

# **PROBLEMS WITH EXPANSIVE PYRITIC SHALES IN EAST TENNESSEE**

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## **ABSTRACT**

Economic costs of damage due to expansive soils and rocks in the U.S. has been estimated at \$6 to 11 billion annually, which is more than the combined annual damage costs of earthquakes, floods, and tornadoes (Nuhfer et al. 1993). Considerable research and money have been directed towards controlling and preventing damage from these hazards, while relatively little attention has been given to damage caused by expansive shales. Expansive shale problems have been encountered in Norway, Canada, Sweden, Pennsylvania, West Virginia, and Ohio. However, this project focuses on a particular type of shale, called Sevier shale, which is common in East Tennessee. Sevier shale contains iron disulfide ( $\text{FeS}_2$ ) or pyrite, also known as "fool's gold." Pyrite can oxidize to form sulfate minerals, and in the presence of calcite, can produce gypsum crystals. The volume increase and accompanying heave pressures can cause extensive structural damage, collapse of culverts, failure of retaining walls, and mine floor deformation. In forming effective remediation and/or prevention practices for these situations, it would be useful to examine typical on-site recommendations and identify those which appear most successful. Therefore, this project examines several case studies in East Tennessee, evaluates testing procedures that predict expansion potential, and identifies the most effective management practices.

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## I. INTRODUCTION

Shale is a sedimentary rock formed by the accumulation of various clay, silt, and sand particles, and it comprises approximately 70 to 80 percent of all sedimentary rocks (Ackenheil 1980). Due to its abundance, it is often used as an engineering material in forming fills, embankments, roadway bases, and foundations, and it is also often encountered in excavations. The shale type that is the subject of this report, called the Sevier shale, is common in East Tennessee and is a black, carbonaceous, slightly calcareous fissile shale of the Ordovician system. The Sevier shale contains iron sulfide ( $\text{FeS}_2$ ) or pyrite, which is known commonly as “fool’s gold.” Swelling of these shales is caused primarily by the formation of secondary minerals and accompanying volume changes induced by the chemical alteration of sulfide minerals (Dubbe et al. 1984).

Pyrite is generally considered stable under normal conditions, but in the presence of both air and water, it oxidizes and expands within the shale. A molecule of pyrite consists of close-packed hexagonal sheets of sulfide ions between which iron is present. This configuration occupies a volume of 26.14 cubic angstroms. When the pyrite is oxidized, however, it becomes a sulfate, which has a structure of an atom of sulfur surrounded by four atoms of oxygen in tetrahedral form and which occupies a volume of 94.4 cubic angstroms (Dubbe et al. 1984). Therefore, there is a 3-fold theoretical volume increase per packing unit in the oxidation of pyrite. However, this prediction does not consider the density of minerals formed. The primary reactions that the pyrite can undergo are as follows (Morgenstern 1970):



There are many secondary minerals formed in the reactions listed above (see Table 1).

However, the following reaction, occurring when calcite and sulfuric acid are both present, causes the formation of gypsum crystals (Morgenstern 1970) :



**TABLE 1. Secondary Minerals Formed in the Weathering of Pyrite (Spanovich 1969)**

| <b>Mineral</b> | <b>Physical Description</b>                       | <b>How Formed</b>                                               |
|----------------|---------------------------------------------------|-----------------------------------------------------------------|
| Rozenite       | aqua to white, stringy                            | Dehydration of melanterite by sulfuric acid, no excess of water |
| Coquimbite     | blue-green or white crystals, soluble             | Alternate wetting and drying of rozenite                        |
| Jarosite       | yellow, dusty powder                              | Reaction of coquimbite with illite in presence of moisture      |
| Kaolinite      | white powder                                      | Remains with jarosite                                           |
| Melanterite    | aqua to white, soluble                            |                                                                 |
| Limonite       | rusty, red powder                                 | Breakdown of jarosite                                           |
| Gypsum         | white or yellow crystals, usually in rosette form | Reaction of calcium and sulfuric acid                           |

While the secondary minerals rozenite, coquimbite, jarosite, kaolinite, and limonite serve only to occupy voids formed in the expansion process, the growth of gypsum crystals is believed to be the primary cause of heave in these shales (Dubbe et al. 1984). The growth of melanterite crystals may also be a factor, but they are far more difficult to detect and study due to their solubility in groundwater. It is important to note that gypsum is considerably less dense than pyrite; in a typical gypsum veinlet, only 27% of

the plane surface area is occupied by gypsum crystals while the remaining 73% is void space. Therefore, where gypsum is formed, a 5 to 8-fold increase in the original sulfide mineral volume is more realistic, corresponding to a heave of 4 to 4.5 inches in a 4 to 5 foot pyritic shale layer (Westinghouse 1990). Such uplift forces can create heave pressures in the range of 10,000 to 12,000 pounds per square foot; however, ultimate heave pressures that far exceed these values can be expected (Spanovich 1969).

In addition to water and air, another external stimulus that is thought to catalyze the oxidation of pyrite is autotrophic bacteria. There is some controversy however, as to whether bacterial assistance is required for this process, but it is generally undisputed that, if present, the bacteria do accelerate the oxidation process in low pH conditions (Berard 1970). In general, thiobacilli bacteria are most active in the early stages of the reaction, while ferrobacilli bacteria are most active when the production of sulfuric acid creates a low pH environment (Dubbe et al. 1984).

## **II. FACTORS THAT INCREASE LIKELIHOOD OF EXPANSION**

### **A. Excavation and Site Grading**

Prior to the 1970s, expansive pyritic shales were a relatively unknown problem, due mainly to technological limitations in performing deep excavations. Deep excavations and site grading may remove weathered portions of shale and thus expose fresh sulfide-bearing layers to air and moisture. In addition, removal of overburden can cause rebounding and fracturing, exposing even more surface area to weathering mechanisms (Dougherty and Barsotti 1972). It is also important to note that if these beds were

previously beneath the water table and therefore could not oxidize in the absence of air, many times the dewatering of the construction site will trigger oxidation and expansion of the sulfide-bearing stratum (Dubbe et al. 1984).

### **B. Use in Fills**

As mentioned previously, shale is commonly used as an engineering material, particularly in fills. When fresh pyritic shale is excavated and broken up, its increased surface area and sudden exposure to air and moisture together increase heaving potential. This issue is of particular importance in projects dealing with retaining walls, culverts, and/or highways.

### **C. Slab-on-Grade Construction**

Though rock is generally considered a sound base for structures, placing foundations and floor slabs directly on sulfide layers increases the potential for structural damage. If the layer begins to oxidize and expand, it takes the path of least resistance and produces heave in the floor slab. In addition, insufficient insulation between the floor slab and shale layer can transmit heat into the oxidizing layers and thus catalyze the reaction (Dougherty and Barsotti 1972).

### **D. Lightly-Loaded Structures**

Many modern buildings are considered “lightly loaded” structures and are unable to fully counteract heaving pressures from expanding shales. Examples of these types of

structures are schools, houses, hospitals, and office buildings. Various authorities have suggested that a minimum dead load of 4–10 ksf on a footing is needed to counteract the uplift forces due to crystal growth (Dougherty and Barsotti 1972). Recently, however, findings have shown that this range should be higher, approximately 10–12 ksf (Westinghouse 1990).

#### **E. Heated Tunnels and Basements**

The aforementioned oxidation reactions occur more readily in warm environments, particularly in areas where there is little or no insulation between the shale bedrock and tunnels or basements. In addition, a temperature gradient can produce an upward migration of water and dissolved oxygen which can trigger sulfide oxidation (Berard 1970). The role of heat is also significant in cases where expansion has occurred in “hot line” trenches, which carry heating or steam lines (Dougherty and Barsotti 1972). In many structures, damage occurs in lesser-used portions of buildings such as basements or tunnels, and therefore can go unnoticed for a long period of time.

### **III. TYPICAL MANAGEMENT PRACTICES IN EAST TENNESSEE**

In the past, damage due to expansive shales has been attributed to frost heave, differential settlement, subsidence, or poor construction practices (S&ME Job 1401-93-022-A 1993). Now, the Sevier shale formation in East Tennessee is better understood and has been identified as a sulfide bearing shale and therefore potentially expansive; thus, it is becoming common practice for engineering and geological consultants to

employ preventative measures before construction. For facilities that are already constructed, several remediation procedures are being suggested and tested. What follows are typical procedures for determining expansion potential of pyritic shales and typical on-site recommendations for remediation or prevention.

#### **A. Typical Procedures for Determining Expansion Potential**

Many testing schemes are available for evaluating expansion potential in a pyritic shale layer. These include, but are not limited to, general rock core inspection, joint surface inspection, bacterial cultures, free swell test, modified swell test, induced gypsum crystal growth, and total sulfur analysis (Dubbe et al. 1984). If the shale layer has already been weathered, a general inspection of the core may determine the presence of gypsum and/or pyrite. However, additional tools are often necessary to see the microscopic presence of these minerals. Scientists will often inspect portions of joint surfaces through scanning electron microscopes and through x-ray diffraction. Both techniques are useful for examining the mineralogy and secondary mineral formation in the shale (Ibid.). In addition, bacterial cultures can be useful in determining whether bacteria present in the shale are of the type that oxidizes ferrous iron to ferric iron (Penner et al. 1970). The free swell test can give an indication of swelling potential by placing a shale specimen in an apparatus that allows for swelling in all directions, but measures swelling only in the vertical direction. The apparatus is stored under conditions of 100% humidity, then strains are calculated from the dial gage readings and plotted as a function of elapsed time (Dubbe et al. 1984). The modified swell test is similar to the

free swell test, except the sample is submerged in water, a constant load is applied, and expansion is allowed to occur only in the direction of the load (Ibid). Though the latter two tests are simple and inexpensive, they are time-consuming, for pyritic shale expansion occurs over long periods of time. In an induced gypsum crystal growth test, a sample is exposed to solutions of  $\text{CaCl}_2$  and  $(\text{NH}_4)_2\text{SO}_4$  under the same head at opposite fluid inlets, then removed and analyzed for gypsum formation (Ibid.). Because it is difficult to mimic the exact conditions in which the oxidation of pyrite forms gypsum, this test may not be a good indicator of what occurs in the field.

One of the more common and more useful techniques is total sulfur analysis. The total sulfur content of a shale sample consists of sulfate sulfur, sulfide or pyritic sulfur, and organic sulfur (Westinghouse 1990). The amount of sulfate sulfur present gives an indication of the amount of oxidation and expansion that has already occurred, while the amount of pyritic sulfur indicates the expansion that can occur if all of the sulfides are converted to sulfates. The organic sulfur content is measured only to complete the total sulfur measurement (Ibid.).

## **B. Typical Recommendations for Remediation or Prevention**

To date, there are several possible actions for remediation or prevention of expansive shale problems in East Tennessee; some recommendations are as follows:

1. Remove or deeply bury the pyritic shale layer
2. Expose layer to weathering and allow it to expand before construction
3. Adjust groundwater levels to flood the shale layer
4. Introduce a limestone aggregate base onto fresh shale surface
5. Flood the shale layer with potassium hydroxide
6. Apply an impermeable bitumen coating to fresh shale surface
7. Install rock bolts in foundations
8. Build a swell-resistant structural floor system

Of these possibilities, 1) and 2) are perhaps the most impractical. Shale layers can be too thick to excavate, and the heaving process can take years, and there is no way to tell whether all the shale has been fully oxidized. In addition, the construction site and project design may not lend themselves to burying the shale layer under 10 feet of fill. Adjusting groundwater levels in order to prevent exposure to air is also impractical; it would be difficult to control groundwater levels as precisely as is needed to prevent both expansion and flooding of basements, tunnels, etc. Introducing a lime layer to increase the pH can be counter-productive, for the lime can initially react with sulfuric acid to produce gypsum (Dougherty and Barsotti 1972). Flooding the shale layer with potassium hydroxide (KOH) can also raise the pH, destroying bacteria and slowing the reaction, but this method can be counterproductive if the normality of the solution is too high with

respect to KOH. Because pyrite is stable in a reducing environment, increasing the pH favors its breakdown (Coveney and Parizek 1977). In past studies, 0.01 N and 0.1 N KOH solutions have stopped the growth of catalyzing bacteria and thus slowed the heaving process (S&ME Job 1401-89-096-A 1993). However, a 1 N solution has been shown to accelerate the process by causing the pyrite to break down, exposing more surface area to air and moisture. Therefore, if increasing the pH is the most desirable approach, it seems preferable to flood the shale with either a neutral or only slightly acidic solution (Coveney and Parizek 1977). Applying a coat of bitumen can be expensive, but it has been proven fairly effective in preventing exposure to moisture and air. The last two recommendations, building a structural floor system and installing rock bolts, have proved effective as preventative measures, and they will be discussed at further length in the case studies.

#### **IV. CASE STUDIES**

The following case studies give insight into the types of problems that have occurred in East Tennessee, how they were recognized, and typical recommendations for correction. Cost estimates for remediation or preventative procedures are listed wherever available.

##### **A. Johnson City Public Library**

The Johnson City Public Library is located on the southeastern corner of the intersection of South Roan Street and Water Street in Johnson City, Tennessee. The

library rests on a syncline ridge in the Sevier Shale Formation of the Middle Ordovician System (Westinghouse 1990). Part of the ridge was excavated and a retaining wall was built and back-filled with pyritic shale to create a site for the library. The building is a 20,000 ft<sup>2</sup>, triangle-shaped, single-story structure with a slab-on-grade. The retaining wall at the back of the building is 24.5 feet high, and building's foundations are shallow spread footings (Ibid.). This case history was described in a Westinghouse Environmental and Geotechnical Services report, Structural Distress Investigation of the Johnson City Library, by John Long and P. Alan Williams (1990).



Fig. 1. Heaving of floor under bookshelves at JC library

The library was constructed in 1979, and signs of floor slab displacement (see Fig. 1) in the northern section of the building were detected within one year (personal communication, Tim Siegel 1998). An investigation was conducted in 1982 by Barge, Waggoner, Sumner, & Cannon, but it was concluded that instability of foundation materials was the cause. The floor slab was repaired, but over the next few years,

cracking and displacement of the floor slab continued to occur, and signs of heaving spread to the southern section of the building. In 1989, another investigation was initiated by Westinghouse (now Soil & Material Engineers). Preliminary data collection included the excavation of test pits, sampling from boreholes, a survey of building elevations to note changes from the investigation in 1982 to the current investigation, and the installation of thirteen crack gages. In most areas, a 0.3-foot crushed limestone base and a 3- to 6-foot shale fill, on top of black shale bedrock with thin limestone layers, was discovered under the floor slab (Westinghouse 1990). Though all soil and rock materials were wet, no groundwater was encountered in the test pits. It is likely that springs and seeps through the bedrock are present under the building. Several geotechnical tests were conducted on collected samples, including grain size analysis (ASTM D422, D1140), Atterberg limits (ASTM D423, D424 method), unit weight, moisture content (ASTM D2216), Standard Proctor moisture-density relationship (ASTM D698), Standard Proctor one-point verification, and the consolidated-drained direct shear test (EM 1110-2-1906). In addition, an x-ray diffraction analysis was conducted on samples of the bulk shale and scrapings from joint surfaces, which all showed the presence of gypsum crystals. A total sulfur analysis was also conducted on several samples, which showed a sulfide sulfur content of 0.08–0.63 % and a sulfate sulfur content of 0–0.49 %. Because a shale sample with as little as 0.1% sulfide sulfur is considered expansive and 1–2% is considered highly expansive, it is evident that there is significant expansion potential in nearly all areas where samples were taken. Further analysis of this site showed that the dead load pressure on the column footings was 400–1600 psf, much lower than potential heave

pressures. The materials behind the retaining wall to the east of the site did contain pyritic shale, but the wall showed no sign of damage (Ibid.).



Fig. 2. Tilting of floor and separation between floor and wall in recreation room

At the conclusion of the investigation, the cause of heaving was determined to be the growth of secondary minerals (mainly gypsum) in the shale fill and bedrock from the oxidation of pyrite. The general heave rate was determined to be 0.25 inches per year (Westinghouse 1990). Some of the most noticeable structural damage included heaving of the floor slab of 4–5 inches in some areas, heaving of the column footings of approximately 1.2 inches, cracking of the brick veneer on the outside of the building, a 1-inch displacement of the sidewalk, mis-aligned window sills and door frames, and bulging of the walls. Photos of typical distress are shown in Figures 2-5. Though the retaining wall showed no damage, it was thought that it might later experience creep-like translation or rotation due to gypsum formation in the backfill.

The three recommendations for remediation given by Westinghouse were as follows:

- Option 1.) Remove current floor slab and install a structural floor system with an 18 inch crawl space,  
Apply a bitumen coating to bedrock surface,  
Use existing footings or install intermediate footings with a 10 ksf design bearing pressure (dead load),  
Install resin-anchored rock bolts with a 10 ksf prestress in areas where dead load is not 10 ksf,  
Replace backfill of retaining wall with non-calcareous stone wrapped with filter fabric,  
Install rock bolts in the footing of the retaining wall.  
Estimated Design Life = 50 years  
Estimated Costs = \$ 700,000 (not including design fees)



Fig. 3. Cracking of floor slab in staff area

- Option 2.) Temporarily repair areas with most damage and threat to the public, including floor slab, partition walls, and ceiling, until a new library can be constructed
- Estimated Design Life = 3 – 5 years  
Estimated Cost = \$ 15,000 (not including cost of new library)
- Option 3.) Maintain current building through periodic maintenance construction  
Conduct procedures in Option 2.) with a 3 – 5 year frequency.  
Estimated Design Life = 10 – 15 years  
Estimated Cost = \$ 15,000 every 3 – 5 years

In the end, Option 3 was chosen for maintenance of the current building until the new, \$12 million library could be built 3 blocks away.



Fig. 4. Misaligned door frame due to heave in floor slab



Fig. 5. Misaligned door frame at women's restroom

### **B. Gymnasium at Old Southside Junior High/Science Hill High School**

This site is located directly behind and to the east of the Johnson City Library. A gymnasium is the only standing portion of a structure that originally housed the Science Hill High School, then the Southside Junior High in 1960. The gymnasium was added in 1938, but the main school building was demolished in 1979. Similar to the library, the gymnasium site was cut into the shale ridge (see Figs. 6-7). Over several decades, extensive cracking has occurred in the interior plaster finish and in the masonry of the south and west walls and in the bleachers in the southwest corner of the building (S&ME Job T9048 1979).

Though it is unknown when structural distress was first noticed, the first major effort to correct the problem was the installation of two reinforced concrete buttresses in the storage room at basement level in 1955. In 1978, an investigation was initiated by Soil and Material Engineers (S&ME) for the City of Johnson City in order to examine the continuing structural distress, including the severe cracking in one of the buttress walls.



Fig. 6. Gymnasium of the Old Southside Junior High School, view towards SE

Samples of the bedrock and backfill of the south wall were analyzed through x-ray diffraction. The bedrock samples showed relatively sound, unweathered shale, while the backfill samples showed growth of gypsum crystals (Ibid.).

Though damage to the west wall was attributed to instability of the wall footing, the primary cause of damage to the south wall and southeastern corner was excessive lateral pressure in the shale backfill due to gypsum growth. The lateral stress on the wall was inducing bending stresses approaching the wall's moment resisting capacity. It was

noted that hydrostatic pressures behind the wall could also have been a factor, for the gymnasium experienced occasional plumbing and roof leaks and possible higher



Fig. 7. Steep shale embankment adjacent to gymnasium

groundwater levels. Though damage to the roof and the west wall would require some repair, S&ME recommended that most of the repairs be conducted on the south wall, which included the following (S&ME Job T9048):

- Option 1.)     Remove the locker room floor slab at least 12 feet back from the wall
- Remove existing backfill, replace with #67 stone compacted in place, and install a drain pipe
- Install a tieback system at mid-height of the wall, anchored in shale and extending through wall and connected to a whaler

In the end, the gymnasium was abandoned and to this author's knowledge, no major repairs were conducted. To date, the building is still unused and deteriorating rapidly.

### **C. Hospital\*, Kingsport**

Structural distress was first noticed in 1978 in Building C of this hospital, only two years after it was built. Lightly-loaded floor slabs in this area, particularly in the basement mechanical room, showed signs of heaving. It is important to note that all of the floor slab in the mechanical room heaved significantly except for one ~10 foot by 5 foot section in the middle of the room (personal communication, J.M. 1998). A steamer tank there was apparently sufficiently heavy to dampen the heaving process. At this time, the hospital began to monitor the heave, but no remedial action was taken. In 1984, the heaving appeared to cease. Groundwater levels were lowered around this time to prevent groundwater contamination from some leaking storage tanks (personal communication, J.M.\* 1998). It is the author's opinion that levels were lowered enough to prevent a thermal gradient and upward migration of water into the shale layer. Therefore, the shale layers may no longer be exposed to adequate moisture to maintain the heaving process.

Around 1991, plans were proposed to build an addition onto Building C and to build Building D across the street. In order to determine the potential for heave in the new building sites, the hospital consulted Gresham, Smith and Partners and S&ME. Three soil test borings were drilled to 10 feet below finished floor elevation of both buildings, and a total sulfur analysis was conducted. The bedrock was found to be potentially

\*Names and addresses withheld for client privacy

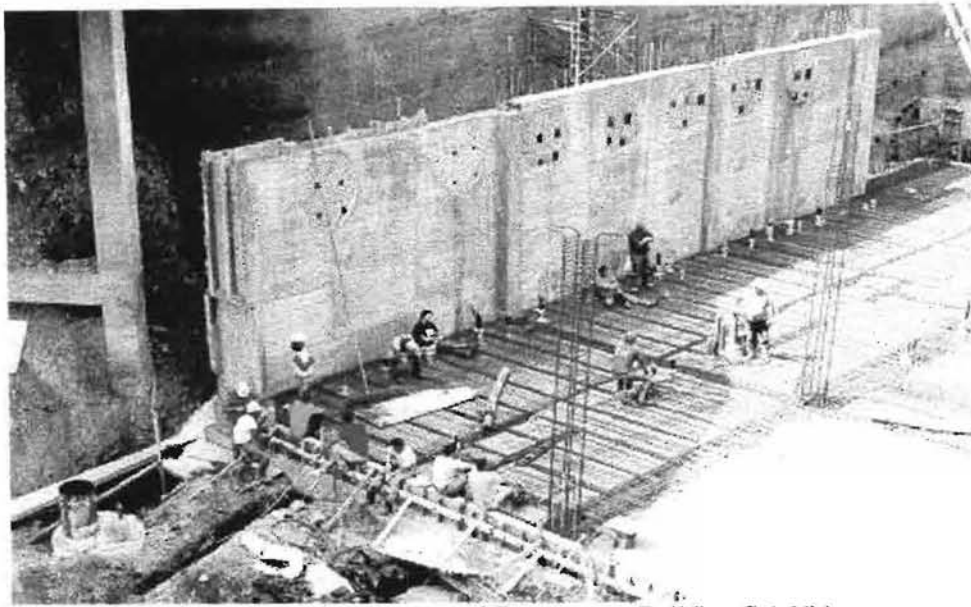


Fig. 8. Carton forms in the structural floor system, Building C Addition

expansive to highly expansive black, carbonaceous shale (S&ME Job 1401-91-362-A).

As a result, the consulting engineers recommended the following preventative measures (S&ME Job 1401-91-362-A):

Building C Addition:

- Option 1.) Seal exposed shale bedrock with asphaltic coating immediately after final cut elevation
  - Install resin-anchored rock bolts to minimum 10 ksf prestress
- Option 2.) Construct a structural floor system with crushable cells (see Figs. 8-10)
  - that allow for 8 - 10 inches of expansion under the floor slab
  - Place a vapor barrier between the cells and shale layer
  - Cover fresh shale surface with clayey soil or heavy polyethylene sheeting to prevent sulfate attack on floor slab
  - Use Type V concrete in all caissons to prevent sulfate attack
  - Install resin-anchored rock bolts to 10 ksf prestress

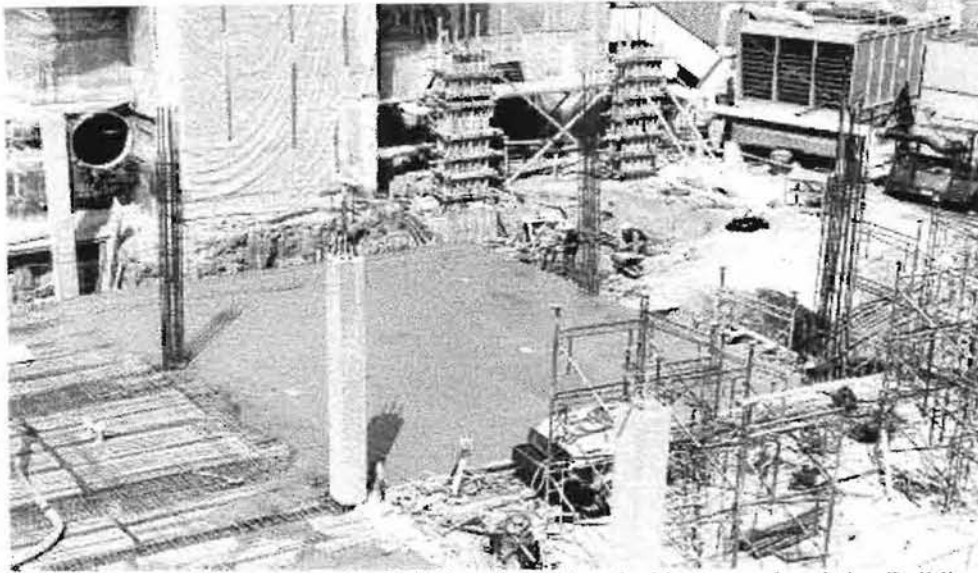


Fig. 9. Structural floor system for Building C Addition, looking towards existing Building

#### Building D:

- Option 1.) Construct a structural floor system with crushable cells under the proposed lower level parking garage
- Option 2.) Pave the level with asphaltic concrete to allow for flexibility of slab
  - Do not tie slab to structural frame
  - Seal fresh shale surface with asphaltic sealer
  - Install resin-anchored rock bolts in footings with 10 ksf prestress
  - Use Type V concrete in footings to prevent sulfate attack

Ultimately, a structural floor system was constructed for the Building C addition, and the lower level of Building D was paved with asphaltic concrete. Rock bolts were installed in both areas, and Type V sulfate-resistant concrete was used in the caissons and footings (personal communication, J.M. 1998). To date, these areas have experienced no structural distress.

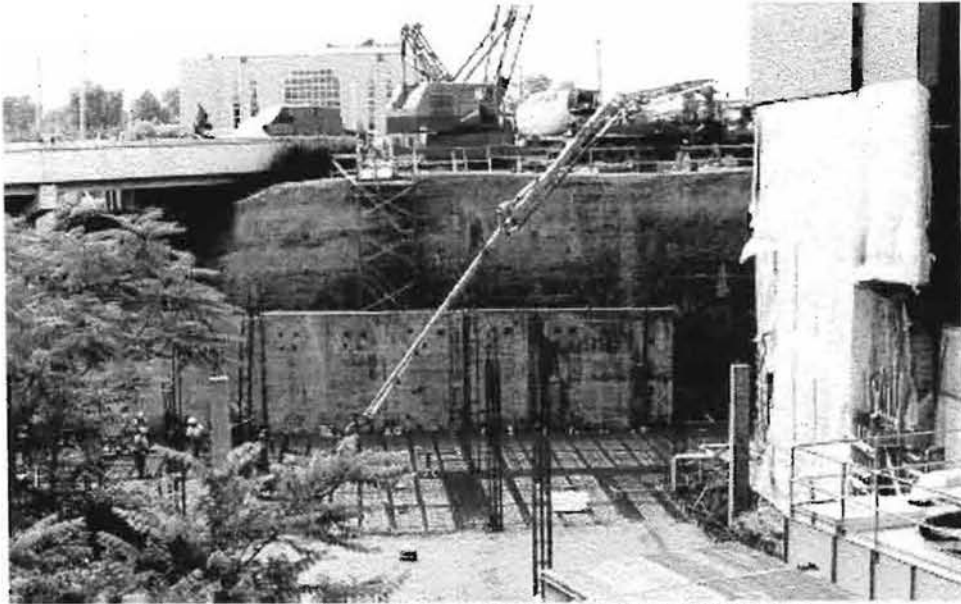


Fig. 10. Excavation and floor system for Building C Addition

#### **D. Fort Henry Mall, Kingsport**

The Fort Henry Mall is located at the intersection of Fort Henry Drive and Memorial Boulevard in Kingsport (see Fig. 11). Heaving of the floor slab and buckling of partition walls were noticed near the movie theater lobby, a Naturalizer Shoes store, and a Lens Crafters store of Fort Henry Mall in the early 1990s, and investigations were conducted in early 1992 and 1993 by S&ME (S&ME Job 1401-93-022-A). Based on visual observations, heave had reached one to two inches in some locations. This heaving resulted in broken floor tiles, mis-aligned doors, aesthetic problems, and possible unsafe walking conditions. During the investigation, it was determined that at some point, pumps were installed in a corridor behind the movie theater screens in order to prevent flooding of this area during periods of elevated water table. The pumps now maintain the

water level below the corridor slab level, and this lowering of the water table is believed to have been a factor in the floor slab heaving (Ibid.).



Fig. 11. Fort Henry Mall, main entrance

Borings were drilled at the site, and hard, black, calcareous shale was encountered immediately below the vapor barrier and base course of crusher run. Total sulfur analysis and bacteriological testing were conducted on samples; the percentage of sulfide sulfur in the samples ranged from 0.603 to 0.874 %, while the percentage of sulfate sulfur ranged from 0.089 to 0.302 % . As was expected, more oxidation and therefore higher sulfate sulfur content was encountered at higher elevations in the shale. From these values, the theoretical remaining heave would be 8 to 15 inches, which could occur over several decades. Apparently, heaving has occurred and is expected to occur only in the floor slab areas, not in the column footings where loading is sufficient to counteract the heave (S&ME Job 1401-93-022-A).

The following recommendations were provided by S&ME for Fort Henry Mall (S&ME Job 1401-93-022-A):

- Option 1.) Remove the damaged floor slabs  
Install a structurally-supported slab with rock bolts
- Option 2.) Install rock bolts directly through the floor slab
- Option 3.) Conduct minor repair on floor slab  
Saturate shale with water directly under slab
- Option 4.) Inject potassium hydroxide to kill bacteria and slow reaction
- Option 5.) Maintain current floor slab until extensive repairs can be conducted in the future.

Option 1.) and 2.) were perhaps the most expensive and disruptive practices, but Option 2.) was highly recommended due to the documented success of rock bolts. Immediate repair included grinding down discontinuities in the floor slab and tiles, and leaving a space between the top of damaged walls to allow for movement without buckling. Rock-bolting was chosen as a long-term repair, with a recommended installation depth of 10 feet and a lateral spacing of three to four feet (S&ME Job 1401-93-022-A). To date, no significant heaving problems have been noted.

### **E. Meadowview Convention Center and Hotel, Kingsport**

The Meadowview Convention Center and Hotel is located on Meadow View Parkway, directly off Exit 52 of I-181 (see Fig. 12). Construction of the facility began in 1995, and by this time, geotechnical engineers in East Tennessee had become much more familiar with pyritic shale problems. In the preliminary design stage, geotechnical exploration showed that black, unweathered, Sevier shale was present at the foundation and/or floor slab subgrade elevation. Therefore, preventative measures were taken to insure no structural distress would occur (personal communication, Tim Siegel 1998).



Fig. 12. Meadowview Convention Center and Hotel, main entrance

S&ME was responsible for the rock testing and evaluation of the site, and tests were conducted to determine the sulfide sulfur content of the shale at foundation subgrade elevation. In the north and northeast of the site, the sulfide sulfur content was found to be

0.447 to 0.515 %, which on the basis of laboratory tests, classified the shale as marginally expansive. However, an excavation of 3 to 12 feet uncovered hard, unweathered shale in the basement and escalator pit area, and the sulfide sulfur content there was found to be 0.703 % (S&ME Job 1401-92-390-G). Because this area was particularly susceptible to expansion, S&ME recommended that rock bolts, pre-stressed to 10 ksf, be installed in the shallow foundations. In addition, S&ME recommended that crushable cells that allow for 8–10 inches of vertical heave should be placed beneath the basement floor slab (personal communication, Tim Seigel 1998).

Ultimately, the installation of rock bolts was determined to be too expensive. Instead, the initial site grade was raised 4 feet in order to build the center on the more weathered shale layers and a floor system was constructed in the basement and escalator pit areas. The pit was built on six piers, and cardboard forms were placed under the footing to allow for up to 10 inches of expansion (personal communication, Jim Belgeri 1998). These preventative measures appear successful; no structural distress has been observed.

#### **F. Buried Box Culvert, Sullivan County**

A reinforced concrete box culvert near Hwy. 391 in Sullivan County failed under a black shale and limestone gravel fill in 1995. A total sulfur analysis was conducted on backfill shale samples from the site and from a nearby cut slope, which showed that the sulfide sulfur content was 0.04 - 0.32 % and the sulfate sulfur content was 0.08 - 1.17 %

(Drumm et al. 1998). These percentages, along with a high total sulfur content, show that the pyritic shale could experience significant expansion. Though there are many factors that affected the culvert's performance, it is likely that expansion of the pyritic shale backfill contributed to its failure (Ibid.).

The culvert was replaced with a much thicker and stiffer culvert, and the backfill materials were placed with less compactive effort (Drumm et al. 1998).

## V. CONCLUSIONS AND RECOMMENDATIONS

Problems associated with expansive pyritic shales in East Tennessee are now more easily recognized and understood than they were twenty years ago. It is important that all engineers and geologists in East Tennessee be aware of the expansion potential and continue to suggest preventative measures at sites where they are known to exist. Chosen methods for remediation or prevention are almost always dictated by individual site conditions and available funds; in general, however, the uses of rock-bolted foundations, structural floor systems, and a bitumen sealer on the fresh shale surface appear to be the most effective and practical measures. All of the remediation and prevention methods taken in the aforementioned case studies are new; that is, their effectiveness in the long-term control of this problem remains to be seen. Establishing on-site, continuous monitoring programs would be extremely useful in measuring the effectiveness of these methods.

Further research is needed in determining the precise role of bacteria in the expansion process. As was mentioned earlier, there is some controversy about whether bacteria are necessary for the oxidation process to proceed and whether methods of controlling their growth are effective. Laboratory testing may be useful in comparing samples in which bacteria are allowed to flourish and participate in the reaction with those in which the bacteria are not present, and measuring the subsequent heave. In addition, further research on the role of melanterite in the expansion process could be useful. Though melanterite is very soluble and is hard to detect in boreholes in which water has been injected, it occurs as small, fibrous crystals similar to gypsum and could be a contributor

to expansion. Furthermore, a useful research tool for further classification of pyritic shale problems would be the formation of a GIS database. Such a database would include GPS coordinates of sites affected by expansive shales and information about site conditions and remediation/prevention measures. These sites could be mapped on a geologic map in order to note areas of the Sevier shale that exhibit the most problems.

Expansive pyritic shales are indeed capable of causing significant damage to many types of structures. For this reason, engineers and geologists in East Tennessee should be aware of this geologic hazard when analyzing any site for development. The site should be evaluated for the presence of pyritic shale, and the proper preventative measures should be employed before construction begins.

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\*Name withheld for client privacy

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**APPENDIX B:**  
**Form Used by Author in the Classification and Characterization of**  
**Expansive Pyritic Shales Problems in East Tennessee**

# Expansive Pyritic Shales in East Tennessee Classification Form

**1. Structural / Geotechnical / Environmental / Transportation / Other problem?**

**2. Site Address, GPS Coordinates, and Description of Area:**

**3. How and when was problem first recognized?**

**4. Describe problem:**

**5. Remediation or prevention process: what steps taken, what agencies involved, what tests conducted/measurements taken, length of evaluation process, etc.:**

**6. What were recommendations?**

**7. What was done? Give reasons for choice of method:**

**8. Was this method successful? How is success monitored?**

**9. Other comments:**