REPAIR OF THE CZAR SHAFT SINKHOLE

by

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Abstract. After a portion of the Queen Mine parking lot collapsed into a sinkhole, an engineering study was conducted to confirm that the cause of the damage was settlement into the Czar Shaft in Bisbee, Arizona. Historical records were researched to describe and locate the original shaft, and a seismic refraction survey was performed to define the foundation conditions within and around the shaft. Recommended mitigation measures were developed to repair the parking lot. Mitigation included design and construction of a flexible geosynthetic cap and telltale settlement monitoring system.

Additional Key Words: geotextile, settlement, subsidence.

Introduction

The City of Bisbee operates the underground Queen Mine as a tourist attraction. Tourists park in a lot 18 meters by 46 meters (60 feet by 150 feet) in dimension set into the northeast side of a limestone hill overlooking Bisbee. In March of 1995 the center of the parking lot collapsed under the weight of a tour bus. After safely removing the tour bus, a sinkhole roughly one meter deep (three feet) and 4.5 meters (fifteen feet) in diameter was found under the parking lot, as presented in Figure 1. Water was flooded into the sinkhole at a rate of 20,000 to 40,000 liters (five to ten thousand gallons) per day for a one week period, in an attempt to consolidate the underlying fill. Subsequent excavation in search of lateral settlement limits widened the sinkhole to a diameter of 12 meters (40 feet). Settlements within the sinkhole of 25 to 33 centimeters (10 to 13 inches) per day were observed during the flooding. The settlement stopped when the flooding was discontinued. The sinkhole was temporarily backfilled with 32 truck loads of soil and rock. The City of Bisbee contracted with DEI Professional Services (DEI) to confirm the cause of the sinkhole, and to develop a mitigation design to bridge and cap the failure.

Figure 1: Queen Mine Parking Lot Sinkhole

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Investigation

DEI reviewed available literature relating to the site and conducted a limited geotechnical field investigation as part of the study. The field work included seismic profiling of the sinkhole, and additional sinkhole water flooding and settlement measurement.

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Literature Review

Research of historical information relating to the site was conducted from literature and publications in the Bisbee Mining and Historical Museum. The Czar Shaft was sunk by the Copper Queen Company in 1885 to a depth of 134 meters (440 feet). The Shaft provided access to a carbonate copper ore deposit, (Graeme, 1981). The carbonate ore is found within early Cretaceous limestone rock included in the Bisbee Group. (Nations, 1983). The proximity of copper-rich igneous rock and limestone rock produced a classic zone of enrichment. Metallic solutions percolated into seams and fractures in the porous limestone, depositing metal-rich minerals, (Francaviglia, 1982).

Of particular interest in the Francaviglia publication were early 1900 period photos of the Czar Shaft site that show considerable construction related filling of the site. The filling was necessary to produce a flat bench on the side of the limestone hill for the mining buildings relating to the Copper Queen Mine and the Czar Shaft operations.

The Czar Shaft operated for sixty years until closure in 1944. The conditions within the shaft were reportedly very wet and cold. The shaft was capped with concrete in 1961 to stop trespassing. Shaft timbers reportedly decomposed from the lack of air, and in 1973 the head-frame collapsed. The shaft was then closed by backfilling, (Graeme, 1981).

Field Investigation

The parking lot is situated on the northeast side of a limestone hill. The Shaft is approximately 45 meters (150 feet) to the left of the Queen Mine Tour buildings, as shown in Figure 2. The sinkhole area in the parking lot is in the center of Figure 2, and barrels ring the temporarily backfilled area. Considerable filling is evident in the areas around the parking lot.

A limited geotechnical field investigation was conducted to differentiate the loose Shaft fill from the surrounding fill and native rock materials. DEI assisted AGRA Earth and Environmental in performing a refraction seismic survey of the sinkhole area. A 12-channel Geometrics signal enhancement seismograph was used for velocity data recording. Maximum depths of 4.5 to 6 meters (15 to 20 feet) were investigated using ten foot wide intervals for the geophones. Two seismic lines were run through the sinkhole, and two seismic lines were run on the inside and outside portions of the parking lot. Loose fill inside the sinkhole exhibited compression wave velocities of 225 meters per second (mps). Fill on the sides of the sinkhole exhibited significantly higher velocities below a depth of three meters, with a range of 430 to 800 mps. The line closest to the limestone hill detected the limestone at a three meter depth, with a velocity of 2,100 mps.

Figure 2: Temporarily Backfilled Sinkhole

The shallow seismic investigation confirmed the horizontal limits of the sinkhole to the immediate area of the surface expression of the settlement. The investigation also revealed that the pad for the original mining operations and parking lot was composed of a mixture of loose and medium dense fill overlying a dipping contact with the original limestone hill.

Additional water flooding was conducted in an attempt to initiate settlements within the fill over the Shaft. From May 15 through May 29 (15 days) from 27,000 to 40,000 liters (7,000 to 10,000 gallons) per day of water was run into the depression. Four measurement points were monitored within the depression, and at the end of the flooding no significant settlement was observed in any of the measurement points. Approximately 15 centimeters (six inches) of total settlement was observed in the fill on the northeast side of the sinkhole when the material was first wetted. No additional settlement was observed after repeated flooding.

Results and Conclusions

The investigation confirmed that the Czar Shaft was originally located under the parking lot sinkhole. The historic review revealed past foundation distress problems related to settlement movement within the Shaft fill materials. These movements include the collapse of the original headframe over the Czar Shaft. Soils surrounding the Czar Shaft fill are not sufficiently dense to support concentrated loading from a rigid structural cap without possible significant settlement and movement.

The settlement into the Czar Shaft is similar to problems experienced with limestone sinkholes in karst areas of the country. Construction techniques employed to stabilize these features include the placement of thick reinforced concrete slabs, injection of cement grout under high pressure, and filling of voids with solids and concrete. Complicating geotechnical conditions at the Czar Shaft site include significant thickness of non-engineered fill in the upper portion of the shaft area.

DEI concluded that a structurally reinforced cap bearing on the adjacent fill was not a positive or economical alternative to repair the sinkhole. A mitigation measure was selected to bridge over minor future settlements beneath the parking lot. The mitigation allows for monitoring and future additional corrective measures for more significant settlements, should they occur.

A flexible geosynthetic cap was designed to distribute the parking lot loading over the densified existing and new Czar Shaft fill. The design was based on engineering judgement that considered the removal of as much loose overburden as site access and utilities would allow, and replacement of the loose overburden with geotextile reinforced fill.

The planned construction consisted of excavation of the sinkhole area to a depth of 4.5 meters (15 feet). The excavation had a flat bottom ten feet wide, and was nine meters (thirty feet) in length. Side slopes were designed as one to one (horizontal to vertical), with a rectangular top of excavation 12 meters (40 feet) wide and 18 meters (60 feet) long. Fill was specified as imported or excavated material consisting of clean sand, gravel and cobbles. The material was well blended with no isolated nests of gravels and cobbles, no particles larger than 30 centimeters (12 inches), and less than 8 percent passing the No. 200 sieve. The fill soils were free of organic matter, construction debris, and other deleterious materials. Due to the coarse nature of the fill, the compaction was specified as 85 to 95 percent of the maximum relative density. The compaction was evaluated visually by the engineer's representative without testing.

High strength woven geotextile fabric was detailed in an alternating pattern between subsequent fill layers. A wide roll width of 5.5 meters (18 feet) was specified to reduce overlap connections between sheets.

The geotextile was specified as a woven polypropylene fabric with the following minimum average roll values:

Property	Method	Value
Grab Tensile	ASTM D-4632	500 lbs.
Elongation	ASTM D-4632	20%
Wide Width	ASTM D-4595	4800 lbs. / ft.
Elongation	ASTM D-4595	18%
Mullen Burst	ASTM D-3786	1350 psi
Puncture	ASTM D-3786	140 lbs.
Trap. Tear	ASTM D-4533	250 lbs.
Roll Width	-	18 ft.
Roll Length	-	150 ft.

The geotextile was selected based on its high strength, flexibility, and resistance to biological and chemical degradation. Availability and shipping delivery also were important to the timing of the construction. For estimating purposes the material cost of the geotextile was approximately $2.00 per square meter.

Details of the design showing the placement of the geotextile sheets into each of the five layers filling the excavation are presented in the following Figures 3 through 7.

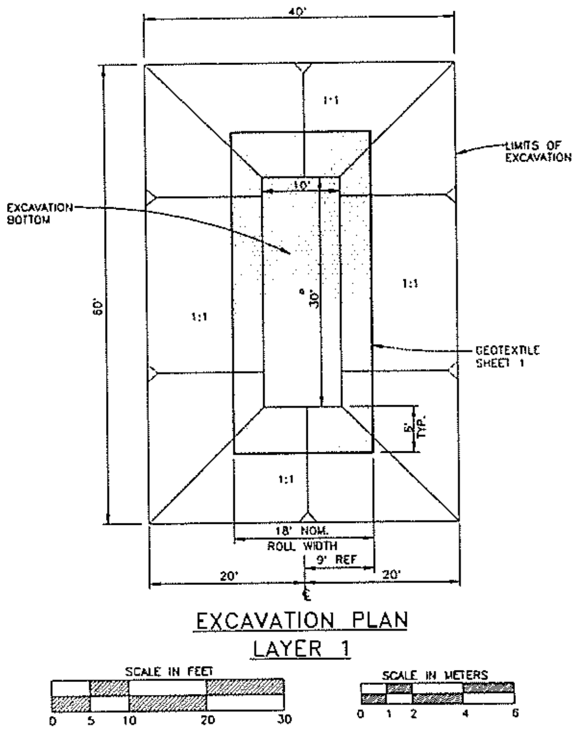

Figure 3: Plan View of Layer 1

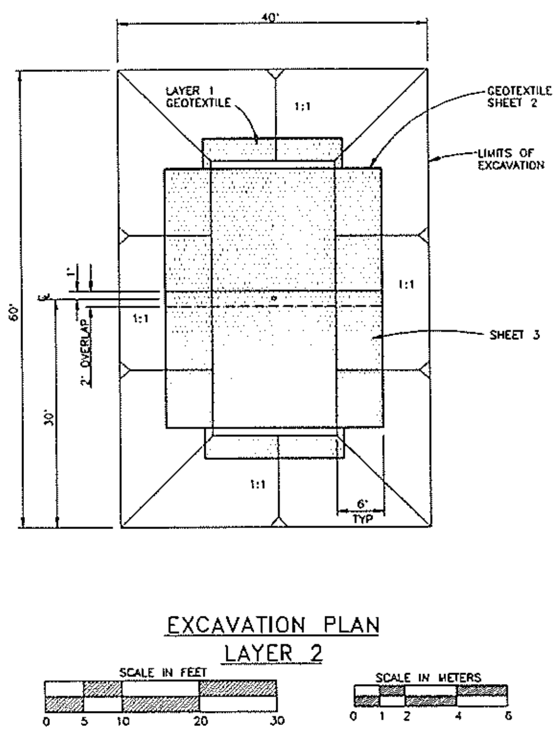

Figure 4: Plan View of Layer 2

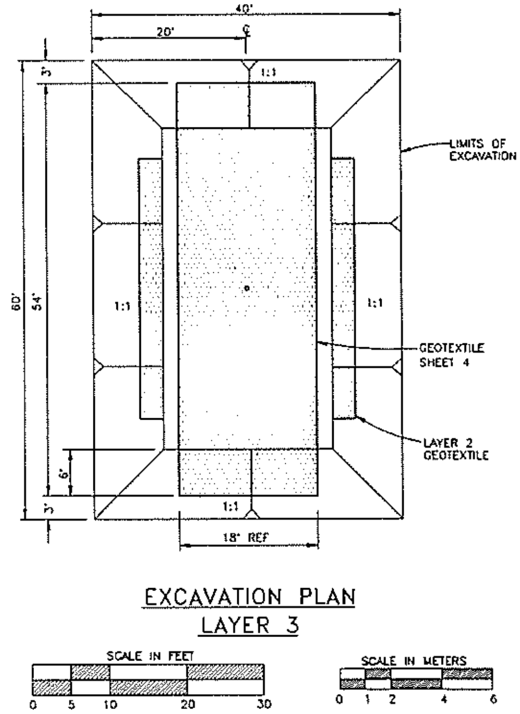

Figure 5: Plan View of Layer 3

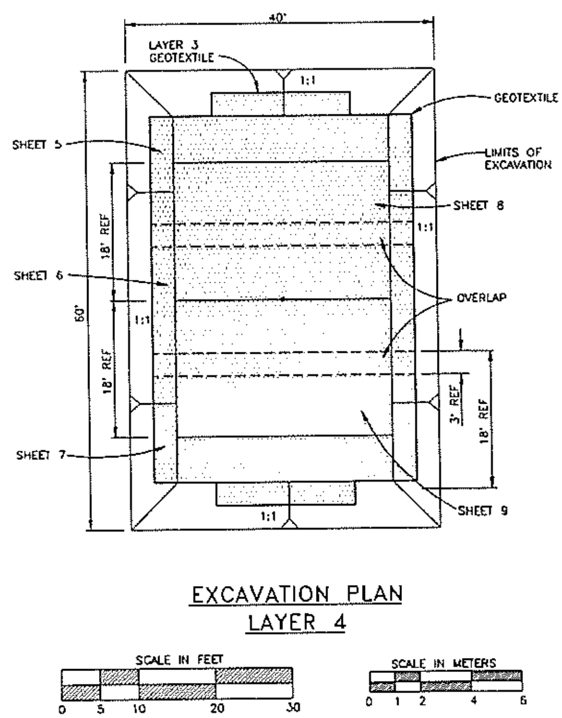

Figure 6: Plan View of Layer 4

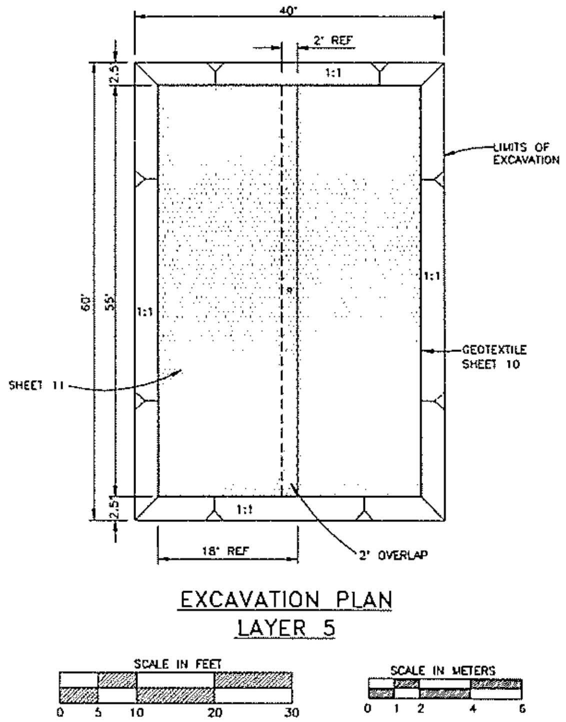

Figure 7: Plan View of Layer 5

Geotextile sheet arrangement on the side slopes of the excavation was carefully controlled to develop the maximum frictional resistance in the outer portions of each geotextile sheet. Care was taken not to overlap geotextile from one layer on top of another layer. This mitigated the significant loss in frictional resistance when one side of the geotextile is bedded against another sheet of geotextile. Frictional resistance of the geotextile sheet is similar to the backfill soil frictional strength if the geotextile is bedded on both sides by the soil. The full tensile capacity of the geotextile can be mobilized after a few feet of burial in the backfill soil. Figures 8 and 9 present sections through both the long and short axis of the excavation and geosynthetic cap system.

A telltale system was incorporated into the design to allow for periodic monitoring of the settlement of the Czar Shaft fill under the geosynthetic reinforced cap. A steel plate was specified to be placed in the center of the excavation, beneath the first layer of geotextile. A 15.25 centimeter (six inch) diameter Schedule 40 PVC pipe extends from the bottom of the excavation to the surface. The pipe provides an access port for the 2.0 centimeter (0.75 inch) diameter telltale pipe that extends from the bottom steel plate to the surface.

Construction

Construction started on August 11, 1995 with material removed from the planned excavation by a Cat 235L Trackhoe. All excavation and compaction operations were continuously monitored by a field engineer representative of DEI. Workers and equipment were not allowed into the bottom of the excavation because of the unknown Shaft fill conditions below the bottom of the excavation.

Excavated material was picked up with a Kawasaki 85Z2 loader and placed into a stockpile. DEI originally specified compaction with a vibrating plate compactor or compaction wheel attached to the end of the trackhoe bucket. The contractor was unable to provide the proper equipment, and elected to use the trackhoe as a battering ram to compact the soil with multiple impacts of the bucket. The base and side slopes of the excavation were compacted with repeated blows of the trackhoe bucket. A fire hose was used to supply water to the fill prior and during compaction.

The settlement plate and pipe were installed through the first layer of geotextile. Fill was then placed and compacted in two lifts totaling 90 centimeters (36 inch) thick over the geotextile. A minimum overlap of adjacent geotextile sheets was maintained at 0.6 meter (two feet). The geotextile was held in place during backfilling with steel spike nails driven into the walls of the excavation. The first 90 centimeter (36 inch) layer of fill was complete by the end of the second day of construction. By the end of the third day the third layer of geotextile was in place and covered with a lift of fill.

The settlement monitoring pipe was extended upward through each layer of the filling operations. On the fourth day the fill was placed over the fourth layer of geotextile, and a self propelled tamping foot compactor (Ingersoll Rand SD40D) was used to compact the fill layers. By the fifth day of construction the final geotextile layer was installed and the fill over the geotextile was compacted. Figures 10 and 11 present details of the settlement plate and telltale.

The contractor returned to the site several weeks after finishing the filling of the excavation to pave the filled portion of the parking lot, and to finish the surface completion of the telltale monitor. DEI

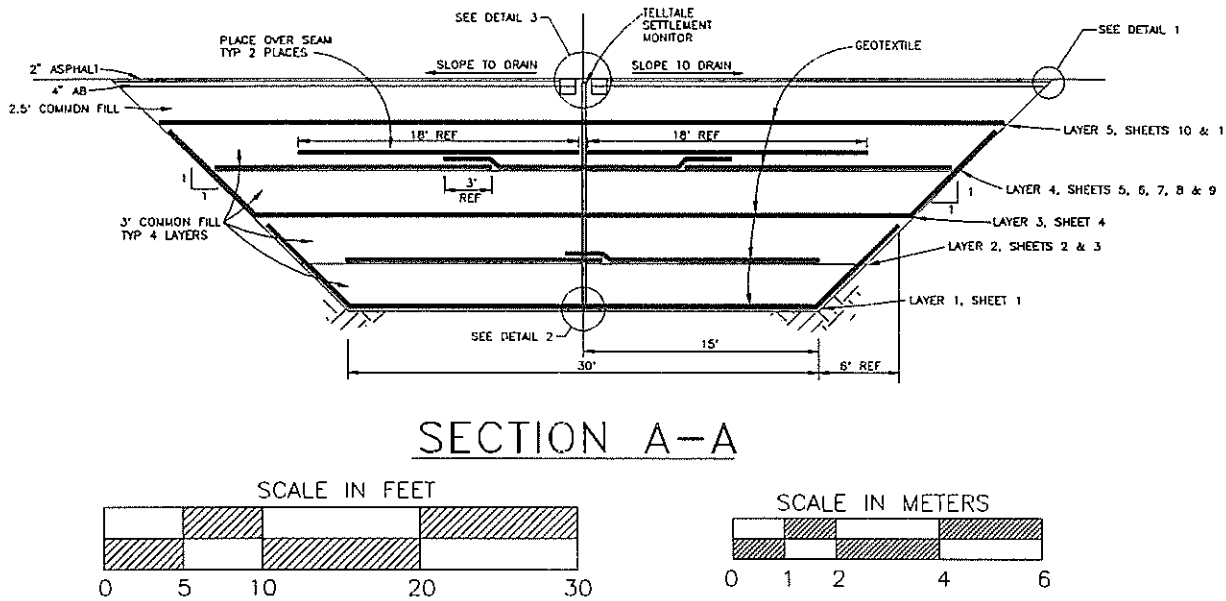

Figure 8: Section through the long axis of the cap.

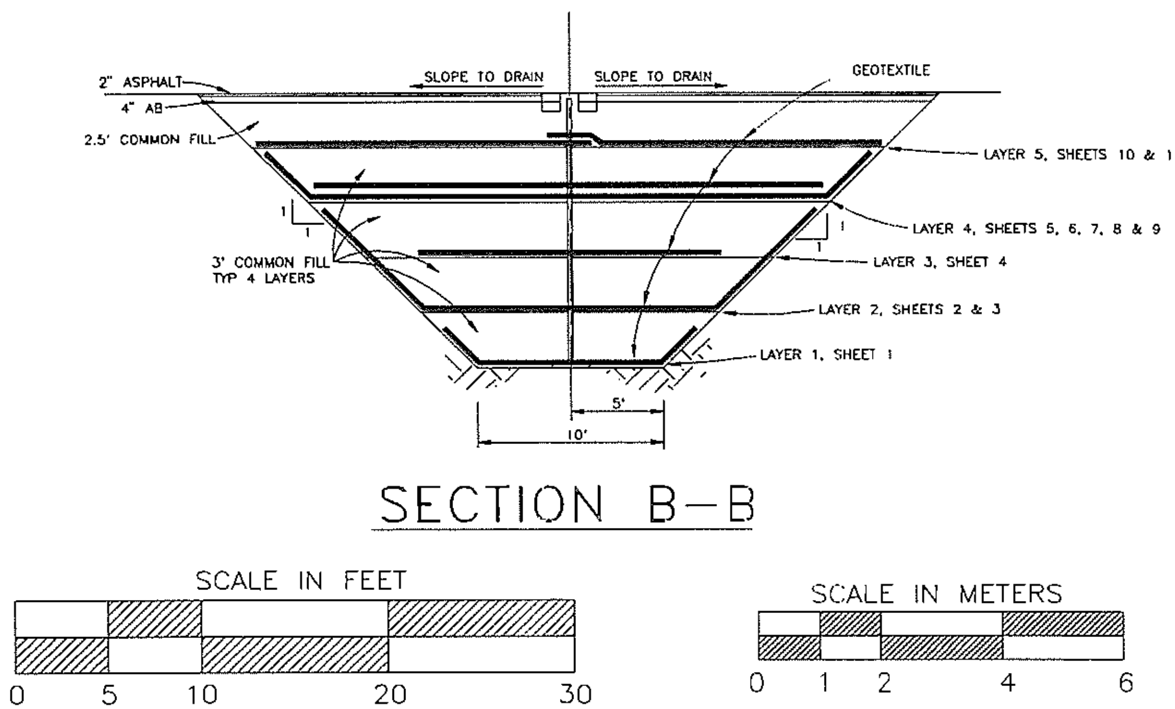

Figure 9: Section through the short axis of the cap.

returned to the site on November 6, 1995 to observe the completed construction. Figures 12 through 17 present photographs of the construction.

Telltale Settlement Monitoring

The telltale settlement monitor will be periodically inspected by representatives of the City of Bisbee. DEI suggested a monitoring frequency of weekly for the first month, then monthly for one year, then quarterly or twice yearly after the first year. Through the end of March 1996 there had been no measurable settlement beneath the geosynthetic cap. The intent of the geosynthetic cap and telltale settlement monitoring is to provide an engineering system to safely bridge minor settlements in the underlying shaft. The system will also provide a means to monitor and mitigate more significant settlements that may occur in the future. Monitoring will detect significant settlement and allow possible mitigation before the progression of damaging and potentially unsafe settlements. Mitigation will consist of injection of concrete grout through the monitoring pipe to fill any voids forming under the cap. If necessary this process can be repeated to maintain the integrity of the cap.

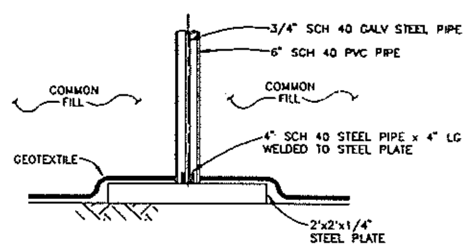

Figure 10: Detail of Settlement Plate

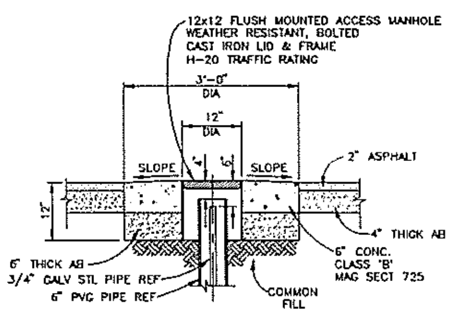

Figure 11: Detail of Settlement Telltale

Figure 12: Excavation of Sinkhole

Figure 13: Compaction of Fill Over Layer 1

Figure 14: Placement of Layer 2

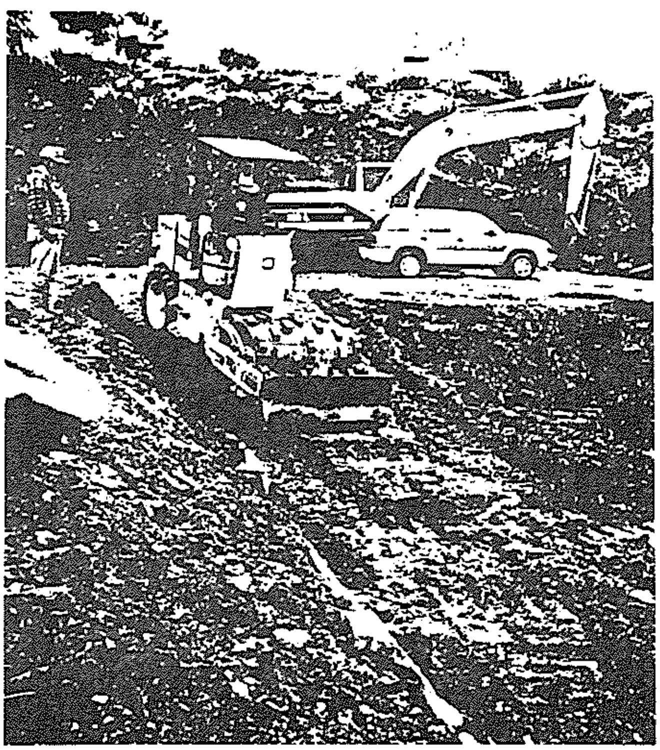

Figure 15: Compaction of Fill Over Geotextile

Figure 16: Completed Repaved Parking Lot

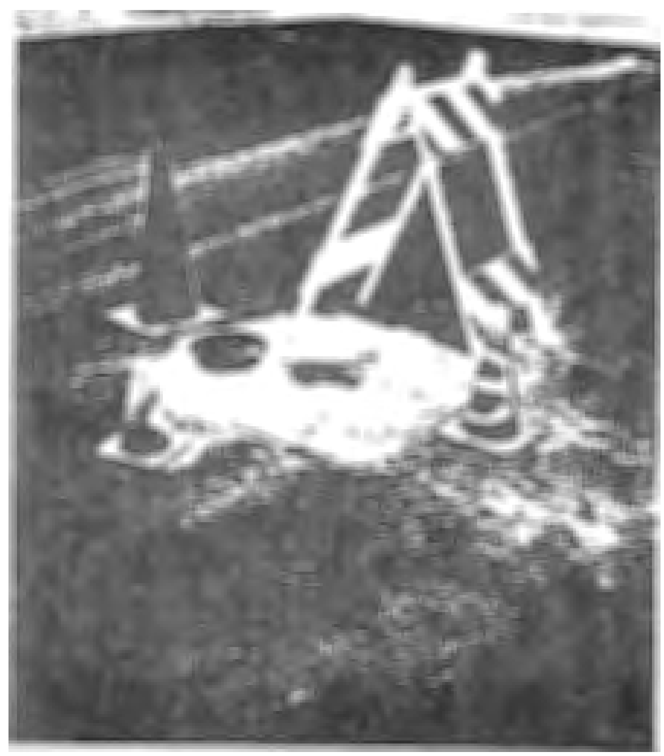

Figure 17: Settlement Monitoring Pipe

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