CITY OF DENTON

Concrete Pavement Failures Analysis

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Executive Summary

The purpose of this report is to investigate concrete pavement failures in a number of areas around the City of Denton as identified by City staff. The City of Denton has spent a significant portion of available maintenance dollars to repair concrete streets, often earlier than would be expected. The need to reduce those expenditures has driven the City staff to undertake this investigation.

The aim is to identify the likely causes of the failures, determine what methods of repair should be used, and make recommendations to help the City prevent or at least reduce these failures in the future. The investigation included field observations, a significant geotechnical investigation, and review of record drawings and City of Denton specifications and procedures. A total of 71 bores were taken on 61 different streets.

Failures

The failures that were observed were entirely in concrete pavements, mostly in far southeast Denton, in subdivisions constructed within the last twenty years. During the investigation, three primary failure modes were observed. They are:

1. Joint spacing deficiencies
2. Settlement, particularly over utility trenches
3. Subgrade heaving

Causes

The investigation shows a variety of causes for the failures, but they can be boiled down to a few primary issues:

1. The geologic formations in this area consist of a variety of underlying soil types that include highly expansive clays, sand seams, silt and limestone layers. Many of these soil types are not conducive to stable construction. Extreme weather changes compound the effects of these soils on construction.
2. Design of public improvements has often not included a site-specific geotechnical investigation to adequately address these soil and groundwater conditions.
3. Construction methods have in many cases not followed City of Denton and project-specific specifications sufficiently to deal with these conditions.

Repairs

Repairs of existing failures will for the most part require removal and replacement of the damaged concrete pavement. However, a crack sealing program can be used to delay many of the repairs, and forestall further damage, particularly for the older streets.

Recommendations for New Construction

Since we cannot change the soils or weather we have in this area, our recommendations focus on the design and construction methods and processes of public improvements. These recommendations can also be boiled down to just a few major components.

- First, require a detailed geotechnical investigation with design recommendations for each project, and establish specific criteria and guidance for identifying potential problems on that particular site, including soil conditions and groundwater.
- Second, improve adherence to the standard and project-specific construction specifications. That will require a significant increase in the presence of construction inspectors on the project sites, and increased materials testing efforts. It is our opinion that had the existing City standards been consistently adhered to, the failure rate of the concrete pavements we observed would have been dramatically decreased.
- Conduct random proof testing of trenches to ensure compliance with the specifications.

Next Steps

- Quantify needed repairs and develop cost estimates
- Modify existing specifications and requirements to incorporate recommendations herein
- Hire and train additional inspection staff
**Introduction and Approach to Evaluation**

The City of Denton has retained Teague Nall and Perkins, Inc. (TNP) to evaluate concrete pavement failures that have occurred in various locations throughout Denton, particularly in the far southeast part of Denton. The Appendix includes a Key Map of the study area, with local zones shown, followed by Bore Location Zone Maps of each particular zone.

The City of Denton has experienced significant concrete pavement failures in residential subdivisions, again particularly in the far southeast part of Denton. The purpose of this report is to identify what those failures are, identify the most likely cause of the failures, propose remedial action for repair of the distressed areas, and to make recommendations for new construction that would help prevent these failures in the future.

The subdivisions that have been evaluated in this report were built at various times, ranging from 1997 to 2017. While pavement failures are not unexpected after 20 years of service, many of the failures occurred long before the end of the service life of the pavement. It is our intent to determine if the failures in the older subdivisions could have been prevented, extending the life of the pavement, and to recommend the possible changes in specifications and procedures intended to prevent those failures.

TNP conducted a similar assessment of concrete pavement failures for the City of Denton in 2005, focused on utility trench settlement failures in the Wind River subdivision. This current investigation expands on the 2005 study, both in terms of geographic limits and types of failures, and is also intended to provide recommendations to help prevent premature pavement failures in the future.

The pavement failures that are the subject of this evaluation include pavement cracking and subsidence, heaving and vertical displacement, and joint problems. Pictures throughout this report show physical evidence of the failures. In addition, the Appendix includes a picture of each studied location, arranged by bore number.

The evaluation is based on the following investigation:

- **Visual observations of the sites**
  Preliminary field investigations were conducted by the TNP team, which included the staff of GEE Consultants, to develop visual understanding of the failures, identify the locations where geotechnical bores would be helpful, and to document the failures with pictures. The evaluation team identified the limits and degree of the failures, determined the locations for the bores to be taken, and looked for apparent contributing causes of the failures.

- **Geotechnical Investigation**
  This effort included a geotechnical investigation undertaken by GEE Consultants as a subconsultant to TNP. A total of 71 borings were taken at the locations shown on the above referenced maps. The boring logs are included in the Appendix of this report. The geotechnical investigation included analysis of subsurface soil conditions, ground water, and analysis of the pavement itself. Where possible, bores were taken directly over utility lines, particularly the sewer lines.

- **Evaluation of Record Drawings**
  Record drawings for the subject streets were provided by the City of Denton and were evaluated by the project team to identify contributing factors to the failures. Because many of the failures are consistently along the center of the roadway, the location and depth of the sanitary sewer system, which is generally
installed along the center of the street, was of particular interest. The Appendix includes annotated record drawings for each location studied.

By this process the TNP team has attempted to identify the most likely causes for the pavement failures. It must be noted that because there are a number of variables that are involved in such a failure, it is difficult to pinpoint with absolute certainty exactly why each failure occurred. However, it is possible to identify those factors that are most likely to have caused the failures.

Finally, recommendations are presented for repair of existing failures and possible strategies for preventing damage in new construction by making modifications to the City of Denton construction specifications and procedures.

**Failures and Likely Causes**

The geotechnical bores were strategically placed to provide representative samples of the failures observed in the subject areas of Denton. They are not intended to be considered an exhaustive catalog of the failures. The following log describes the location of each bore, and a summary of the failure mode observed at that location. A review of this log and the accompanying pictures suggests that the primary failures observed in this investigation are:

1. Joint Spacing
2. Settlement, particularly over utility trenches
3. Subgrade Heaving

The attached geotechnical investigation includes a detailed description bore list of each failure mode and highlights likely causes. The following is a brief overview of each of these primary failures and the likely causes for the failures.

1. **Cracks and Damage at Joints**
   The geotechnical investigation included an evaluation of the pavements, with respect to joint spacing, reinforcing, and concrete strength. There are instances of improper joint spacing, and a few isolated instances of reinforcing bars missing or at the bottom of the pavement. The most common problem with the pavement itself was improper joint spacing. Table No. 4 of the geotechnical report shows selected observations of joint spacing and the spacing that should have been expected, based on the pavement thickness. Typically the contraction joint spacing (measured in feet) is to be 2.5 times the thickness of the pavement (measured in inches). In this instance, the problem is a lack of compliance with the City of Denton specifications. Compressive strength in the pavements tested was almost universally in conformance with City of Denton standards.

   In general, it does not appear that most of the failures are due to problems with the pavement itself but with the soil under the pavement. Because of this, the bulk of this report will focus on the soil beneath the pavement.
2. Settlement, particularly over utility trenches

Throughout the study area, one of the most prevalent failure types was settlement, especially over sanitary sewer lines. This failure mode is evidenced by cracks running parallel to the center of the street, typically midway between the center of pavement and the curb. Generally, the center of the pavement has dropped, creating what amounts to an inverted crown. In the 2005 study, a number of the failures investigated showed void spaces between the subgrade and the pavement, illustrating that the failure was in the subgrade, not the pavement. A number of likely causes for these failures have been identified, as discussed below.

a) Construction, compaction and inspection

In order to ensure safe working conditions for workers in construction trenches, OSHA has established minimum trench safety regulations that require one of the following methods of trench protection: 1) benching, which consists of sloping the sides of the trench to the outside at an angle where the soil will not fall or move back towards the trench; 2) trench boxes, which allow for a narrow trench and provide support for the steep trench walls; 3) trench boxes in combination with benching; and 4) shoring. Based on our experience many utility lines, and in particular the sewer lines, are installed using benching, often in conjunction with trench boxes, for trench safety. The illustration below shows how benching and trench boxes appear in a cross section view. It can be seen that the deeper a utility line is, the wider the top of the excavation will be when benching is employed. The benching method can result in trenches that are as much as twenty feet wide at the top. One of the biggest disadvantages of benching is that the soil removed from the trench must be replaced and adequately compacted because it will be the base that supports the roadway. If the trench is not properly backfilled, the potential for eventual pavement failure is very high. The picture to the left illustrates that failure, with settlement at the center and cracks parallel to the utility.

Proper compaction of the trench backfill, regardless of the trench safety method used, is absolutely necessary in order to provide a stable base for the roadway. Proper compaction requires mechanical methods (a sheepsfoot roller is generally most effective), adequate moisture in the soil, and compaction of thin enough lifts (generally 8” to 12”) to ensure proper density is reached. City of Denton standards require that fill beneath proposed pavement, including utility trench lines, should be compacted to a minimum of 95% of the dry density of the material (called the Standard Proctor method), placed in lifts of no more than 12” deep. It is critical that this compaction effort begins at the bottom of the trench and continues all the way to the surface. If the depths of the lifts being compacted are too great, the weight of the sheepsfoot roller is distributed over too large an area to
provide sufficient compaction. If this compaction effort is done properly, pavement failure due to trench settling will be nearly non-existent.

In order to provide the contractor with feedback regarding his compaction efforts, and to provide the City with assurance that the compaction is adequate, density testing is typically done during the compaction process. A qualified technician employed by a geotechnical engineering firm, at the expense of the contractor, does this density testing. Samples of the material are evaluated to determine an optimum density and moisture content. Density tests are then taken throughout the backfill process on varying lifts. Based on the testing done, the geotechnical report that accompanies this report clearly concluded that proper compaction was not universally done in the failed areas.

It is our opinion that in many cases, adequate compaction is not performed because there is insufficient inspection and density testing done to ensure compliance with the specifications.

b) Geology

Another primary contributing factor to the pavement failures at utility trenches is related to the geological conditions found in the study area. The various geological formations that underlie the subject area are described in detail in the Geotechnical Investigation found in the appendix of this report. Briefly, these soils can include various layers and seams of sands, silts, clays, and gravels. These soil conditions result in a subsurface condition that can include sand layers adjacent to clay layers that can trap groundwater. The sands can wick moisture away from the clays leading to very dry conditions. As the clays are then exposed to moisture, there is an increased potential for swelling and loss of strength.

c) Weather cycles

Weather cycles can also have an impact on subgrade soils. The variety of soil types found in the City of Denton react in different ways to wet and dry cycles. Clay soils shrink when dry and swell when wet, so alternating drought and rainy periods can cause the clay soil to repeatedly shrink and swell. In addition, clay soils experience significant loss of strength when moisture increases. Sandy soils allow moisture to move. It is not uncommon to find pockets or seams of sand that hold water where adjacent clay soils do not allow a way for the water to escape. Construction of utility lines can cut through such seams and create conduits for groundwater to move.

In spite of weather conditions, it is very important to maintain proper soil moisture levels during construction, especially in utility trenches and other areas where soil is to be placed and compacted. It can be very difficult to keep moisture levels high enough during dry periods of a Texas summer, but adequate compaction is nearly impossible without moisture levels at or above optimum moisture levels.

d) Other Causes

In addition, we have found that at times the utility trenches can serve to conduct groundwater along the pipe system, a phenomenon known as “piping”. Piping results in the movement of soil particles such as silt and sand being carried by the excess water along the ditch lines through voids and open graded materials such as the crushed rock that is typically used as embedment around sanitary sewer lines. When these soil particles are carried by piping along the utility line they leave behind voids in the soil. Eventually, when enough soil particles have been transported from their constructed position, there is insufficient support for the roadway, and failures result.

Trees can be another cause of pavement settling, affecting pavement more than utility trenches. The trees draw moisture from the soil, and adversely affect clay soils by causing the soil to shrink. When the roots extend to or under the pavement, settling can occur. It is not at all uncommon for the cracking to take on a semi-circular pattern that mirrors the tree’s canopy.
3. **Subgrade Heaving**

Subgrade heaving, resulting in vertical displacement of the pavement, is a function of the tendency for the clay soils to expand with increases in moisture levels. Evidence for this condition is cracking and breaking of the pavement, pushed upward due to pressure from the expanding soils underneath. Potential vertical rise (PVR) tests are conducted to quantify the tendency of the soil to expand in response to increased moisture. The geotechnical report discusses this potential rise extensively.
Repair Recommendations

Program
The following procedure is recommended for repairing the damaged concrete pavement. The recommendation takes into account that many of the streets that were evaluated in this investigation are already at or nearing 20 years old. It should be noted that while the streets would have been designed for a 20-year design like, it is not generally expected that the streets will require reconstruction in 20 years. Particularly for residential streets, with proper maintenance and assuming quality construction, concrete streets are expected to last well beyond 20-years without reconstruction.

1. Identify the sections of pavement that must be repaired immediately or soon. This assessment will be based on the severity of the damage and the impact on safety and drivability.
2. Conduct a robust crack sealing program to rout and seal cracks in all other damaged areas, regardless of the cause of the cracks. Sealing the cracks with a flexible crack sealant to eliminate the intrusion of additional water into the subgrade may slow or arrest the continued deterioration of the street, allowing the eventual repairs to be spread out over a longer period of time.
3. Continue the current program of replacing the panels identified above for near-term replacement.
4. Continue to evaluate the areas not targeted for near-term replacement, and add them to the replacement program if they deteriorate to the point that they “make the list”.

Full Repair
Replacement of panels damaged by utility trench backfill will require removal of the pavement in the failed areas, excavation of the trench backfill, replacement and recompaction of the trench backfill, and replacement of the pavement. The extent of the excavation of the trench backfill should be based on density testing taken at various intervals in the exposed trench to determine the necessary depth of trench backfill material. This option is quite expensive, may require complete reconstruction of the street in the affected areas, and will make homes adjacent to the affected areas virtually inaccessible during construction. Further, it will be difficult to determine what the actual limits of the repair area should be, since it is possible that there are other pending failures that are not yet visible. While complete reconstruction of the trench backfill and pavement is probably the most sure and lasting means of repair, it may not be worth the cost and disruption for streets that are already nearly twenty years old.

Alternate Repair
An intermediate alternative will require removal of the existing pavement, but would only require removal of approximately 12” of subgrade over the utility trench, which would be replaced with cement treated base material or flexbase. The new concrete pavement would be 9” thick. The intent would be for the cement treated base and thicker concrete pavement to form a bridge over any possible future voids. While this alternative is also fairly expensive, it would be less intrusive and less expensive than complete replacement of the entire trench backfill.

Foam or grout injection
Foam or grout injection consists of injecting cementitious grout or polyurethane foam into the ground through holes drilled through the pavement. The grout or foam displaces loose soil and thereby compacts soil around the grout. The grout or foam then hardens. This method can only be used in limited situations, where the concrete panel has settled but has not cracked or been otherwise damaged. This method of repair can result in adjusting the concrete panel back into position as the grout or foam expands and spreads out under the pavement. The foam does tend to weaken and eventually fail over time, so it may have to be repeated later. However, it appears that this method would be by far the least intrusive to the neighborhood, and the City owns equipment for foam injection.
**Heave Repairs**
Repairing pavement sections damaged by heaving will also require removing the existing pavement. Since the heaving is caused generally by expansive soils, it will be necessary to remove those expansive soils to a depth to be determined by site-specific soils testing. Replacement may be with soils with more appropriate characteristics (say with a lower plasticity index or to achieve a PVR of less than 4.5”), or with the removed materials stabilized with lime or cement and place at suitable moisture levels, or with flexbase. Once the subgrade is properly addressed the pavement can be replaced.

**Additional Analysis**
In order to identify the limits of necessary repairs, it may be useful, once a location is identified for repair, to do additional boring beyond the limits of the visible pavement damage. This will support a decision to extend the repairs to areas that are likely to see failures in the near future. When the repairs are caused by sanitary sewer trench failures, it may also be useful to TV the sewer line to ensure there are no separated joints or other conditions that would continue to lead to failures.
Recommendations for Failure Prevention in New Construction

As indicated previously, the pavement failures observed in this analysis are largely not related to the pavement itself, but to the soil under the pavement. The key problems appear to be:

1. Joint spacing
2. Settlement, particularly in utility trenches
3. Subgrade Heaving

The following recommendations are, ideally, intended to comprise a comprehensive plan to minimize pavement failures in new construction. The City could, of course, choose to implement only some of the recommendations, based on funding or other resource limitations. Many of these recommendations require only changes in procedures or requirements, or require additional effort or cost on the part of a developer. It should be noted that money spent to avoid problems during construction can pay for itself many times over in reduced premature replacement of concrete streets.

1. General
   a. Due to the wide variability of soils in Denton, require a geotechnical investigation for all development projects, prepared based on soil samples obtained on the site, and prepared by a professional geotechnical engineer. This geotechnical report would be submitted as part of the Development Review process. The investigation will include an analysis of existing soil conditions, presence of ground water, suitability of the soil for use as fill or backfill, and site-specific recommendations for compaction and moisture content both for utility trenches and pavement subgrade, and recommendations for any necessary treatment deeper than the subgrade.
   b. In order to ensure adherence with City requirements, increase City inspector presence on the site. Several of the significant problems encountered could have been alleviated with sufficient inspector presence, including compaction, joint spacing, rebar placement and others. Inspectors probably cannot adequately oversee more than three to five projects, depending on the type of project and the activity on the project at any given time. Even at that, additional inspection presence (full-time) may be necessary at critical points in a given project.
   c. Conduct a Mini-Preconstruction Meeting on site prior to beginning utility construction. Dig multiple test pits at this meeting to observe groundwater and soil conditions.
   d. Prohibit all excavation and fill within proposed rights-of-way during clearing and grading operations unless a Pre-Construction meeting has been conducted and an inspector is assigned to the project.

2. Joint spacing
   a. Require a joint spacing plan to be prepared by a professional engineer, either as a part of the plans or as a shop drawing submittal.
   b. Require contractor to mark sawed joints on the pavement for approval prior to sawcutting.
   c. Require an inspector on site when concrete is poured to check the rebar to ensure compliance with specifications.

3. Trench settlement
   A significant contributor to pavement failure in Denton is the failure of utility trenches under the pavement. Most notably this is seen in sanitary sewer trenches. Numerous streets show significant settling along the trench line, often resulting in what amounts to an inverted crown.
   a. Prohibit trench benching

      One means of reducing the backfill and compaction needed is to narrow the utility trench by requiring a trench box for all trenching greater than 5’ deep. The trench box would need to be placed all the way to
the top of the trench. Compaction equipment used must be able to compact the full width and depth of
the trench.

b. Install clay dams

Require clay (or flowable fill) dams per current City standards to be shown on the plans and installed in
sewer and storm drain line trenches to prevent piping and reduce the transport of fines along the pipe line.
COD Standard details call for clay dams. No specific locations or spacing are specified (per plans). Minimum
requirements should be set, such as a clay dam every 300’ to 500’.

c. Require geotechnical engineer to provide recommendations for trench backfill, including proper moisture
content and suitability of using native soil or need for select material.

d. Revise specifications to require trench backfill to be mechanically compacted as follows, based on the soil
plasticity index (PI):

\[
\begin{array}{c|c|c}
\text{PI} & \text{Min. Requirement} \\
\hline
\leq 15 & \text{98%} \\
15 < \text{PI} \leq 35 & \text{98% to 102% at or above optimum moisture} \\
35 < \text{PI} & \text{95% to 100% at or above optimum moisture}
\end{array}
\]

all using Standard Proctor (ASTM D695) density. Density testing should begin with the first lift above
the crushed rock embedment shown on the details. Density tests should be taken at least every 150’
along the trench, for every foot of depth. The contractor must be required to provide adequate safety
measures, compliant with OSHA requirements, for the lab technician to safely do the testing at all depths
of the trench. Failed tests will trigger additional testing, at the Contractor’s expense, on either side of the
failed test to determine the extent of the uncompacted area.

e. Revise procedures to require random proof testing of trench backfill prior to completion of the installation
of the utilities. This testing to be at locations and depths identified by the City Inspector. Failing density
tests will trigger additional testing at the expense of the contractor along the utility installation to identify
the limits of improper compaction. Failed areas so identified will be removed and recomпacted and
retested, all at the expense of the contractor. Do not permit any subgrade preparation until all proof
testing is complete and accepted.

f. The Materials Testing laboratory to be used by the contractor must be identified prior to Pre-Construction
and approved by the City.

g. Ensure proper trench dewatering, based on the geotechnical design and the mini-preconstruction test pits.

4. Subgrade heaving

a. Many of the soils in the Denton area are subject to moderate to significant volumetric changes with
changes in moisture. Potential Vertical Rise (PVR) is a metric used to quantify this tendency for soil to
swell with the introduction of additional moisture. This analysis should be part of the geotechnical
investigation completed for the project, and should include recommendations for reducing the PVR to not
more than 4.5". The geotechnical design report should indicate how the PVR will be reduced and may
include placing a thicker layer of lime, using moisture conditioning, replacing expansive soils with more
suitable material, or a combination of these or other methods.

b. Where the PVR is greater than 4.5”, extend lime stabilization outside the edge of pavement a distance of
5’, capped with a sheet of 10 mil polyethylene to prevent water intrusion into the subgrade. Alternatively,
the poly sheet could extend a distance of 2’ behind the curb due to street trees and utilities.

5. Other impacts on pavements

a. Trees near the pavement can result in the roots drawing moisture out of the soil, resulting in settling.
Limit trees to a distance of one-half the mature height of the tree from the edge of the pavement, or install
root barriers.
b. Install edge drains along streets, particularly adjacent to ponds or other water sources, to capture surface flows. Edge drains can be connected to inlets and installed along the curb.

c. Soluble Sulfates

i. Require soluble sulfates testing as part of the geotechnical investigation. If sulfates are found at a concentration of greater than 2,000 ppm the geotechnical investigation should recommend measures to mitigate for the impact of those sulfates, such as the use of flexbase to replace lime or cement treatment, or a chemical injection such as EcSS 3000.

ii. Do not allow imported fill from the Eagle Ford formation (see Appendix). This will require that borrow sources be identified and approved (and possibly tested) prior to fill being transported to the site.