GEOSYNTHETIC BASED UNDERGROUND STORMWATER DETENTION SYSTEM

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ABSTRACT

Stormwater management is a vital component on roadway construction and site development projects. Stormwater detention ponds are often utilized to protect neighborhoods against flooding and streams from environmental degradation. Detention systems are located underground where land is expensive or where there are other concerns such as safety or mosquitoes. Pipes, pipe arches and concrete vaults are typically installed in underground systems. Geosynthetic materials are utilized in a new underground stormwater detention system which offers advantages over traditional systems. Essentially, a geotextile or geomembrane liner system is installed within an excavation. Around the perimeter of the excavation, walls are constructed with geosynthetic reinforcement and open graded stone creating a large underground chamber. Inlet and outlet pipes extend through the perimeter liner system and wall face into the chamber. A reinforced concrete roof is installed above the open chamber and supported by the perimeter abutments/walls. Finally, the liner system is installed over the stone surface before the cover soil brings the site to grade. A large open chamber is constructed with reinforced stone having a high porosity that contributes to the storage capacity. This geosynthetic based underground detention system (GDS) has among other attributes the advantage of low cost, well established AASHTO design standards, small footprint and ease of inspection and maintenance.

INTRODUCTION

Detention systems release stormwater through an outlet at a controlled rate. Retention, or recharge, systems percolate the stormwater into the water table. Flood control is the primary design objective for both systems while stream bank erosion protection is an additional consideration. The standard of practice is to insure that the post-development flow from a site does not exceed the pre-development flow for a given storm event. From a practical standpoint, many urban and suburban neighborhoods were developed along water bodies and expanded outward. The streams, creeks and gullies that pass through these neighborhoods see greater flows as development expands upstream. The most fundamental role of stormwater management is to protect these vulnerable communities from flooding.

Another key concern is the quality of the stormwater flowing into receiving water bodies. The Environmental Protection Agency (EPA) has enacted the National Pollution Discharge Elimination Stormwater (NPDES) Program to regulate the discharge of stormwater. Many states are in the process of enacting legislation to protect local waterways from stormwater pollution. At a minimum these regulations will limit the turbidity of stormwater discharge on construction sites to 280 NTU's by 2014 (2011 for sites greater than 20 acres).

TRADITIONAL UNDERGROUND DETENTION SYSTEMS

Concrete vaults have a long history in stormwater detention. These modified box culverts are simple, structurally sound and easy to inspect and maintain. They can be precast or formed and poured on site. Concrete vaults are the most expensive underground stormwater detention system.

High density polyethylene (HDPE) pipes dominate the small diameter pipe market but are not manufactured above 60 inch (152.4 cm) diameters.

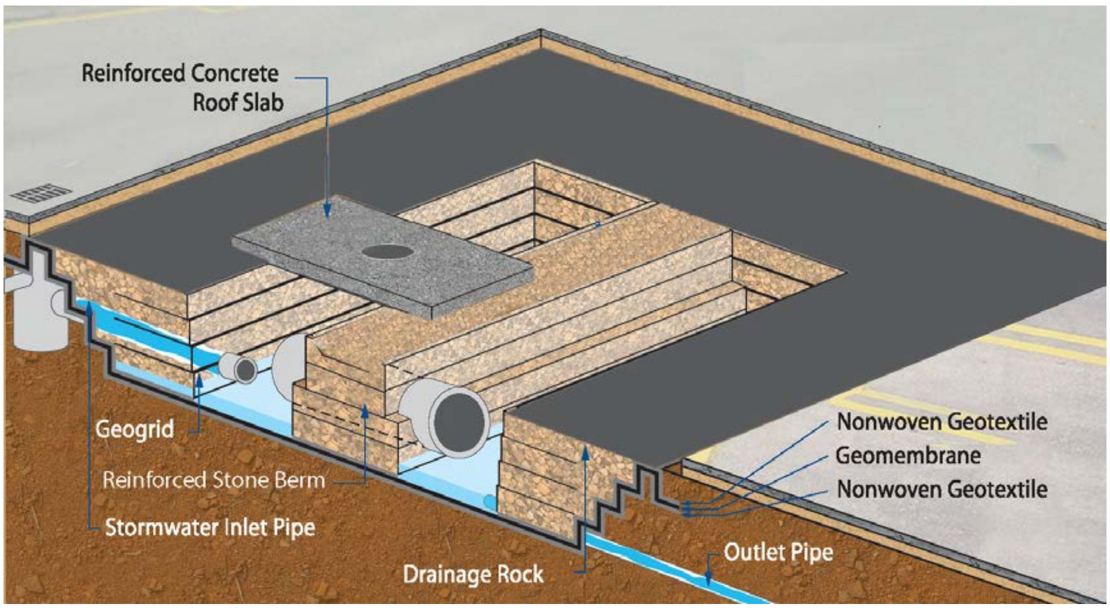
Corrugated steel pipe (CSP) is manufactured up to 144 inch (365.8 cm) diameters. Pipe volumes increase exponentially with diameter so it is economical to design with large diameter pipes giving some consideration to permitting issues for oversized freight.

CSP and HDPE pipes are flexible pipes that transfer stresses to the surrounding soil. Design standards are based on structural backfill properties and compaction efforts. As a result, State Department of Transportation (DOT) specifications set specific gradation and compaction requirements for flexible pipes. In most instances imported structural backfill is required which increases overall project costs.

Half round plastic pipe arches are fairly new to the stormwater detention market. By eliminating the need to backfill below the haunches of round pipe these pipe arches can be more tightly spaced. Also, the open bottom eliminates the flow restrictions and accelerated degradation associated with perforations in round pipes on retention applications. These pipe arch systems are designed with an open graded stone backfill. The 40% stone porosity increases the system's storage capacity and makes plastic pipe arches cost effective at low profiles.

GEOSYNTHETIC BASED UNDERGROUND STORMWATER DETENTION/RETENTION SYSTEM (GDS)

In traditional detention systems the storage chamber is a manufactured product designed to withstand sidewall and overburden pressures. The nature of the GDS system is to create a storage chamber with stabilized stone sidewalls capable of supporting a roof. Given the application, water forces are an important design consideration. If water drains from the chamber faster than it drains from the backfill, the perimeter walls will experience a rapid draw down condition. The use of angular, open graded, ¾ - 1 ½ inch (19-38 mm), washed stone eliminates pore pressures and has the added benefit of increasing storage capacity with a 40% void ratio. It is the combination of the large chamber and the porosity of the stone utilized to construct the chamber that makes a GDS system cost effective.



Geosynthetic based underground detention system (GDS).

DESIGN STANDARDS

Innovation in the civil engineering market, particularly the transportation segment, can be challenging. The scrutiny applied to new technologies reflects the replacement costs and safety issues that might result from a failure. While still innovative, the GDS system is comprised of components with well established design and performance histories.

LINER SYSTEM

The GDS starts with a liner system, critical to keep the surrounding native soil from piping into the perimeter stone. In detention applications, a geomembrane is installed with appropriate geotextile layers for protection against the angular stone. In retention applications, a geotextile is installed to allow for percolation. In the past, detention systems were the standard of practice. In recent years many stomwater practitioners have focused on maintaining the pre-development water balance by recharging the water table. However, the percolation rate of the native soil and in certain regions the presence of karst limits the use of recharge systems. More importantly, long term clogging issues present the biggest challenge to underground stormwater recharge systems.

GDS liner system

PERIMETER WALLS

The perimeter walls are designed as mechanically stabilized earth (MSE) structures based on the design procedures outlined in AASHTO (1999a). In order to maintain optimum flow a wrap facing is utilized at the wall face. While MSE structures have been used for years along river channels and more recently to stabilize the walls around surface detention ponds, it was considered prudent not to underestimate water forces. Geogrid reinforcement was selected to positively confine the stone aggregate and optimize flow. Another early design decision proved to be fortuitous. The geogrids were spaced at 9 inch (22.8 mm) lifts to further confine the stone and to insure compaction in each lift.

GDS perimeter walls

GEOSYNTHETIC-REINFORCED SOIL TECHNOLOGY

The number of bridges in the United States requiring repair or replacement is daunting. The Federal Highway Administration (FHWA) has developed the Bridge of the Future Program to address this issue. One of the program's initiatives is the Geosynthetic-reinforced soil (GRS) integrated bridge system (1). The goal of this bridge system is to simplify the design and reduce the cost of simple single span bridges 70-90 feet (21-27m) long. GRS design methodology is based on the performance of several full-scale experiments and production abutments as well as an increasing list of real world applications. This methodology is distinctly different from well established MSE design standards. The differences can most readily be seen in the reinforcement material's properties and spacing. GRS structures are characterized by tightly spaced geosynthetic layers with much less consideration paid to the long term strength of the reinforcement. By definition the 9 inch (22.8 mm) spacing selected for the GDS walls allows them to be classified as GRS structures which also meet MSE design standards.

While the GRS classification helps quantify an extra degree of conservatism in the design, the big benefit is much more practical. Close inspection of the FHWA GRS integrated bridge cross section reveals that the bridge superstructure rests directly on the GRS abutment wall. The GRS bridge abutment design does not include a bearing pad.

BEARING SILLS

The original GDS system design had a concrete bearing curb. However, it was apparent that the self weight of the roof and the overburden soils locked the deck in place. The bearing curb, while a standard feature to structural engineers, might be considered extraneous to geotechnical engineers.

GRS bridge abutment test results demonstrated that the concrete bearing curb was not necessary. Bearing sills on the GRS structures were loaded to 13 Tons/SF (1,244 kPa), the maximum load of the equipment, without failure. Small cracks were observed in the concrete wall facing at 4 Tons/SF (382.8 kPa) which sets a serviceability limit for design purposes (2). The field performance of the bridge abutments supports the test data.

Another beneficial feature of the GRS bridge design was the pavement performance at the interface of the roadway and the bridge abutment. The typical “bump” at the approach interface is almost undetectable with equally impressive performance in the areas of cracking and settlement.

Recognizing that relative lengths of bridge spans are very long and that the decks are at grade, the placement of the roof deck directly on the perimeter walls of a GDS underground stormwater system is a natural application for the GRS technology.

The typical sill area for the concrete deck atop the detention system perimeter walls is limited to 2 Tons/SF. Immediately below the bearing sill the stone size is reduced and additional reinforcement layers are included. A geotextile wrap is added to the wall face in this area to prevent raveling of the smaller stones. Upon placement of the concrete roof and cover soil it has been observed that there is no movement whatsoever in the area of the bearing sill.

GDS bearing sill

ROOF DECK

The roof deck for the GDS system is designed to AASHTO bridge standards (Section 3.24.12, “Distribution of loads and design of concrete slabs”). The roof deck can be installed flush with the surface but this requires the roof to match a sloping surface precisely. Pipe plumbing and aesthetic issues generally favor burying the roof. The roof deck can be cast in place but precast panels simplify and speed construction. The precast panels are sized to optimize freight and enable an excavator to pick and place the slabs on site. The elevation of the roof deck is typically set such that the minimum clearance allows for a road base and asphalt overlay. The bottom elevation of the deck must also be checked to make sure it does not rise above the lowest upstream manhole cover/grate. Manhole access is provided in the roof deck to enable inspection and maintenance of the chamber.

GDS roof deck installation

System Features

The storage volume of the chamber combined with the porosity of the stone utilized to construct the chamber allow for a much smaller GDS footprint than pipes or pipe arches.

Much like pipes, GDS systems become more efficient with depth. As mentioned earlier, pipe volumes increase exponentially with diameter while costs rise at a linear rate making large diameter pipes more efficient. Given that the roof is the most expensive component of the GDS system, unit costs also decrease with depth.

A single chamber GDS system can be extended to store any stormwater volume. However, site constraints might limit the length of a GDS system. In these instances interior piers, or two sided walls, may be constructed within the chamber to increase the chamber width.

DETENTION APPLICATIONS

In detention applications the most cost effective solution involves locating the roof of the detention system as high as the surface grades and upstream manholes permit while lowering the floor as low as the outfall elevation will allow. An overflow device is needed to protect against upstream flooding on storms that exceed the maximum design storm event. Typically overflow is provided in a manhole immediately downstream of the detention system. Within the manhole, a weir is installed between the inlet and outlet pipes with a top elevation set at the high water elevation in the detention system. Orifices within the weir are sized and located to insure that smaller design storm event outflows do not exceed preconstruction rates.

RETENTION APPLICATIONS

Retention applications allow for deep systems with consideration for soil permeability and the elevation of the water table. Retention systems require an overflow device similar to the detention system weir described above. However, the major concern in recharge/retention systems is clogging of the geotextile floor.

Traditional leach pads are comprised of a stone layer above a geotextile filter. This cross section creates a “gap graded” condition. In addition, stormwater flow carries a sediment load, much of it suspended, on a regular basis into the leach pad. Lastly, the planar geotextile concentrates sediment on a “sheet”. Each one of these issues is a red flag for clogging. While Best Management Practices (BMP’s) upstream of the leach pad can limit the sediment load and the percentage of suspended solids, the accumulation of a critical clogging load is a function of time. In these circumstances, engineers need to consider two factors; risk and accessibility. The overflow weir protects the upstream development from flooding. However, the geotextile is inaccessible. The repair cost for clogging is the replacement cost for the entire system. The movement from detention systems to recharge/retention systems will largely depend on the ability to address the issue of clogging.

ECONOMICS

Site conditions, local regulations and regional commodity prices influence the relative cost of all detention systems. However, some generalizations regarding the cost effectiveness of the GDS system can be made. The concrete roof and stone comprise the major material cost items. Given the stone porosity’s contribution to storage capacity, the concrete roof cost becomes even more significant. At depths of 6-8 feet (1.83-2.44 m) GDS material costs are roughly 60 percent of pipe and pipe arch systems, before accounting for excavation and installation costs. As the available profile on a project increases the relative cost advantage of the GDS system improves.

On tight sites, on sites where off site hauling is required, on sites where rock is present or where stormwater treatment is required, GDS systems can offer additional savings.

GDS system installed and partially covered.

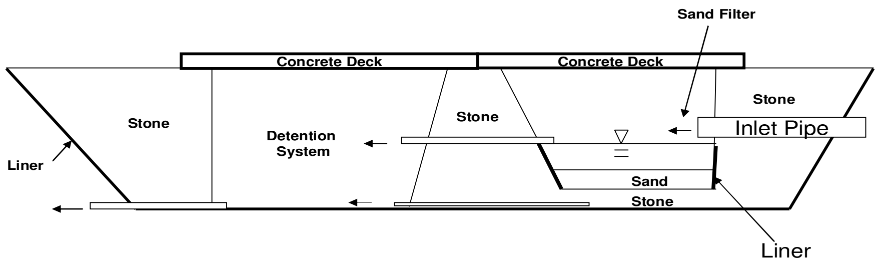
INSPECTION AND MAINTENANCE

Detention systems collect sediment. Backhoes can remove sediment from above ground ponds. With the exception of concrete vaults and large diameter pipes, most underground detention systems are inaccessible. Maintenance involves backwashing and localized removal from outside the system. The large open GDS chamber allows for easy inspection and maintenance. In retention applications, it is the only system that enables the inspection and, where needed, replacement of a clogged geotextile. As the stormwater quality regulations evolve the ability to inspect and maintain detention systems will increase in importance.

STORMWATER QUALITY

Sand filters are a time proven pollutant remover. However, in underground applications the cost of the concrete vault required to house the sand filter is expensive. As a result, many new technologies are entering the marketplace to meet regulatory pollutant removal requirements. These technologies include vortex chambers and filter cartridge systems housed in smaller concrete vaults.

The GDS system enables the construction of a traditional sand filter by lining the chamber walls. Interior piers may be constructed within the chamber to provide the required sand surface area. The performance of the system mimics that of a concrete vault sand filter but at a much lower cost.



GDS stormwater treatment and detention system.

GREEN SOLUTION

Stormwater volumes are typically stored in a product, like pipe, manufactured in a plant and shipped to a jobsite. This traditional solution entails shipping the entire storage volume on a series of trucks. Flexible pipe, the most common detention system, also requires a structural backfill imported from the local quarry. The GDS storage chamber is constructed on site with geosynthetics which can easily fit on a single truck. The porosity and weight of the stone used to form the chamber results in far fewer truck loops from the local quarry. The precast roof panels can be manufactured locally and will require a fraction of the trucks needed to ship pipe. Combined with a reduced excavation these advantages make GDS a "green" solution where underground stormwater detention is required.

CONCLUSION

GDS systems offer a cost effective alternative to traditional underground stormwater detention and retention systems. A smaller footprint will provide engineers with more design flexibility. As stormwater quality regulations are enacted those responsible for compliance will appreciate the accessibility of the large open GDS chamber. No other retention system enables the inspection and replacement of clogged geotextiles. Lastly, the chamber enables the construction of an efficient underground sand filter where regulations require stromwater treatment.

The liner, reinforced walls and concrete deck comprising GDS systems are designed to AASHTO standards. While the system is novel the components have been thoroughly vetted by the engineering community.

The nation's infrastructure needs are great and stormwater management requires a growing percentage of construction budgets. GDS systems offer engineers an innovative tool to accomplish more with less.

ACKNOWLEDGEMENTS:

FHWA Bridge of the Future Program, Geosynthetic-reinforced soil (GRS) integrated bridge system.

REFERENCES:

(1) Adams. M., The GRS bridges of Defiance County. *Geosynthetics*, Vol. 26, No. 2, 2008, pp. 14-21.
(2) Adams. M., Schlatter. W., Stabile. T., Geosynthetic Reinforced Soil Integrated Bridge System, *EuroGeo4*, 4th European Geosynthetics Conference, Edinburgh UK, September 2008, Paper Number 271.
(3) Crum, Douglas A. Geotextiles in dams: Forging federal guidelines, *Geosynthetics*, August, 2008.

NOTE:

GeoStorage Corp. owns a patent (US #7,473,055 B2) related to the Geosynthetic Based Underground Stormwater Detention Systems discussed in this paper. Terence G Sheridan is the inventor listed on the patent.