

DRAINAGE RECOMMENDATIONS FOR MSE WALLS CONSTRUCTED WITH MARGINAL FILLS

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ABSTRACT

Soils specified for use as infill in MSE structures by current national MSE wall design documents are often not available or not economically feasible for use. Soils which do not comply with the national guidance documents are often chosen for use in wall construction. Choosing non-compliant soils for fill requires special considerations relative to drainage issues. Soil-moisture related conditions which present cause for concern are highlighted along with details demonstrating mitigation methods. Additional considerations relative to structure performance, QA/QC, contractual and design related matters are raised.

INTRODUCTION

Granular soils are typically the preferred material for use in SRWs due to their high strength, ease of compaction, ability to dissipate excess pore water pressures and their inherent resistance to soil creep. The characteristics of the soils “suggested” by the NCMA (National Concrete Masonry Association, 1997) and/or “mandated” by the Federal Highway Administration (FHWA) (Federal Highway Administration, 1997, AASHTO, 2000) for use in MSE walls are well known and generally consist of granular soils. For the purposes of this discussion, the soils which comply with either the NCMA or the FHWA and AASHTO criteria will be referred to as “compliant” soils.

When “compliant” soils are not available or not economically and readily available, relaxing of the fill specification to allow finer grained, silty, clayey and poorly draining, fills often occurs. These non-compliant soils have been deemed “marginal” soils.

Marginal soils which extend beyond the NCMA and the FHWA/AASHTO criteria and discussed herein are those soils which are non compliant because they possess up to greater than 35 percent fines and/or exhibit plasticity indices greater than 20. The soils considered herein are not expansive or likely to exhibit soil creep under the loading conditions created in the reinforced soil structure.

Many SRW's have been successfully constructed with marginal soils. However, several walls that have been constructed with marginal soils have experienced distress. While the reasons for distress are many, frequent factors contributing to distress include generation of pore pressure, development of seepage related problems, and inadequate treatment of drainage related issues.

The purpose of this paper is to review the currently prescribed soil characteristics for use with MSE walls, establish soil conditions which may be of concern when using marginal soils for MSE wall infill, and offer some drainage related details for consideration in dealing with marginal soils in MSE wall structures.

BACKGROUND

North American design procedures adopted for MSE wall designs include those proposed by both the National Concrete Masonry Association (NCMA) and the American Association of State Highway and Transportation Officials (AASHTO, 2000) via the Federal Highway Administration Demonstration 82 Project (FHWA, 1997). None of the organizations mandated the use of “free draining soils” for use in wall construction. However, both organizations limit the characteristics of the infill soils to those that are granular in nature and somewhat permeable. The soils of the “reinforced” portion of MSE structures “suggested” for use by the NCMA and “mandated” for use by AASHTO/FHWA are provided in Table 1.

Table 1 – Soil characteristics for use within “reinforced” portion of MSE walls as prescribed by national design standards

Characteristic	AASHTO/FHWA (mandated)	NCMA (suggested)	Marginal Soils
Percent Passing 4 inch Sieve	100	100-75	--
Percent Passing No. 4 Sieve	-	100-20	--
Percent Passing No. 40 Sieve	0-60	0-60	--
Percent Passing No. 200 Sieve	0-15	0-35	>35
Plasticity Index	6	20	>20

At the time of development of the NCMA and AASHTO/FHWA documents, the authors of the documents had the benefit of only a “limited” number of instrumented segmental walls. Hence, the soil characteristics chosen for use with the AASHTO/FHWA design procedure were based on a combination of the “then existing” MSE soil criteria (AASHTO/FHWA) and performance consideration of instrumented structures. The criteria set by NCMA for “suitable” soils included consideration of essentially the same data considered by AASHTO/FHWA but with significantly greater influence of observation and performance of a wide variety of structures constructed with soils outside the realm of those required by AASHTO/FHWA. Additionally, the authors of the NCMA document were somewhat influenced by the commercial impact that would result from severely restricting the soils acceptable for incorporation in the reinforced soil volume. Both criteria have cost implications.

The NCMA “suggested” criteria permit for a much higher percentage of fines and are of generally lower quality than the AASHTO/FHWA “mandated” criteria. AASHTO/FHWA soils typically have to be manufactured and are generally very expensive because of their gradation requirements while soils meeting the NCMA criteria are typically more abundant and thus more economical. In a never ending pursuit of enhancing the economics of MSE walls, a demand

exists for the use of “marginal” soils within the reinforced zone of wall structures which extends beyond the characteristics accepted by AASHTO/FHWA or NCMA.

CONDITIONS FOR CONCERN

Adverse conditions where pore water pressure generation and/or loss of strength due to wetting are of concern in geosynthetically reinforced marginal fills have been well documented by Christopher et. al. (1998) and Zornberg (1994). The general conditions which raise cause for concern include the following:

1. Generation of pore water pressures from within the reinforced fill
2. Wetting front advancing into the reinforced fill
3. Seepage configuration established within the reinforced fill

Generation of pore water pressures within the reinforced fill - When compacted wet of optimum and subsequently loaded, fine-grained, poorly drained soils can develop excess pore pressures. If not accounted for in design, these pressures can lead to stability and consolidation induced settlements, especially if the reinforced soil mass is subjected to post construction loading or surcharges.

Incorporation of horizontal and vertical linear or planer drainage inclusions can be implemented as a means of mitigating the potential development of excess pore water pressures. The design and detailing of these inclusions is beyond the scope of this paper. However, general design concepts include horizontal layering of permeable inclusions to promote drainage and minimize excess pore pressures. Heavy-weight non-woven fabrics, geonets, and specialty geogrid systems which incorporate a linear drainage structure may be appropriate products for use in dissipating pore pressures and enhancing the internal drainage of marginal fills.

Zornberg et. al. (1995) have incorporated both conventional heavy weight non-woven geotextiles and drainage/reinforcement composites to reinforce and drain marginal fills on a US Highway project. The geosynthetics consisted of both conventional heavy weight non-woven fabrics as well as polypropylene non-woven carrier fabrics reinforced with a biaxial network of high modulus polyester yarns. Geosynthetics used in the design of such systems must be selected to maximize both the high modulus reinforcement as well as the in-plane hydraulic transmissivity characteristics of the products. Figure 1 provides a typical detail of a system designed to dissipate pore pressure build up within the reinforced soil mass. Additional details of such products and their applications are readily available in the literature.

Wetting front advancing into the reinforced fill – Loss of soil shear strength may occur due to a post construction wetting front, particularly on soils compacted dry of optimum. Shear strength losses can adversely affect the structures stability and result in unanticipated hydrostatic pressures developing at the back of the reinforced soil mass.

While the advancing front is normally thought to advance horizontally, vertical infiltration of precipitation, irrigation or other surface sources must also be considered. Typical methods of dealing with surficial infiltration include sloping and capping the reinforced soil mass with a layer of “impermeable” soils, collecting, redirecting and discharge of surface runoff

via drainage swales, ditches, curbs and gutters, and grading of surface soils to direct sheet flow away from the wall structure (Figure 2).

Incorporation of an aggregate drainage blanket (or prefabricated drainage composite, PDC) at the back-cut are often employed where seepage is anticipated from the retained soils (Figure 3). Incorporation of a collector pipe and frequent discharge lines must be included (Figure 4). If prefabricated drainage composites are incorporated as part of the drainage design, an evaluation of the reinforced soil/prefabricated drainage composite/retained soil interface and overall structure stability is necessary. For this reason, a system of chimney drains (discrete “vertical” drainage panels separated by non-drained spaces) and collector panels/drain lines are often chosen over coverage of the entire back-cut with PDC panels.

While it is difficult for the designer to know how the interface between the reinforced fill/retained fill will be developed during construction, caution is advised in arbitrarily recommending PDC’s be used at the back-cut in the case of a false fill at the interface. An alternative solution should be provided which may incorporate a combination of benching, drainage composites, drainage pipe and drainage aggregate (Figure 5).

Seepage configuration established within the reinforced fill – Seepage flows resulting in destabilizing forces can develop in the reinforced soil volume via drainage from the backfill soil mass (both seasonal as well as altered drainage conditions) as in the case of hillside sliver fills, rapid drawdown and tide pool elevation changes in structures subjected to flooding or normal inundation cycles, and infiltration of surficial moisture ponded or otherwise collected above or behind the reinforced soil mass.

Collection and discharge of moisture from within the reinforced soil mass is typically accommodated via an aggregate drainage layer near and/or within the wall face (Figure 3 and top portion of wall in Figure 6), blanket drains at the base of the wall (Figure 3), and/or drainage galleries within the reinforced soil mass; especially where rapid drawdown or inundation are anticipated (Figure 6). It should be noted however, that reliance on the drainage medium at the wall face to collect and drain moisture from the reinforced soil mass may be ill-founded since the low permeability of marginal fills will limit the amount of moisture transmitted to the frontal drainage system. Efforts to prevent moisture from entering the reinforced soil mass are considered to be more productive than collecting it after it has been introduced. Surface drainage and diverting structures along with collection systems near the back-cut are considered to provide greater benefit than drainage systems at the wall face.

UNIQUE CONSIDERATIONS

There are many situations which require collected moisture through the reinforced soil mass. Coverage of all of the potential cases is beyond the scope of this paper. However, a few unique cases area provided herein as a means of providing “seed” for future design.

Discharge of Collected Moisture Thru Wall Face – Discharge of collected moisture thru the retaining wall face is commonly conducted. In low flow, relatively small diameter pipe applications, it is important to fit the segmental units around the pipe so as to not allow voids to

exist where backfill or drainage aggregate may be lost through the openings (Figure 7). On larger diameter, high flow applications, utilization of a concrete pipe collar and bond break help to ensure that minor relative movements between the wall and conduit do not adversely affect the integrity of the structural system (Figure 8). In both cases, appropriate erosion control devices must be installed near the outfall in order to prevent surficial erosion, back-cutting and potential undermining of the wall foundation.

Drop Inlets – Installation of drop inlets or other similar devices which carry water and will penetrate the geosynthetic reinforcement should be kept as far from the wall face as practically possible or relocated to an area beyond the extent of the geosynthetic reinforcement. If these systems must be placed within the reinforced soil mass they should be installed in concert with the wall infilling process in order to ensure that future disturbances of the reinforcement is not necessitated. It is important to ensure that soil stresses and reinforcement loads are transferred from the geogrid, through the drop inlet structure and to the wall face. One connection/load transfer method is provided in Figure 9. Utilization of flexible fittings and conduit systems that have the potential for tolerating moderate deformations is encouraged. Implementation of flexible drainage systems will aid in the prevention of seepage from the drainage system and subsequent saturation of the infill soils during flood events should unanticipated minor strains occur in the wall system.

QA/QC FOR POORLY DRAINING FILLS

As with conforming fills, a proper QA/QC program is essential for walls constructed with poorly draining fills. However, because of the higher moisture sensitivity and greater criticality of compaction in marginal fills, closer scrutiny is warranted during the QA/QC process. Specific items that should be addressed include moisture control, selection of compaction equipment and control of surface runoff during construction.

For reasons stated earlier, moisture control during the soil placement process should be maintained at relatively tight tolerances - typically plus or minus 1% of optimum. Compaction of marginal soils significantly wet or dry of optimum can result in adverse latent problems.

Compaction equipment selection should be chosen based on the soil type being compacted. It is unlikely that rubber tired equipment, plate compactors, or large vibratory equipment will perform well in these soils. Utilization of sheeps foot or similar kneading type compaction equipment should be employed.

Site management of surface water flow will be especially important in preventing saturation of recently placed fills. Grading of the area surrounding the wall to ensure that water is routed away from the reinforced soil mass should be conducted at the end of every day.

DESIGN AND CONTRACTUAL ISSUES

Employing marginal fills in the construction of SRW systems can have a significant impact on wall costs and performance. However, employing marginal fills in wall construction is also somewhat unique and without well accepted standards to guide the design and

construction professionals. Employment of the wall design professional by the owner (rather than the contractor) will ensure that the owners' interests are properly represented. Because of the sensitivities of using marginal soils, the owners' representative (the engineer) should be continuously reviewing the soil quality and characteristics for compliance with the considerations incorporated in the design. There should be no room left for wall construction with soils outside the range of those considered in the design.

Incorporation of the wall design professional in the early project development phases will aid in ensuring that the unique considerations of the site are evaluated, understood, and considered. Selective grading to ensure that the most economical soil sources are secured for wall construction as well as grading and drainage issues as discussed above can be incorporated during the design phase. Having the engineer on board early in the design phase can minimize last minute, costly surprises and changes.

PAST PERFORMANCE

Performance of MSE structures constructed with marginal fills has been documented in the published literature by Mitchell et. al. (1995), and others. However, most of the instrumented structures constructed with marginal fills reported on in the published literature have been constructed as part of a research project and were conducted in a laboratory setting or under highly controlled conditions. Only a few commercial structures constructed with marginal fills have been instrumented and monitored for performance. One such example has been provided by Sandri (2000). In the Sandri (2000) case history, the maximum structure height was 14.9 m, it was a constructed as part of a mass grading project and the monitoring captured the effects limited seismic activity. Its performance has been deemed excellent.

It is difficult to determine how many "successful" structures truly exist that have incorporated "marginal" soils since "failures" are difficult to define and seldom selected as a topic about which to brag. However, it is the opinion of the author that the general retaining wall industry has experience a high rate of success in attaining exceptional performance where marginal soils have been used in MSE wall construction. Universal concerns where marginal soils are incorporated include potential for greater structure post-construction total strains, potential for greater compaction related problems, and potential for increased exposure to liability should a problem with the structure arise. Minimizing the impact of all of the above can be achieved by recognizing the above concerns and employing marginal soils where their adverse potential impacts will be minimal.

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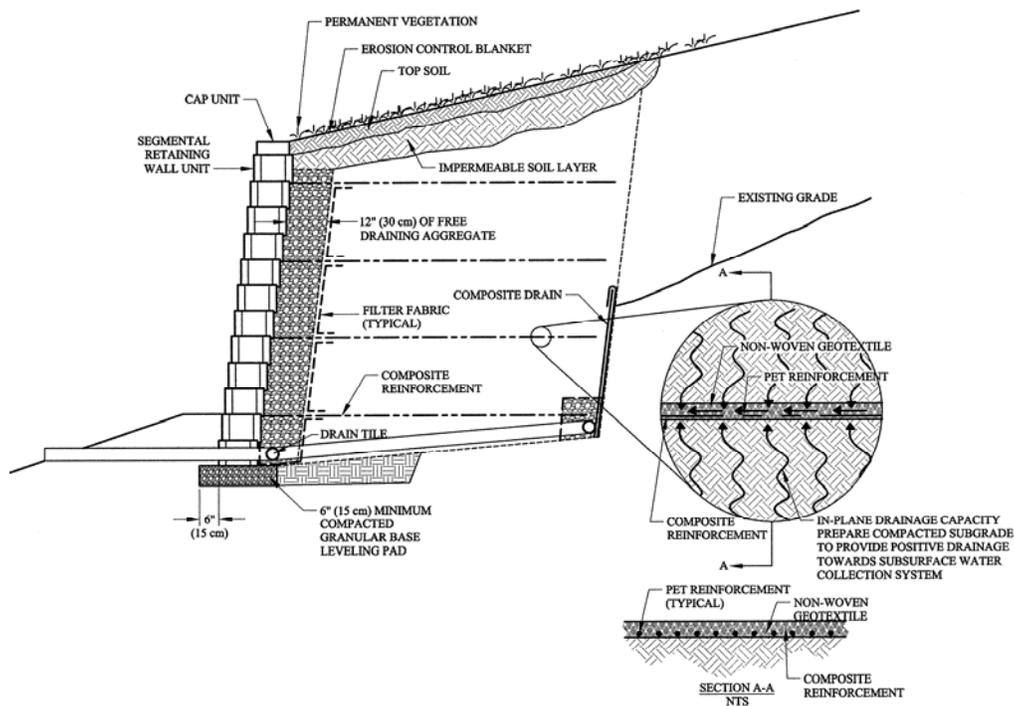


Figure 1 – Internal drainage provided by specialty geo-drainage reinforcements

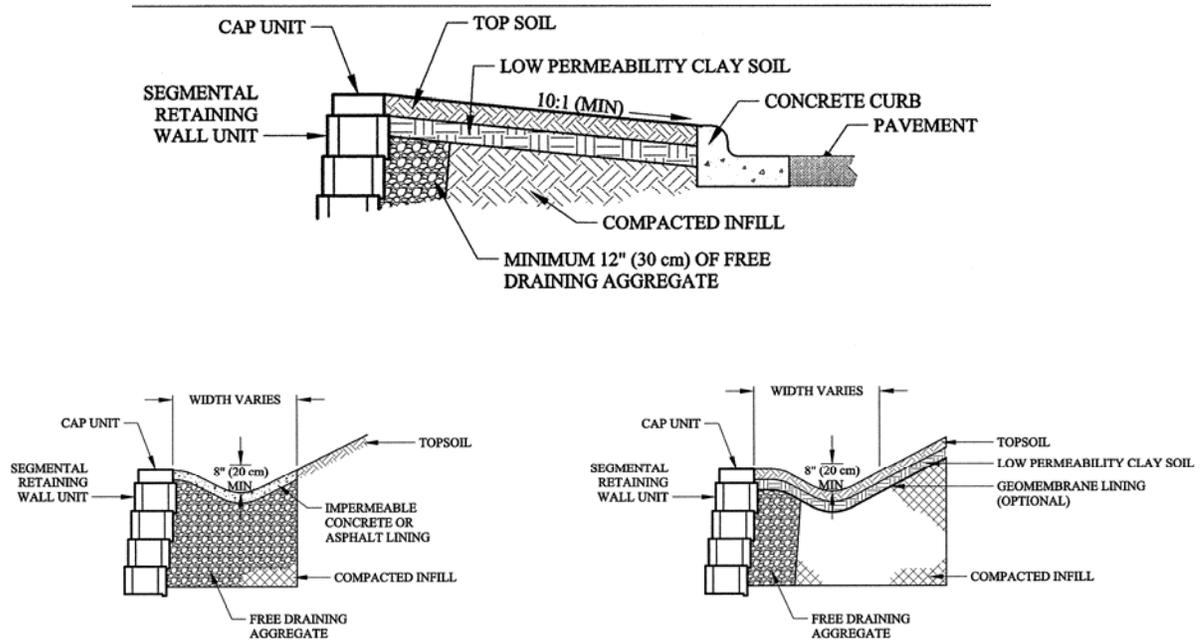


Figure 2 – Prevention of surface infiltration via the use of grading, drainage swales, curbs, gutters, and impermeable surface coverings

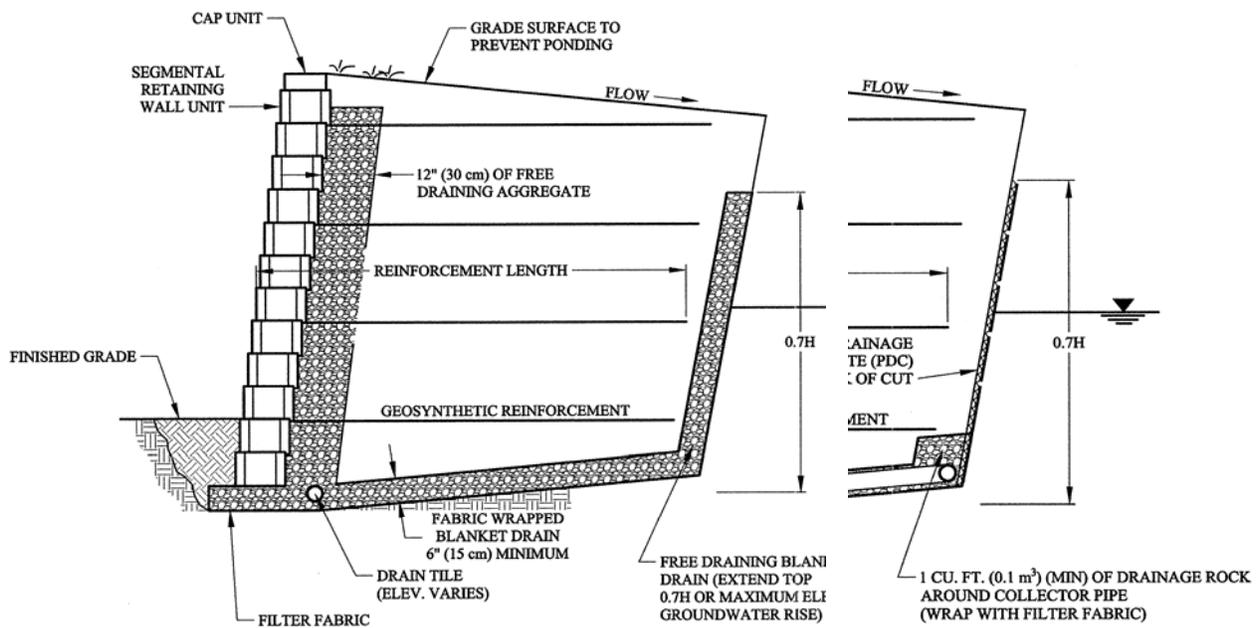


Figure 3 – Collection of ground water behind wall using aggregate drainage blankets or prefabricated composite chimney drains

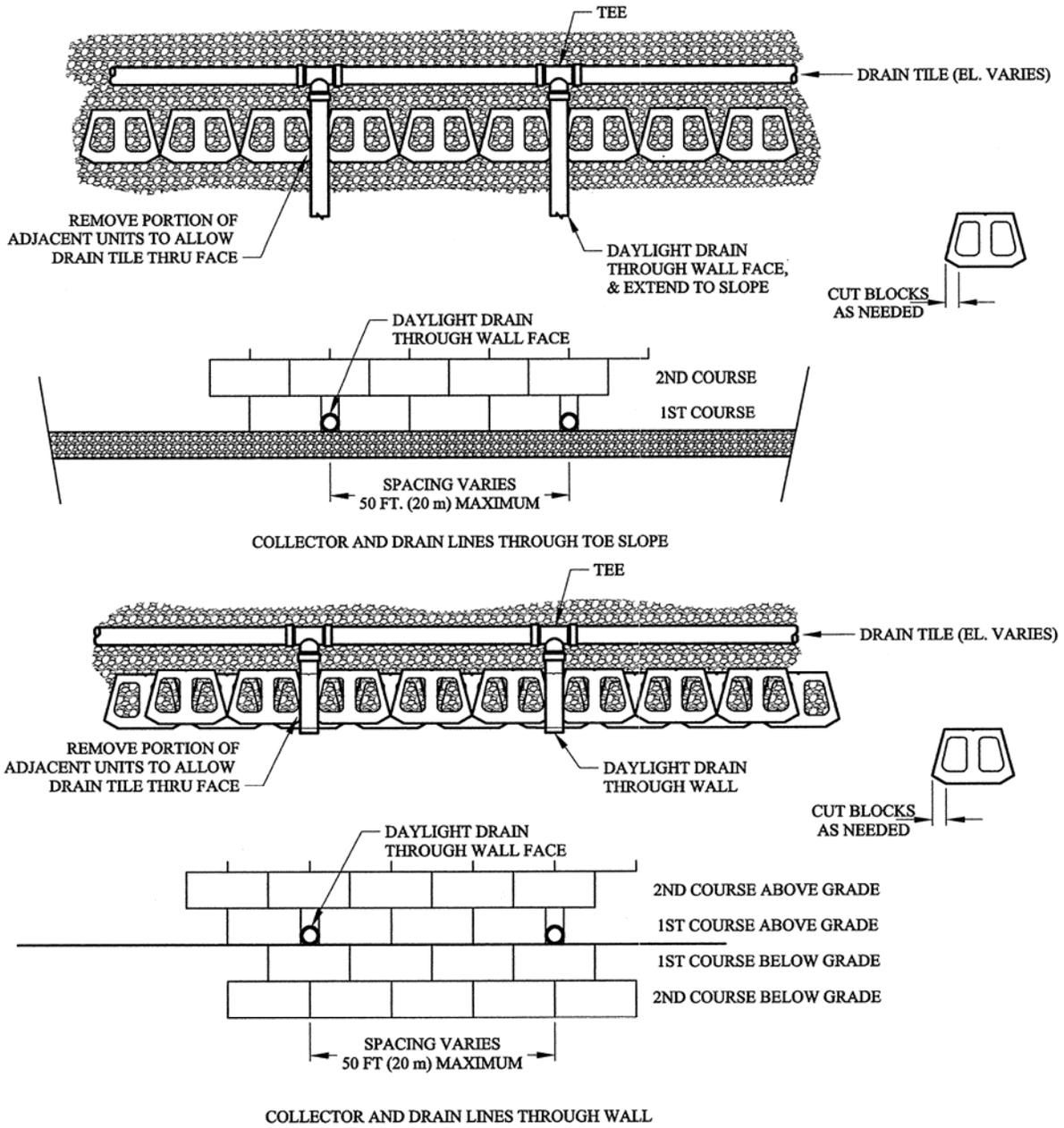


Figure 4 – Drainage of collected moisture from the face of the wall or at the toe of the wall

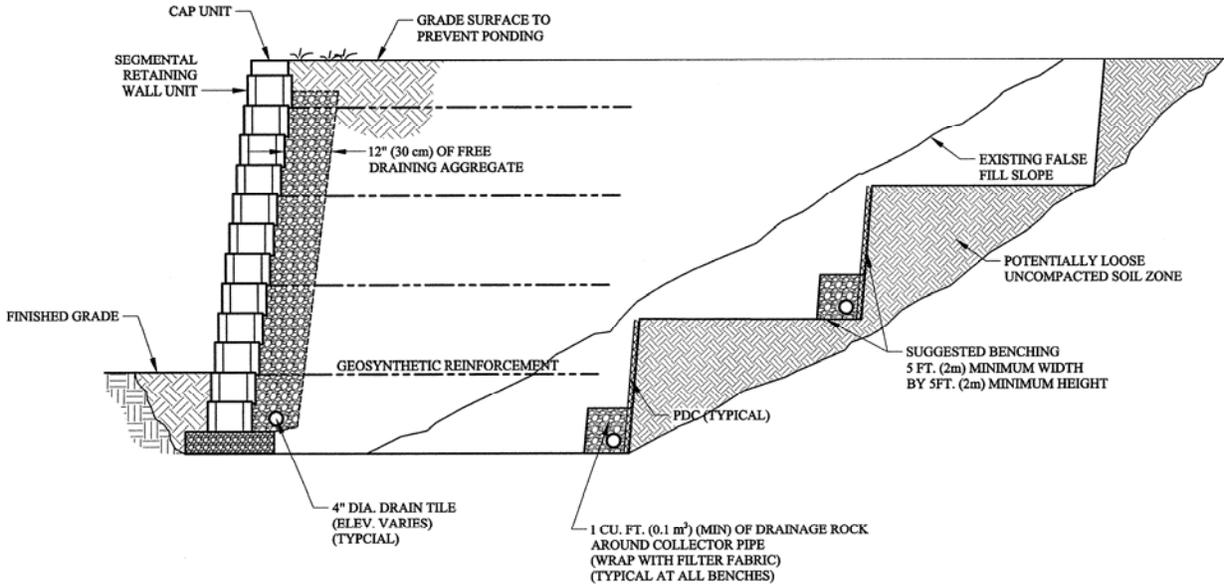


Figure 5 – Benching and drainage at false fills

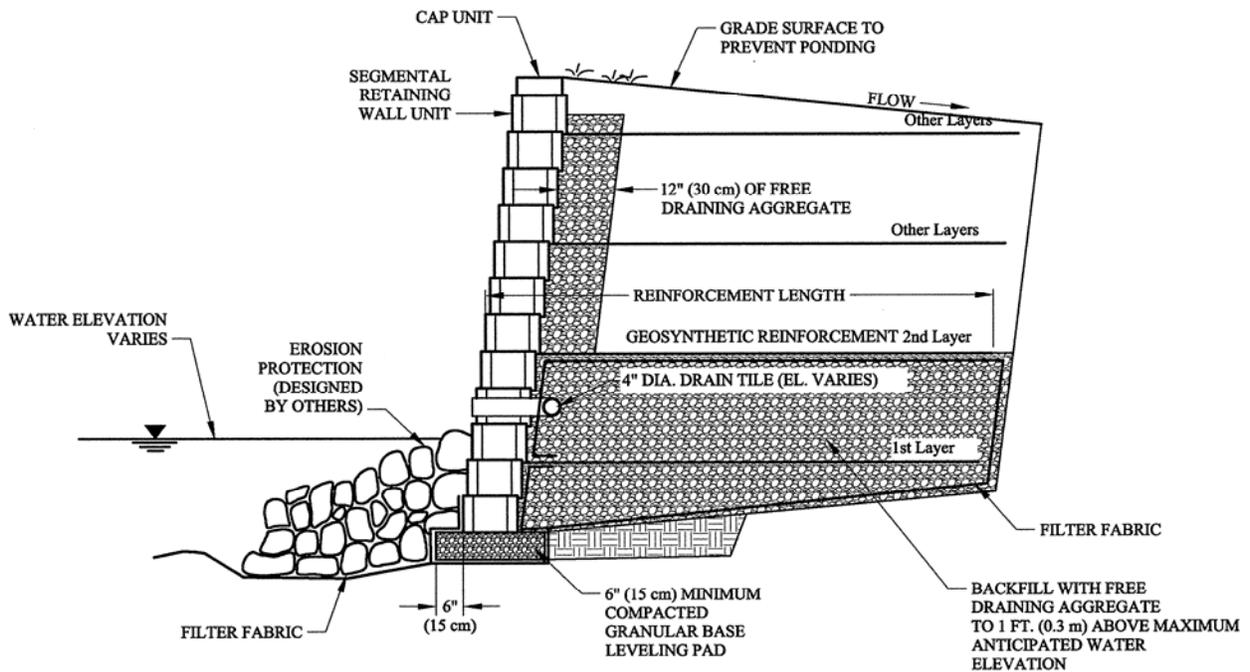
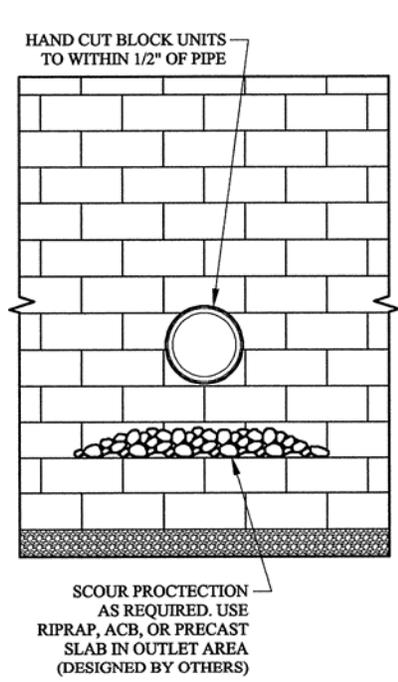
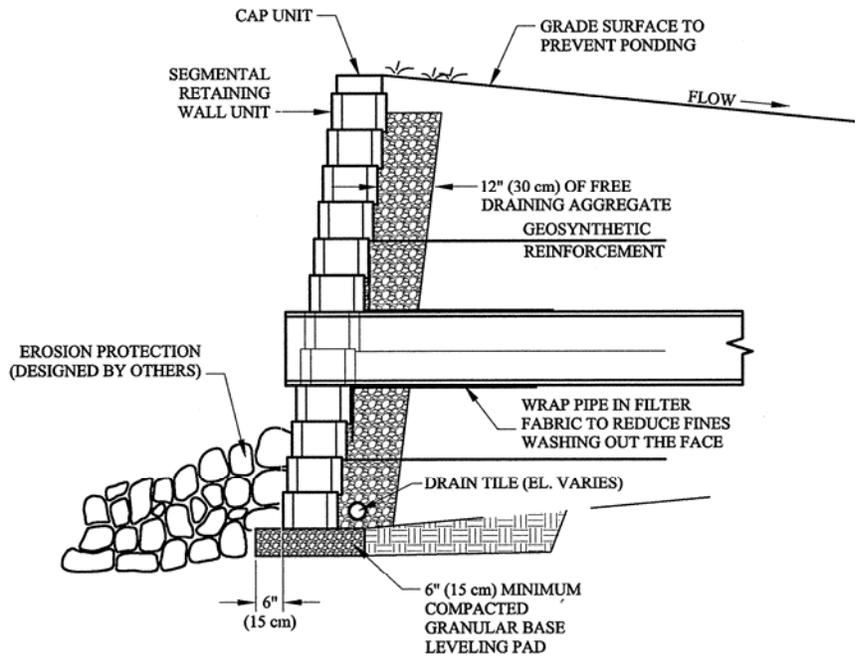


Figure 6 – Incorporation of free draining fill within the reinforced soil mass to reduce the potential for hydrostatic pressures in areas which may experience inundation.

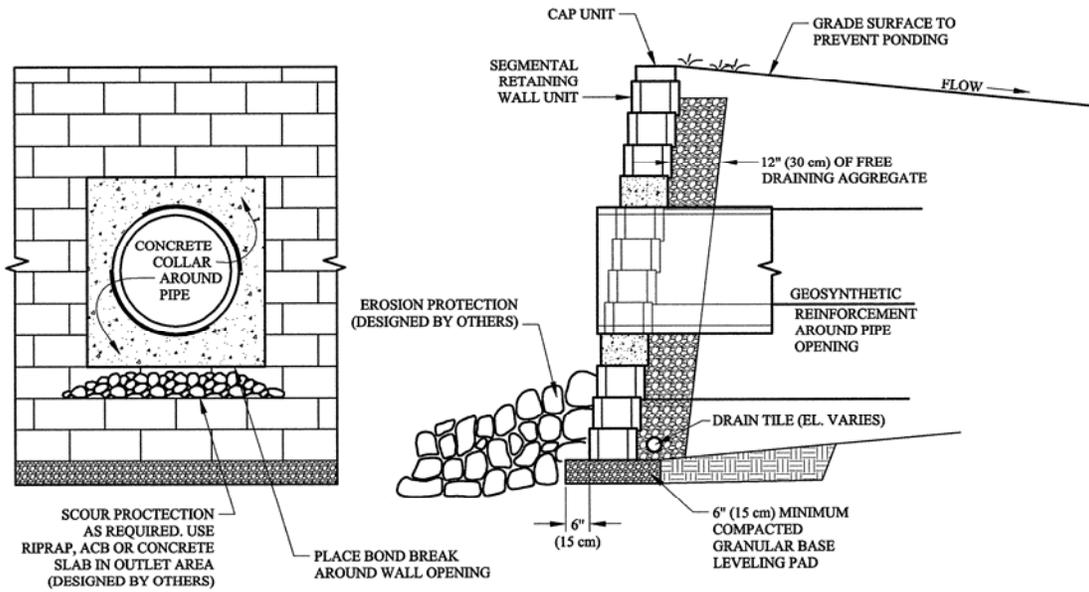


FACE VIEW



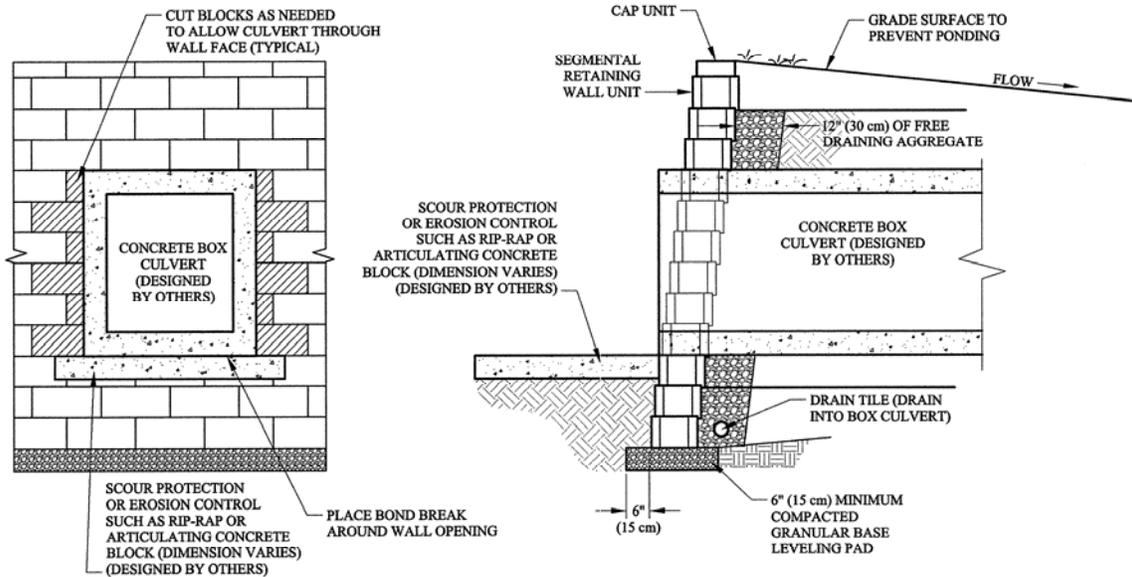
SECTION VIEW

Figure 7 – Protrusions thru the wall face where “low flows” are anticipated.



FACE VIEW

SECTION VIEW



FACE VIEW

SECTION VIEW

Figure 8 – Protrusions through the wall face where “high flow” may reasonably be anticipated.

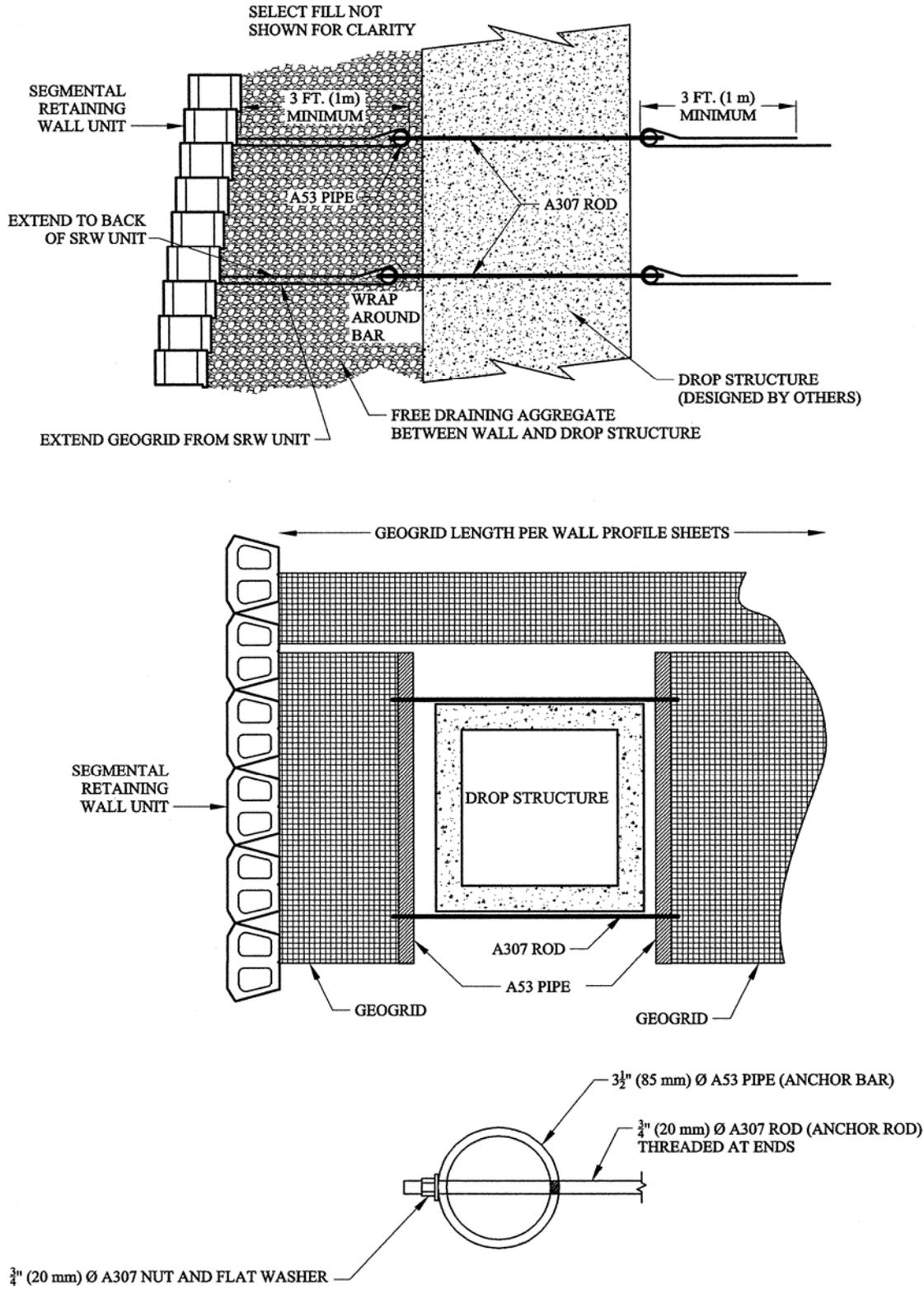


Figure 9 – Stabilizing vertical drainage structures near face of wall