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Collapse of Underground Storm Water Detention System

Shopping malls have large roof areas and large paved areas for parking. In many cases, during heavy rainfall, the drainage from these roofs and parking lots will overload the municipal storm sewer system. Therefore, many municipalities require a temporary storm water detention system on the property of the mall, when the mall is being built or enlarged. These detention systems are unusually located under the parking lot pavement and have various constructions.

Figure 1 shows the components of the system that failed. They are made from injection molded high-density polyethylene (HDPE). The main chambers are composed of an arch with inclined legs and are 7'-3" long. The inclined legs are each on a base which is set on top of a crushed stone base course, toe to toe with the adjacent main chamber. The top of the spaces between the main chambers are covered with arched fillers. The main chambers are butted end to end to form a row. The ends of the rows are covered as shown in Figure 1, with covers for the main chambers and different covers for the spaces between the main chambers.

Figure 2 *(page 2)* shows a plan of the storm water detention system that failed. It is located in a suburban mall in Massachusetts. Figure 3 shows a section through the storm water detention system, taken as shown on Figure 2. As shown on Figure 3, crushed stone and filter fabric were placed between the sides of the system and the edge of the excavation. Crushed stone and filter fabric were also placed between the end covers and the edge of the excavation, similar to the detail at the sides of the system. The top of the system was filled with compacted gravel, which varied in depth from 3.2 to 4.0 feet.

Figure 1. Storm water detention system components as assembled.

The subject storm water detention system was constructed in the middle of July 1997 and collapsed on August 31, 1997. Figures 4 and 5 *(page 3)* show the collapse of the northerly field of the storm water detention system. The collapsed southerly field can be seen in the background of Figure 4.

Figure 6 *(page 3)* is a photo from Test Pit No. 2 (see Figure 2 for location). The legs of the main chamber units buckled and were squashed such that the paving above dropped 24 inches.

Figure 7 *(page 4)* shows photos from Test Pit No. 1. The same as observed in Test Pit No. 2, the legs of the main chamber buckled and the whole system dropped down 24 inches to the top of the crushed stone base.

Figure 8 shows the rebound of the legs after they were removed from the collapse.

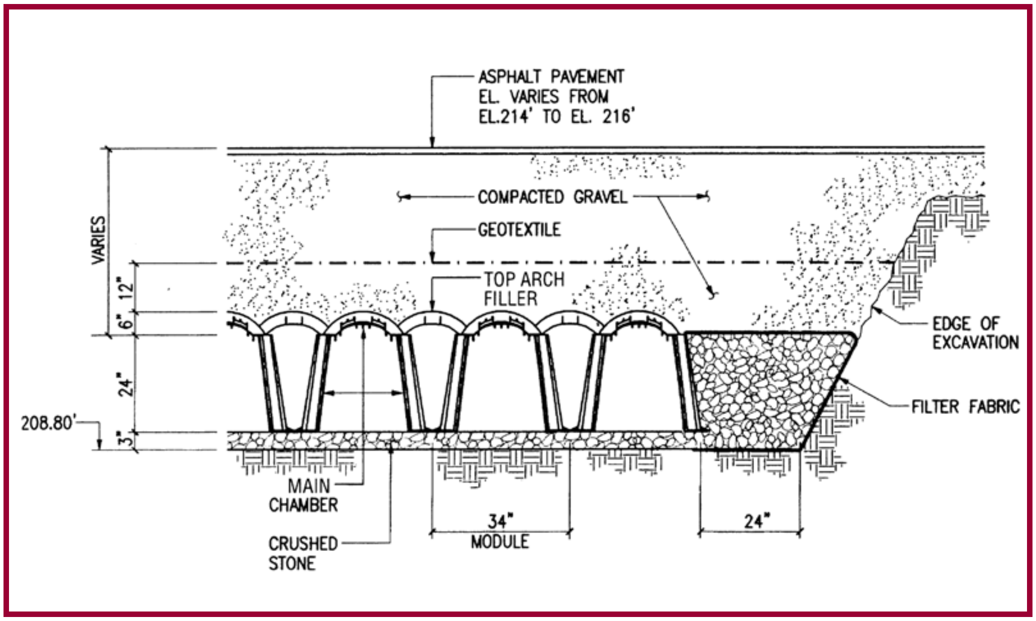

Figure 3. Section through storm water detention system showing design requirements.

Structural Behavior

Plastics, in general, and HDPE in particular, are viscoelastic, which means that the material keeps deforming under sustained load. This behavior is also called *creep*. Figure 9, adapted from Jansen (1989)[1] shows typical values of this behavior for various levels of stress for tensile test specimens. In the figure, the term *strain* is the change in length divided by the original length. Note that each division on the horizontal time axis is a change in magnitude by a factor of 10.[2]

Strength and stiffness are two structural properties of particular interest in this investigation. Stiffness is a measure of the resistance to deformation, and is defined as the force required to deform a component per unit of deformation (such as pounds of force per inch of deformation due to that force or put another way, the force divided by the deformation). For example, if one places a 1000 lb tensile load on a rod, and the rod stretches 1 inch, its axial stiffness would be 1000 lbs per inch; if it takes 2000 lbs to stretch the rod 1 inch, its axial stiffness would be 2000 lbs per inch.

There are two separate measures of stiffness, one applicable to the material of a component and the other to the geometry of the cross-section of the compo-

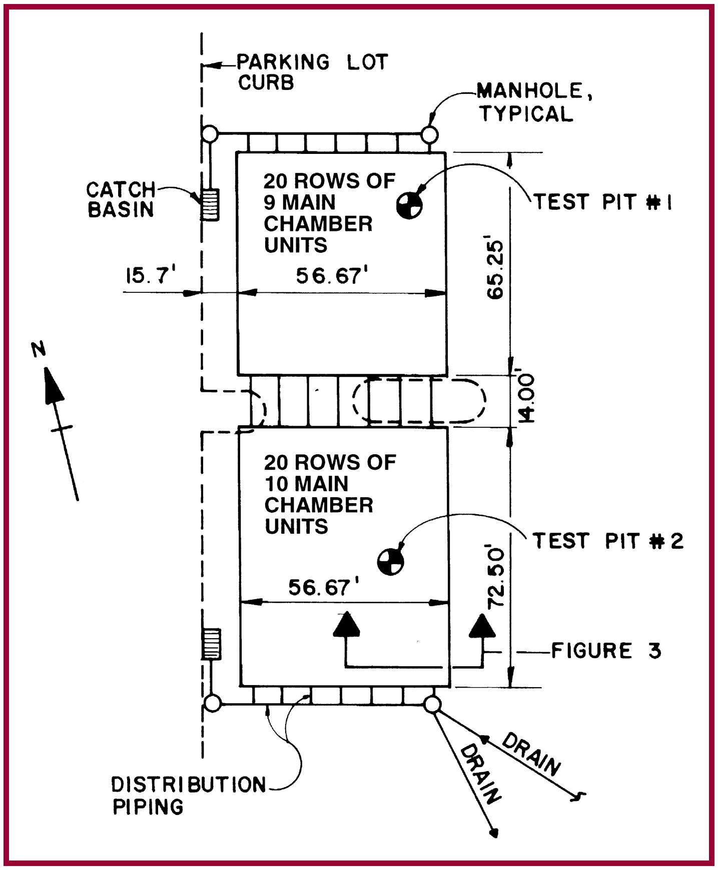

Figure 2. Plan of storm water detention system.

Figure 4. East side of collapse of northerly field, looking south. The collapsed southerly field is in the background.

Figure 5. South side of northerly field, looking east.

nent. The material stiffness is called the *modulus of elasticity* and is defined as the ratio of stress divided by strain for an elastic material.[3]

Figure 11 *(page 6)* depicts a structural member in compression such as a column. *P* is the load on the column, *L* is the length of the column, and *d* is a small imperfection (exaggerated in the figure). If the member was ideally elastic and straight, *d* would be zero. The critical load, P_{CR}, the load at which the ideal column buckles is:

$$P_{CR} = 9.87\frac{EI}{L^2} \qquad \text{EQ-1}$$

Where *E* is the modulus of elasticity, and I is the stiffness of the cross-section of the column due to its geometry, called the *moment of inertia*. As the equation shows, the buckling strength is proportional to the stiffness of the column, not its crushing strength.

A real column will not be perfectly straight, and will have a small imperfection, represented in exaggerated form by the deformation *d*. With this deformation, the load P will cause the column to bend, which reduces the buckling strength calculated by EQ-1 by a small amount.

Figure 6. Test Pit No. 2 showing the top of a main chamber removed. The buckled legs of the main chamber are partially visible, and extend under the top arch fillers on each side.

The legs of the main chamber are compression members, which behave as just described. However, the main chamber is composed of a viscolelastic material, which causes the small imperfection *d* to continually increase under a sustained compression load, which can lead to buckling of the legs after a period of time.

To determine the buckling strength under sustained load, the value of *E* in EQ-1 must be one that ac-

(continued on page 5)

Figure 7. Test Pit No. 1. Top photo: center arch is top of a main chamber; adjacent arches are fillers over the spaces between main chambers. Center photo: near side arch filler cut away revealing collapsed legs of main chambers. Bottom photo: after removal of main chamber arch and near side arch filler. All arches are resting on the crushed stone base, 24” below their original positions.

Figure 8. Recovery of deformation with time. The middle photo of Figure 7 shows the buckled shape when the arched filler was cut out; The top photo in this figure shows partial recovery of the deformation of one of the legs of the main chambers within a 1/2 hour after being cut out. The bottom photo shows full recovery of most of the deformation days after it was originally excavated by the contractor.

counts for the creep, which is called here the *effective modulus of elasticity*. Due to increasing deformations under sustained load, the effective modulus of elasticity of HDPE is reduced dramatically with time. Typical values of the effective modulus of elasticity are plotted versus time in Figure 10, as adapted from Janson (1989).[1] This figure demonstrates that the decrease in effective stiffness of the HDPE under sustained load, due to creep, is dramatic.

The stress in the main chamber legs due to the weight of the long term superimposed load (i. e. the paving and compacted gravel), as shown on Figure 3, varied from 270 psi to 420 psi. As shown on Figure 10, the effective Modulus of Elasticity for an axial loaded member with a sustained stress midway between 200 and 500 psi at one hour is 80,000 psi, but after 1000 hours (42 days) the effective Modulus of Elasticity will drop to 38,000 psi, and after 100,000 hours (11 years) it will drop to 24,000 psi. These values may be low for the subject HDPE, but the trends will be similar for a higher strength HDPE; i.e. the original Modulus of Elasticity will be reduced to approximately 50% after 1000 hours and 30% after 100,000 hours.

Cause of the Collapse

The manufacturer of the HDPE components specified criteria for the design of the storm water detention system, the details of which are shown on Figure 3. The manufacturer specified that the depth of the compacted gravel backfill above the top of the main chamber units be a minimum of 18 inches and a maximum of 48 inches. The actual depth of the compacted gravel backfill of the subject storm water detention system varied between

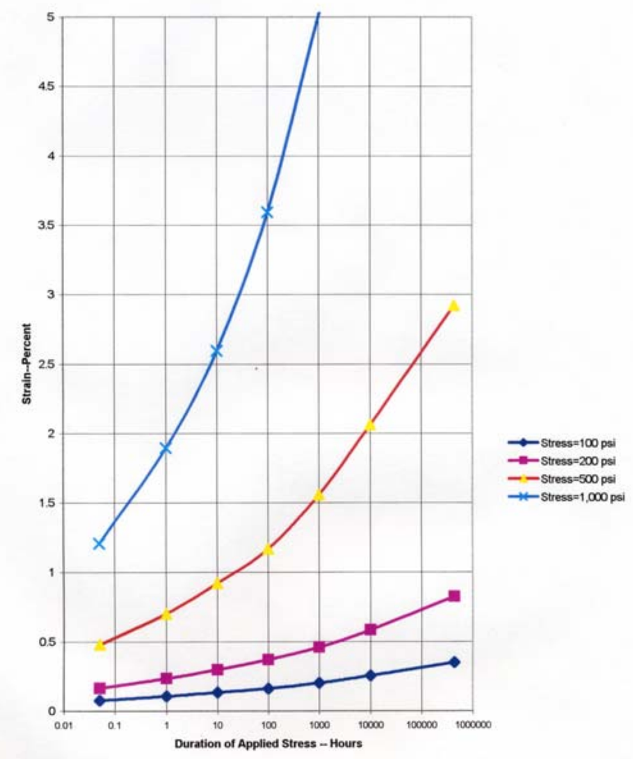

Figure 9. Strain versus time at various levels of sustained stress (adapted from Janson)**.**

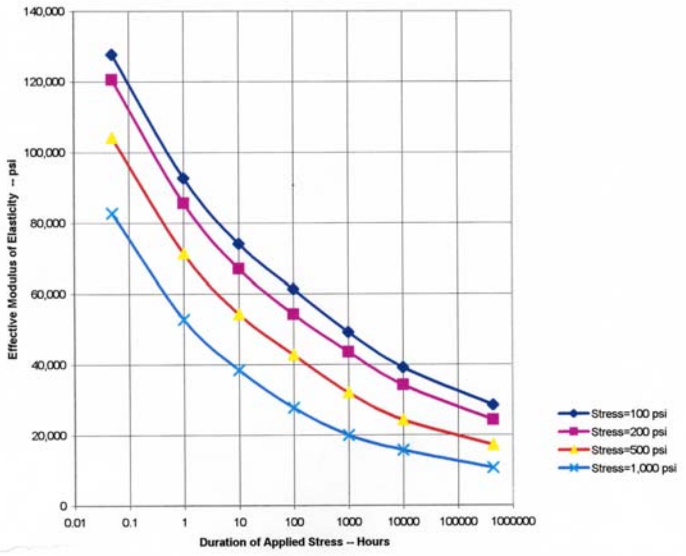

Figure 10. Effective modulus of elasticity versus time for HDPE at various levels of sustained stress (adapted from Janson)**.**

38 and 48 inches. The estimated modulus of elasticity at 1 hour of sustained load is 110,000 (AASHTO, 1991).[4] Calculations based on this modulus indicate that the legs of the main chamber unit would not buckle. When the legs of the main chamber units collapsed, the compacted gravel backfill had been in place approximately 1½ months or 1100 hours. As the trends of Figure 10 show, the effective modulus of elasticity would be reduced by approximately 50% in that time, and calculations indicate that the legs of the main chamber unit would buckle under this reduced modulus.

The cause of the collapse was that the manufacturer did not understand the creep characteristic of the viscoelastic HDPE material used

■ Principal Rubin M. Zallen investigated this failure.

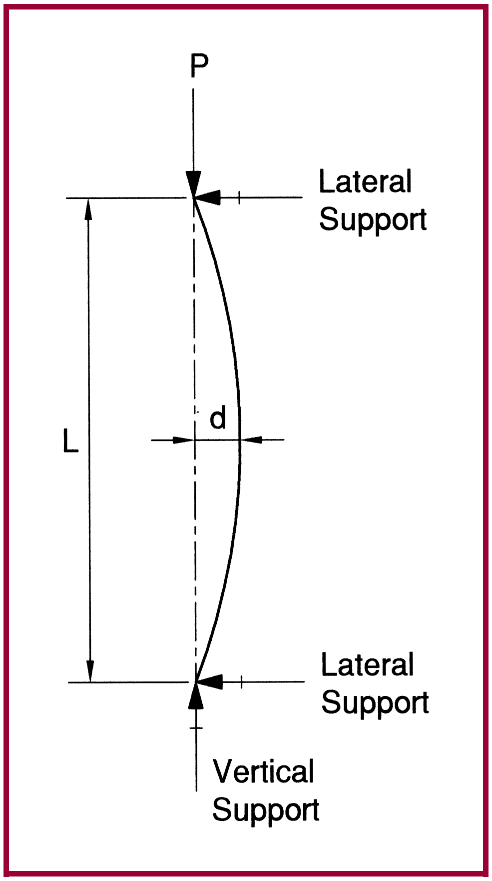

Figure 11. Axial compression member.

End Notes

1. Janson, L_E. (1989). *Plastic Pipes for Water Supply and Sewage Disposal*. Magnestams Reklam/ Christenson Grafiska AB, Lerum.
2. Called a logarithmic scale.
3. If a structure or component is loaded, it will deform; if the deformation returns to zero after it is unloaded, the material from which the structure or component is made is elastic by definition.
4. AASHTO (1991). *Standard Specifications for Highway Bridges*, Section 18, *Soil-Thermoplastic Pipe Interaction Systems*. American Association of State Highway and Transportation Officials, Washington, DC.

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