Geologic controls on foundation damage in north-central Texas

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Abstract: Damaged house foundations in Denton, Texas were evaluated within the context of local geology. Addresses of 78 damaged structures were compiled from local foundation repair companies. The Cretaceous age Grayson and Woodbine formations outcrop in the study area. Marl and montmorillonitic clay are predominant constituents of the Grayson formation. The Woodbine formation consists of sand and sandstone interbedded with clay. Textural and compositional differences in these parent materials have lead to significantly higher plasticity indices for Grayson residual soils. The distribution of damaged foundations was superimposed on a geologic map to determine the number and spatial density of damages in each formation. A 324 percent higher damage density was calculated for the Grayson formation. Results of this study suggest that (1) expansive soils pose a significant hazard to foundations in Denton, and (2) the magnitude of this hazard is controlled in part by underlying rock formations.

Introduction

Expansive soils are one of the most costly geologic hazards. Each year they cause over $2 billion in damage to roads, buildings, buried utility pipes, and other structures in the United States (Chen 1988; Keller 1996), and some estimates are as high as $6 billion/year (Pipkin and Trent 1994). In fact, expansive soils cause more damage in the United States than all other natural hazards combined, including earthquakes, floods, tornadoes, and hurricanes (Rollings and Rollings 1996; Montgomery 1997). The potential for damage is especially severe in montmorillonitic clay soils that undergo significant temporal changes in moisture content. These conditions apply to many parts of the southwestern United States.

Approximately one-fifth of the houses in the United States are located on expansive soil (Chen 1988). Climate and parent material are major controls on soil formation and ultimately govern expansion hazard. In regions that are prone to expansive soil damage, geologic mapping should be a critical component of land use planning. The objectives of this study were to (1) evaluate the spatial distribution of damaged foundations relative to geologic conditions in Denton, Texas, and (2) discuss measures for mitigating future damage in the region.

Background

Expansive soils include clay minerals that undergo significant volumetric changes with fluctuations in moisture. Swelling is caused by the attraction of water molecules to plates of certain clay minerals, especially montmorillonite (Chen 1988). Layers of water molecules are added between plates as the clay expands or swells (Keller 1996). A soil’s Atterberg limits reflect the activity of the clay minerals present and, therefore, they are widely used to help identify expansive conditions (Rollings and Rollings 1996). Generally, expansive clays have a high plasticity index, reflecting a tendency to take up lots of water while in the plastic state (Brown 1979).
Sedimentary rocks that contain montmorillonite often yield expansive soils. These include shale, claystone, limestone, and marl rich in magnesium (Terzaghi et al. 1996). Volcanic ash can weather to montmorillonite, and its presence in sedimentary rocks promotes the formation of expansive soils.

Extreme disintegration of parent material, alkaline conditions, strong hydration, and restricted leaching promote the formation of montmorillonite (Chen 1988). Under these conditions, magnesium, calcium, sodium, and iron cations may accumulate in the soil. Montmorillonite most often forms in semi-arid regions, where there is enough water available for altering the parent rock, but not enough to flush away the requisite cations.

Volumetric changes in expansive soils are particularly troublesome in large areas of the southwestern United States, India, Australia, parts of Africa, and the Middle East (Bowles 1996). These regions are subject to long dry periods and periodic heavy rains of short duration. In the United States, Colorado, Texas, and Wyoming experience the most severe expansive clay problems (Chen 1988). Portions of these states are characterized by large surface deposits of clay and alternating periods rainfall and drought.

Slab-on-grade foundations are especially vulnerable to cracking from volumetric changes in the underlying soil (Godwin 1993). Day (1994) described two types of expansive soil movement that affect slab-on-grade foundations: (1) short-term cyclic heave and shrink around the perimeter of the foundation, and (2) long-term progressive heave beneath the center. The perimeter heaves during the rainy season and settles during dry periods. The amount of cyclic heave/shrinkage depends on the moisture content of clay deposits beneath the perimeter footing. Moisture changes depend on the severity of drought/rainy seasons, the influence of drainage and irrigation, and the presence of live tree roots which can extract moisture and cause shrinkage (Godwin 1993).

Progressive swelling under the slab occurs by thermo-osmosis and capillarity. Thermo-osmosis, a seasonal phenomenon, is the migration of moisture vapor from areas of high to low temperature. During the summer especially, soil under the slab’s center is cooler than exterior soils, so moisture moves to soil under the slab. Capillarity is the upward movement of moisture that is not allowed to evaporate (due to the slab barrier). Maximum heave under the center of a foundation may not be reached for many years after construction (Day 1994).

Previous studies have documented the destructive effects of expansive soils on concrete foundations, especially those beneath lightly-loaded structures such as houses. In a study conducted for Carrollton, Texas, 26 to 36 percent of the ten-year old homes surveyed had suffered damage to sheet rock and brick veneers that was attributed to expansive soils (Allen and Flanagan 1986). Carrollton resides on plastic clay soils derived from the Cretaceous-age Eagle Ford (shale) formation. Chen (1988) estimated that 30 percent of the homes on the Taylor (marl) formation in San Antonio had significant foundation damage.

Many foundations cannot withstand the positive (downward) and negative (upward) movements associated with expansive soils. Upward movements are most destructive — swell pressures can exceed 200 metric tons per square meter (Allen and Flanagan 1986; Chen 1988). Moisture that contributes to upheaval may originate from improper drainage, underground water, and domestic sources such as leaks in supply or waste systems. Houses seldom provide the huge restraining pressures required to control subgrade swelling (Bowles 1996).

Study area

Denton is located in north-central Texas, at the updipl edge of the Gulf Coastal Plain (Figure 1). The city has a population of approximately 80,000. Most of the residential development is within the bold area in Figure 1.

Slab-on-grade foundations are used extensively in north-central Texas. For lightly-loaded buildings such as houses, the slab is typically 10–12 cm thick. A grid of interior and exterior grade beams is trenched into the house’s footprint before the concrete is poured. Typically these beams are 50–70 cm thick, 25–30 cm wide, and 3–4 m apart from one another. Cast in concrete, the steel-reinforced slab and beams are components of a monolithic structure (Chen 1988; Allen and Flanagan 1986). This type of construction is used in more than 95 percent of the new houses built in the study area.

The widespread use of slab-type foundations can be attributed to significantly lower construction costs compared to alternative, pier-reinforced structures. The cost of a typical slab in north-central Texas is US $34/m². Each pier, a cylinder of steel-reinforced concrete extending 3–5 m below grade, adds approximately US $100–120. A 200 m² house requires about 40 piers.

Many of the houses in the study area built before 1970 have pier and beam foundations, comprising a combination of concrete and wooden beams. Typically, a beam is built upon a concrete footer. There is a perimeter beam around the outside of the house. Inside the perimeter, there is a grid of concrete posts extending below grade. Wooden beams run across the