Report No. CDOT-DTD-R-93-12

CURTAIN DRAINS

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Final Report
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Prepared in cooperation with the
U.S. Department of Transportation
Federal Highway Administration

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16. Abstract

Geocomposite curtain drains were installed in a slope in the right of way above S. H. 550 north of Durango, Colorado to mitigate subsurface drainage and slope stability problems. The installation to the required depth of 12 feet was very difficult because of moisture in the trench and collapsing trench walls. A "crib box" was used for worker safety, but this hindered the proper installation. Most of the panels were installed in a partially collapsed position with the top of the panels buried about four feet deeper than planned. This affected the performance of the system.

The water table was lowered locally by about two feet, but groundwater still came to the surface further down the hill. Only small to moderate flows came from the curtain drain system. This was presumably due to the collapsed panels and the dense clayey soil. There were no slope stability problems during the five and a half years of evaluation, although there was slight swelling in one or two places on the slope. The effectiveness of the system, based on flows and groundwater measurements, did not appear to decrease significantly over time. Excavation of a portion of the curtain drain revealed that the material was in good condition and the fabric was not clogged.

Implementation

Using parallel drainage systems to shallower depths, with at least one near the bottom of the hill, rather than one deep system such as on this project, is recommended for safety and ease of installation, as well as improved drainage performance. If the filter fabric chosen is designed for the right soil type, clogging should not be a problem, at least in the first few years.

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1. INTRODUCTION

1.1 Material Background

When a highway is built into the side of a slope, there is the potential for problems from surface runoff and groundwater from the hill above the roadway. The two primary problems with which highway designers, constructors and maintenance personnel are concerned are slope stability and moisture related damage to the pavement or pavement structure.

When there is a potential for one of these two problems, mitigation measures must be taken. If the problem is slope stability, there are three basic methods of mitigation during design and/or construction. These are:

1. Lessen the severity of the slope by grading work or if necessary changing the alignment of the roadway.[1]
2. Install some sort of retaining wall.
3. Provide positive drainage of the surface and ground water. This may involve the use of a "Curtain Drain".

If the problem is moisture under the pavement, mitigation measures include:

1. Raise the surface elevation of the roadway.
2. Make the side ditches deeper.[2]
3. Place interceptor drains, also called under-drains, between the slope and the roadway. (If the pavement moisture problem is from rain or surface water on the roadway, this is a separate problem that can be solved by providing positive drainage by the use of a drainable base and edge-drains.)

Option "3" for each problem above can involve the use of geocomposite materials or the use of a "French Drain" consisting of geofabric surrounding coarse backfill with or without a collector pipe at the bottom. The main differences between a "curtain drain" and an "interceptor drain" or "under-drain" is that the former is usually placed further from the edge of the roadway in the hill above the roadway, and usually extends deeper into the ground. Geocomposites, as used in the project presented here, have been in use for this purpose since the early 1980's.

These geocomposites consist of a polyethylene or PVC structural core surrounded by a geofabric filter. The filter should allow moisture through without allowing fines through or clogging. A perforated drain pipe is placed within the geofabric at the bottom of the system. On this project, the curtain drain consisted of a polyethylene core enveloped in a non-woven fiber material, as shown in Figure 1.

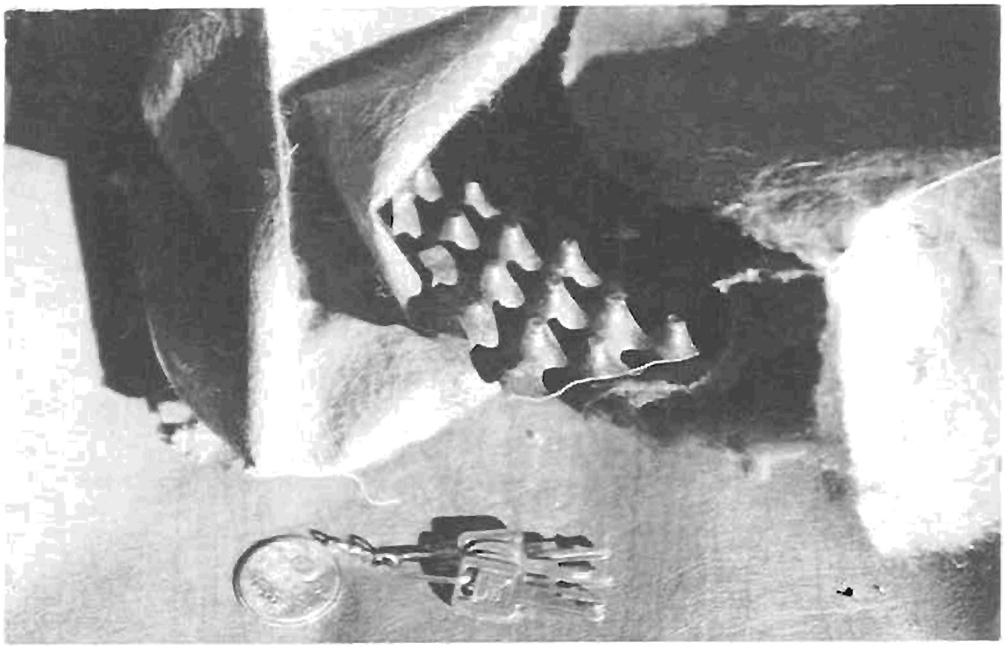


Figure 1 This photo shows the "egg-crate" core of the curtain drain surrounded by the non-woven filter material.

1.2 Project Background

U.S. Highway 550 near Electra Lake has had a history of problems with a muddy slope and moisture under the pavement. Project CXFC 20-0550-21 was initiated in 1986 to widen the roadway through this area. During the design process it was determined that slope stability and subsurface pavement moisture problems were likely. In order to mitigate these problems, it was decided to place curtain drains in the slope above the highway. These curtain drains were to intercept the groundwater at the top of the slope and conduct it to the opposite side of the roadway. Appendix A shows the plans and specifications for this project.

Figure 2 The curtain drains were placed within this hill on the west side of US 550 south of the Purgatory Ski Area.

COLORADO PROJECT NO. CXFC 20-0550-21

STATE HIGHWAY NO. 550

LA PLATA COUNTY

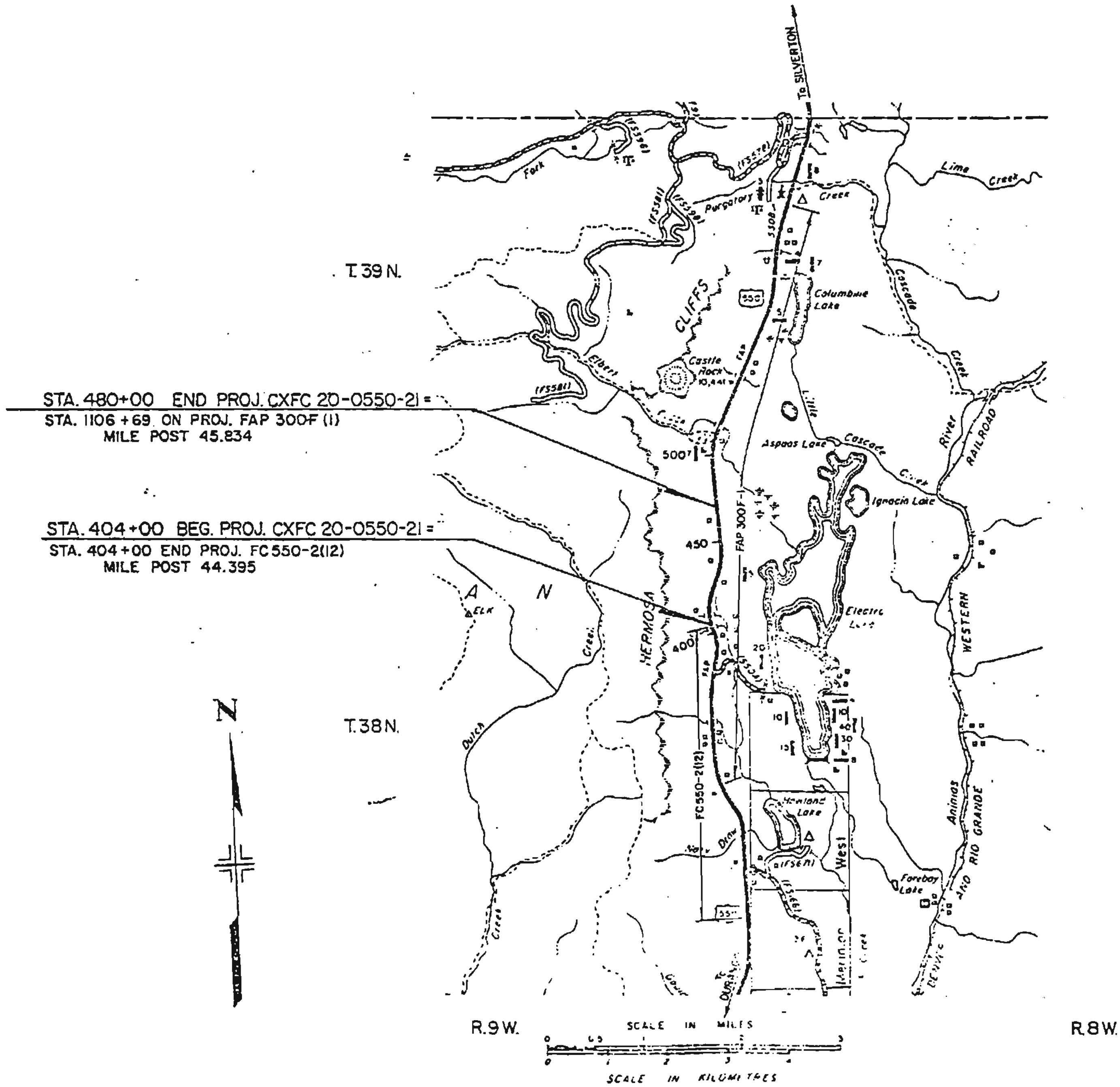


Figure 3 Site map of project location

2. CONSTRUCTION

On July 1 and 2, 1987 Werner Hutter of CDOT was at the project site north of Electra Lake on S.H. 550 to observe the installation for the Research Branch. This particular site was the third of four curtain drain sites in the state.

About 427 meters (1400 feet) of curtain drains were installed on this project in two phases. The first 213 meters (700 feet) were at the downhill end to the south. This section involved trenching to about two meters (six feet) in relatively stable soils. Moisture was not a big problem at that location during construction.

Figure 4 Pictured here is the installation on the south end of the project. The trench was dug in relatively dry soil which made it easy to hang the curtain drain sections from the fence, place them neatly and backfill the trench.

The second phase, stations 431^{+73} to 438^{+75H}, had great amounts of surface and subsurface moisture. A temporary drainage ditch located adjacent to the drainage system was dug in order to intercept some of this water. Groundwater necessitated the placement of the drainage system to a depth of 3.7 meters (12 feet). Figure 5 shows the abundance of water in the initial trench at this site.

Figure 5 This is the initial phase of trenching at station $431+^{73}$ to $438+^{75}$. A stream of water can be seen flowing in the bottom of the trench.

The combination of depth and moisture posed constant cave-in threats, so the Contractor, Kirkland Construction, used a crib-box six meters (20 feet) long by 3 meters (10 feet) high and 1.5 meters (5 feet) wide to protect the workers and facilitate the placement of the curtain drain sections.

Two backhoes were used in the project. The leading backhoe operator excavated the trench approximately 1.5 to 3 meters (5 to 10 feet) ahead of the crib-box. Perforated flexible drain pipes were placed through the open lower end of curtain drain sections and lowered into the trench. Each curtain drain section was stapled to the previous section in the trench one at a time. While workers held the drain sections with hooks, as shown in Figure 6, the trailing backhoe operator placed approximately 30 centimeters (one foot) of Class 3 granular material over the lower part of the curtain drain sections, followed by about 1.5 meters (five feet) of excavated material. The tops of the curtain drain sections were then lowered below the crib-box braces and the leading backhoe operator used the bucket to advance the box.

It was during this phase of the installation that the drain sections were buried deeper than they should have been. The drains did not reach near the top of the trench as they should have. Instead, they appeared to be buried about one to one and a half meters (four feet) below the surface. (Upon excavation it was found that the depth was a little more than one and a half meters (five or six feet).)

The last phase of the installation was to backfill the trench with excavated material. The material in this particular area consisted of mostly shaley clay.

Figure 3 On the north side of this project it was necessary to use a trench box to keep the moisture saturated walls of the trench from collapsing. In this photo, the installation operation is progressing away from the camera. The perforated pipe is being fed through the bottom of the next drain section. When the leading backhoe pulls the trenchbox forward, the men on the right side of the photo will use the sticks with hooks to lower the drain sections under the brace and pull them back into place.

At the end of the project, it was decided that additional measures needed to be taken to intercept the surface runoff and the water that infiltrated the top layers of the soil. A small drainage ditch was dug near the right-of-way fence above and to the west of the curtain drains. Two sets of 46cm (18 inch) corrugated steel pipe were used to connect this ditch to the roadside ditch. The roadside ditch, in turn, had cross culverts diverting the water into the adjoining landowner's property. There was a fairly strong run-off in both the interceptor ditch and the 46 cm (18 inch) pipes.

Figure 9 After the curtain drain was installed, it became apparent that there was a need to collect surface runoff as well. This ditch was dug at the top of the hill next to the right-of-way fence. The water was channeled to the roadside ditch.

3. PERFORMANCE

3.1 General Performance of the Curtain Drain

The curtain drains were placed to stabilize the slope at this location. From that standpoint, they have performed well. Only slight bulging in the slope was observed in 1993. Since the years in which this evaluation took place were relatively dry years until 1993, it is likely that the slope would have remained stable even without the curtain drains.

Though the flow coming from the system was low, a local drawdown of the water table of approximately 0.6 meters (two feet) was observed across the curtain drain. Nuclear moisture gage results are discussed later in this section.

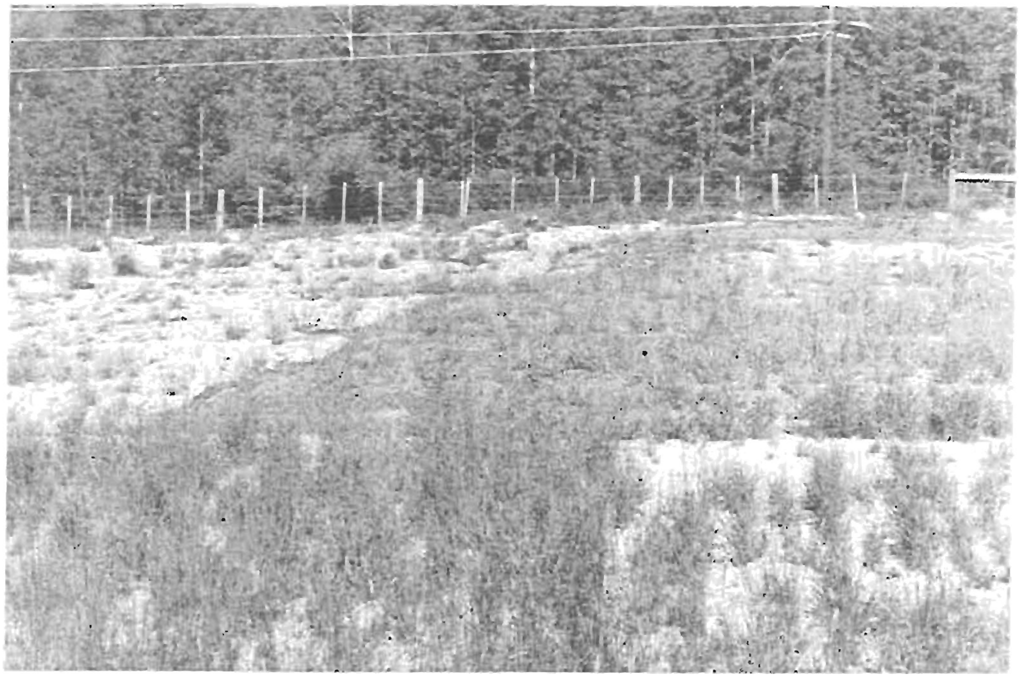


Figure 10 The dark area in the middle of the photo is where the surface is saturated on the slope below the interceptor ditch and curtain drain. This shows that the system is not completely effective. This photo was taken in July of 1989.

Figure 11 Water in the ditch at the base of the hill indicated that the ground water level just barely reached the bottom of the ditch in October of 1988.

In May of 1990, The surface of the ground was mostly dry. Some of the area downhill and adjacent to the small channel at the top of the hill was wet. This surface moisture did not, however, extend to the moisture probe holes on the downhill side of the curtain drains.

In 1991 there was a little bit more precipitation. No field trip was taken to the site that year, but according to reports from the maintenance forces, there were not any problems with instability on the slope.

Slight bulging on the slope occurred sometime during 1992 or 1993.

Figure 12 At the bottom of the hill on the other side of the roadway cattails and other dense wetland vegetation can be seen where the ground water reaches the surface.

3.2 Groundwater Measurement

From 1987 to 1990 groundwater was measured with a nuclear moisture probe in galvanized steel conduits that were placed in the ground on both sides of the curtain drain. In 1993, monitoring wells were placed in the ground on both sides of the curtain drain and water level measurements were taken by direct measurement that year. The nuclear measurements are discussed in section 3.2.1 and the monitoring wells are discussed in section 3.2.2.

3.2.1 Moisture Tubes and Nuclear Moisture Measurement

A down-hole nuclear moisture probe was used from 1987 to 1990 to measure soil moisture content. Based on the results from this testing, the top of the "saturated zone" could roughly be found. This saturated zone consists of the water table and the capillary fringe above it.

3.2.1.1 Theory and Method

The neutron logging device used on this project consisted of an Americium 241 - Beryllium radioactive source and a detector device within a stainless steel shaft attached to a 4.9 meter (16 foot) cable which enabled the shaft to be lowered into the moisture tubes. The source emits neutrons. The emitted neutrons are slowed and scattered by collisions with nuclei of hydrogen atoms. The detector counts the number of neutrons that are slowed and reflected. Thus with this device, the higher the number of "slow" neutrons detected, the higher the hydrogen content in the soil. In the ground, almost all of this hydrogen is in the form of water. Thus the neutron count can be used to determine the water content.[3]

Within the saturated zone, higher neutron counts indicate more porous soils, since these soils have the capacity to hold more water. Above the water table, the neutron-logging equipment can be used to measure the moisture content, but not the porosity or percent of voids filled.[4]

The standard count is obtained by taking readings at the site with the probe inside its protective sleeve. This reading is approximately the same as that obtained in a soil with 10 pcf of water. Higher readings indicate higher moisture contents. Where no reading is given, readings were considered invalid.

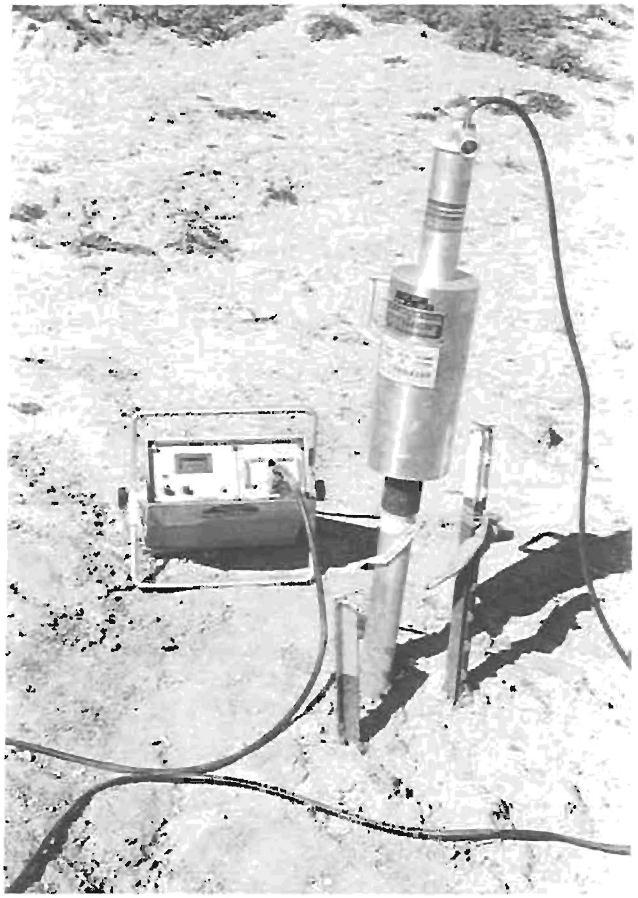


Figure 13 This photo shows the nuclear device used to measure the moisture content of the soil. The nuclear source is in a cylinder attached to the end of the cable which can be lowered to the full 3.7 meter (twelve foot) depth of the tubes. Moisture content measurements were taken at one foot depth intervals the whole length of the tubes.

3.2.1.2 Installation of Moisture Tubes

Moisture tubes were installed on both sides of the curtain drain to permit monitoring of moisture profiles after project completion.

A pair of five centimeter (two inch) diameter rigid conduits was placed on each side of the crib-box in the open trench. However, as the box was pulled forward, the shear forces bent the conduit to such an extent that they were no longer usable. It was decided that because of the soft soil mass it would be easier to push the 3.7 meter (12 foot) tubes into the ground with the bucket of a backhoe. Four galvanized steel pipes were placed by this method, two on each side of the curtain drain. Figure 14 shows the final stage of the moisture tube installation, which went extremely well.

The northwest and southwest holes are uphill of the curtain drains, the northeast and southeast holes are about five meters (16 feet) away on the downhill side of the curtain drains.

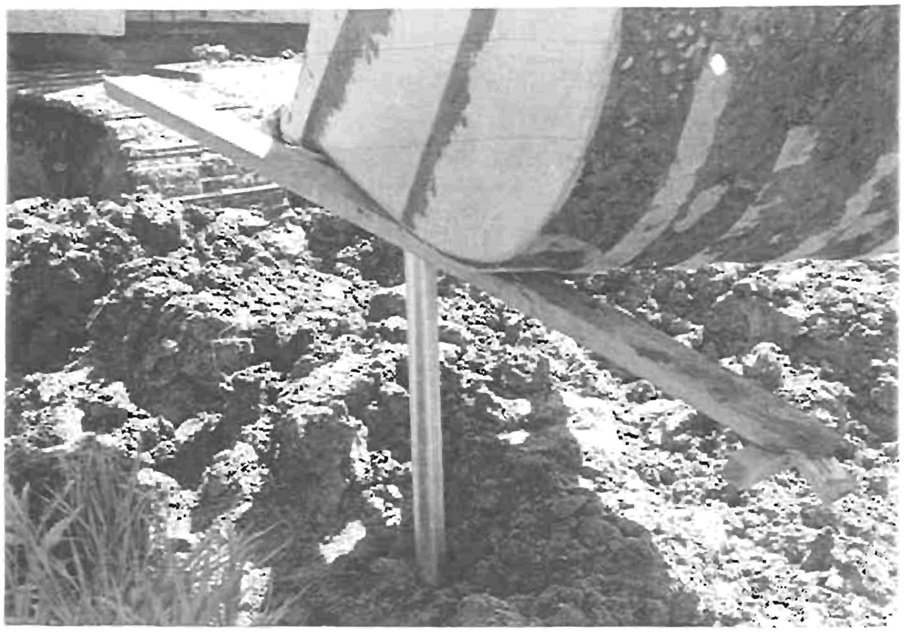


Figure 14 The 3.7 meter (twelve foot) long galvanized pipes were capped at the bottom and pushed into the ground with the backhoe as seen here. Two tubes were placed on each side of the curtain drain. These were used throughout the project for moisture measurements.

3.2.1.3 Report on Performance of the Tubes

A field trip was taken in November of 1987 to establish baseline moisture profiles for the curtain drain installation north of Electra Lake on S.H. 550. Only one of the four pipes was available for that test. Two of the other pipes were either clogged or bent, and the last pipe had been buried when the slope was graded subsequent to the curtain drain installation. Measurements were only taken in the one usable tube.

In the Spring of 1988 the tubes were repaired. After this they performed well, except that water sometimes needed to be drained before readings could be taken. In May of 1990, two of the holes needed to be drained of water before readings were taken, one of them was an uphill hole and one a downhill hole. The area around the downhill hole also had to be dug out about 0.6 meters (two feet) down to fix the pipe, which had broken apart at a coupling.

Figure 15 This moisture tube is adjacent to the interceptor ditch on the uphill side of the curtain drain.

Figure 16 Water sometimes got into the tube. This made it necessary to extract the water from the tube as is being done in this photo.

3.2.1.4 Report on results of testing

Consistently throughout the testing period, the water table on the downhill side of the curtain drain was approximately 0.6 meters (two feet) lower from the ground surface than the water table above the curtain drain. Over three years of testing, the water table on either side varied by no more than one quarter to three quarters of a meter (one or two feet). The dense clay at this site makes groundwater transport very slow. Figure 17 is a cross section diagram that shows the location of moisture tubes, the curtain drain, the roadway, and representative water table at one of the two nuclear moisture tube locations.

Appendix D shows all the measurements expressed as one-minute counts, ratios to the standard count, moisture content and moisture percent by volume based on the ratio to the standard count. It is assumed that there is very little hydrogen content in the soil itself and that the soil is saturated since the measurements are constant below a meter or so. Therefore, the moisture percent is also the percent porosity of the soil mass. Within this saturated zone, variations in moisture percent may be caused only by variations in density of the soil or void space that is not interconnected.

In November of 1987, moisture measurements on the one usable pipe revealed the moisture to be relatively constant to the 3.7 meter (12 foot) depth. The moisture content was approximately 38%. Since the measurements were constant, it is likely that the soil was saturated.

Though the tables in the appendix show measurements expressed as one-minute counts, the testing was usually done with two minute counts. Readings were taken for two minutes at a time at each one-foot interval starting between 6" and 12" from the bottom and working up to the top of the hole. In the saturated zone, slightly higher readings were recorded in the uphill holes. This may indicate the soil was slightly more compacted in the downhill holes. Moisture reduction across the curtain drain was large near the surface. This most likely shows that the water table dropped locally about 0.6 meters (two feet) by removal of ground water by the curtain drain.

One factor that may be artificially raising the water table above the curtain drain is that water may be infiltrating from the drainage ditch.

CROSS-SECTION OF CURTAIN DRAIN
STATION 434+50

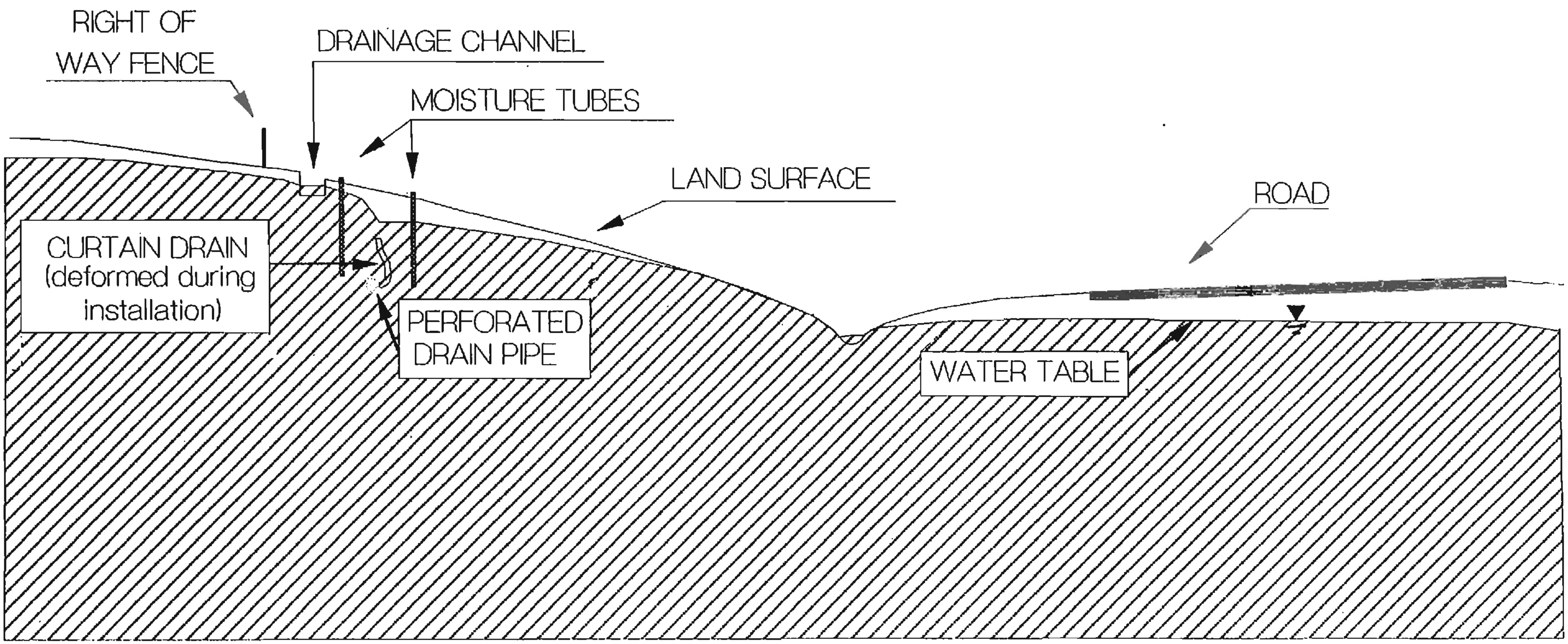


Figure 17 Moisture tube diagram

3.2.2 Monitoring Wells

Monitoring wells were installed at this site in July of 1993 to verify the inferences of the nuclear logging gages. One set was installed near the moisture tubes at station 434+50. A second set was installed 45 meters (150 feet) to the south (about 30 meters (100 feet) south of the southern moisture tubes).

When the wells were drilled, no water was found in the bottom of the wells, although the clayey soil was wet. Small stones that were dropped into the well made a thud as they hit the bottom. This situation was temporary. Within a few days, a few meters of water had risen in the wells. This experience shows how slowly water moves through dense clayey soil.

Figure 18 The cohesiveness of the clay was demonstrated by the way strips of mud were peeled off the auger during the installation of the monitoring wells.

After about two weeks, the water level had stabilized. The set of wells installed near the moisture tubes at station 434+50 verified the inferred water table level. The water table in the wells was about 0.6 meters (two feet) lower than the saturated zone found by the nuclear gages. The wells measure the true potentiometric surface (level to which water rises in a tightly cased well; or total head), whereas the saturated zone which was measured by the nuclear gages includes the capillary fringe[5] which in this case is assumed to be about 0.6 meters (two feet) above the water table. Table I shows the monitoring well measurements.

TABLE I

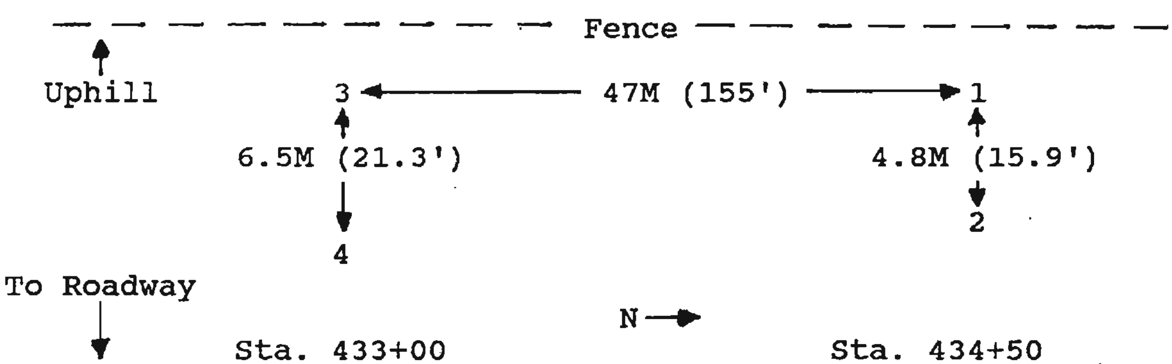
MONITORING WELLS AT CURTAIN DRAIN SOUTH Of PURGATORY

On Thursday, July 8, 1993, four water level monitoring wells were installed in the vicinity of the curtain drain south of Purgatory. The following measurements were made.

DEPTH TO WATER FROM GROUND SURFACE

DATE	Well No. 1	Well No. 2	Well No. 3	Well No. 4
20July93	1.3M	2.0M	2.3M	1.4M
26July93	1.3M	2.0M	2.3M	1.4M
03August93	1.4M	2.2M	2.3M	1.6M
09August93	1.4M	2.2M	2.3M	1.6M
23August93	1.3M	2.0M	2.4M	1.6M

Following are the approximate dimensions of the well array. North is to the right.



As can be seen in the table, the set of wells to the south at station 433 do not exactly show the same information. The downhill hole at this location was placed further down the hill on a steeper section. The water in this hole is closer to the surface than the uphill hole. This is probably due to the groundwater coming closer to the surface due to the steepness of the slope. There are cattails and other wetland vegetation growing at the bottom of the slope where the groundwater daylights. Figure 19 shows the cross section of the roadway and roadside features at this location south of the moisture tubes.

CROSS-SECTION OF CURTAIN DRAIN
STATION 433+00

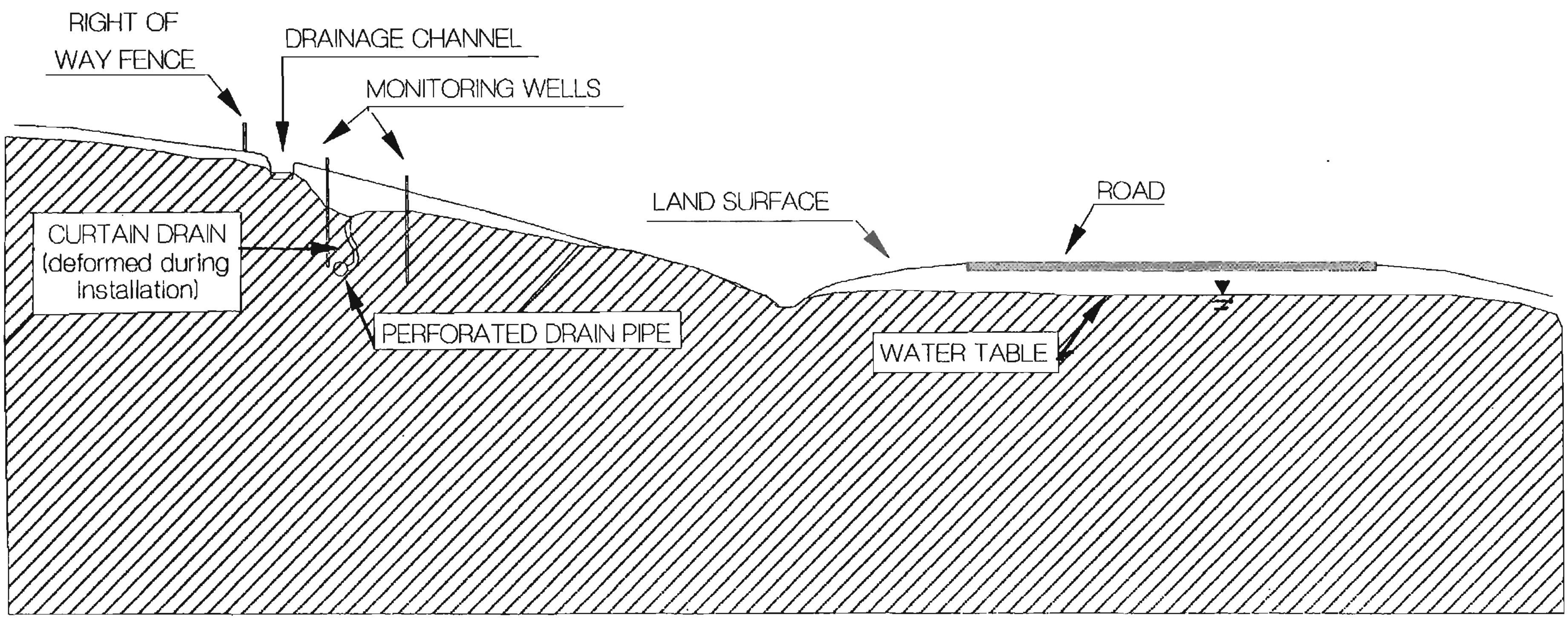


Figure 19 Monitoring well diagram

3.3 Pipe Flow

The curtain drain system on this project was designed to collect some infiltrated surface flows as well as ground water and channel this water along the perforated drain pipe to a cross culvert. Figure 8 on page 7 shows a manhole during construction where two curtain drain systems feed into the cross culvert.

It was expected that with the great amount of moisture in the area during construction, there should have been an increasing amount of flow from the curtain drain system as the project progressed. This was not the case during the two-day period of construction that was observed. Subsequent phone conversations with the project engineer revealed that the flow did not increase. A well had to be drilled for the adjoining property owner to provide the water to his property that he lost due to the construction project. It had been hoped that the water from the curtain drain would provide the necessary water.

Figure 20 A relatively small amount of water, as seen coming from this pipe on the east side of the roadway, was collected by the system. The most observed was about 20 liters (5.3 gallons) per minute. The water in the foreground is from the roadside ditches and the channel above the curtain drain.

For the first five years, it was difficult to determine exactly how effective the curtain drains were, because the years of evaluation were all relatively dry years in terms of snowfall and run-off. However, there was still less water than expected coming out of the drain. The flow from the pipe was a few gallons per minute. Some early observations were erroneous because the wrong exit pipe was observed. The proximity of other pipes in the area made it difficult to tell which one was coming from the underdrain.

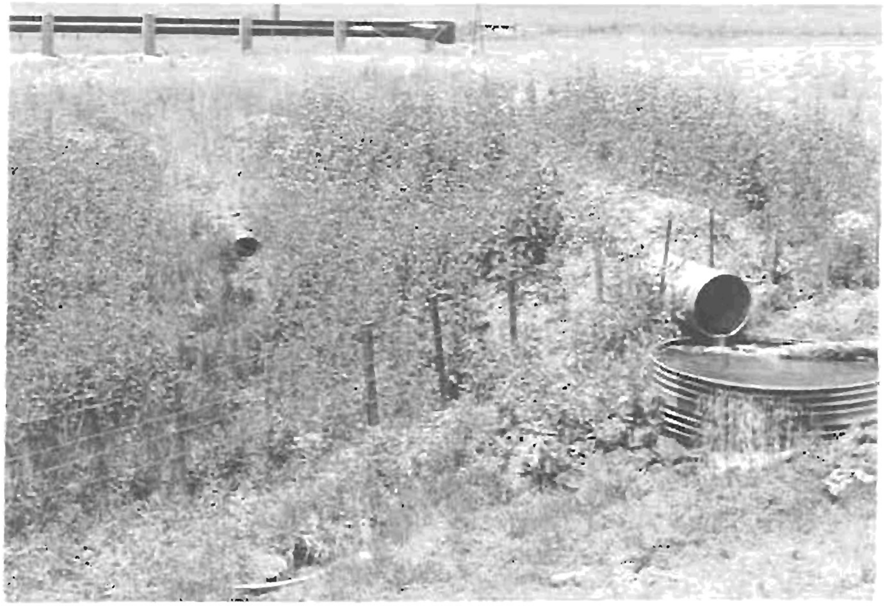


Figure 21 The culvert feeding into the tank on the right is bringing water from the ditch at the top of the slope on the other side of the roadway. The culvert to the left carries water from part of the southern section of curtain drain. This culvert is carrying very little water.

The final year of evaluation, 1993, was a wet run-off year. The snowpack was high, but very little rain occurred in the spring and early summer. There was slight swelling of the ground on the slope, but the run-off was mostly over with by the beginning of July. Maintenance personnel reported that flows in late May and early June were higher coming from the system.

When a section was excavated and examined in September of 1990, The perforated pipe at the bottom of the panels was accidentally ruptured. A significant amount of water was found in the pipe. It was difficult to tell if the water had been flowing or standing in the pipe.

At the exit of the curtain drain system there was a lot of sedimentation. This filled up almost half of the exit culvert. The sedimentation may be from too large an opening size in the filter fabric or from holes in the system.

On a separate construction project in the summer of 1993, three underdrains were installed parallel to each other on a slope about one and a half kilometers north of this curtain drain site. The collective flows from these drains was approximately 600 liters or 150 gallons per minute (rough estimate from observation).

Even in clayey soil, 213 meters of curtain drain placed within a water table would have been expected to produce more water than was obtained on this project. The low flow from the curtain drain that occurred throughout the evaluation period could be a combination of several factors. These include: the limited hydraulic conductivity of the clayey soil, collapsing of the panels during installation, lowering of water table due to dry years, or clogging of the filter fabric, though the latter did not appear to be the case upon excavation. It is also possible that the filter fabric was not appropriate for the soil type to most efficiently transport water without clogging.

4. EXCAVATION

In September of 1990 a trip was made to the site to excavate a section of the curtain drain and determine if it was clogged, if it was installed properly, and if it was draining properly. The backhoe reached the top of the curtain drain at a depth of 1.8 meters (six feet) about halfway between the upper and lower moisture tubes. The downhill side of the curtain drain was excavated an additional 1.8 meters, and a 15cm (six inch) by 15cm piece of the curtain drain was cut out and examined.

The inside of this piece was completely clean, and the outsides of the filter cloth had only traces of dirt on them. The plastic core of the sample had a few traces of moisture on the uphill side, and was completely dry on the downhill side. The filter fabric was compressed partway into the polyethylene core, but this was probably not a problem since the flow from the soil was slow. At the point where adjacent panels were to overlap, a 20cm (eight inch) gap was found in some places.

The fabric from the excavated piece of drain panel was tested by a modified permitivity test and was generally found to be only slightly less permeable than the virgin filter fabric of the same manufacturer. The specifications for this fabric are in Appendix C.

The downhill side was backfilled, and then the uphill side was excavated. When the backhoe reached the bottom of the curtain drain, a section of the drainage pipe at the bottom of the system was accidentally ripped up. Some water from the uphill side of this pipe poured into the hole. This flow seemed to decrease slightly after a short period of time. The hole was widened to provide better access to the damaged pipe. This however cut into some nearby springs and let more water into the hole. The banks began to collapse and fill in the hole again. A two meter section of perforated 8" pipe was finally placed next to the bottom of the uphill side of the curtain drain to hopefully transfer water around the missing pipe section.

The pipe would not have been damaged had it been beneath the curtain drain as expected. Instead it was about 0.6 meters (two feet) off center to the uphill side. No groundwater was encountered flowing next to the curtain drain.

Since the clay is fairly uniform in the curtain drain area, very little water permeates the ground. The majority of the subsurface water transport in this area appears to come through fissures in the clay formation.

Figure 22 In September of 1990, a section of the drain was excavated with a backhoe and examined. The top of the curtain drain was found at a depth of almost two meters (six feet). The water in this photo at the bottom of the trench is due to the accidental cutting into the perforated pipe.

Figure 23 A piece of the curtain drain was cut out for further examination.

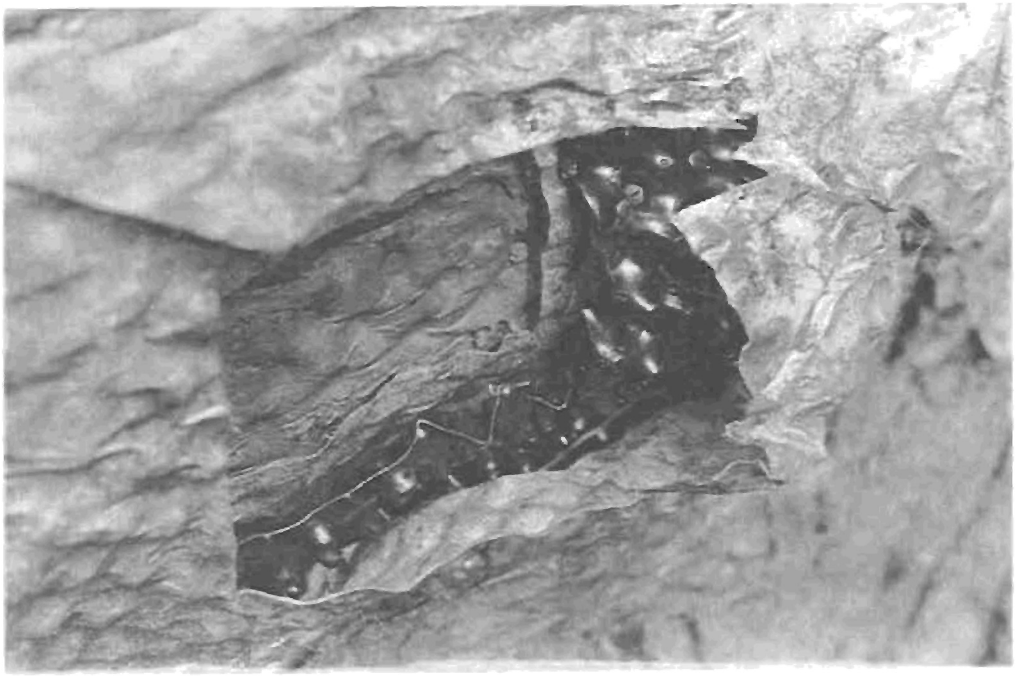


Figure 24 This is a close-up of the area where the curtain drain section was removed. The fabric did not appear to be clogged on either side of the curtain drain. The indentations in the fabric show that the soil was pushing in against the sides and intruding into the open space. There were a few beads of water on the uphill side of the plastic core.

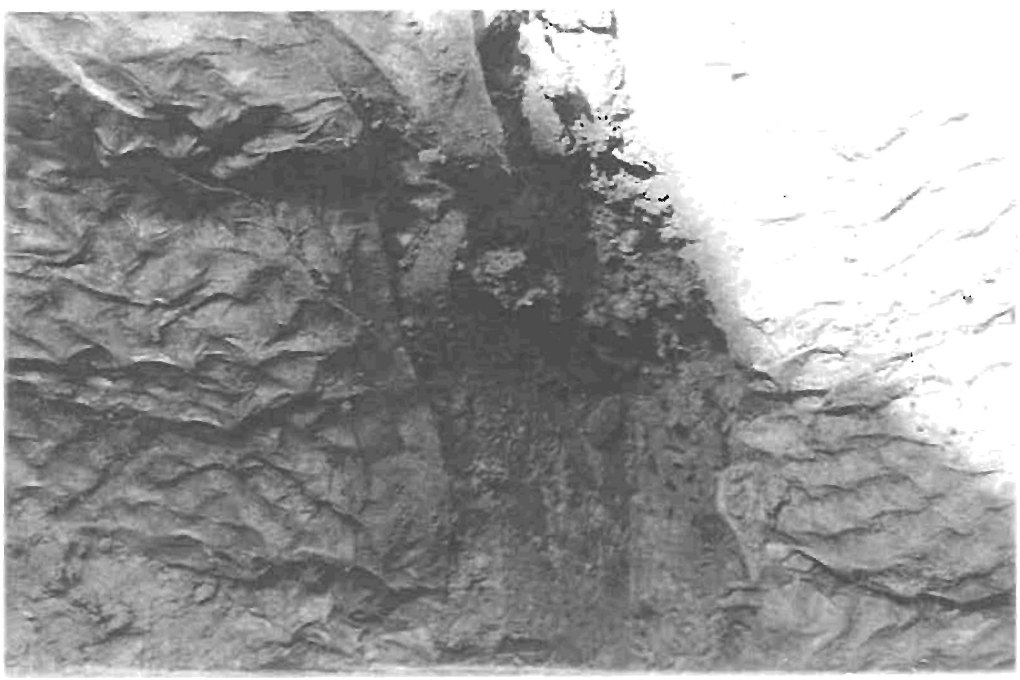


Figure 25 This photo shows a 20cm (eight inch) gap where adjacent curtain drain sections pulled apart, presumably during construction.

5. CONCLUSIONS

The curtain drains at this site drained some of the groundwater, but due to problems during construction and the dense clay, the drains were not as effective as they could have been. The slope remained stable except for very slight swelling.

A localized drop in the water table of approximately 0.6 meters (two feet) was registered across the curtain drain. Downhill from the curtain drain groundwater gradually came closer to the surface. On the bottom one quarter to one third of the slope this water reached the surface and supported wetland vegetation. An additional drain system should have been placed near the bottom of the slope.

Dense clay in this area made water transport slow. Some variations in compaction or soil components resulted in slight variations in moisture content within the groundwater saturated zone. These variations were found to be in the same locations each year of testing. Most of the water transport in the soil mass took place through fissures.

The years of evaluation were all relatively dry years except 1993 in terms of snowfall and run-off. Still, because of the lack of water transport through the clayey soil and the collapsed curtain drain panels, less water than expected came from the curtain drain system.

A ditch above the drain was effective at removing water from the slope.

The collapsing of the drain panels effectively reduced the cross-sectional area of interception. Gaps were present between panels. The perforated pipe at the bottom of the drain panels was about 0.6 meters (two feet) off center due to the placement and backfilling process.

There was a lot of sedimentation in the bottom of the culvert exit from the curtain drain. This sedimentation may be from too large an opening size in the filter fabric or from holes in the panels or the collector pipe.

The filter fabric did not appear to be clogged. Though the fabric intruded into the space in the polyethylene core, this did not appear to be a problem in clayey soil. If a great deal of flow were occurring due to fissures or springs, the reduced flow area might cause problems. With the greater soil pressure that occurs at depth, there is a greater chance of the fabric being pushed into the core and the flow impeded.

When installing deep drains such as these, a trenchbox is important for the safety of the workers, but interferes with proper placement of drains.

Groundwater monitoring wells are more accurate than nuclear moisture probes for measuring the depth of the water table. A problem that is evident with both types of ground water measurement is that when they are installed in clayey soil such as this, water migrates very slowly, so rapid changes in moisture may not be recorded instantly in the wells. A pressure transducer or similar device linked to a data logger that regularly records the depth of water in the wells is helpful to avoid missing changes in water levels. A flow meter at the outlet of the system would also make measurement easier, more accurate, and continuous.

When using the nuclear moisture probe method, the moisture tubes can be unreliable and difficult to work with because they can get water in them, which precludes taking readings, and they have a tendency to separate at the couplings.

6. IMPLEMENTATION

Geocomposite drains are currently used on five to ten CDOT projects a year. CDOT now only uses these types of systems next to retaining walls.

Because of the collapsibility of the drains and the danger associated with instability of the trench walls, it is better to install sections shallower. Rather than install one curtain drain to a depth of 3.7 meters (twelve feet), it is easier and probably more effective to install two French drains parallel to depths of 1.5 to 2 meters if they are properly spaced. This can be done because a lowered water table will rise again toward the surface downhill from the first drain. The installation should coincide with the lowest ground water level of the year if possible. I advise against using geocomposite drains in slope stability applications.

Care should be taken to avoid collapsing the drain panels during installation and backfill. The panels should overlap slightly so that gaps do not form between panels. Safety should be the most important item for the contractor during construction. Before doing an installation of this type of drain in the future, trench side stability needs to be determined. If the drains cannot be installed without the aid of a trenchbox, alternative ways to address the problem need to be considered. Using the trenchbox method it is virtually impossible to get the geocomposite drain installed at the proper vertical and horizontal alignment and overlaps.

When specifying geocomposite drains on a project it is important to specify a fabric which is matched to the soil conditions to avoid clogging or excessive sedimentation in the system. If possible, exit culverts should be steeper to provide enough energy in the flow to remove sedimentation from the pipe. Current standard plans and specifications are shown in Appendix E.

A drainage ditch dug at the top of a slope such as on this project can be very effective at removing moisture and keeping the surface of the slope relatively dry. This water must be transported away from the slope to avoid re-infiltration or erosion of the slope.

Groundwater monitoring wells should be used instead of nuclear moisture gages for ease of measurement and accuracy if all that is needed is the groundwater level or potentiometric surface. These wells are more common and less expensive than the nuclear method.

The use of a flow meter to continuously measure the flow from the system, and a series of monitoring wells to get a more detailed profile of the groundwater elevation is recommended to more accurately determine the effectiveness of the drain systems.

Cost data from this project is presented in Appendix B.

FOOTNOTES

1. Chapter 300 - Geometric Cross Section, ROADWAY DESIGN MANUAL, State of Colorado, Department of Highways, Division of Highways, Denver, Co., 1990, P. 3-3

2. IBID

3. Fetter, C.W., APPLIED HYDROGEOLOGY, Second Edition, Merrill Publishing Company, Columbus, Ohio, 1988, p. 517

4. IBID

5. IBID, p. 91

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Chapter 800 - Drainage, ROADWAY DESIGN MANUAL. State of Colorado, Department of Highways, Division of Highways. Denver, Co. 1990.

Fetter, C.W. APPLIED HYDROGEOLOGY, Second Edition. Merrill Publishing Company. Columbus, Ohio. 1988.

Kraemer, S.R. and Smith, A.D. GEOCOMPOSITE DRAINS, Vol I: Engineering Assessment and Preliminary Guidelines. FHWA. McLean, Virginia. October, 1986.

APPENDIX A

PLANS AND SPECIFICATIONS FROM PROJECT CXFC 20-0550-21

Jan. 15, 1987

REVISION OF SECTION 506
CURTAIN DRAINS
COLORADO PROJECT NO. CXFC 20-0550-21

Section 506 of the Standard Specifications is hereby revised for this project to include the following:

DESCRIPTION

This work shall consist of furnishing and placing Curtain Drains at locations shown on the plans.

MATERIALS

Curtain Drains shall consist of one of the following alternates or approved equal:

(1) Hydraway Drain as manufactured by Monsanto Company, 800 N. Lindbergh Blvd., St. Louis, Missouri 63146, Phone: 800-325-4330.

(2) Miradrain as manufactured by Mirafi Inc., P.O. Box 240967, Charlotte, NC 28224, Phone: 800-438-1855.

(3) Eljen drain as manufactured by Eljen Development Corporation, 15 Westwood Road, Storrs, CT 06268, Phone: 203-429-9486.

Perforated pipe shall be 8'" diameter and shall conform to ASTM F667.

CONSTRUCTION REQUIREMENTS

Installation of Curtain Drains shall conform to the manufacturer's recommendations.

METHOD OF MEASUREMENT

Curtain Drains will be measured by the square yard of drain installed, completed in place and accepted.

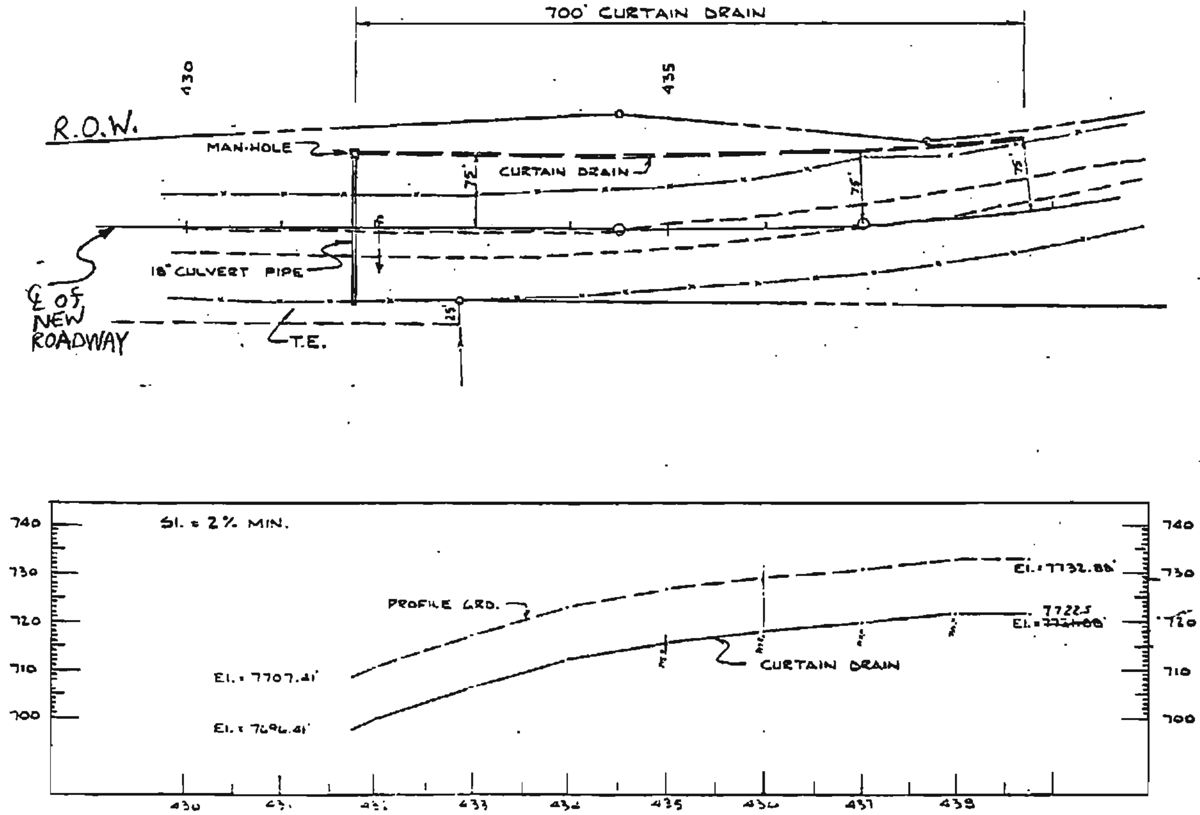
BASIS OF PAYMENT

The accepted quantities of Curtain Drains will be paid for at the contract unit price per square yard.

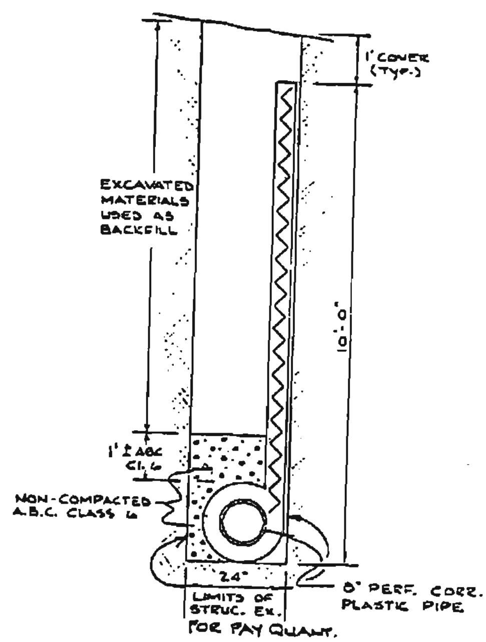
Payment will be made under:

Pay Item	Pay Unit
Curtain Drain	Square Yard

Pins, and other connecting devices will not be measured and paid for separately but shall be included in the work. Perforated pipe and non perforated pipe will be measured and paid for in accordance with Section 605.



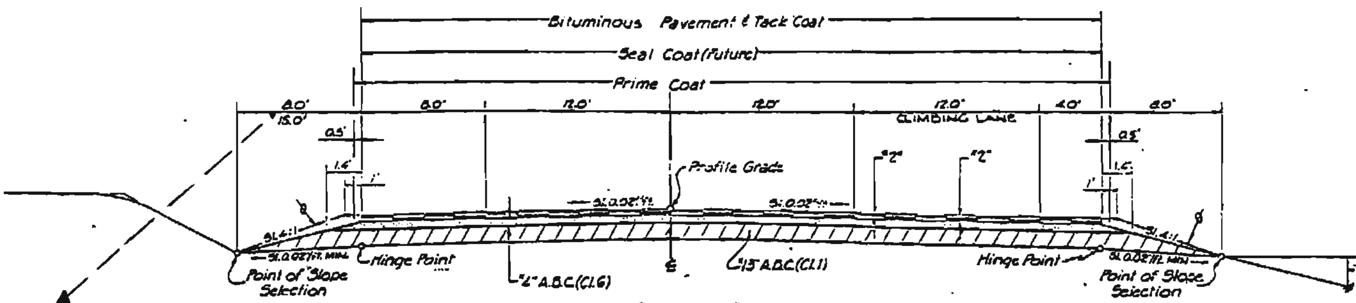
CURTAIN DRAIN DETAIL
STA. 431+73 To STA. 438+75



TYP. SECTION ~ CURTAIN DRAIN

ALTERNATE TYPE INSTALLATION PROCEDURES MAY BE ALLOWED, BUT SHALL BE APPROVED IN WRITING BY THE ENGINEER.

TYPICAL SECTIONS



SECTION C

*Sta 426+00 to Sta. 439+00, Lt

✗STA. 400+00 TO STA 404+00, APPROACH TO PROJECT
STA. 404+00 TO STA. 463+00

✗Subgrade constructed under previous project FC 550-2(12).

The depth and width of the side ditch shall be varied where necessary in order to provide proper drainage.

Break points on slopes and in bottoms of ditches shall be rounded on construction for a pleasing appearance.

See Standards for Details of Cut Slope Treatment, Flaring, and Widening.

FILL SLOPE		CUT SLOPE	
4:1	0' to 4'	4:1	0' to 10'
3:1	10' to 20'	3:1	10' to 15'
2:1	over 20'	ɪ 2:1	over 15'

ɪ Steeper in Special Cases

ϕ The Contractor will be required to place A.B.C.(Special) to this line after completion of the paving operation.

* Approximate Thickness

Material shall be placed in separate courses at the following approximate rates per 100 lin. ft. of roadway:

			SECTION C
Bituminous Pavement	Top Layer		59 Tons
	Bottom Layer		59 Tons
Base Course	Class 6		110 Tons
	Class 1		418 Tons

The rates shown have been determined from information available at the time of design. Rates should be adjusted during construction to obtain the approximate thickness.

APPENDIX B

COSTS OF THIS CURTAIN DRAIN PROJECT

CURTAIN DRAIN PROJECT
CXFC 20-0550-21
North of Durango -- Electra Lake

Project -- Eljen Drain

Polyethylene "egg carton" shaped core panels 10 feet by 10 feet enveloped by nonwoven filter cloth, with 8-inch perforated, drain pipe.

Manufacturer -- Eljen Development Corporation
Storrs, Connecticut
(Phone 203-429-9486)

Item	Quantities	Cost	Unit Cost
Drain Panels	1,751 sq. yds.	$35,010	$20.00
Perforated pipe	1,575 feet	15,750	10.00
Nonperforated pipe	52 feet	780	15.00
ABC, Class 6 Bedding Material	268 tons	2,171	8.10
Structural Excavation	1,319 cu. yds.	6,595	5.00
Subtotal		$60,316	

Miscellaneous

Item	Quantities	Cost	Unit Cost
Manhole	3	$ 4,500	$1,500
Structural Excavation	386 cu. yds.	1,930	5
Structural Backfill	162 cu. yds.	1,620	10
18" Culverts	432 feet	8,640	20
Subtotal		$12,190	

Project Total $77,006

Cost per linear foot of curtain drain
(exclusive manholes and associated materials)

$$\frac{\$60,316}{1,576\ ft} = \$38.27/ft$$

Box: 12' high
6' wide
20' long

Curtain Dr. Lengths
440' (33') 240' (2') 700'
200'

APPENDIX C

PRODUCT SPECIFICATIONS

ELJEN®

LEADERSHIP IN COMPOSITE DRAIN TECHNOLOGY

LANDSCAPE AND CONSTRUCTION GRADE 1 MATERIAL SPECIFICATIONS

ELJEN DRAINAGE CORE

PROPERTIES	METHOD	VALUE
CORE MATERIAL	PLASTIC	POLYSTYRENE
COMPRESSIVE STRENGTH	ASTMD-1621 (MODIFIED)	4300 PSF
GEOMETRY	CUSPATED	WAFFLE LIKE
CORE CONFIGURATION (BOTTEM CORE)	STANDARD	SOLID DOUBLE CORE
CORE WIDTH	STANDARD	3/4 INCH
CORE DEPTH	STANDARD	5/8 INCH
FLOW RATE (LATERALLY THRU DRAIN)	STANDARD*	15.9 G.P.M.**
*Testing Authority available upon request		**Per lineal foot of material at 1% grade

ELJEN DRAINAGE FABRIC

WEIGHT (OZ/SQ YD)	ASTM D-3776	4
TENSILE STRENGTH LBS	ASTM D-4632	145
ELONGATION AT BREAK (96)	ASTM D-4632	115
MULLEN BURST STRENGTH (PSI)	ASTM D-3786	170
PUNCTURE STRENGTH	ASTM D-3787 (MODIFIED)	55
A.O.S. (EQUIVALENT SIEVE)	ASTM D-4751	70/100
MODULAS AT 10% ELONGATION (LBS)	ASTM D-4632	785
TRAP TEARS (LBS)	ASTM D-4533	75
COEFFICIENT OF PERMEABILITY (CM/SEC)	ASTM D-4491	0.03
FLUX (GAL/SQ FT/MIN)	ASTM D-4491	60
PERMITTIVITY (SEC - 1)	ASTM D-4491-85	.8
ACCELERATED WEATHERING STRENGTH	(FED)STD#191-5804 (Retained after 500 hrs (%))	80

ELJEN BINDING METHOD

EXTERNAL BINDER	STANDARD	SEWN
TYPE STITCHING	STANDARD	LOCK STITCH
TYPE THREAD	STANDARD	HB92 NYLON
TENSILE STRENGTH	STANDARD	11 LBS
THREAD GAGE	STANDARD	210X4 DENIER
CHEMICALLY IMPERVIOUS	STANDARD	ALL NATURAL

APPENDIX D

NUCLEAR MOISTURE GAUGE MEASUREMENTS

CURTAIN DRAINS - ELECTRA LAKE

STANDARD COUNT 4837 — 11/6/87

Ft from Ground Surf.	S.W. PIPE 1-MINUT COUNTS	RATIO TO STD	MOIST. CONT.	MOIST. PCT.	S.E. PIPE 1-MINUT COUNTS	RATIO TO STD	MOIST. CONT.	MOIST. PCT.	% REDUCTI
▼ 1	3944	0.815	16.6	26.6					
2	5125	1.060	23.4	37.5	N				100
3	5183	1.072	23.8	38.1	O				100
4	5098	1.054	23.2	37.2					100
5	5125	1.060	23.4	37.5	R				100
6	5216	1.078	24	38.5	E				100
7	5349	1.106	24.8	39.7	A				100
8	5226	1.080	24	38.5	D				100
9	5267	1.089	24.3	38.9	I				100
10	5143	1.063	23.5	37.7	N				100
11					G				100
12					S				
	(15" or so exposed)				(20" or so exposed)				

STANDARD COUNT: 4837 — 11/6/87

Ft from Ground Surf.	N.W. PIPE 1-MINUT COUNTS	RATIO TO STD	MOIST. CONT.	MOIST. PCT.	N.E. PIPE 1-MINUT COUNTS	RATIO TO STD	MOIST. CONT.	MOIST. PCT.	% REDUCTI
1									
2	N				N				
3	O				O				
4									
5	R				R				
6	E				E				
7	A				A				
8	D				D				
9	I				I				
10	N				N				
11	G				G				
12	S				S				

▼ Indicates approximate location of the top of the saturated zone based on these measurements.

CURTAIN DRAINS - ELECTRA LAKE

Ft from Ground Surf.	STANDARD COUNT 4840 S.W. PIPE 1-MINUT COUNTS	RATIO TO STD	MOIST. CONT.	MOIST. PCT.	5/26/88 S.E. PIPE 1-MINUT COUNTS	RATIO TO STD	MOIST. CONT.	MOIST. PCT.	% REDUCTI
▼ 1	3581	0.740	14.6	23.4	2812	0.581	10.9	17.5	25
2	5008	1.035	22.6	36.2	3398	0.702	13.8	22.1	39
3	5286	1.092	24.4	39.1	4382	0.905	18.9	30.3 ▼	23
4	5197	1.074	23.8	38.1	5055	1.044	22.9	36.7	4
5	5158	1.066	23.6	37.8	4959	1.025	22.3	35.7	6
6	5217	1.078	23.9	38.3	5106	1.055	23.3	37.3	3
7	5320	1.099	24.6	39.4	5137	1.061	23.4	37.5	5
8	5260	1.087	24.2	38.8	5155	1.065	23.5	37.7	3
9	5263	1.087	24.2	38.8	5000	1.033	22.6	36.2	7
10	5156	1.065	23.5	37.7	4919	1.016	22	35.3	6
11	5164	1.067	23.6	37.8					
12									
	(15" or so exposed)				(20" or so exposed)				

Ft from Ground Surf.	STANDARD COUNT: 4840 N.W. PIPE 1-MINUT COUNTS	RATIO TO STD	MOIST. CONT.	MOIST. PCT.	5/26/88 N.E. PIPE 1-MINUT COUNTS	RATIO TO STD	MOIST. CONT.	MOIST. PCT.	% REDUCTI (30 MIN
1					389	0.080	0	0.0	
▼ 2	4849	1.002	21.6	34.6	3683	0.761	15.2	24.4	30
3	5343	1.104	24.7	39.6	4853	1.003	21.7	34.8	▼ 12
4	5353	1.106	24.8	39.7	5018	1.037	22.7	36.4	8
5	5320	1.099	24.6	39.4	4988	1.031	22.5	36.1	9
6	5219	1.078	23.9	38.3	5089	1.051	23.1	37.0	3
7	4941	1.021	22.2	35.6	5085	1.051	23.1	37.0	-4
8	5171	1.068	23.6	37.8	5009	1.035	22.6	36.2	4
9	5103	1.054	23.2	37.2	5086	1.051	23.1	37.0	0
10	5114	1.057	23.3	37.3	5209	1.076	23.9	38.3	-3
11	5069	1.047	23	36.9	4979	1.029	22.5	36.1	2
12	5282	1.091	24.3	38.9	5028	1.039	22.7	36.4	7

▼ Indicates approximate location of the top of the saturated zone based on these measurements.

CURTAIN DRAINS - ELECTRA LAKE

Ft from Ground Surf.	STANDARD COUNT 4842 S.W. PIPE 1-MINUT COUNTS	RATIO TO STD	MOIST. CONT.	MOIST. PCT.	10/19/88 S.E. PIPE 1-MINUT COUNTS	RATIO TO STD	MOIST. CONT.	MOIST. PCT.	% REDUCTI
1	2286	0.472	8.5	13.6	3366	0.695	13.5	21.6	-59
▼ ~~2~~	~~4708~~	~~0.972~~	~~20.8~~	~~33.3~~	3515	0.726	14.7	23.6	29
3	5176	1.069	23.5	37.7	4619	0.954	20.1	32.2	▼ 14
4	5187	1.071	23.7	38.0	~~4954~~	~~1.023~~	~~22.3~~	~~35.7~~	~~6~~
5	5226	1.079	24	38.5	5032	1.039	22.7	36.4	5
6	5198	1.074	23.8	38.1	5261	1.087	24.2	38.8	-2
7	5364	1.108	24.9	39.9	5159	1.065	23.5	37.7	6
8	5247	1.084	24.3	38.9	5073	1.048	23	36.9	5
9	5291	1.093	24.4	39.1	4870	1.006	21.7	34.8	11
10	5091	1.051	23.3	37.3	5085	1.050	23.1	37.0	1
11	5134	1.060	23.4	37.5					
12									
	(15" or so exposed)				(20" or so exposed)				

Ft from Ground Surf. .)	STANDARD COUNT: 4842 N.W. PIPE 1-MINUT COUNTS	RATIO TO STD	MOIST. CONT.	MOIST. PCT.	10/19/88 N.E. PIPE 1-MINUT COUNTS	RATIO TO STD MOIST. CONT. MOIST. PCT.	% REDUCTI 30 minu
▼ ~~1~~	~~4946~~	~~1.021~~	~~22.2~~	~~35.6~~	N		100
2	5399	1.115	25.1	40.2	O		▼ 100
3	5404	1.116	25.1	40.2		~~filled with water~~	~~100~~
4	5340	1.103	24.7	39.6	R	to within 3 feet of	100
5	5160	1.066	23.5	37.7	E	surface	100
6	4805	0.992	21.3	34.1	A		100
7	5227	1.080	23.9	38.3	D		100
8	5108	1.055	23.2	37.2	I		100
9	5172	1.068	23.6	37.8	N		100
10	5049	1.043	22.9	36.7	G		100
11	5290	1.093	24.4	39.1	S		100
12							

▼ Indicates approximate location of the top of the saturated zone based on these measurements.

CURTAIN DRAINS - ELECTRA LAKE

Ft from Ground Surf.	STANDARD COUNT 4843 S.W. PIPE (14" EXPOSED) 1-MINUT COUNTS	RATIO TO STD	MOIST. CONT.	MOIST. PCT.	6/22/89 S.E. PIPE (17" EXPOSED) 1-MINUT COUNTS	RATIO TO STD	MOIST. CONT.	MOIST. PCT.	% REDUCTI
1	3056	0.631	12	19.2	3185.5	0.658	12.6	20.2	-5
▼ 2	4815	0.994	21.5	34.5	3715.7	0.767	15.3	24.5	29
3	5165	1.066	23.5	37.7	4588.5	0.947	20.1	32.2	▼ 14
4	5124	1.058	23.3	37.3	~~4965.5~~	~~1.025~~	~~22.3~~	~~35.7~~	~~4~~
5	5175	1.069	23.5	37.7	5059.7	1.045	22.9	36.7	3
6	5225	1.079	24	38.5	5268	1.088	24.2	38.8	-1
7	5343	1.103	24.7	39.6	5175	1.069	23.5	37.7	5
8	5238	1.082	24.1	38.6	5079	1.049	23	36.9	5
9	5282	1.091	24.3	38.9	4854	1.002	21.6	34.6	11
10	5125	1.058	23.3	37.3					
11									
12				(SE READINGS ARE ABOUT 4" LOWER THAN SW)					
	(15" or so exposed)				(20" or so exposed)				

Ft from Ground Surf.	STANDARD COUNT: 4843 N.W. PIPE 1-MINUT COUNTS	RATIO TO STD	MOIST. CONT.	MOIST. PCT.	6/22/89 N.E. PIPE 1-MINUT COUNTS	RATIO TO STD	MOIST. CONT.	MOIST. PCT.	% REDUCTI
▼ 1				0.0				0.0	
2	5185	1.071	23.7	38.0	3605	0.744	14.7	23.6	38
3	5432	1.122	25	40.1	4646	0.959	20.4	32.7	▼ 18
4	5368	1.108	24.9	39.9	5129	1.059	23.3	37.3	6
5	5319	1.098	24.5	39.3	4931	1.018	22.1	35.4	10
6	5202	1.074	23.8	38.1	5158	1.065	23.5	37.7	1
7	4964	1.025	22.3	35.7	5096	1.052	23.1	37.0	-4
8	5223	1.078	23.9	38.3	4988	1.030	22.5	36.1	6
9	5122	1.058	23.3	37.3	5076	1.048	23	36.9	1
10	5129	1.059	23.3	37.3	5206	1.075	23.8	38.1	-2
11	5069	1.047	23	36.9	4964	1.025	22.3	35.7	3
12				0.0				0.0	

▼ Indicates approximate location of the top of the saturated zone based on these measurements.

CURTAIN DRAINS - ELECTRA LAKE

Ft from Ground Surf.	STANDARD COUNT 4790 S.W. PIPE 1-MINUT COUNTS	RATIO TO STD	MOIST. CONT.	MOIST. PCT.	5/21/90 S.E. PIPE 1-MINUT COUNTS	RATIO TO STD	MOIST. CONT.	MOIST. PCT.	% REDUCTI
▼ 1	4768	0.995	21.5	34.5	2881	0.601	11.3	18.1	47
2	5197	1.085	24.2	38.8	4543	0.948	20.1	32.2	17
3	5284	1.103	24.7	39.6	4741	0.990	21.4	34.3 ▼	13
4	5159	1.077	23.9	38.3	5075	1.059	23.3	37.3	3
5	5141	1.073	23.8	38.1	4932	1.030	22.5	36.1	5
6	5345	1.116	25.2	40.4	5109	1.067	23.6	37.8	6
7	5299	1.106	24.8	39.7	5176	1.081	24	38.5	3
8	5223	1.090	24.3	38.9	5219	1.090	24.3	38.9	0
9	5107	1.066	23.5	37.7	4994	1.043	22.9	36.7	3
10	5209	1.087	24.2	38.8	4858	1.014	22	35.3	9
11									
12									
	(15" or so exposed)				(20" or so exposed)				

Ft from Ground Surf.	STANDARD COUNT 4790 N.W. PIPE 1-MINUT COUNTS	RATIO TO STD	MOIST. CONT.	MOIST. PCT.	5/21/90 N.E. PIPE 1-MINUT COUNTS	RATIO TO STD	MOIST. CONT.	MOIST. PCT.	% REDUCTI
▼ 1	5299	1.106	24.8	39.7	4573	0.955	20.3	32.5	18
2	5563	1.161	26.6	42.6	4807	1.004	21.7	34.8 ▼	18
3	5368	1.121	25.3	40.5	5125	1.070	23.7	38.0	6
4	5202	1.086	24.2	38.8	4951	1.034	22.6	36.2	7
5	4782	0.998	21.6	34.6	5150	1.075	23.8	38.1	-10
6	5228	1.091	24.4	39.1	5065	1.057	23.3	37.3	5
7	5095	1.064	23.5	37.7	4997	1.043	22.9	36.7	3
8	5194	1.084	24.2	38.8	5056	1.056	23.2	37.2	4
9	5045	1.053	23.2	37.2	5197	1.085	24.2	38.8	-4
10					4939	1.031	22.6	36.2	
11					5028	1.050	23.1	37.0	
12									

▼ Indicates approximate location of the top of the saturated zone based on these measurements.

CURTAIN DRAINS - ELECTRA LAKE

Ft from Ground Surf. — 9/26/90 — STANDARD COUNT 4812

Ft from Ground Surf.	S.W. PIPE 1-MINUT COUNTS	RATIO TO STD	MOIST. CONT.	MOIST. PCT.	S.E. PIPE 1-MINUT COUNTS	RATIO TO STD	MOIST. CONT.	MOIST. PCT.	
1	2435	0.506	9.2	14.7	3070	0.638	12.2	19.6	-33
▼2	4690	0.975	20.9	33.5	4054	0.842	17.2	27.6	18
3	5195	1.080	24	38.5	4648	0.966	20.6	33.0	14
4	5236	1.088	24.2	38.8	4948	1.028	22.4	35.9	7
5	5246	1.090	24.3	38.9	4869	1.012	21.9	35.1 ▼	10
6	5139	1.068	23.6	37.8	5076	1.055	23.2	37.2	2
7	5356	1.113	25	40.1	5071	1.054	23.2	37.2	7
8	5243	1.090	24.3	38.9	5181	1.077	23.9	38.3	2
9	5217	1.084	24.1	38.6	4993	1.038	22.7	36.4	6
10	5030	1.045	22.9	36.7	4929	1.024	22.3	35.7	3
11	5103	1.060	23.4	37.5					
12									
	(15" or so exposed)				(20" or so exposed)				

Ft from Ground Surf. — 9/26/90 — STANDARD COUNT: 4812

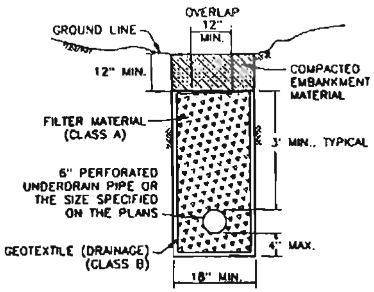
Ft from Ground Surf.	N.W. PIPE 1-MINUT COUNTS	RATIO TO STD	MOIST. CONT.	MOIST. PCT.	N.E. PIPE 1-MINUT COUNTS	RATIO TO STD	MOIST. CONT.	MOIST. PCT.	% REDUCTI
1	N				4085	0.849	17.4	27.9	
2	O				4608	0.958	20.4	32.7 ▼	ERR
3					5147	1.070	23.7	38.0	ERR
4	R				4823	1.002	21.7	34.8	ERR
5	E				5100	1.060	23.4	37.5	ERR
6	A				5082	1.056	23.3	37.3	ERR
7	D				5016	1.042	22.9	36.7	ERR
8	I				5031	1.045	23	36.9	ERR
9	N				5130	1.066	23.6	37.8	ERR
10	G				4957	1.030	22.5	36.1	ERR
11	S				5051	1.050	23.1	37.0	ERR
12									

▼ Indicates approximate location of the top of the saturated zone based on these measurements.

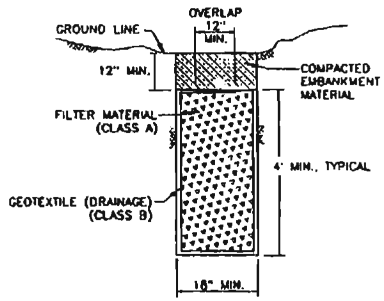
APPENDIX E

STANDARD PLANS (M-STANDARD) AND SPECIFICATIONS APPLICABLE AT THE TIME OF THE PUBLICATION OF THIS FINAL REPORT

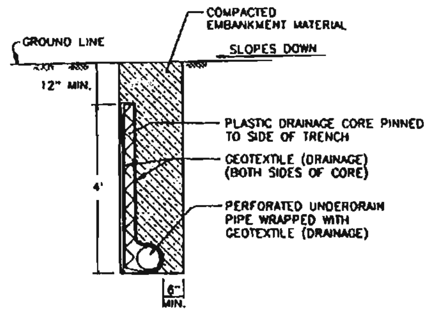
	REVISIONS	M-605-1



PIPE UNDERDRAIN



FRENCH DRAIN



GEOCOMPOSITE UNDERDRAIN

GENERAL NOTES

THE LOCATION AND GRADE OF SUBSURFACE DRAINS AND OUTLET PIPES WILL BE AS SHOWN ON THE PLANS OR AS DIRECTED.

OUTLETS FOR THE EDGE DRAINS ARE TO BE SPACED AT MAXIMUM 600 FT. INTERVALS OR AS SHOWN ON THE PLANS. GEOCOMPOSITE OUTLET CONNECTIONS SHALL BE IN ACCORDANCE WITH THE MANUFACTURER'S RECOMMENDATIONS.

WHERE THE UNDERDRAIN PIPE OUTLETS ONTO A SLOPE OR DITCH, THE OUTLET PIPE END SHALL BE MARKED WITH A DELINEATOR POST, AND HAVE AN ANIMAL GUARD AND AN EROSION CONTROL PAD.

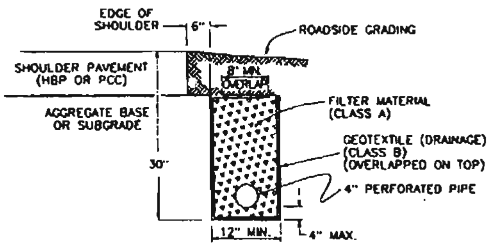
THE GEOCOMPOSITE SHALL BE SECURED TO THE WALL OR TO THE TRENCH SIDE TO PREVENT MOVEMENT DURING BACKFILLING.

DRAIN HOLES IN RETAINING WALL SHALL BE SPACED AT 10 FT. INTERVALS OR AS SHOWN ON THE PLANS.

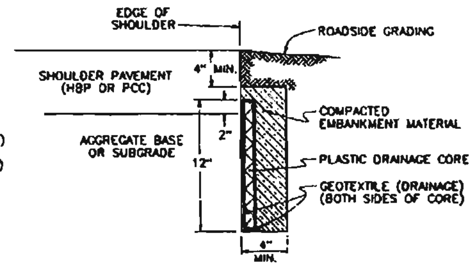
STRUCTURE EXCAVATION AND BACKFILL LIMITS FOR RETAINING WALLS ARE SHOWN ON ANOTHER STANDARD PLAN. ALL EXTRA EXCAVATION AND BACKFILL WORK NECESSARY TO COMPLETE RETAINING WALL, AGGREGATE, AND GEOCOMPOSITE DRAINS IS INCLUDED IN THE DRAIN WORK.

FILTER MATERIAL SHALL BE TAMPED WITH A LIGHT VIBRATORY TAMPER PRIOR TO OVERLAPPING THE GEOTEXTILE FABRIC.

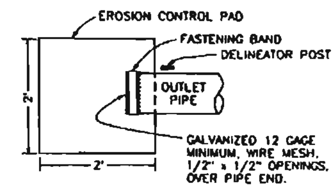
THE EDGE DRAIN TRENCH SHALL BE CONSTRUCTED AFTER PLACEMENT OF THE AGGREGATE BASE AND SUBBASE.



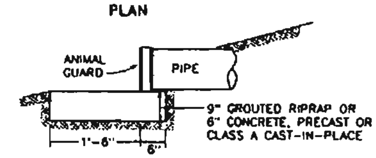
PIPE EDGE DRAIN



GEOCOMPOSITE EDGE DRAIN

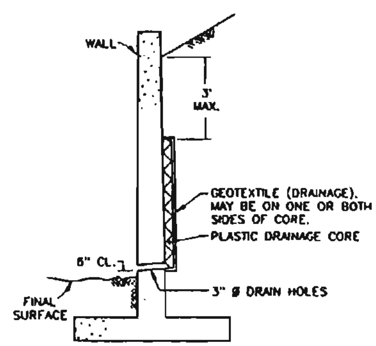


PLAN

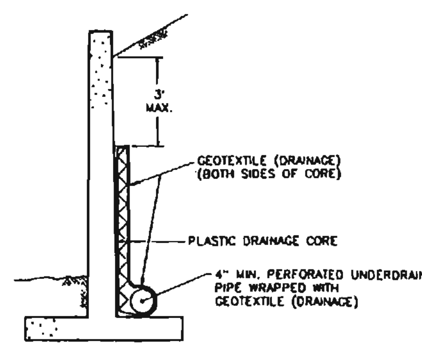


PROFILE

OUTLET PIPE END TREATMENT



GEOCOMPOSITE DRAIN WITHOUT PIPE



GEOCOMPOSITE DRAIN WITH PIPE

COLORADO
DEPARTMENT OF TRANSPORTATION

SUBSURFACE DRAINS

DATE REVISED	ISSUED BY STAFF DESIGN BRANCH	STANDARD PLAN NO. M-605-1
	DATE: NOV. 1, 1992	SHEET 1 OF 1

SECTION 605
SUBSURFACE DRAINS

DESCRIPTION

605.01 This work consists of constructing underdrains, edge drains, geocomposite drains, and french drains, in accordance with these specifications and in conformity with the lines and grades shown on the plans or established.

MATERIALS

605.02 Materials shall meet the requirements specified in the following subsections:

Corrugated Steel Pipe	707.04
Bituminous Coated Corrugated Steel Pipe	707.05
Drain Tile	706.04
Vitrified Clay Pipe	706.06
Corrugated Aluminum Pipe	707.07
Plastic Pipe	712.12
Gaskets	705.03
Filter Material	703.09
Geotextiles	712.08
Geocomposite Drains	712.13

Pipe for subsurface drains shall be any type of pipe material listed above. When corrosion resistant pipe is specified on the plans, the materials shall conform to the requirements of Section 624 for the corrosion resistance number specified.

Subsurface drain outlet pipe may be perforated or nonperforated, and shall meet the requirements specified in subsections 707.04, 707.05, 707.07, or 712.12.

CONSTRUCTION REQUIREMENTS

605.03 Pipe Underdrain and Pipe Edge Drain. The trench shall be excavated to the dimensions and grade shown on the plans. Sufficient Geotextile (Drainage) (Class B) shall be placed along the bottom and sides of the trench as shown on the plans to provide the required overlap over the top of the filter material. Filter material of the class designated on the plans shall be placed in the bottom of the trench for its full width and length.

Perforated pipe shall be placed with the perforations down and the pipe sections shall be joined securely with the appropriate coupling fittings or bands. Joining shall conform to the applicable requirements of subsection 603.07 except as noted above.

After the pipe installation has been inspected and approved, the designated filter material shall be placed to a height of 12 inches above the top of pipe. Care shall be taken not to displace the pipe or the covering at open joints. The remainder of the filter material shall then be placed to the required height; the drainage geotextile folded over the top of the filter material, and the remainder of the trench backfilled.

605.04 Geocomposite Drains. The geocomposite drain for subsurface drainage behind a retaining wall shall be placed along the full length of the wall. It shall be attached to the wall with an approved adhesive or in accordance with the manufacturer's recommendations.

The trench for geocomposite underdrain and geocomposite edge drain, for subsurface drainage at pavement edge and elsewhere as specified on the plans, shall be excavated to the dimensions and grade shown on the plans. The geocomposite drain material shall then be placed along the downhill side, or the pavement side, of the trench and secured to the trench side.

Backfill shall be placed so as to avoid damage to the geocomposite drain material.

605.05 French Drain. The trench for french drain shall be excavated to the width and depth shown on the plans. The trench shall be lined with Geotextile (Drainage) (Class B) and filled with the designated filter material to the depth shown on the plans. The drainage geotextile shall be folded over the top of the filter material. Any remaining unfilled upper portion of trench shall be backfilled with embankment material.

605.06 Subsurface Drain Outlet. The trench for subsurface drain outlet shall be excavated to the width and depth necessary to place the pipe on a drainable grade, as shown on the plans or as directed. Pipe shall be laid in the trench with all ends joined securely with the appropriate couplings, fittings or bands. After inspection and approval of the pipe installation, the trench shall be backfilled and compacted in accordance with subsection 206.03.

Where the outlet pipe ends on a slope or ditch, it shall be constructed with an erosion control pad, and an animal guard. The location shall be marked with a delineator post that conforms to Section 612. The animal guard screen shall be held securely in place with a coupling or fastening band or by another approved method.

METHOD OF MEASUREMENT

605.07 Pipe underdrain and pipe edge drain will be measured by the linear foot of pipe of the size specified placed and accepted. French drain will be measured by the linear foot of trench excavated and filled with filter material and accepted. Geocomposite underdrain and geocomposite edge drain will be measured by the linear foot along the base of the geocomposite drain material for the full length installed and accepted. Geocomposite drain both with and without pipe will be measured by the square yard of geocomposite drain material placed on the vertical wall surface and accepted. Subsurface drain outlet will be measured by the linear foot of pipe placed and accepted from the end of a subsurface drain to the discharge end of the outlet pipe.

BASIS OF PAYMENT

605.08 The accepted quantities of subsurface drains will be paid for at the contract unit price for each of the pay items listed below that appear in the bid schedule.

Payment will be made under:

Pay Item	Pay Unit
_"Perforated Pipe Underdrain	Linear Foot
French Drain	Linear Foot
Geocomposite Underdrain	Linear Foot
Geocomposite Drain without Pipe	Square Yard
Geocomposite Drain with Pipe	Square Yard
Geocomposite Edge Drain	Linear Foot
Pipe Edge Drain	Linear Foot
Subsurface Drain Outlet	Linear Foot

Payment shall be full compensation for all work and materials required to complete the item including drainage geotextile, drainage core, securing devices, adhesives, sewn seams, pipe, filter material, excavation, and backfill. Payment for subsurface drain outlet shall include the erosion control pad, the animal guard, and the delineator post.

3. 3″ x 3″ x 3/8″ structural steel angles conforming to ASTM A 36 or better.
4. Used rails, pipe or angles may be used provided the material is not rusted or damaged to such an extent that the strength of the stakes is affected.

Soil anchor stakes shall be of the lengths called for on the plans.

712.10 Anti-stripping Additives. All anti-stripping additives shall be heat stable, concentrated, refinery grade.

712.11 Epoxy. Epoxy used for bonding new, or wet concrete, to old concrete shall be an approved product and shall be of the type specifically intended for bonding wet concrete to existing concrete. Each container of epoxy shall conform to ASTM C 881.

712.12 Plastic Pipe for Underdrains. Polyethylene perforated or nonperforated corrugated pipe shall conform to AASHTO M 252.

Perforated or nonperforated Polyvinyl Chloride Pipe-Smooth Interior, Smooth or Ribbed Exterior, shall conform to ASTM F 758 or ASTM F 949.

712.13 Geocomposite Drains. Geocomposite drains, underdrains, and edge drains for subsurface drainage shall be constructed of a drainage geotextile and a semi-rigid drainage core. A drainage pipe collector may also be included in the drain system.

The drainage geotextile shall conform to the physical requirements of subsection 712.08, Table 712-3, for the Geotextile (Drainage) (Class B). The drainage pipe collector, when used, shall conform to the requirements designated in subsection 605.02 for the type of pipe used.

The semi-rigid drainage core shall be constructed of material that will not deteriorate in subsurface conditions, and shall conform to the physical requirements of Table 712-8.

TABLE 712-8

Physical Requirements for Drainage Core

Property	Value	Test Method
Compressive Strength, lb./sq. in.	20	ASTM D 1621
In-Plane Flow Capacity (Transmissivity) Gal./min./ft. (min.)	10	ASTM D 4716
Minimum Core Thickness, inch	0.5	

712.14 Plastic Pipe. Plastic pipe shall conform to the following requirements for the type of pipe used:

Ribbed Type: AASHTO Interim Specifications Bridges, Section 18, Soil Thermoplastic Pipe Interaction systems; material specifications are ASTM F 894 for polyethylene, and ASTM F 794 for poly (vinyl) chloride.

Corrugated Type: AASHTO M 294.

Smooth Type: ASTM F 679.

Couplings shall be as recommended by the pipe manufacturer.