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Mitigating Frost Heaves and Dips Near Centerline Culverts

The purpose of this TRS is to serve as a synthesis of pertinent completed research to be used for further study and evaluation by MnDOT and the Local Road Research Board. This TRS does not represent the conclusions of CTC & Associates, MnDOT or LRRB.

Introduction

Minnesota county engineers have sometimes observed heaves and dips near centerline culverts during cold winter months. In these instances, during the late winter and early spring, the area where a culvert has been replaced does not heave or heaves only slightly, while the roadway on either side of the replaced culvert heaves. The heave and dip disappear entirely, or nearly entirely, during the late spring and early summer when the road embankment thaws.

Possible causes for this phenomenon include:

- Improper application or lack of taper in the installation.
- Improperly addressed compressible foundation soils.
- Poor compaction of backfill materials.
- Use of granular, nonfrost-susceptible soils rather than native soil for backfill.

CTC & Associates conducted a literature search and surveyed representatives from transportation agencies in cold-climate states in the United States and provinces in Canada that may have experience with heaves and dips near centerline culverts during cold weather, and practices to mitigate them. Some publications use the term “differential frost heave”; for purposes of this report, this cold weather heave-and-dip phenomenon is referred to as a “frost dip.”

Summary of Findings

Information for this Transportation Research Synthesis was gathered in two topic areas:

- Survey of Practice.
- Related Research.

Survey responses and an examination of recent research netted relatively little information about the frost dip phenomenon and how to address it. While five survey respondents reported observing frost dips above culverts, only one indicated plans to use insulation to attempt to mitigate a frost dip. This respondent is skeptical that the application of insulation will remove the frost dip entirely. The most significant recent publication addressing frost dips (or, as this publication refers to them, sags or depressions) provides limited information about the use of insulation to mitigate this phenomenon.

The following summarizes findings in each topic area.

Survey of Practice

An email survey was distributed to 24 states and four Canadian provinces with cold climates to inquire about their experience with frost dips and practices to mitigate them. Eight state DOTs and one Canadian province responded to the survey. Of these, only five respondents—Maine, New Hampshire, Vermont, Wisconsin and Saskatchewan—provided complete responses to the survey questions. The other four respondents—Iowa, Michigan, Ohio and Pennsylvania—have little or no experience with frost dips but did provide information about the significance of backfill in addressing concerns about settlement and compaction.

The email survey gathered information in five topic areas:

- General observations about frost dips.
- Practices that increase the likelihood of frost dips.
- Practices to reduce or eliminate frost dips.
- Use of insulation to reduce or eliminate frost dips.
- Other respondent feedback.

The following summarizes findings in each topic area.

General Observations about Frost Dips

Some of the respondents offered additional perspective on their responses. The Wisconsin DOT respondent cited several factors that affect the development of frost dips: temperature changes, material used in backfill, soil types, traffic and the condition of the roadway surface. In Saskatchewan, frost dips are more likely to occur in conjunction with deep patches than over centerline culverts. A deep patch is a pavement repair method for localized base failures due to loss of subgrade support. The Saskatchewan respondent provided information about successful efforts to mitigate frost dips associated with deep patches.

Practices That Increase the Likelihood of Frost Dips

All five respondents noted that the use of material other than native soil to backfill a newly installed culvert increases the likelihood of a frost dip. In Vermont and Wisconsin, older roads with a poor base or lacking a free-draining subbase are more likely to experience frost dips. The Saskatchewan respondent noted that frost dips are most pronounced at sites where the excavation has vertical or steep side slopes.

Practices to Reduce or Eliminate Frost Dips

The Saskatchewan respondent provided the most detail about installation practices to mitigate frost dips, noting that frost dips are more likely to occur when this installation practice is not followed: An excavation side slope of

8:1 for fill heights up to 2 meters, with a transition to a 4:1 slope for fill heights of 4 meters and above by holding the toe of the slope constant.

Backfill was again highlighted in other respondents' practices to mitigate frost dips. In Maine, when backfilling the pipe in native soil to subgrade is not possible, installers use a 40:1 taper from the top of the pipe to subgrade. The New Hampshire respondent advised replacing too-wet excavated material with a silty borrow material. Compaction was addressed by the Vermont and Wisconsin respondents:

- Equipment operators in Vermont turn off vibration of compaction equipment when passing over culverts.
- Wisconsin crews refill the backfill with the original material lifted out with several compaction levels.

Use of Insulation to Reduce or Eliminate Frost Dips

While none of the respondents have experience with the use of insulation to mitigate frost dips, the Saskatchewan respondent described a plan to use rigid sheet building insulation to address problems with a single culvert installation. The test site is a culvert that was installed using nonfrost-susceptible backfill in an area of frost-susceptible soils. The rigid insulation will be placed on top of the subgrade, stepping down the thickness of the insulation as the insulation moves away from the center of the culvert to provide a tapered transition into and out of the location. The respondent commented that he does not expect this measure to totally eliminate the frost dip.

Note: MnDOT engineers report that insulation has limited value in eliminating a frost dip. Insulation may be useful when trying to reduce the load on highly compressible in-place soils beneath a culvert. If used to soften the impact of a frost dip, rigid board insulation should be extended many feet on either side of the culvert for the width of the roadway and either tapered as it is placed away from the culvert or dipped into the road embankment.

Other Respondent Feedback

All four of the remaining respondents who reported little or no experience with frost dips did, however, mention issues with compaction and pavement settlement. In 2006, Iowa DOT changed its backfill type and method to address pavement settlement at newly installed pipe culverts due to poor compaction. Michigan and Pennsylvania DOTs also attributed pavement settlement to poor or improper compaction. In Ohio, backfill settlement or loss is identified as the cause of rarely occurring pavement dips above culverts.

Related Research

While a literature search identified few publications on the topic of heaves and dips near centerline culverts, common themes are noted in the publications that were found—the significance of the type of backfill used and efforts to address inadequate compaction.

A 2014 TRB conference paper provides the most extensive evaluation of practices to mitigate frost dips through an examination of construction and maintenance solutions to pavement sags and depressions (what could be considered frost dips) at through-grade culverts in Manitoba. Field investigations indicated that the type of backfill material used and settlement of backfill material contributed to culvert performance. The authors provide recommendations for mitigation of road roughness over culverts, including measures to minimize settlement of backfill material due to inadequate compaction.

This conference paper also includes a reference to a 2007 Maine DOT report that examined the use of insulation in culvert installations. While not specifically referring to the frost dip phenomenon, the Maine DOT report is the only publication cited in this TRS that addresses the use of insulation in culvert installations in some detail. Researchers examined the performance of extruded polystyrene insulation placed both above and below shallow cross pipes as a method to distribute differential heave over larger distances. Placing insulation above the culvert reduced abrupt differential frost heaving. Also significant was a transition zone from the culvert centerline of 9 meters to 30 meters.

Other publications provide information about:

- The use of polystyrene insulation beneath the culvert bedding material on the bottom and sloped sides of the excavation for culverts installed in permafrost regions (2010 Transportation Association of Canada guide).
- "Reverse frost heave" at pipeline crossings, where the ground above the pipeline does not heave as much as the adjacent ground (2009 conference paper).
- Frost load, which develops "primarily as a consequence of different frost susceptibilities of the backfill and the sidewalls of the trench and the interaction at the trench backfill-sidewall interface." To minimize frost load, agencies should use a backfill material that has equal or lower frost susceptibility than that of the sidewall (2008 University Transportation Center research report).

Detailed Findings

Survey of Practice

Survey Approach

An email survey was distributed to 24 states and four Canadian provinces with cold climates to inquire about their experience with frost dips and practices to mitigate them. The states were:

- Alaska.
- Colorado.
- Connecticut.
- Delaware.
- Illinois.
- Iowa.
- Kansas.
- Maine.
- Maryland.
- Massachusetts.
- Michigan.
- Missouri.
- Montana.
- Nebraska.
- New Hampshire.
- New York.
- Ohio.
- Pennsylvania.
- South Dakota.
- Utah.
- Vermont.
- Washington.
- Wisconsin.
- Wyoming.

The Canadian provinces receiving the survey were British Columbia, Manitoba, Ontario and Saskatchewan.

The survey consisted of the following questions:

1. Have you observed frost dips occurring in your state/province?
2. Have you identified specific road-building practices that appear to increase the likelihood of frost dips occurring?
3. Does your agency employ specific practices to reduce or eliminate frost dips associated with centerline culverts?
4. If insulation is one of these practices, please describe your installation method, including:
    - Type of insulating material used.
    - Placement of the insulating material.
    - Typical culvert depth.
    - Backfill material used.
    - Other aspects of the installation process unique to efforts to reduce or eliminate frost dips.

    A. What has been the result of your insulation efforts in mitigating frost dips?
5. Have you used practices other than insulation to mitigate frost dips?

Eight states and one Canadian province responded to the survey. Of these, six respondents reported experience with frost dips. None of the respondents reported experience with the use of insulation as a frost dip mitigation measure, though one respondent is considering its use to retrofit a single culvert.

Summary of Survey Results

Of the nine responses received, only five respondents—representatives from state departments of transportation in Maine, New Hampshire, Vermont and Wisconsin, and the Ministry of Highways and Infrastructure in Saskatchewan—provided complete responses to the survey questions. Respondents from Iowa, Michigan, Ohio and Pennsylvania DOTs reported little or no experience with the frost dip phenomenon in their states but did provide information about concerns with pavement settlement and compaction.

This summary of responses is organized in the following topic areas:

- General observations about frost dips.
- Practices that increase the likelihood of frost dips.
- Practices to reduce or eliminate frost dips.
- Use of insulation to reduce or eliminate frost dips.
- Other respondent feedback.

The full text of the survey responses begins on page 8 of this report.

Following is a summary of findings by topic area.

General Observations about Frost Dips

Some of the respondents reporting experience with frost dips provided additional perspective on their survey responses.

- The Maine DOT respondent qualified his responses as related to what Maine DOT calls "cross culverts" (pipes perpendicular to the roadway). While noting that cross culverts may differ from the centerline culvert installations of interest to MnDOT, the respondent suggested that the same principles apply to both types of installations.
- In New Hampshire, frost dips are most likely to occur on secondary roads with poor drainage and very little roadway base material.
- The Wisconsin DOT respondent cited several factors that affect the development of frost dips: temperature changes, material used in backfill, soil types, traffic and the condition of the roadway surface.
- In Saskatchewan, frost dips are more likely to occur in conjunction with deep patches than over centerline culverts. A deep patch is a pavement repair method for localized base failures due to loss of subgrade support. Efforts to mitigate frost dips associated with deep patches include:
    - Excavating the subgrade to a sufficient depth to bridge the soft soils (typically 0.5 meter to 1 meter) and replacing with granular base material.
    - Reducing the depth of excavation and placing a woven geotextile under the granular base material.
    - Softening the transition into and out of the dip by not using vertical excavation slopes.

Practices That Increase the Likelihood of Frost Dips

All five respondents noted that the use of material other than native soil to backfill the culvert increases the likelihood of frost dips. Other observations include:

- *Vermont*. Using material other than that taken from the excavation is most problematic for roads that were never engineered (older roads without a free-draining subbase).
- *Wisconsin*. Frost dips occur when granular backfill that does not compact well in layers has been used on old, less-traveled highways with poor bases; in these cases, the pipes are 3 feet to 6 feet under the pavement.
- *Saskatchewan*. Frost dips are most pronounced where the excavation has vertical or steep side slopes. Standing water adjacent to the road embankment is also a contributing factor.

Practices to Reduce or Eliminate Frost Dips

When asked about practices to reduce or eliminate frost dips, respondents again highlighted the significance of the backfill used when installing culverts. More detailed observations include:

- *Maine*. When backfilling the pipe in native soil to subgrade is not possible, installers use a 40:1 taper from the top of the pipe to subgrade.
- *New Hampshire*. If the excavated material is too wet, a borrow material that is somewhat silty can be used to backfill around the pipe and below subgrade.
- *Vermont*. Existing culverts are being marked to alert compaction equipment operators to turn off the vibes as the equipment passes over the culvert.
- *Wisconsin*. In addition to backfilling with the original material, the application of several compaction levels has provided the best long-term solution to frost dips. The respondent noted that this practice is commonly used on airport runways.
- *Saskatchewan*. The backfill standard for culverts is to use an excavation side slope of 8:1 for fill heights up to 2 meters with a transition to a 4:1 slope for fill heights of 4 meters and above by holding the toe of the slope constant. When installation practices deviate from this standard, frost dips are more likely to occur. The province has also tried various road shimming practices with limited success. The respondent noted that this practice "usually trades a winter dip for a summer hump, although the abruptness of the dip or hump can to some extent be mitigated."

Use of Insulation to Reduce or Eliminate Frost Dips

None of the respondents reported experience with the use of insulation to mitigate frost dips, though Saskatchewan is considering the use of rigid insulation as a retrofit for one culvert installation. The Maine DOT respondent questioned the potential effectiveness of insulation, noting that "the mechanism causing the heave would not be mediated by insulating the pipe."

The Saskatchewan Plan

The first documented use of insulation in Saskatchewan will seek to remedy a frost dip over a culvert that was installed using nonfrost-susceptible backfill in an area of frost-susceptible road embankment. This proposed use will be the first application of insulation to culvert installations. The respondent is aware of some successful efforts to address localized pavement heaving due to frost action with the installation of rigid insulation, but design details for those efforts were not documented.

The agency proposes placing rigid sheet building insulation on top of the subgrade, stepping down the thickness of the insulation when moving away from the center of the culvert to provide a tapered transition into and out of the location. The respondent does not expect this measure to totally eliminate the frost dip.

Other Respondent Feedback

All four of the remaining respondents who reported little or no experience with frost dips did, however, address issues with compaction and pavement settlement.

- *Iowa*. In 2006, the agency changed standards for backfill type and method for newly installed pipe culverts. These changes were made to address pavement settlement issues that were attributed to poor compaction. Today, a granular backfill material is used, and pipe backfill material is compacted by flooding. For cover heights of less than 4 feet, a flowable mortar cap is installed to cap and stabilize the backfill material that has been consolidated by flooding.
- *Michigan*. The respondent attributed the agency's problems with pavement settlement to poor compaction of the backfill, also noting that the pavement settlement is not exclusive to cold weather conditions.
- *Ohio*. In rare cases, the agency has noted dips in pavements above culverts and attributes the dips to backfill settlement or loss.

- *Pennsylvania*. Any dips observed occur in both winter and summer and are typically due to improper compaction or pipe failure.

Survey Results

The full text of the five survey responses from respondents with experience with frost dips is provided below. For reference, an abbreviated version of each question is included before the response. The full question text appears on page 5 of this report. Following the full-text survey responses is information provided by the remaining four respondents reporting little or no experience with frost dips.

Full-Text Survey Responses

Maine

Contact: Scott Bickford, Assistant Highway Program Manager, Maine Department of Transportation, 207-215-3857, Scott.Bickford@maine.gov.

The respondent provided the information below before responding to the survey questions.

> The responses below are for what we call cross culverts (pipes perpendicular to the roadway). Not sure if your centerline culvert is the same thing or something running parallel to the roadway. Either way I think the same basic principle is in action. We have seen many issues with "reverse frost heaves" (frost dips) on pipes that were backfilled with granular material. Basically, the material over the top of the pipe doesn't heave and the material adjacent heaves, causing a dip over the pipe.

1. **Observe frost dips?** Yes.
2. **Identified road-building practices that increase likelihood of frost dips?** Yes. Replacing native soil with granular, nonfrost-susceptible material in the pipe trench.
3. **Practices to reduce or eliminate frost dips:** Backfill the pipe in native soil to subgrade. Where this cannot be done, utilize 40:1 tapers from the top of pipe to subgrade.
4. **Use of insulation to reduce or eliminate frost dips:** N/A. The mechanism causing the heave would not be mediated by insulating the pipe.

4a. **Result of insulation use:** N/A.

5. **Other practices to mitigate frost dips:** Backfill the pipe in native soil to subgrade. Where this cannot be done, utilize 40:1 tapers from the top of pipe to subgrade.

New Hampshire

Contact: Shaun M. Flynn, District Construction Engineer, Bureau of Construction, New Hampshire Department of Transportation, 603-271-2571, SFlynn@dot.state.nh.us.

1. **Observe frost dips?** Yes, we have seen this occur especially on secondary roads with poor drainage and very little roadway base materials.
2. **Identified road-building practices that increase likelihood of frost dips?** Yes. When backfilling the culvert if clean granular backfill is used versus the existing material present the frost dip is likely to occur.
3. **Practices to reduce or eliminate frost dips:** Whenever possible re-use the excavated material at the pipe level. If the material is too wet to work with, use a borrow material that is on the silty side as backfill around the pipe and below subgrade.
4. **Use of insulation to reduce or eliminate frost dips:** Not typically used.

4a. **Result of insulation use:** N/A.

5. **Other practices to mitigate frost dips:** Backfill practices noted above.

Vermont

Contact: David Hoyne, Director, Construction & Materials Bureau, Highway Division, Vermont Agency of Transportation, 802-828-2593, David.Hoyne@vermont.gov.

1. **Observe frost dips?** Yes.
2. **Identified road-building practices that increase likelihood of frost dips?** Yes, a newly installed culvert or a resurfacing project over existing culverts. The new installation of the culvert backfilled with material other than that taken from the excavation results in dissimilar material and the frost heave. This is especially so for roads that were never engineered (older roads without a free-draining subbase). The other issue is when a resurfacing project causes consolidation around the culverts or damages older culverts due to density requirements.
3. **Practices to reduce or eliminate frost dips:** We have start[ed] marking existing culverts such that the compaction equipment turns off the vibes as they pass over.
4. **Use of insulation to reduce or eliminate frost dips:** Have not tried insulation.

4a. **Result of insulation use:** N/A.

5. **Other practices to mitigate frost dips:** We have discussed using similar material as backfill as that taken from the excavation, but this [has] proved difficult for many reasons.

Wisconsin

Contact: James P. Hughes, State Maintenance Engineer, Wisconsin Department of Transportation, 608-266-1202, James.Hughes@dot.wi.gov.

1. **Observe frost dips?** Yes, it varies based on several factors: temperature changes, material used in backfill, locations based on soil types and traffic, and finally, on condition of roadway surface as to rather it has cracks (size and quantity) and is allowing water into base material.
2. **Identified road-building practices that increase likelihood of frost dips?** Yes, when surrounding soils have a [California bearing ratio] under 3.0 (very old less traveled highways with poor bases) and then you fill with granular backfill and do not compact well in layers and the pipe is 3 feet to 6 feet under pavement, these tend to have potential for largest dips in the roadway.
3. **Practices to reduce or eliminate frost dips:** It appears refilling the backfill with the original material lifted out with several compaction levels results in best long-term solution to these dips. It's a common practice used on airport runways if/when needed.
4. **Use of insulation to reduce or eliminate frost dips:** No experience with insulating.

4a. **Result of insulation use:** Fill with the same material taken out, use layered compaction and eliminate as much of the differential frost heave as possible. [Note: Given Hughes' response to the previous question, this does not appear to relate to the use of insulation, instead referring to other practices to mitigate frost dips.]

5. **Other practices to mitigate frost dips:** No, I do not know of an instance where [insulation] has been used. It's possible it has been tried, but I have no knowledge of it.

Hughes provided the information below about culvert installation and maintenance practices not related to the use of insulation:

- **Typical culvert depth.** I would say typically not less than 3 feet and most within 12 feet of surface. The very deep culverts typically are not a problem because they are usually placed when the highway is constructed and boring or lining is performed for long-term maintenance.
- **Backfill material used.** Depending where, granular material OR original material removed.
- **Other aspects of the installation process unique to efforts to reduce or eliminate frost dips.** Annual sealing of the cracked pavement over the culverts to keep water out of the base.

Saskatchewan

Contact: Douglas Ross, Senior Road Design Engineer, Technical Standards Branch, Ministry of Highways and Infrastructure, Government of Saskatchewan, 306-933-6039, Douglas.Ross@gov.sk.ca.

1. **Observe frost dips?** Yes, we have observed frost dips over some culverts. We have also observed frost humps where the pavement over the culvert raises. Both of these appear in the winter and disappear in the summer. To date they have been treated as isolated occurrences and the Ministry has not made a concerted effort to track and address the issue with respect to their occurrence in conjunction with culverts.

   We have not yet been able to come up with a cost-effective solution to the locations where we are experiencing frost humps since you cannot do anything at the surface except to spread the impact out through pavement shimming. These locations are typically signed with bump signs during the winter.

   A more common occurrence is the presence of frost dips in conjunction with deep patches. Deep patches are a pavement repair method for localized base failures due to loss of subgrade support. The subgrade is excavated out to a sufficient depth to bridge the soft soils (typically 0.5 to 1 m) and replaced with granular base material. These excavations are typically vertical and where they are done in frost-susceptible silt soils we get frost dips with near vertical edges. In areas where we have silty embankment material it is usually not feasible to incorporate 8:1 tapers on the excavation slopes due to issues with the material stability. We have had some success in reducing the magnitude of the dip through reducing the depth of excavation and placing a woven geotextile under the granular base material. The transition into and out of the dip can be softened by not using vertical excavation slopes.
2. **Identified road-building practices that increase likelihood of frost dips?** Typically, we have not had an issue with respect to new road construction. Where it has been occurring is when we are replacing culverts and the existing frost-susceptible embankment material that is excavated is replaced with a material that is not frost-susceptible. The effect is most pronounced where the excavation has vertical or steep side slopes. Another contributing factor is if there is standing water adjacent to the road embankment.
3. **Practices to reduce or eliminate frost dips:** We try wherever possible to reuse the existing embankment material.
   - Our backfill standard for culverts is to use an excavation side slope of 8:1 for fill heights up to 2m with a transition to a 4:1 slopes for fill heights of 4 m and above by holding toe of the slope constant. This has not always been followed in practice and in these cases can result in pavement settlement or frost dip issues over culverts.
   - We are currently considering the use of rigid insulation as a retrofit on one frost dip problem culvert installation which used nonfrost-susceptible backfill in an area of frost-susceptible road embankment. The answer to Question 4 is specific to this initiative.
   - We have tried addressing the issue through various road shimming practices but have had limited success. This usually trades a winter dip for a summer hump although the abruptness of the dip or hump can to some extent be mitigated.

4. **Use of insulation to reduce or eliminate frost dips:**
    - **Type of insulating material used:** Rigid sheet building insulation.
    - **Placement of the insulating material:** The insulation is proposed to be placed on top of the subgrade. Concept is to step down the thickness of the insulation as you move away from the center of the culvert to provide a tapered transition into and out of the location to reduce the impact of the frost heave area on the road profile. We do not expect to be able to totally eliminate the frost dip.
    - **Typical culvert depth:** The culvert depth is not considered to be a factor in this location.
    - **Backfill material used:** Not planning to excavate the existing backfill material because of issues associated with working with the existing embankment material.
    - **Other aspects of the installation process unique to efforts to reduce or eliminate frost dips:** None.

4a. **Result of insulation use:** Not known with respect to culvert installations; currently in the planning stage. I have been told that we have had some success in dealing with localized pavement heaving due to frost action with the installation of rigid insulation, but I do not have the design details since this work has not been documented.

5. **Other practices to mitigate frost dips:** See answer to Question 3.

Other Respondent Feedback
Respondents from Iowa, Michigan, Ohio and Pennsylvania DOTs reported little or no experience with frost dips but did describe other types of pavement distress.

Iowa
Contact: Melissa A. Serio, Earthwork Field Engineer, Office of Construction and Materials, Iowa Department of Transportation, 515-239-1280, Melissa.Serio@dot.iowa.gov.

The respondent provided the following in response to the survey questions:

Iowa DOT has experienced settlement issues at newly installed roadway pipe culverts likely due to poor compaction. To resolve these issues, we changed the backfill type and method in 2006.

We switched to a granular backfill with a maximum of 4% passing the No. 200 sieve. Gradations 1, 35, 36 are acceptable [see Related Resources below].

Flooding is the method of compaction and shall be per supplemental specification [see Related Resources below].

Additionally, for cover heights less than 4 feet, a flowable mortar cap is installed [see the upper left detail in the plan available at http://www.iowadot.gov/erl/current/RS/content_eng/dr101.pdf]. Purpose of flowable mortar is to cap and stabilize the backfill material that has been consolidated by flooding.

Related Resources:

Aggregate Gradation Table, Appendix, Standard Specifications for Highway and Bridge Construction, Iowa Department of Transportation, effective date: October 20, 2015.
http://www.iowadot.gov/erl/current/GS/content/Appendix.htm#AggregateGradationEnglish
This appendix includes tables and charts, including this one that associates particular grades with sections of the Standard Specifications.

Supplemental Specifications for Backfilling and Compaction of Pipe and Reinforced Box Culverts by Flooding, SS-15003, Standard Specifications for Highway and Bridge Construction, Iowa Department of Transportation, effective date: October 20, 2015.
http://www.iowadot.gov/specifications/ss/2015/SS-15003.pdf
From the document:

> This specification describes backfill and compaction requirements for culverts using flooding. Apply Sections 2402, 2415, 2416, and 2417 of the Standard Specifications unless modified by this specification.

Michigan

Contact: Gary Mayes, Maintenance Engineer, Michigan Department of Transportation, 517-322-3315, MayesG@michigan.gov.

The respondent provided the following in response to the survey questions:

> In regards to you[r] questionnaire on our experience with cold weather dips in the pavement directly over centerline culvert replacements. I can't say that any of us in the maintenance section recall any issues with [this] type of distress. We have had problems with pavement settlement due to poor compaction of the backfill. This, however, was not exclusive to cold weather conditions.

Ohio

Contact: Steve Slomski, State Construction Geotechnical Engineer, Office of Construction Administration, Ohio Department of Transportation, 614-466-4318, Stephen.Slomski@dot.state.oh.us.

The respondent provided the following in response to the survey questions:

> We have not observed the culvert 'frost dip' phenomenon that you have described. Rarely, dips in the pavement above culverts will occur, but that is generally attributed to backfill settlement or los[s]. Pavement heave is generally the frost damage that we get in Ohio.

Pennsylvania

Contact: Rebecca S. Burns, Chief, Bureau of Project Delivery, Innovation and Support Services Division, Pennsylvania Department of Transportation, 717-787-6989, ReBurns@pa.gov.

The respondent provided the following in response to the survey questions:

> We have not observed dips over cross-pipes or culverts due to frost. The dips we observe may occur in both summer and winter months [and] are typically due to improper compaction or pipe failure.

Related Research

While a literature search identified few publications on the topic of heaves and dips near centerline culverts, the publications cited below present some common themes: the significance of the type of backfill used and efforts to address inadequate compaction. The most significant findings include a 2014 TRB conference paper that examines construction and maintenance solutions to pavement sags and depressions (what could be considered frost dips) at through-grade culverts in Manitoba, and a 2007 Maine DOT report that examines the effectiveness of using insulation at shallow cross pipe installations.

"Toward Best Practices for Construction and Maintenance of Through-Grade Culverts to Mitigate Pavement Roughness in Cold Climates," Leonnie Kavanagh, Haithem Soliman and Ahmed Shalaby, *TRB 93rd Annual Meeting Compendium of Papers*, Paper #14-4728, 2014.
Citation at http://trid.trb.org/view/2014/C/1289562
In this investigation into the causes for culverts with excessive bumps, dips or sags over roadways, the authors note in the conference paper's abstract that "[t]he surface roughness at a culvert location can be caused by inadequate compaction of granular base material, erosion of the backfill or supporting materials, and/or differential frost heaving. The objective of this study is to recommend construction and maintenance solutions to mitigate bumps, sags, and depressions at through-grade culverts on Provincial Trunk Highways (PTH) and Provincial Roads (PR) in Manitoba."

A table on page 6 of the conference paper that ranks the major causes of pavement roughness over culverts is reproduced below. According to the table, the most likely cause of pavement roughness is frost heaving. The use of granular backfill as opposed to native material is among the least likely causes for pavement roughness.

Table 2 Ranking of Major Cause of Pavement Roughness Over Culverts

Causes of Pavement Roughness	**Average Ranking***
Construction method (jacking versus open cut)	4
Deferred maintenance	5
Settlement of backfill material caused by inadequate compaction	3
Differential settlement or swelling	2
Frost heaving	1
Insufficient cover	3
Use of granular backfill as opposed to native material	4

*Ranking scale is 1 to 5 where 1=most likely cause, 5=least likely cause

Results of field investigations that examined four culverts (two with poor performance and two classified as good performing), which appear on page 14 of the conference paper, indicate that the type of backfill material used and settlement of backfill material contributed to culvert performance. Highlights from the investigation follow:

- *Poor performing culvert #1*. Pavement roughness was likely caused by settlement of the backfill material around the culvert. The settlement was likely due to inadequate compaction of the clay backfill during construction and the short transition zone (1:1 slope) between the backfill and surrounding material.
- *Good performing culvert #2*. The use of granular backfill (instead of clay) indicated that the backfill material had an influence on road roughness.
- *Poor performing culvert #3*. The excessive roughness was caused by settlement of the granular base around the culvert due to voids from the jacking operations. The settlement was exacerbated by the excessively shallow depth of cover over the culvert (0.5 meter) and high traffic. Inadequate compaction at the culvert ends during the open cut operation may also have been a contributing factor. Additional field testing during the spring thaw will be required to verify whether frost action was also a contributing factor in the excessive pavement roughness.
- *Good performing culvert #4*. The greater depth of cover over indicated that the depth of cover had an influence on road roughness.

A table on page 14 of the conference paper that summarizes recommendations for mitigating road roughness at culverts is reproduced below.

Table 8 Recommendations for Mitigating Road Roughness at Culverts

Recommendation	Rationale
• Longer transition zones (9 m) from culvert • Frost tapers • Insulation on top of culverts in frost zones	• Minimize differential settlement due to frost heave
• 1 meter minimum depth of cover over culvert • Use of granular backfill over culvert with adequate transition zone • Adequate compaction of backfill • Maximum lift thickness of 150 mm • Geotextiles between each lift • Test strip density (around culverts) in lieu of Proctor as quick measure of compaction	• Minimize settlement of backfill material due to inadequate compaction
• Use of innovative rehabilitation or repair techniques such as culvert liners, slab jacking over culverts, and lightweight fills (density < 1000 kg/m3) • Reinforcement over culverts (geogrid, bar mat on concrete pavements) • Grouting around culverts installed by jacking method	• Increase strength of culvert to carry ground and traffic loads and reduce culvert deflections • Alternative method to patching depressions over culverts

Primer on Developing and Managing Transportation Infrastructure in Permafrost Regions, Transportation Association of Canada, June 2010.
http://tac-atc.ca/sites/tac-atc.ca/files/site/doc/resources/primer-permafrost2010.pdf
While this document focuses on effective practices for addressing the effect of permafrost (defined as a ground condition of either soil or rock that remains at or below 0°C (or 32°F) for long periods), the publication's recommendations with regard to culverts may be of interest to MnDOT. From page 5 of the document:

> Culverts in permafrost regions require constant maintenance and should be used only when necessary. Where large diameter culverts cannot be avoided, it is recommended to use riveted or bolted culverts and consider installation of polystyrene insulation beneath the culvert bedding material on the bottom and sloped sides of the excavation.

"Differential Frost Heave at Pipeline-Road Crossings," Gerry Ferris, *The 14th Conference on Cold Regions Engineering*, 2009.
Citation at http://trid.trb.org/view/2009/C/904547
From the abstract:

> Essentially all areas of Canada are affected by significant seasonal frost penetration. The effect of the frost penetration on roads and highways, especially the amount of total frost heave and the effect of the subsequent thaw, varies with soil type. Road design and construction must consider the effects of frost heave and subsequent spring thaw. The location and amounts of differential frost heave are especially important to pavement performance. Frost heave behavior can be manifest at pipeline crossings as "reverse frost heave", where the ground above the pipeline does not heave as much as the adjacent ground. If the amount of differential heave within pipeline crossing is large, it can lead to rough, and potentially unsafe, driving conditions. In the case of pipeline crossings, if rough road surface conditions

occur in the right of way, highway agencies typically request compensation for additional maintenance costs from the pipeline company. A case study that shows the effects of differential frost heave at a pipeline road crossing is presented.

Use of Trenchless Technologies for a Comprehensive Asset Management of Culverts and Drainage Structures, Ossama (Sam) Salem, Mohammad Najafi, Baris Salman, Diego Calderon, Rahul Patil and Deepak Bhattachar, Midwest Regional University Transportation Center, September 2008.
http://www.uta.edu/ce/cuire/MRUTC07-15%20Trenchless%20Technology%20Final%20Report%2012-08-08.pdf
Researchers investigated the culvert asset management practices of transportation agencies and developed inventory and inspection protocols needed for an effective culvert asset management program. The following excerpt addresses one of the factors that influence the performance or service life of a culvert. From page 26 of the report (page 46 of the PDF):

> **Frost Load**
> The failure of pipes during winter could be attributed to frost load which presents an increased earth load on the buried pipes. In a trench, the frost load develops primarily as a consequence of different frost susceptibilities of the backfill and the sidewalls of the trench and the interaction at the trench backfill-sidewall interface. Trench width, differences in frost susceptibilities of backfill and trench sidewall materials, stiffness of the medium below the freezing front, and shear stiffness and backfill-sidewall interface play important roles in the generation of frost loads. Thus, it is preferable to use a backfill material that has equal or lower frost susceptibility than that of the sidewall in order to minimize the development of excessive differential frost loads.

Alternative Shallow Cross Pipe Installation Method, Michael A. St. Pierre and Dana N. Humphrey, Maine Department of Transportation, April 2007.
Citation at http://trid.trb.org/view.aspx?id=811449
From the abstract:

> The objective of this study was to evaluate the performance of shallow cross pipes insulated with extruded polystyrene insulation as a method to distribute differential heave over larger distances. Research consisted of field testing, instrumentation, and numerical modeling of insulated and uninsulated cross pipes at five selected sites across Maine. The effectiveness of the installation methods with extruded polystyrene insulation placed above and below the cross pipe were evaluated. Cross pipe installations were evaluated based on: influence of insulation, effect on pattern of frost penetration, surface frost heave, influence of soil type, and severity of the freezing season. Heave surveys indicated that pipes that develop heave have greater total heave away from the cross pipe than over the pipe resulting in differential heave. Results showed for sites that experienced significant total heave, the placement of insulation over the cross pipe increased both the magnitude and abruptness of the differential heave. This showed that the length of the transition insulation on each side of the cross pipe was inadequate. The maximum differential heave was observed to occur at the end of the freezing season and start of the spring thaw.

Note: A discussion of the Maine DOT report in the 2014 TRB conference paper, "Toward Best Practices for Construction and Maintenance of Through-Grade Culverts to Mitigate Pavement Roughness in Cold Climates" (see the citation on page 13 of this report), includes these observations:

- Abrupt differential frost heaving at culverts was reduced if the insulation was placed above the culvert and the effective transition zone from the culvert centerline was in the order of 9 meters to 30 meters.
- Longer transition zones help reduce abrupt differential heave by distributing the differential heave over longer distances.

- Insulation around the culvert appeared to be effective in minimizing potential differential frost heaving. However, insulation placed underneath a culvert was found to be ineffective in minimizing differential frost heaving.
- The use of geosynthetics as a method for reducing differential heave at shallow culverts was encouraged.
- The authors recommended backfilling culverts with soil similar to the adjacent subgrade soil to try to maintain the same heave at the culvert as well as the adjacent pavement sections (i.e., differential heaving will not occur since the culvert and pavement will heave at the same level).
