumulation over roads and bridge surfaces, 2) snow accumulation over bridge surfaces but not on adjacent roads 3) snow accumulation over bridges' sides and roadsides, and 4) snow accumulation over bridge sides but not on road sides. We also documented locations where water from overpass bridges seeped down over the roads below. Outside temperatures were recorded during these periods.

Results

This study focuses on determining the reasons for ice formation over bridges more frequently than adjacent roads (preferential icing). Since the bridges' surface temperatures had already been covered in previous research, this paper focuses on the reasons for water accumulation over bridges more frequently than adjacent roads when facing icy conditions. The results of this research are based on field surveys of roads near bridges and over bridges. The research results can be summarized as follows:

1- The number of locations where snow was present on bridges' shoulders, shoulders of roads approaching the bridges, and the adjacent roads (within 300 m of roads approaching bridges) were 76%, 64%, 53% respectively (Figure 2). Only 2% of all the pictures showed snow on both bridges' surfaces and roads surfaces. This is due to the fact that most pictures were taken at the end of the snowstorm where most snow was already removed to the sides of roads. More snow was observed over bridges because snow was piled up against the bridges' parapets. It should be pointed out that during the study, daytime temperature reached 7C°.

2- Water that seeped over bridges' surfaces was found on 68% of all taken pictures, compared to only 14% over adjacent roads. Most of this water came from the melted snow over the bridge because the snow was removed to the sides of the bridge, and piled up against the bridge parapets (Figure 4). Unlike roads where shoulders are lower than the road itself, most bridges' surfaces have gentle cross slope and have same-level shoulders. When the piled up snow melts, water seeps over the bridge's surface especially on bridges with a one-direction cross slope. However, road shoulders are usually lower than the road surface, and when the shoveled snow melts, is seeps towards the soil embankment and is absorbed there (Figure 5).

3- Traffic during day hours was heavier than that of night hours. As a result, roads were drier during the day because melted snow water is dispersed by heavy traffic. However, during early night hours, the air temperature drops below freezing, and traffic on roads becomes lighter. The melted snow water on bridges seeps towards the middle of the bridge and become dangerous ice starting from the sides towards the middle of the bridge's cross section. We have recorded 49 locations were water from melted snow was on the roads' surface when temperatures were below freezing. Thus, water is more likely to become ice and cause road hazard.

4- While this study recorded significant numbers of locations where melted snow water reached the bridge's surface and froze there, similar conditions were also recorded on roads with a super elevations cross sections (Figure 3). On these locations, Snow was piled on the side of the road and the melted snow water seeped towards the middle of the roads and froze there. Thus, the hazardous combination of water and freezing temperatures also exists on some roads.

5- The study showed that most locations where melting snow water seeps on the bridges or roads' surfaces are on roads with one-direction sloped cross sections. Thus, cars' centrifugal forces make accidents more likely to occur. This was also noticed in reviewing many car accident reports and videos (Icy roads, 2016).

6- It should be noted that several research and design considerations were made to make sure water would not accumulate over bridges' surfaces (GKY, 1992). However, snow piling on bridge parapets more likely to block storm water outlets, and makes melted snow water seeping on bridges' surfaces.

7- This study did not address icy rain or icy conditions during major storms where both roads and bridges experience icy conditions. Although these conditions are dangerous for driving, it is also true that drivers are aware of these conditions and act accordingly.

Conclusion

This study addresses the cause of dangerous icy conditions over bridges. The common assumption is that the bridge surface reaches freezing temperature faster than the approaching roads because bridges are not built over soil and lose heat from top and bottom surfaces. However, several field studies and computer simulation that are presented in this paper suggested that the main reason for bridge surface freezing is contributed to the surface conditions and properties of bridges. In addition, this paper suggests that while freezing temperature of bridges set the condition for dangerous ice formation over bridges, water over bridges during freezing conditions is what completes the dangerous cycle. The field study showed that during snowstorms, melting water from snow is the main source of ice over bridges and other roads with similar conditions. This study suggests that reducing the risk of ice over bridges can be greatly reduced by better snow cleaning practices over bridges. Snow should be removed from the bridge shoulders and should not be piled up against the bridge parapets. Thus, melting water will not seep towards the bridges or road surfaces and freezes later. Also, a combination of applying high solar absorption/low emitting paint over bridges, as suggested in previous research (Abaza, 2007), will raise the surface temperature of bridges' to levels similar to that of adjacent roads especially during early hours of the night. Another measure that should go hand in hand with this is to improve bridge surface drainage, and implement better snow removal practices, which will significantly reduce the risk of icy conditions over bridges.

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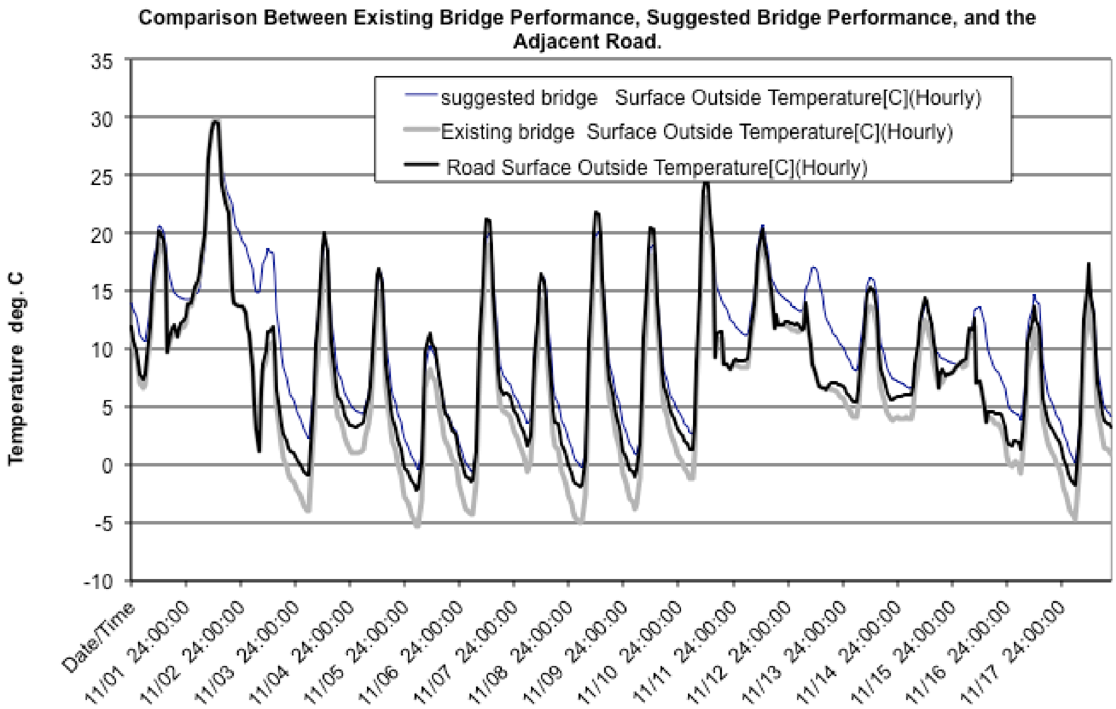

Figure 1-a . *Comparison Between Existing Bridge surface temperature, adjacent roads to bridges, and bridge surface temperature with improved surface properties (Source, Abaza, 2006)*

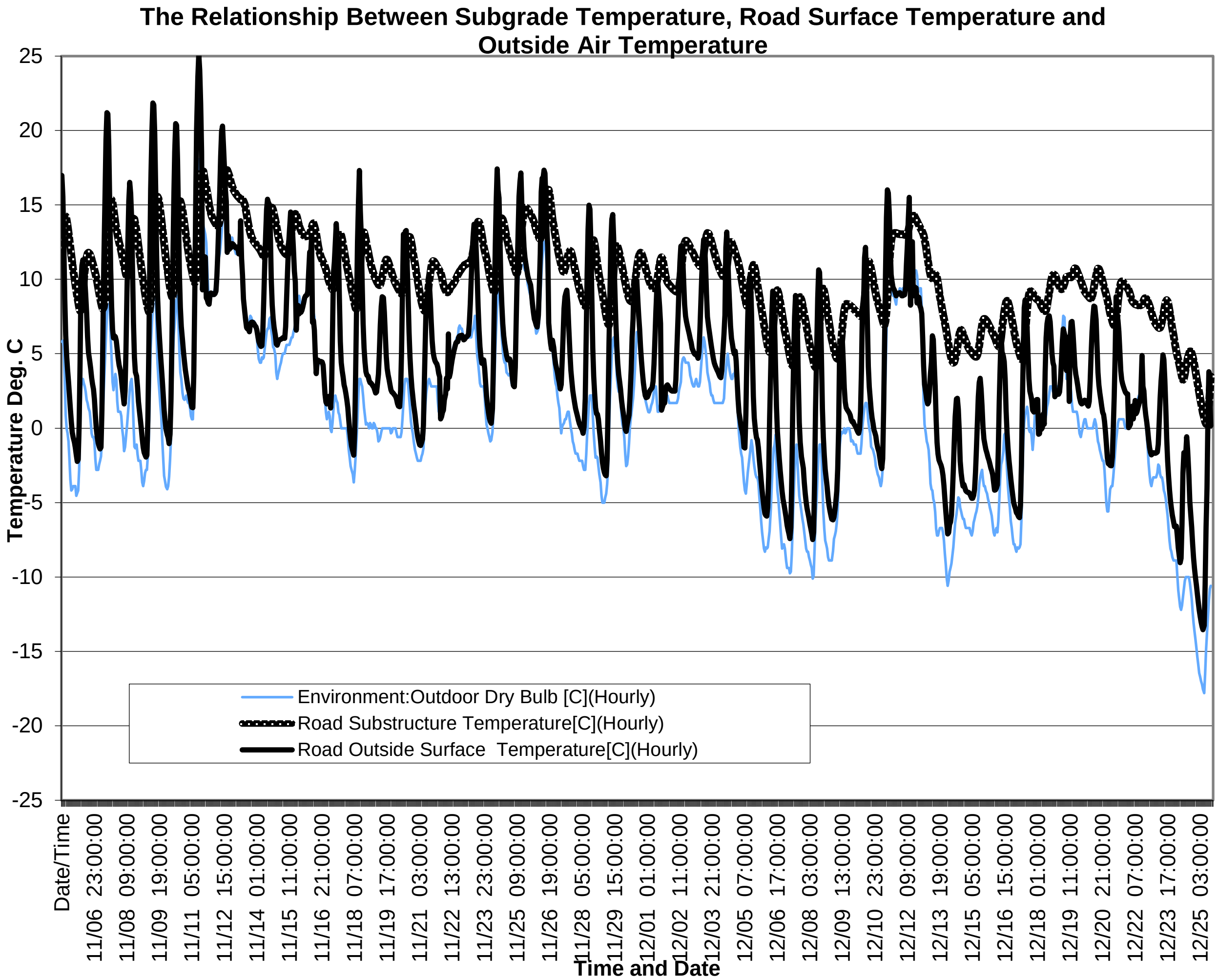

Figure 1-b . *Comparison Between Existing Bridge surface temperature, adjacent roads to bridges, and bridge surface temperature with improved surface properties (Source, Abaza, 2006)*

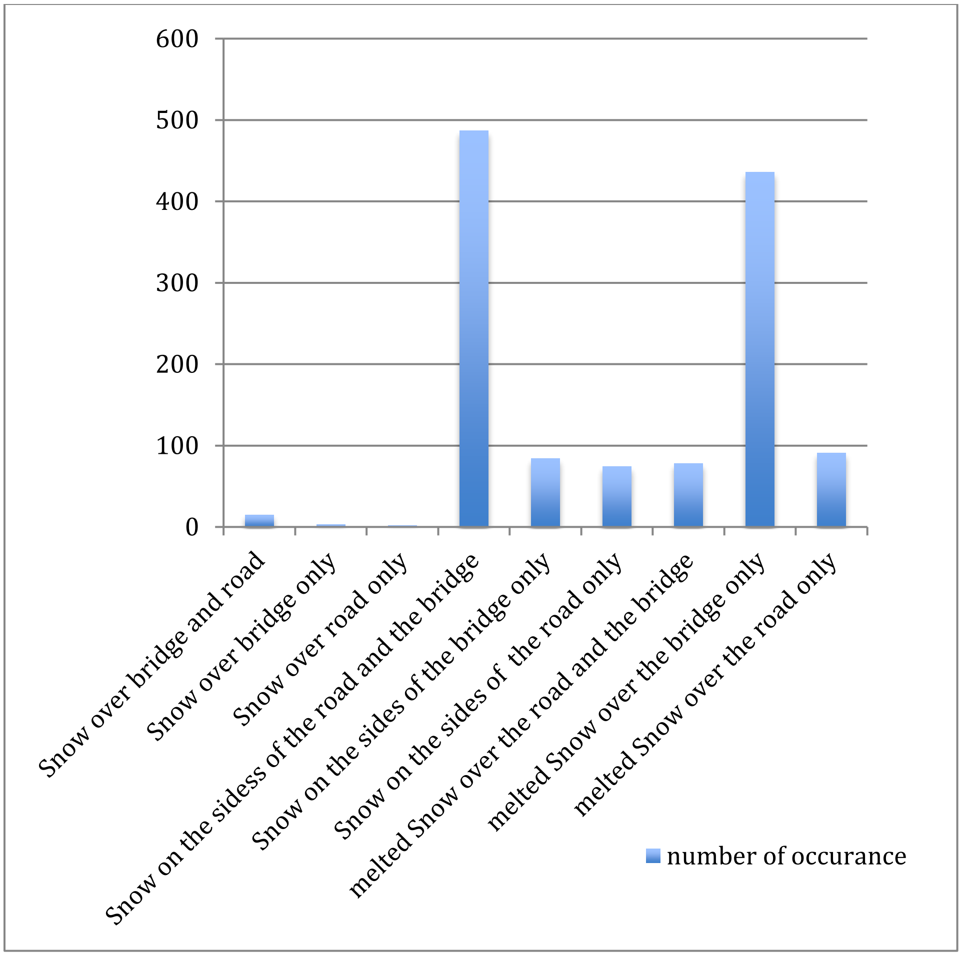

Figure 2: Numbers of Snow accumulation that were observed over bridges and roads after snow storm.

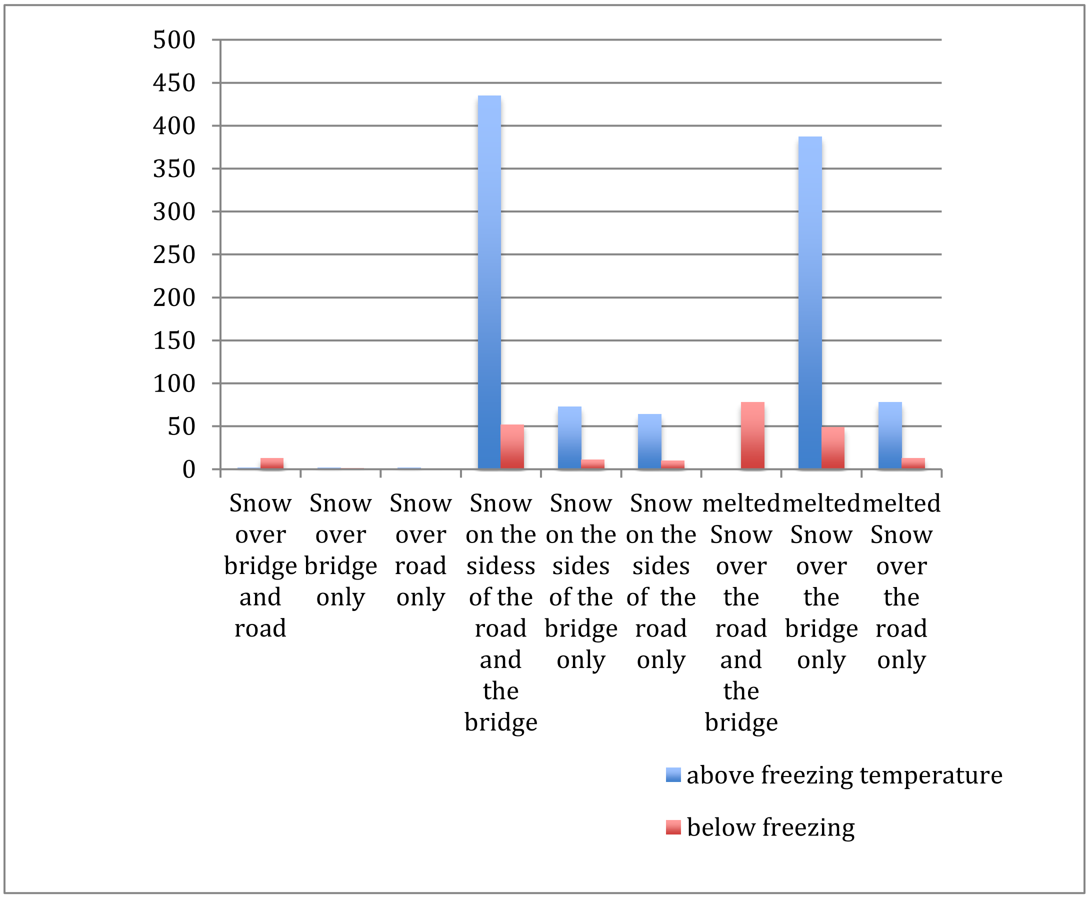

Figure 3: number of incidence with above and below freezing temperatures over roads.

Figure 4: A typical melting snow water seeping over bridge surface during afternoon hours.

Figure 5: Snow removed to the side of the road. Melted snow is absorbed by soil.

Figure 6: Melted snow water runs over roads on areas with one side cross section sloped roads.

Figure 7: melted snow water is collected on road from an overpass bridge