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GSI White Paper #4
Reduction Factors (RFs) Used in Geosynthetic Design

Part I - Separation and Reinforcement Applications Using Geotextiles and Geogrids

Part II - Filtration and Drainage Applications Using Geotextiles

Part III - Drainage Applications Using Geonets, Geocomposites and Geospacers

by

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Part I - Separation and Reinforcement Applications Using Geotextiles and Geogrids

Introduction to the Three-Part Series

It has long been practiced that the as-manufactured properties of many geosynthetics are reduced when they are used for design purposes. In so doing, one takes an ultimate test value and modifies it into an allowable, or design, test value. This practice is used in many materials and is one-half of the technique known as “load and resistance factor design”, or LRFD, which is used by many highway agencies. In LRFD, loads are increased and resistances are reduced so as to arrive at a conservative and safe final design. Of course, the degree of conservatism is important and often a matter of contention between the parties involved, but that issue is not addressed in this paper.

This three-part commentary is focused on the resistance aspects of geosynthetics and is presented in three board topic areas based on the primary functions that geosynthetics typically serve; they are (i) geotextiles and geogrids used in separation and reinforcement, (ii) geotextiles used in filtration and drainage, and (iii) geonets, geocomposites and geospacers used in drainage. We will address separation and reinforcement in this first part, then geotextile filtration and drainage in the second part, and finally geonets, geocomposites and geospacers used in the third part.

Commentary Regarding Geomembranes

The concept of “Reduction Factors (RF’s)” is to include into the measured test property of a material those influences that are not included in the test protocol, per se. A typical example as described in this White Paper is to include a RF for long-term creep into the as measured laboratory short-term test performance of the geotextile or geogrid under investigation. For materials that are adequately simulated in the test protocol there are no reduction factors (or the RF's = 1.0 and thus have no effect) applied to the as-measured test properties. Such materials are steel, concrete, soil and rock. The goal in these traditional construction materials is to simulate their behavior in the laboratory test and then use the (global) factor-of-safety for unforeseen considerations in both design and testing.

Geomembranes fall into this category as well. The design should be such that tensile stresses do not occur, nor should short term installation damage by using proper CQC/CQA procedures or long-term damage by using appropriate protection materials (geotextiles or fine sandy soils). Lastly, long-term chemical effects are generally not a factor via the inherent inertness of most geomembranes. Under severe environmental or containment scenarios, the candidate geomembrane should be evaluated for "compatibility" per ASTM immersion and testing protocols. Thus, all of the conventional reduction factors used for geotextiles and geogrids appear as 1.0's when considering geomembranes, and thus reduction factors can be eliminated from consideration in the geomembrane design process.

<u>Separation and Reinforcement Reduction Factors</u>

The usual equation for allowable strength of geosynthetics (wide-width, grab, puncture, tear, impact, etc.) is as follows.

$$T_{allow} = T_{ult}\left[\frac{1}{RF_{ID} \times RF_{CR} \times RF_{CBD} \times RF_{SM}}\right] \tag{1}$$

where

T_{allow} = allowable (or design) strength,

T_{ult} = ultimate (or as-manufactured) strength,

RF_{ID} = reduction factor for installation damage,

RF_{CR} = reduction factor for creep,

RF_{CBD} = reduction factor for chemical and biological degradation, and

RF_{SM} = reduction factor for seams (if appropriate).

The numeric values for all of the above items are both site-specific and material-specific. The latest edition of the textbook *Designing with Geosynthetics* presents Table 1 for common application areas involving geotextiles and geogrids. Note that all values are listed as ranges allowing the designer considerable latitude. Commentary on each of the reduction factors follows:

Table 1 - Recommended Strength Reduction Factor Values for Use in Equation 1.

Area	Range of Reduction Factors		
	Installation Damage	Creep*	Chemical/Biological Degradation**
Separation	1.1 to 2.5	1.5 to 2.5	1.0 to 1.5
Cushioning	1.1 to 2.0	1.2 to 1.5	1.0 to 2.0
Unpaved roads	1.1 to 2.0	1.5 to 2.5	1.0 to 1.5
Walls	1.1 to 2.0	2.0 to 4.0	1.0 to 1.5
Embankments	1.1 to 2.0	2.0 to 3.5	1.0 to 1.5
Bearing and foundations	1.1 to 2.0	2.0 to 4.0	1.0 to 1.5
Slope stabilization	1.1 to 1.5	2.0 to 3.0	1.0 to 1.5
Pavement overlays	1.1 to 1.5	1.0 to 2.0	1.0 to 1.5
Railroads	1.5 to 3.0	1.0 to 1.5	1.5 to 2.0
Flexible forms	1.1 to 1.5	1.5 to 3.0	1.0 to 1.5
Silt fences	1.1 to 1.5	1.5 to 2.5	1.0 to 1.5

*The low end of the range refers to applications which have relatively short service lifetimes and/or situations where creep deformations are not critical to the overall system performance.

**Previous editions of this book have listed biological degradation as a separate reduction factor. There is no evidence, however, of such degradation for the typical polymers used to manufacture geotextiles. Thus, it is currently included with chemical degradation as a combined reduction factor.

Installation Damage - This item has been quantified in several research projects with accompanying papers that are available in the technical literature. The nature of the subgrade, cover soil, and installation equipment counterpointed against the particular geosynthetic material gives rise to the use of the lower or upper values. The option always exists to construct a test pad in the field to determine a more project-specific and precise value.

Creep - Of all reduction factors to be discussed, creep has had the most attention given to it. This is appropriate since it is typically the largest value used in the calculation. The disadvantage of creep testing is the long testing time required. Considerable current attention is being given to time-temperature-superposition (TTS) and stepped isothermal method (SIM) testing. Both are very quick in comparison to the original efforts using standard creep testing on individual test specimens. The open literature is abundant in this regard.

Chemical/Biological Degradation - These two degradation mechanisms were originally considered separately. As time progressed, it became clear that biological degradation did not occur with the high molecular weight resins used in the manufacture of geosynthetics. Thus, biological degradation should be eliminated entirely. However, if it is eliminated people will then ask where it is, and so it is currently combined with chemical degradation. Regarding the latter, one must know the site-specific environmental conditions and be aware of extremes, e.g., organic solvents, very high (or low) pH groundwater, and the like. The values listed in Table 1 are not based on research to the extent of the other values. That said, the values are the lowest and have the least impact on the allowable, or design, strength.

Seams - If seams are involved in strength related designs, a reduction factor can be added to the equation. The numeric value is very tractable. Using wide width strength test results of the unseamed material versus the seamed material (ASTM and ISO are nicely set up in this regard), the ratio is the desired reduction factor. It varies from 1.0 to 3.0 irrespective of the application area and is not included in Table 1 for this reason.

Others - Other atypical conditions, such as purposely cutting holes in a material, can be added as the site-specific conditions warrant.

Part I - Summary

It appears to the writer that the status of reduction factors in geosynthetic strength applications is in reasonable order, particularly when contrasted to the load estimation which is needed to complete a design. If we as an industry were to segue into LRFD methods it will be seen that much more uncertainty is associated with an estimation of both static and dynamic loads, including hydraulic loads in many cases. A recent paper on probability-of-failure calculations based on statistical variations of input values clearly shows this to be the case.

Part II - Filtration and Drainage Applications Using Geotextiles

Geotextiles, being very versatile materials can serve in many functions. The most widely known is as a filter. In fact, the original name for geotextiles was "filter fabrics". When sufficiently thick, however, they can also serve as drainage materials. The difference between these two functions is the orientation of the flow. In filtration, flow is perpendicular to the geotextile, while in drainage, flow is parallel (or within) the geotextile.

Filtration and Drainage Reduction Factors

The usual equation for allowable flow (permittivity, flow rate or transmissivity) is as follows:

$$q_{allow} = q_{ult}\left[\frac{1}{RF_{SCB} \times RF_{CR} \times RF_{IN} \times RF_{CC} \times RF_{BC}}\right] \tag{2}$$

where

q_{allow} = allowable (or design) flow rate,

q_{ult} = ultimate (or as-manufactured) flow rate,

RF_{SCB} = reduction factor for soil clogging and blinding,

RF_{CR} = reduction factor for creep reduction of void space,

RF_{IN} = reduction factor for adjacent materials intruding into void spaces,

RF_{CC} = reduction factor for chemical clogging, and

RF_{BC} = reduction factor for biological clogging.

The numeric values for all of the above items are both site-specific and material-specific as they were for strength applications, but obviously they are different. The latest edition of the textbook *Designing with Geosynthetics* uses Table 2 for common application areas involving geotextiles by themselves, and the geotextiles on geonets, geospacers and drainage geocomposites. As with Table 1, all values are ranges and furthermore the ranges are broader than those given in Table 1. Thus, the designer has even more latitude for his/her selection. Commentary on each of the reduction factors follows:

Table 2 - Recommended Flow Reduction Factor Values for Use in Equation 2.

Application	Range of Reduction Factors				
	Soil Clogging and Blinding*	Creep Reduction of Voids	Intrusion in Voids	Chemical Clogging**	Biological Clogging***
Retaining wall filters	2.0 to 4.0	1.5 to 2.0	1.0 to 1.2	1.0 to 1.2	1.0 to 1.3
Underdrain filters	2.0 to 10	1.0 to 1.5	1.0 to 1.2	1.2 to 1.5	2.0 to 4.0***
Erosion control filters	2.0 to 10	1.0 to 1.5	1.0 to 1.2	1.0 to 1.2	2.0 to 4.0
Landfill filters	2.0 to 10	1.5 to 2.0	1.0 to 1.2	1.2 to 1.5	2.0 to 5.0***
Gravity drainage	2.0 to 4.0	2.0 to 3.0	1.0 to 1.2	1.2 to 1.5	1.2 to 1.5
Pressure drainage	2.0 to 3.0	2.0 to 3.0	1.0 to 1.2	1.1 to 1.3	1.1 to 1.3

*If stone rip-rap or concrete blocks cover the surface of the geotextile use either the upper values, or include a separate reduction factor.

**Values can be higher particularly for high alkalinity or high turbidity groundwater.

***Values can be higher for extremely high microorganism content and/or growth of organisms and plant/vegetation roots.

<u>Soil Clogging and Blinding</u> - This reduction factor attempts to compensate for upstream soil particles either embedding themselves in a thick geotextile and/or blocking flow above the geotextile's voids. This is a necessary response of the geotextile in "tuning" itself to the site-specific soil and hydraulic conditions. The values seen in Table 2 are the largest of reduction factors for flow applications. They were obtained by comparing permittivity flow rates of various geotextiles as-manufactured (i.e., in-isolation) with that of similar flow tests of different soils placed over the geotextiles in question. More specifically, the tests were short term flow tests via the GRI GT1 test method which was developed in 1986. The lower values generally apply to woven fabrics and cohesionless soils, while the higher values generally apply to nonwoven fabrics and fine-grained soils. Admittedly, there is considerable latitude in selection

of a particular value. Of course, product-specific and site-specific testing can be performed if the situation warrants.

Creep Reduction of Voids - Since thick geotextiles compress under load, a reduction factor should be included to modify the as-manufactured product's flow value over time. It is a long-term phenomenon and the short term permittivity flow tests of GRI GT1 test method were run for times up to 1000-hours to obtain the reduction factors. Also included in this category are long-term transmissivity tests to evaluate flow reductions for in-plane drainage related applications. With both of these situations (permittivity and transmissivity), the option is always available to do the respective tests under product-specific and site-specific conditions.

Intrusion into Voids - This lowest of reduction factors is to compensate for soil particles entering and being retained within the geotextile. Nonwoven needle-punched geotextiles have the greatest tendency in this regard over woven, heat-bonded or burnished geotextiles.

Chemical Clogging - This reduction factor considers that the permeating liquid might carry or precipitate chemicals which can clog the geotextile filter or drain. High alkalinity groundwater will readily precipitate calcium and magnesium in this regard. One might also consider suspended solids in the permeant as a similar phenomenon. Total suspended solids, or TSS, values of greater than 5000 mg/l require high reduction factors. It is difficult to model in laboratory testing and thus the values provided are somewhat subjective.

Biological Clogging - As with chemical clogging, the nature of the permeating liquid is at issue. Liquids high in microbial content, such as landfill leachates, agricultural wastewaters, and sewage biosolids, are all troublesome and result in high reduction factors. Values of biochemical oxygen-demand (BOD) greater than 5000 mg/l are considered high in this regard. This term could also includes plant and vegetative root growth through or within the geotextile, but these are site-specific situations and are very difficult to quantify in this context. As with chemical clogging, these issues are also difficult to model in laboratory testing and thus the values provided are somewhat subjective.

Part II - Summary

It appears to the writer that the status of reduction factors in geotextile flow applications is not as definitive as it is with strength applications. The field scenarios which can be envisioned are much broader and unwieldy in this regard. That said, if LRFD methods are eventually employed in geosynthetic design it again will be seen that the load side of the equation is of a greater uncertainty than these “resistance” aspects of modifying an as-manufactured flow value into an allowable flow value using reduction factors. The paper on probability-of-failure referenced in the first part of this communication shows this clearly.

Part III - Drainage Application Using Geonets, Geocomposites and Geospacers

Part II of this series dealt with reduction factors involving geotextile-filtration (always a primary function for cross-plane flow in hydraulic applications), and geotextile drainage (only a primary function for in-plane flow using relatively thick nonwoven geotextiles). This continuation of the latter situation extends the drainage materials into the much higher flow-rate, or transmissivity, products involving geonets, geocomposites, and geospacers. The analytic formulation is quite similar, but the very open flow channels of drainage cores present some unique aspects of the use of reduction factors in these high-flow drainage geosynthetics.

Drainage Reduction Factors

The requisite equation for flow rate or transmissivity involving geonets, geocomposites, and geospacers changes slightly from Equation 2 presented previously, to Equation 3 following. Note the absence of the reduction factor for soil clogging and blinding, RF_{SCB}, since this is unique to filtration geotextiles and is not particularly relevant to the drainage core, per se:

$$q_{allow} = q_{ult}\left[\frac{1}{RF_{IN} \times RF_{CR} \times RF_{CC} \times RF_{BC}}\right] \tag{3}$$

where

q_{allow} = allowable (or design) flow rate or transmissivity,

q_{ult} = ultimate (or as-manufactured) flow rate or transmissivity,

RF_{IN} = reduction factor for intrusion of geotextiles or geomembranes into the core of drainage product,

RF_{CR} = reduction factor for creep of the drainage core or covering geosynthetics,

RF_{CC} = reduction factor for chemical clogging of drainage core, and

RF_{BC} = reduction factor for biological clogging of drainage core.

The numeric values for all of the above are also site-specific and product-specific as they were for strength applications (Table 1) and geotextile filter and drainage applications (Table 2). For geonets, geocomposites and geospacers, the latest edition of the textbook *Designing with Geosynthetics* gives the values in Table 3. Commentary on each of the reduction factors follows.

Table 3. Recommended drainage reduction factors for use in Equation 3

Application Area	Range of Reduction Factor Values			
	RF_{IN}	RF_{CR}*	RF_{CC}	RF_{BC}
Sport fields	1.0 to 1.2	1.0 to 1.5	1.0 to 1.2	1.1 to 1.3
Capillary breaks	1.1 to 1.3	1.0 to 1.2	1.1 to 1.5	1.1 to 1.3
Roof and plaza decks	1.2 to 1.4	1.0 to 1.2	1.0 to 1.2	1.1 to 1.3
Retaining walls, seeping rock, and soil slopes	1.3 to 1.5	1.2 to 1.4	1.1 to 1.5	1.0 to 1.5
Drainage blankets	1.3 to 1.5	1.2 to 1.4	1.0 to 1.2	1.0 to 1.2
Infiltrating water drainage for landfill covers	1.3 to 1.5	1.1 to 1.4	1.0 to 1.2	1.5 to 2.0
Secondary leachate collection (landfills)	1.5 to 2.0	1.4 to 2.0	1.5 to 2.0	1.5 to 2.0
Primary leachate collection (landfills)	1.5 to 2.0	1.4 to 2.0	1.5 to 2.0	1.5 to 2.0
Wick Drains (PVDs)	1.5 to 2.5	1.0 to 2.5	1.0 to 1.2	1.0 to 1.2
Highway edge drains	1.2 to 1.8	1.5 to 3.0	1.1 to 5.0	1.0 to 1.2

*Creep values are sensitive to the core structure and to the density of the resin used. Creep of the covering geotextile(s) is a product-specific issue. The magnitude of the applied load is of major importance in both situations.

<u>Intrusion into core</u>. Considering the large open spaces in drainage cores, the intrusion of the covering geotextiles and/or geomembranes represents a meaningful reduction factor. Major variables are the spacings of ribs, nubs, or columns; stiffness of the covering geotextiles or geomembranes; and magnitude, orientation, and duration of the stresses applied during service.

The data of Table 3 represents comparative ASTM D4716 testing using solid end platens versus relatively lightweight nonwoven needle-punched geotextiles entering the drainage core as the worst-case situations. In critical situations or for other coverings such comparative testing is recommended.

Creep of core and/or cover-ups. Depending on the site-specific situation and applied stresses, the drainage core might creep as well as the geotextile or geomembrane coverings. Both situations represent a reduction in the in-plane flow rate or transmissivity. The data of Table 3 represents comparative ASTM D4716 tests up to 1000 hours on HDPE biplanar geonets. The situation for other geonets and the many varieties of geospacers requires actual testing. It should be mentioned that the recent development of the stepped isothermal method (SIM) of testing can provide much more timely information than previously possible.

Chemical clogging. This reduction factor considers that the permeating liquid might carry or precipitate chemicals which can clog the geotextile filter or geocomposite drain. High alkalinity groundwater will readily precipitate calcium and magnesium in this regard. One might also consider suspended solids (including fine soil particles less than the geotextile filter’s opening size) in the permeant as a similar phenomenon. Total suspended solids (TSS) values of greater than 5000 mg/l require high reduction factors. It is difficult to model in laboratory testing; thus, the values provided are somewhat subjective.

Biological clogging. As with chemical clogging, the nature of the permeating liquid is at issue. Liquids high in microbial content, such as landfill leachates, agricultural wastewaters, and sewage biosolids, are all troublesome and result in high reduction factors. Values of biochemical oxygen-demand (BOD) greater than 5000 mg/l are considered high in this regard. This term could also include plant and vegetative root growth through a geotextile or within a drainage geocomposite, but these are site-specific situations and are very difficult to quantify in this context. As with chemical clogging, these issues are also difficult to model in laboratory testing, and thus, the values provided are somewhat subjective.

Part III - Summary

As with the Part II - Summary, the status of reduction factors for drainage applications using geonets, geocomposites or geospacers is not as definitive as it is with strength applications. It is further complicated because the transmissivity test method, ASTM D4716, has a quite high statistical variation in comparison to the permittivity test method, ASTM D4491. Particularly subjective are chemical and biological clogging, both of which are difficult to simulate in a laboratory setting.

Conclusion to the Three-Part Series

By way of conclusion of this three-part white paper we offer Table 4 which addresses all of the strength and flow reduction factors that were presented and comments accordingly. While additional research can be profitably done on many of the items, a more direct approach is to simulate site-specific field conditions and perform the requisite tests on the candidate geosynthetic material. In the writer’s opinion, too little project-specific testing is being done presently. There are several commercial laboratories which are well equipped to do such testing.

Table 4 - Critique of Geosynthetic Reduction Factors

Category	Confidence in Values	For Critical Applications
Strength-Related Applications		
- installation damage	high	use upper range value
- creep	high	use upper range value
- chemical/biological degradation	moderate	site-specific testing
- seams	high	use upper range value
Flow-Related Applications		
- soil clogging and blinding	moderate	site-specific testing
- creep reduction of voids	moderate	site-specific testing
- intrusion	high	use upper range value
- chemical clogging	low	go beyond table limits
- biological clogging	low	go beyond table limits

In addition to the above summary table which is pertinent to geotextiles, geogrids, geonets, geocomposites, and geospacers, the need for ongoing investigation should be apparent. When reduction factors are multiplied together, which assumes the worst-case scenario of complete synergy between all reduction factors, the resulting value can be enormous. For example, in leachate collection systems beneath landfills one is taking an as-manufactured flow rate and decreasing it by a combined reduction factor of sixteen (2.0 × 2.0 × 2.0 × 2.0 = 16) under worst-case conditions. This should encourage much more testing than is currently being performed for long-term and/or critical applications. It also leaves open the interesting aspect of future product development which might minimize the adverse effects of such high reduction factors. It is encouraging to see that some products are now available in this regard and others are being currently developed.