U.S. Department of Transportation
Federal Highway Administration

Temperature and Precipitation Impacts to Pavements on Expansive Soils

This case study focuses on the impacts of changes in temperature and precipitation on pavements constructed over expansive soils.[1]

Site Context and Facility Overview

State Highway 170 (SH-170) is a proposed highway in the northern part of the Dallas-Ft. Worth metropolitan area (Figure 1). The highway corridor consists of frontage roads separated by a wide median. The North Texas Tollway Authority (NTTA) plans to construct a 6.5-mile long highway segment with six general purpose lanes in this median.

Figure 1: Map of the project area (indicated in red)

Image Source: Google Maps

This site was selected for study because the corridor is located in the Woodbine Sandstone formation and near the Eagle Ford Shale sedimentary formation—both of which are known to have highly expansive plastic clays that shrink and become hard with drying, then swell and turn soft with moisture. This case study explores how changes in precipitation patterns and temperature could affect the roadway pavement that will be built over these clay soils.

Figure 2: Frontage roads on SH-170. One two-lane frontage road is in the foreground; the other one is faintly visible in the background. The wide, grassy median in the middle is the proposed site of SH-170.

Photo credit: FHWA

Environmental Stressors and Scenarios

This study looked at temperature and precipitation, as these variables affect the performance of pavement materials. For example, the stiffness of the pavement bituminous mixture is dependent on temperature, while soil subgrade stiffness is defined by the moisture content of the soil. Changes in temperature and precipitation also induce changes in other environmental variables such as relative humidity, freeze-thaw cycles, ground water table levels, etc. Together, these factors affect the fundamental properties of pavement materials and the subgrade, and control their structural responses under or in the absence of traffic loading.

Temperature and precipitation projections were obtained from the U.S Bureau of Reclamation (2013) which provides peer-reviewed statistically downscaled data of the World Climate Research Programme's Coupled Model

[1] This snapshot summarizes one of nine engineering-informed adaptation studies conducted under the Transportation Engineering Approaches to Climate Resiliency (TEACR) Project. See https://www.fhwa.dot.gov/environment/sustainability/resilience/publications/ for more about this study and *Synthesis of Approaches for Addressing Resilience in Project Development.*

Intercomparison Project 5. Soil moisture was calculated using the U.S. Geological Survey Modified Thornthwaite Monthly Water Balance Model (TMI).

The projections of future environmental conditions indicate a steady increase in ambient temperature and, possibly, aridity over the course of the 21st century. These changes will have profound effects on the secondary climate variables, such as relative humidity and soil moisture, and consequently affect the performance of pavement materials and subgrade.

Analytical Approach

Overview

This case study involved several different analyses for two reasons. First, both major pavement types—flexible (asphalt concrete) and rigid (reinforced concrete)—needed to be evaluated since the pavement design for SH-170 was not yet selected. Second, damage to the road could occur through different mechanisms. For example, higher air temperatures could soften flexible pavement, making it more prone to rutting. For rigid pavements, the decrease in mean relative humidity due to increasing temperature could worsen the shrinkage of pavement and lead to increased punchout potential. On the other hand, there could be positive effects. For example, the slight decrease in long-term precipitation might actually result in an increase in the load-bearing support offered by the subgrade soil.

To have a holistic view on pavement performance, therefore, it was necessary to understand how pavements would respond to changing climatic conditions at both the material and structural levels. Therefore, the analyses in Table 1 were conducted.

Adaptation Option	Flexible Pavements?	Rigid Pavements?
Impacts on subgrade support conditions	Yes	Yes
Impacts on asphalt binder performance grade	Yes	Yes
Shrink-swell potential	Yes	Yes
Impacts on asphalt concrete dynamic modulus	Yes	No
Structural distresses: Load-related bottom-up fatigue cracking Subgrade rutting Asphalt concrete rutting	Yes	No
Punchout potential of continuously reinforced concrete pavement	No	Yes

Table 1: Summary of analyses for flexible and rigid pavements

These analyses were completed using a number of tools, models, and software packages standard in the pavement industry, for example:[2]

- TMI-Matric Suction models were used to evaluate the impacts of TMI change on subgrade resilient modulus.
- LTPPBind 3.1 software was used to evaluate the adequacy of the asphalt binder used in the base case design and assess the influence of the future temperature projections on asphalt binder requirements.
- The shrinking and swelling potential of soils was evaluated using the Texas Transportation Institute's (TTI) Potential Vertical Rise (PVR) method using the Windows version of the Prediction of Roughness in Expansive Soils (WINPRES) software.

[2] Please see full case study for a more comprehensive discussion on methods.

Results

There will be both beneficial and detrimental effects to the flexible and rigid pavement design options under all future scenarios. Future temperature increases could indirectly benefit pavements as dryer soils with lower soil moisture content will cause a decline in the intensity of soil shrink-swell cycles. Less intense soil shrink-swell could result in increased subgrade support and pavement smoothness for both pavement types. Conversely, higher ambient temperatures could have more direct detrimental effects as increased pavement temperatures result in increased cracking, rutting, and overall reduced performance of the pavement itself.

Figure 3: Example of Damaging Effects of Expansive Soils on Pavements[3]

Adaptation Options

Adaptation options were considered for both flexible pavements and rigid pavements. These adaptation options involved uses of different asphalt binders and increased steel content, respectively. The recommended adaptations are in use today, and essentially represent a slight "upgrade" from the current designs in use at the study location.

Adaptation Option	Future Scenarios	Recommended Adaptation Measure	Anticipated Performance
Flexible Pavement Design	All scenarios	Use stiffer binder	Decreases fatigue damage and rutting by up to 50 percent
Rigid Pavement Design	All scenarios	Use additional steel in CRCP[4]	Decreases crack width by 6 percent
Rigid Pavement Design	Necessary only in warmest scenario	Use stiffer binder for asphalt concrete overlay	Improves the rutting resistance of the asphalt concrete overlay

Table 2: Summary of adaptation options and anticipated performance

Stiffer Asphalt Binders for Flexible Pavements

For flexible pavements, a reasonable adaptation approach would be to use stiffer asphalt binders (e.g., PG 76-YY or equivalent polymer modified binder alternatives) to decrease fatigue damage and rutting. These binders are in use today, and might normally be used in hotter climates or for high-use roads. The temperatures that would indicate the need for these binders are not projected to be reached in the study area until the latter half of the century.

Increase Steel Content in Rigid Pavements

For rigid pavements, an increase in the steel content could be warranted when the road is originally laid. A marginal increase in steel content from 0.72 percent to 0.74 percent would protect against anticipated damage.

[3] Source: Talluri, et al, 2013. See case study for full citation.

[4] Continuously Reinforced Concrete Pavement

Stiffer Binder in Overlay for Rigid Pavements

For rigid pavements, it is standard to put a 2-inch asphalt concrete overlay on the road at age 30. For the warmest scenario (RCP 8.5), a stiffer binder would be needed for this overlay, such as PG 76-XX or equivalent. This adaptation measure would be in addition to the increase in steel content that would be used when originally laying the road.

Recommended Course of Action

All three adaptation measures described above are recommended, depending on whether flexible or rigid pavement is being laid.

Generally speaking, the adaptation measures in this case study involve simple and fairly reasonable cost adjustments at the project level and may prove economically beneficial over a longer horizon. The proposed adaptation measures are proven strategies and are routinely used by Texas DOT for highly trafficked pavements. Furthermore, the impacts of future environmental conditions on pavement performance are not imminent, so the adaptation measures could be gradually implemented at the appropriate point in the pavement's life cycle.

Lessons Learned

- This case study demonstrates that not all impacts will occur in the form of catastrophic events. Rather, some changes can result in impacts that are much more gradual, but still costly in the long run.
- The pavement impacts in this case study can be mitigated using pavement mixes that are widely available and already in use today. There is neither a need for complex re-design or engineering innovations, nor a learning curve as to how to build using these materials.
- The cost premium for these materials is fairly low at the project level, meaning it may not be difficult to implement this measure for a single stretch of highway, such as SH-170. However, all roadways in the area may be exposed to the same stressors, meaning this adaptation measure may be appropriate at a large scale. In that case, the cost premium becomes significantly larger when looking at the extensive roadway network in the area. Applying these adaptation measures at a system-wide scale could have significant budgetary implications for a transportation department.

For More Information

Resources:

Transportation Engineering Approaches to Climate Resiliency (TEACR) project website
www.fhwa.dot.gov/environment/sustainability/resilience/ongoing_and_current_research/teacr/index.cfm

HEC 25 Volume 2: Assessing Extreme Events
www.fhwa.dot.gov/engineering/hydraulics/library_arc.cfm?pub_number=192&id=158

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