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Paving the way to better roads

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Design and construction protocols help mitigate pavement distress caused by high traffic loads and expansive soils.

Increased traffic loading in most American cities is putting pavement under significantly higher stress than its design intended, often leading to major repair work that costs cities, counties, and private developers millions of dollars. But, with proper steps taken when designing and building the road, many expenses may be spared in the long haul.

Consequently, some cities are taking matters into their own hands, enacting development requirements and ordinances to mitigate common pavement distress problems such as higher traffic loading and expansive subgrade soils. Colorado and Texas, because of a significant presence of expansive soils, are among the states taking a closer look at their roads and how to minimize maintenance costs.

The expansion factor

Every U.S. state has expansive soils, which warrant attention from the design community to avoid potential damage. According to a 1982 Federal Emergency Management Agency report, expansive soils have caused billions of dollars of damage to U.S. buildings, roads, pipelines, and other structures. Today, damage from expansive soils is costlier than damage caused by earthquakes, floods, tornadoes, and hurricanes combined.

A Dallas road is so damaged by swelling subgrade that local residents swear you could charge admission for driving on it, comparing the experience to a roller coaster ride. The streets in a subdivision in Frisco, Texas, were constructed using continuously reinforced concrete, which offered a saving grace for several years. Eventually, the expansive soils proved problematic, drainage was lost, and differential movements created significant distress, resulting in the recommendation that the pavement be replaced after only four years of service.

Differential vertical movement caused by expansive soil measures 3.5 inches at a pavement joint failure in the Meadow Creek subdivision in Frisco, Texas.

Nevertheless, even in states with higher concentrations of expansive soils—Texas, Colorado, California, Virginia, North Dakota, Oklahoma, and Montana—the presence of this material is not always recognized and accounted for in the design of pavement systems. Expansive soils must be addressed within education programs and with working engineers. College-level engineering courses often cover expansive soils, but even in states such as Texas where these soils are quite prevalent, the schools do not give the proper emphasis due to such a serious, yet manageable, issue.

Expansive soils (bentonite, smectite, or other reactive clays) expand when the soil particles attract water, and can shrink when the clay dries. Expansive soil can grow to as much as 15 times its original size, thus causing severe damage. Sidewalks, roads, and residential and commercial buildings may be lifted, causing cracks and distortion. Significant attention has been paid to the damage to residential and commercial structures caused by expansive soils, and special foundation systems such as drilled piers and stiffened slabs are commonly used to resist damages. For pavements, however, we have no such tools.

What lies beneath

Prior to paving, the subgrade has to be prepared to support the pavement and traffic loads, as well as to handle changes in volume. Similar to any foundation, the subgrade is essential to a successful project, as essential as the pavement structure and mix design. If the pavement system is not supported by a strong, stable, non-yielding foundation, the pavement can fail, and fail rapidly. Expansive soils must be addressed or costly damage and early failure can occur. Therefore, it is essential to test the subgrade soils to determine the amount of expansion (heave) that is likely to occur and the effect upon the pavement surface. Where calculations indicate, mitigation of expansive soils may include deep moisture injection, removal, and replacement; or excavation, moisture conditioning, and re-compaction of on-site soils.

The traffic factor

Virtually all design methods currently in use are based on the American Association of State Highway Officials (AASHO) Road Test, conducted during the 1950s using trucks with a maximum gross vehicle weight of 40,000 pounds and bias ply tires inflated to a maximum of 75 psi. Today, the maximum "legal" truck weighs 80,000 pounds and has radial tires inflated to more than 130 psi, which exert more than 500 psi at the tire edge. Documented truck weights greater than 120,000 pounds are common. Clearly, traffic data and analysis methods need to be examined carefully and updated.

Current advanced methods of design using elastic layer and finite element analysis techniques allow use of inputs that account for these heavier loads and greater tire pressures. However, the more difficult analysis techniques may not be merited in many instances, such as for subdivision streets that are not subject to these greater truck loads. In these cases, more traditional design methods can be used and the results checked for rutting and fatigue with more complex analysis methods.

Development protocols

In 2004, Frisco city officials called upon CTL|Thompson to investigate 12 pavement sections to find the cause of observed pavement distress typical of problems that were costing the city hundreds of thousands of dollars per year. It was initially believed—before any testing was conducted—that pavement distress was related to the formation of an expansive mineral called ettringite. This mineral forms from the combination of water, soil, sulfate, and free calcium. The free calcium usually comes from a stabilizing product such as portland cement, lime, or fly ash. The reaction of these materials creates the mineral that causes swelling of the treated zone by as much as 40 percent.

As a result of site investigations, however, expansive soils were found to be causing Frisco's pavement-distress problems, not ettringite. Previously, developers, engineers, and contractors in the city did not address expansive soil, having only constructed a temporary working platform directly below the pavement.

Based on recommendations from the investigation, the city of Frisco adopted an ordinance in mid-April 2006 requiring all developers to follow the Engineering Design and Construction Protocol for pavements within the Eagle Ford shale formation in the city of Frisco. (The Eagle Ford shale formation is defined by the presence of highly expansive residual soils and bedrock.) The guidelines require designers and contractors to address expansive soil problems by performing moisture treatment followed by subgrade stabilization. Essentially, the protocol requires that all pavement projects have a subgrade investigation and pavement design. Heave calculations provide for two methods: the Swell Test and the Potential Vertical Rise. A professional engineer must approve, in writing, all of the information and recommendations contained in the subgrade investigation report. More details on this ordinance are posted on Frisco's website at www.ci.frisco.tx.us. To date, this ordinance has reduced the problem of expansive soils under Frisco's roadways.

On a larger scale, the Dallas/Fort Worth metro area and the city of Irving, Texas, are looking to model pavement-design protocols after Frisco's ordinance. Additionally, Denver has had codifications similar to Frisco's in place since the early 1990s, but some Colorado cities are just now adopting such codes, even though it is one of the states with higher concentrations of expansive soils.

A growing cost

In 1980, researchers James P. Krohn and James E. Slosson estimated the annual cost of expansive soil in the United States to be $7 billion ("Assessment of Expansive Soils in the United States," 4th International Conference on Expansive Soils, Denver). This takes into account damage to any structure built over expansive soils. The cost associated with the higher traffic has not been calculated, but analyses suggest the service life of pavements has been reduced by as much as 50 percent.

The presence of expansive soils under a road, if not properly mitigated, can cause damage that may not be apparent at first, but have expensive consequences in the long run. Cities such as Frisco and Denver are aiming to achieve within their pavement protocols a more complete method for design that will greatly reduce later repairs. By combining these expansive subgrade mitigation measures with the advanced analysis techniques and high traffic levels, municipalities and counties can better prepare to cope with the constant budget pressure to reduce costs and the public pressure to improve performance. To coin a well-used phrase, "Pay now, or pay later."

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The sulfate factor

Sulfate is in our drinking water and in the streams we fish. It comes from industrial pollution combustion sources and also occurs naturally. It is a mineral that is relatively harmless, until it reacts with the roads we drive. When mixed with water, calcium, and soil, sulfate explodes to form the ettringite mineral. Ettringite always forms when these constituents are present, or so we have been taught. But, recent research shows that the rule is not always valid.

Sulfate in expansive soils is the key here, as it is essential to understand how the sulfate reaction works so that additional problems aren't created with the introduction of stabilizing materials such as lime, portland cement, and fly ash. In one study, CTL|Thompson analyzed the formation of ettringite in the Eagle Ford shale formation near Frisco, Texas, and how it reacts with soils in the area. The soils in this area are extremely reactive and hold a high swell potential within their three layers. The upper 5 feet are a dark brown, clay-like soil; mid-level is composed of a light tan, clay-like material; and the lower level is a gray, weathered bedrock formation.

Samples from each of the three zones, prepared with as much as 3 percent sulfate, behaved completely differently, even though the components and phase diagram of the Eagle Ford shale formation should lead it to have the same makeup of materials throughout. The top zone was highly resistant to the sulfate, even with as much as 3 percent sulfate. The middle zone was highly reactive with as little as 0.3 percent sulfate. This small dose resulted in significant mineral formation. The bottom layer of the shale produced a middle-of-the-road reaction, neither highly reactive nor resistant.

Since there was no logical explanation as to why these three layers in the same formation reacted so diversely, experts from Texas A & M University were asked to look at the problem and see what could be causing these varied reactions. After analyzing the samples, it was found that the key to trigger the mineral formation was the amount of soluble silica, which typically is not measured.

The city of Frisco was not dealing with ettringite as the cause of its pavement distress, but the investigations into these problems yielded the studies of the Eagle Ford shale formation. The results have quantified the problem of the ettringite formation by providing a procedure to test for sulfate presence.