Development of Spring Load Restrictions on County Roads: Rio Blanco County Experience

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ABSTRACT

Rio Blanco County is located in the rural northwestern corner of the State of Colorado. Recently, there has been a significant increase in the truck traffic on the county roads, due to increased oil and gas exploration activities. The presence of such heavy trucks has raised concerns about the impact of additional truckloads on the pavement conditions of the county roads, particularly due to the seasonal variation in the subgrade soil conditions as a result of temperature variation.

A study was initiated to develop short term Spring Load Restrictions (SLR) guidelines for Rio Blanco County for the spring 2007. This study was based on deflection testing and was successfully completed by late spring 2007. The results from this study were further validated using data collected from sub-surface instrumentation used as part of the on-going Phase 2 of the study to develop long term SLR guidelines for the County.

In spring 2007, the start of the SLR was estimated using a combination of deflection testing and Thawing Index (TI) model. In this approach, the TI model from Minnesota DOT was adopted to define the expected time frame of the start of the spring thawing. Deflection testing was then performed during this time to examine the actual decrease in strength of the pavement structure and thus define the appropriate start of the SLR on the County roads.

The end of the SLR was estimated again based on deflection testing to monitor the pavement condition. The deflection data collected during this project showed that the subgrade soils in the study are susceptible to a reduction in structural strength during the spring thaw season. Additional deflection testing cycles were completed to determine when the pavement regained its strength.

Validation data from the sub-surface instrumentation showed that the TI model might be acceptable to define the start of the SLR based on the forecasted weather conditions, while monitoring moisture content exclusively might not be adequate for determining when SLR can be lifted unless more historical data exists for comparison.

In this paper, the development of the short term SLR policies for spring 2007 for Rio Blanco County is presented, together with the validation of the results of this study using data collected during spring 2008.
INTRODUCTION

Rio Blanco County is located in the rural northwestern corner of the State of Colorado. Due to the geographical and environmental conditions of the County, the air and pavement temperatures vary across seasons, with significant daily temperature changes. Recently, there has been a significant increase in the truck traffic on the county roads, due to increased oil and gas exploration activities. The presence of such heavy trucks has raised concerns about the impact of additional truckloads on the pavement conditions of the county roads, particularly due to the seasonal variation in the subgrade soil conditions as a result of temperature variation.

Freezing and thawing of subsurface soils is a common occurrence in cold regions, which may result in significant damage to roadways. It has been documented that freezing and thawing results in hundreds of millions of dollars in damages to roadways throughout the United States (1). As spring time thawing takes place, the weakened subgrade soils are susceptible to damage caused by vehicles carrying heavy loads due to water in the soils trapped between the road surface and the frozen subsurface. Highway agencies attempt to mitigate this damage by various means including placing load restrictions on roads, such that the reduced axle loads applied to the pavement surface are within the pavement bearing capacity during these weakened conditions (2).

Spring Load Restriction (SLR) policies limit the axle loads of heavy trucks during the spring thaw period. SLR policies have been implemented in many cold climate countries, including the United States, Canada, France, Norway, Finland, and Sweden. In the United States, more than 20 states have implemented spring load restrictions, while all the provinces in Canada are subject to spring load restrictions (3). The policy aims to reduce pavement damage and extend the useful life of roads, which enables road authorities to save on maintenance costs.

The primary concern with load restriction placement is recognizing the right time to put them into place such that the impact to commercial traffic is minimized while the structural integrity of the roadway is maintained. From a structural perspective, the annual thawing of many subgrade soils causes a significant reduction in pavement load carrying capacity such that the hauling of goods at normal load levels imposes additional damage that would not be observed if no thaw weakening was present. However, load restriction has significant financial implications to the movement of goods and services during the annual thaw. It is also recognized that the SLR policy brings additional cost to some road users due to detouring or increased number of truckloads.

Several techniques are being used by various agencies to define the SLR policies. However, since the thawing patterns can vary significantly due the localized environmental conditions and subgrade soil types, any technique adopted by any given agency should be based on its local conditions. Rio Blanco County has some unique attributes such as the relatively high elevations and the possibly different subgrade soil type in the mountainous area. Although these conditions might be common throughout the Rocky Mountains and other mountainous regions, very few studies have been conducted in dry-freeze climates, particularly at altitude. As a result, a study was initiated in early in 2007 to develop guidelines for SLR policies in the County based on local conditions for spring 2007 and beyond.

Due to the relatively late start of the study, the study was divided into two phases. Phase 1 was a short term study designed specifically to develop guidelines for SLR for the 2007 spring season only on specific county roads, based on deflection data and weather conditions. Phase 2 was designed to develop long term SLR policies for the countywide roads. It involved
instrumentation of representative pavement sections within the study area in the fall of 2007 with monitoring ongoing through the summer of 2009. The instrumentation included temperature and moisture probes to collect air and pavement temperatures, and soil moisture levels. In addition, deflection testing is performed to monitor the changes in the pavement strength throughout the study period and to evaluate the normal (benchmark) pavement structural strength.

In this paper, the development of short term SLR policies (Phase 1 of the study) for Rio Blanco County is presented, together with the validation of the results of this study using data collected during spring 2008 as part of Phase 2.

**SPRING LOAD RESTRICTIONS BACKGROUND**

A study to define SLR policies should address when to start and when to end the SLR, and what load levels are allowed during the SLR period. Several techniques are being used by various agencies to define the SLR policies, especially to define the start of the SLR. The techniques are mainly based on deflection testing or on analytical models. When deflection testing is used, a testing program is set to test the pavement on regular basis in order to detect the start of the thawing of the subgrade soil.

As soon as the weakness is detected, the SLR is instated. Analysis models are usually based on establishing a relationship between the weather trends and the start of the subgrade thawing. These models are created from historical data for the road conditions and the weather patterns.

Some authorities in the United States have implemented the use of the Freeze Index (FI) and Thaw Index (TI) concepts, which are measures of the duration of below and above freezing temperatures. As an example, studies performed at the Washington DOT have shown that it is possible to estimate the start of the thaw period based on the date when a particular level of TI is surpassed. This approach is also used by Minnesota DOT (3).

Ending the SLR is primarily based on deflection testing, since the restriction needs to stay instated until the subgrade soil has regained its strength after the excess thawed water trapped in the soil has adequately drained. However, some agencies use a pre-defined closure period, which may range from 4 to 10 weeks.

The allowable load level during the SLR period is dependent on the local soil conditions and the pavement structure. Therefore these levels have to be defined based on the deflection testing results during normal subgrade conditions (summer conditions) and weakened load conditions (spring conditions).

**SHORT TERM STUDY – SPRING 2007**

Figure 1 shows the approach used in this Phase, where a critical period for the start of the thawing period was defined based on a literature survey of other agencies, the historic weather patterns of the study area, and the monitored weather conditions, forecasted and observed. During this period, regular deflection testing is performed on representative sections on the roads to identify possible structural weaknesses due to thawing. As soon as any weakness is detected, the SLR is enforced. Based on the deflection data collected, the allowable load levels during the SLR period are determined. The same process was later repeated to detect the subgrade strength gain and when to lift the SLR.
The start of the SLR was estimated by first using the Thawing Index (TI) model from Minnesota DOT and the forecasted weather conditions in the study area to define the expected start of the SLR. Although this model was developed for a different region, it was used as a guidance to estimate the start of deflection testing period, which was then carried out during this time period to examine the actual decrease in strength of the pavement structure, such that the SLR was started as soon as the subgrade weakness was observed. The end of the SLR was estimated based on deflection testing, with three deflection testing cycles completed to estimate when the pavement regained strength.

**Thaw Index Model**

The TI model used by Minnesota DOT (5) was adopted and used to define the time period when the spring thawing was expected to happen in Rio Blanco County. The Thaw Index (TI) shown in Equation [1] represents the positive cumulative deviation between the mean daily air temperature ($T_{\text{mean}}$) and a reference freezing temperature ($T_{\text{ref}}$) for successive days.

$$TI = \sum (T_{\text{mean}} - T_{\text{ref}})$$

[1]

Based on historical records in Minnesota and further research by the Department, a TI value of between 10 and 25°C-days (18 and 45°F-days) signaled the beginning of the load-restricted period. In 2000, a comprehensive review of additional records and data was conducted and Minnesota DOT further refined the TI equation to include the use of a variable reference temperature initially set at -1.5°C (29.3°F) on February 1st and increasing by 0.56°C (1°F) each week in February and March to account for additional pavement warming from solar radiation (5).
Sections Selection

Representative sections on the main county roads within the study area (the County) were selected for monitoring. These sections were selected on County Roads 5 and 7 (CR-5 and CR-7). CR-5 is an undivided two lanes road with an approximate length of 67.5 km (42 miles). It starts at the east end at an elevation of 2190 m (7,200 ft), and ends in the north at an elevation of 1770 m (5,800 ft). CR-7 is also an undivided two lanes road, with an approximate length of 32 km (20 miles). It starts at its south end at an elevation of 1830 m (6,000 ft), and ends to the north at an elevation of 1950 m (6,400 ft).

The selected sections were distributed along the length of the roads. In total, 5 sections were selected for the project; 3 sections on CR-5 and 2 sections on CR-7. Each section was 152 m (500 ft) in length and was further subdivided into 15.2 m (50 ft) subsections. The sections were clearly marked to ensure that the successive deflection testing cycles are performed at exactly the same testing locations.

Weather Data

The weather data collected for this study was primarily temperature data that included historic data, in addition to forecasted temperature data and actual recorded daily temperatures. The historic data was analyzed to define the window for the possible start of the spring thawing based on the TI analysis. The forecasted data was used to estimate the start of the deflection testing.

Historic Weather Data

Historic temperature records for the study area were downloaded from the National Oceanic and Atmospheric Administration (NOAA) databases, through the Long Term Pavement Performance (LTPP) web site (7). Daily temperature data for 23 years, starting 1980 through 2002, were available. This data was extracted and analyzed to identify the expected start date of the subgrade thawing. As mentioned earlier, based on the model, the start of the spring thawing is expected when the TI ranges between 10 and 25°C-days (18 and 45°F-days).

Figure 2 shows the historic possible start dates of thawing. The dates shown in the figure represent the dates when the TI reached a value of 10°C-days (18°F-days). The darker line in the figure indicates the first time in the season the TI value reached 10°C-days, while the light-colored lines indicate that the TI decreased within that year and then increased again to reach the 10°C-days again within the same year. As an example, in 1983 the TI reached 10°C-days on Feb 18th and did not go below this value again, while in 1988, historic records show that the TI reached 10°C-days on Mar 1st, then the temperature cooled down and the TI reached that same value again on Mar 18th. Based on the historic records analyses, the spring thawing could be expected to start in the County on any date between Feb 11th and Mar 21st.
Daily temperature data was monitored online (8, 9) and used to calculate the TI over the analysis period using Equation [1]. Figure 3 shows the TI calculated based on the forecasted and actual mean daily temperatures in the study area. The forecasted TI was used to estimate the appropriate time frame for performing deflection testing in order to start the SLR. The actual TI was monitored to ensure the accuracy of the forecasted TI and to be used for future studies. It should be noted that data shown in the figures were collected on a daily basis. Therefore, at any given day, it was not possible to estimate how the temperature would change beyond the long term 10-days forecast.

Based on the forecasted temperatures in 2007, the start of the spring thawing could have occurred between Feb 10th and Feb 13th, between Feb 22nd and Feb 24th, or any day after Mar 5th. However, based on discussions with the County and the forecasted temperature data, it was decided to ignore the first window, since it was very early in the season, as compared to historic records. Actual deflection testing started on Feb 17th to identify the possible start of spring thawing based on actual field measurements, since the TI model was not calibrated to the conditions of the County.
Deflection Testing

Deflection testing was performed using a Strategic Highway Research Program (SHRP) calibrated Falling Weight Deflectometer (FWD). Deflection data was recorded using 9 sensors for three load levels at each testing location. Each section was tested at a 15.2 m (50 ft) interval, with a total of 11 testing points within each section. Deflection testing was completed on 12 different days on each section, divided into four different cycles as shown in Table 1. The objective of deflection testing cycle is also shown in the table.

Table 1 FWD Testing Cycles

<table>
<thead>
<tr>
<th>Cycle</th>
<th>Start Date</th>
<th>End Date</th>
<th>Number of days</th>
<th>Objective</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cycle 1</td>
<td>02/17/07</td>
<td>02/22/07</td>
<td>6</td>
<td>Estimate start of spring thawing</td>
</tr>
<tr>
<td>Cycle 2</td>
<td>03/21/07</td>
<td>03/22/07</td>
<td>2</td>
<td>Estimate end of spring thawing</td>
</tr>
<tr>
<td>Cycle 3</td>
<td>04/01/07</td>
<td>04/03/07</td>
<td>3</td>
<td>Estimate end of spring thawing</td>
</tr>
<tr>
<td>Cycle 4</td>
<td>04/20/07</td>
<td>04/20/07</td>
<td>1</td>
<td>Confirm end of spring thawing</td>
</tr>
</tbody>
</table>

Cycle 1 was the longest cycle and it lasted for 6 days. The main objective of this cycle was to confirm the start of spring thawing using deflection testing, while the other cycles had the objective of estimating the time when the pavement would regain its strength after the moisture trapped within the pavement structure had drained away.

Figure 4 and Figure 5 show the average normalized deflection, with no temperature correction, readings for deflections D1 and D5 for sections S-501 through S-702, respectively. In the figures, each data point represents the average of 33 readings (11 testing points and three load levels). D1 is the deflection measured at the center of the load plate and is a good indicator...
of overall pavement strength. D5 is measured at a distance of 0.61 m (24 in) from the center of the loading plate, and based on the thickness of the pavement structure in the sections considered in the analysis; it can be used as an indicator of the subgrade strength.
It should be noted that deflection data, rather than backcalculation results, was used to define the starting and ending of the SLR since it was measured data that did not include any approximation or analytical assumptions that could be used for the backcalculation process.

**Implementation of the Load Restriction**

As can be noted from the figures, the results show that the deflection values on Feb 17th were relatively low for all sections, and these values started to increase over time. The sections on CR-5, with the exception of S-501 showed no significant decrease in strength (increase in deflection), until the second testing cycle (March 21). Section S-501 did not show any decrease in strength throughout the study period, while both sections on CR-7 showed a significant reduction in strength by Feb 21st or Feb 22nd.

**Starting the SLR**

Based on results shown in the previous figures and the TI data, three options were available for the County after the end of the first testing cycle (Cycle 1). These options were:

- Start the SLR on both CR-5 and CR-7
- Start the SLR on CR-7 and monitor TI for CR-5
- Do not start the SLR and monitor TI

Based on discussions within the County, it was decided to delay the start of the SLR and monitor the TI until it reaches a critical value, since CR-7 is subjected to relatively less traffic than CR-5. As shown in Figure 3, the TI was forecasted to start increasing during the week starting March 5th, and as a result the County decided to start the SLR on Mar 5th, 2007 for the 2007 spring season.

**Ending the SLR**

Again, based on the data shown in the previous figures, some of the sections seemed to have regained some strength during the Cycle 3 or Cycle 4 of the data collection cycles. However, due to the fact that there were no previous records of benchmark strength of the pavement during summer time, it was not possible to definitely identify when the pavement had regained its strength. It should be noted also that the deflections measured on Feb 17th were performed when the pavement was in a frozen state, where the pavement would appear stronger than its normal state. Based on these results and following discussions within the County, the County decided to lift the SLR by the second week of April 2007.

**Allowable Load Levels during SLR**

The approach described in Figure 6 was used to evaluate the allowable load levels during the SLR period. Due to the absence of any historical records regarding the strength of the pavement structure and the expected loss in strength due to thawing, the following were assumed:

- The reference deflections for any sections are the deflections measured on Feb 17th, although the pavement on that day might appear stronger than the summer strength.
- The thawed deflections were assumed to be the deflections measured on Feb 22nd, although the pavement might weaken further during the thawing period.
- The pavement structure for each section was structurally adequate to carry the traffic loads during benchmark conditions, although some of the sections appeared structurally inadequate.
The mechanistic computer programs, EVER Series, developed by Washington DOT (10) were used for the analysis. EverCalc software was used for backcalculation to evaluate the pavement material properties based on the applied load and measured deflections, while EverStress was used for forward calculations to evaluate the stresses and strains within the pavement structure resulting from the applied loads.

VALIDATION OF SHORT TERM PROGRAM

As mentioned earlier, a two-year study was initiated in the fall of 2007 to develop long term SLR policies for the County. This study included the instrumentation and deflection testing of the five sections considered in the short term study over two freeze-thaw cycles/seasons. The objectives of the study included addressing some of the observations in the short study such as defining the actual moisture content for the base and subgrade materials during the spring thawing period, investigating why Section S501 was not affected by the spring thawing, etc. The instrumentation of the sections was completed in the fall of 2007, and deflection testing for the first freeze thaw cycle was carried out during spring 2008. This data was used to validate the results of the short term study.

The instrumentation included temperature and moisture probes to collect air and pavement temperatures, and soil moisture levels. In addition, deflection testing was performed using the same testing protocol followed in the short term study.
The additional data collected in spring 2008 also included weather data, which was used in conjunction with data collected from the instrumentation to confirm the suitability of using the TI equation to estimate the start of the spring thawing in the County.

Although the long term study has not been completed, since another cycle of testing will be carried out during spring 2009, the data collected in spring 2008 was used to validate the SLR policies implemented in 2007 and 2008.

Instrumentation

The five pavement sections considered in the short term study were instrumented to collect data to monitor the effect of daily and seasonal environmental parameters on the pavement response. The critical parameters measured are air, pavement, and soil temperatures at various depths, and moisture content of the base and subgrade material.

Temperature probes and Time-Domain Reflectometers (TDR) were permanently installed in the pavement are used to continuously measure the subsurface temperatures, granular and subgrade materials moisture content. A data logger was installed in an equipment cabinet to automatically record the temperature profiles. The data from the data loggers was downloaded and used in the analysis. An air temperature probe was permanently installed and continuous readings taken through the project duration. This data is supplemented from neighboring weather stations.

Ground Temperature Data

Ground temperatures were monitored by a series of nineteen in-ground temperature probes placed at various depths from just below the ground surface extending to approximately 1.8-m (72-in) below the ground surface. The in-ground temperature data provided information in respect to frozen/thawed subsurface materials. The temperature probes provided information on the progress of the thaw by showing what depth below the surface was above or below freezing and the depth of frost penetration. Figure 7 shows a sample of the observed mean daily temperature data for one of the sections at different depths over February and March of 2008.

![Figure 7 Observed In-Ground Mean Temperatures at various Depths for a Representative Section](image-url)
As can be noted from the figure, starting Feb 20th and for a period of almost three weeks, the subsurface temperature was slightly below 0°C, which indicated that the spring thawing could have started at any given day within this period for that particular section. Overlaying in-ground temperature data from progressive time periods, it is possible to monitor the thawing from both the top-down and bottom-up directions, and when the thawing of the frost is complete. Analysis of all the temperature data for all the sections indicated one of the sections completely thawed by Mar 6th 2008.

Moisture Content Data

Moisture content in the pavement structure and subgrade was monitored by a series of five to six TDR probes placed at various depths from just below the asphalt concrete surface extending into the subgrade. TDR probes work by transmitting pulses from one end of the probe to the other. The amplitude of the pulse, as well as the time it takes to reach from end to end is measured, and is then used to determine the resistance characteristics of the material surrounding the probe.

Moisture content data is important as once thawing is complete the increase in moisture due to the melting of the frost will result in weaker pavement conditions due to lower subgrade strengths. Monitoring the drainage process of the pavement structure and subgrade is used to estimate the date for ending the SLR.

Figure 8 shows the estimated volumetric moisture data with depth collected for a representative section within the study area during March and April 2008. As can be noted from the figure, the moisture content of the soil increased during March and started to decrease by the second half of April.
Deflection testing

Deflection testing, using FWD, was performed in the fall of 2007 to establish baseline strength of the pavement, thus allowing for accurate evaluation of the loss in strength during the spring thaw period. FWD deflection testing in the spring thawing period was used to assess the weakened pavement structure. Testing also followed into the pavement strengthening phase where the pavement structure regains strength and transitions back to the summer/fall baseline.

Discussion

The same approach used for the development of the SLR policies in 2007 was used for 2008, supplemented with the additional data collected using the instrumentation. The start of the SLR was estimated using a combination of deflection testing, TI model and in-ground temperature data. In this approach, a TI model from Minnesota DOT was adopted to define the expected time frame of the start of the spring thawing. Deflection testing was then performed during this time to examine the actual decrease in strength of the pavement structure.

It was observed that the effectiveness of the Thaw Index model from the Minnesota Department of Transportation in predicting the spring thaw depended heavily on the accuracy of the local weather forecast. Based on the experience garnered from this project, the local weather forecast and TI model could only provide an accurately predicted Thaw Index value for up to one week, which is acceptable and this model might be suitable to be used by the county in the future to define the start of the SLR based on the forecasted weather conditions.

The end of the SLR was estimated based on deflection testing and the use of TDR probes to monitor the pavement condition. Additional deflection testing cycles were completed to determine when the pavement regained strength. Deflection data from the thawing and spring period of 2007 were used as bench marks in determining the removal of the SLR in 2008. It should be noted that the moisture content levels in the pavement structures of all instrumented sections did not change significantly with time. The maximum range of moisture contents were 7% to 8% although the average variation was smaller. Therefore, monitoring moisture content exclusively might not be adequate for determining when SLR can be lifted unless more historical data exists for comparison.

SUMMARY AND CONCLUSIONS

This paper summarizes the study conducted to develop short term SLR guidelines for Rio Blanco County for the spring of 2007, and the validation of these policies using data collected from instrumented test sections in the fall of 2008. These guidelines were developed based on weather data and deflection testing of sample sections within the study area.

The start of the SLR was estimated using a combination of deflection testing and TI model. In this approach, a TI model from Minnesota DOT was adopted to define the expected time frame of the start of the spring thawing. Deflection testing was then performed during this time to examine the actual decrease in strength of the pavement structure. The validation data showed that this approach was generally acceptable in defining the start of the SLR based on the forecasted weather conditions.

The end of the SLR was estimated based on deflection testing to monitor the pavement condition. The deflection data collected during this project showed that the pavement structure and subgrade soils in the study are susceptible to a reduction in structural strength during the spring thaw season. Three additional deflection testing cycles were completed to determine when the pavement regained its strength. Validation data from the TDRs showed that the variation in
the subgrade moisture content, although observed, had a relatively small range. As a result, monitoring moisture content exclusively might not be adequate for determining when SLR can be lifted unless more historical data exists for comparison.

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