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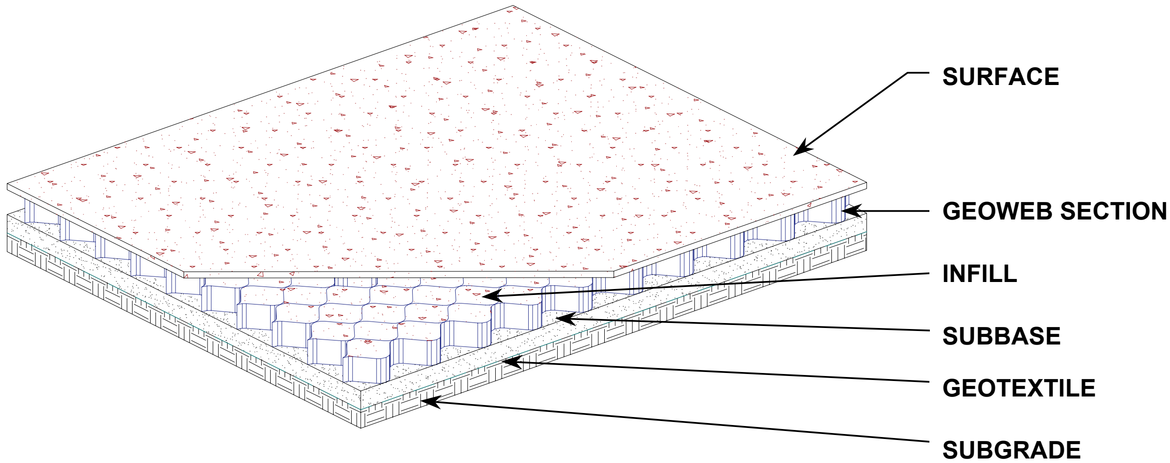
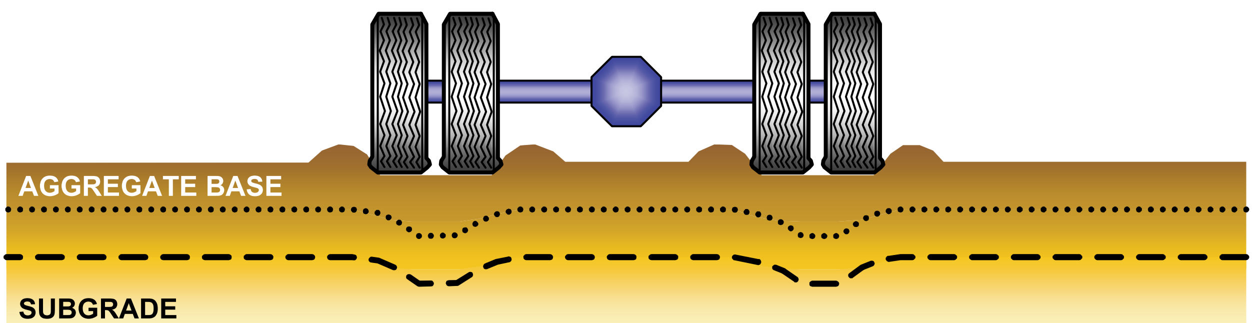
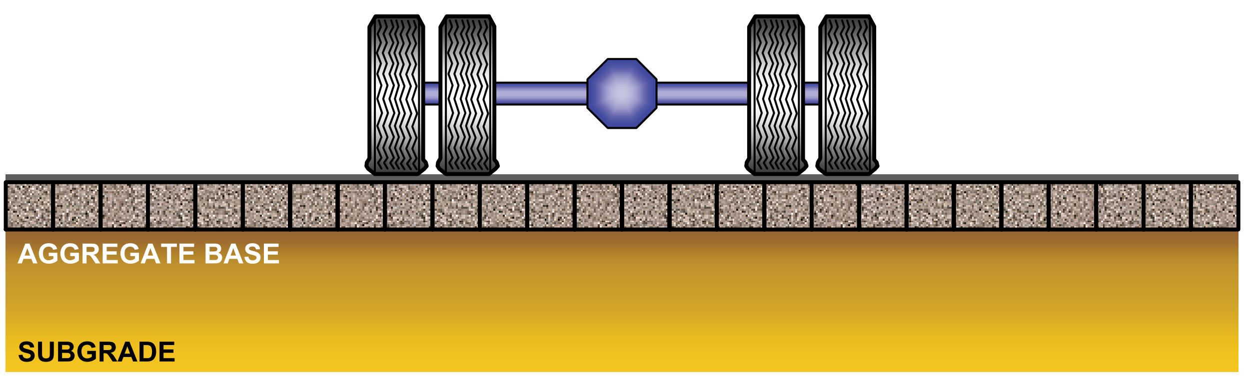
GEOWEB® LOAD SUPPORT SYSTEM
TECHNICAL OVERVIEW





UNCONFINED GRANULAR PAVEMENT SYSTEM



THE GEOWEB GRANULAR PAVEMENT SYSTEM

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GEOWEB® LOAD SUPPORT SYSTEM TECHNICAL OVERVIEW

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GEOWEB® LOAD SUPPORT SYSTEM TECHNICAL OVERVIEW

Introduction

Natural aggregate / soil construction materials for road base and other load support applications are inherently unstable compared to other construction materials such as steel and reinforced concrete. This is because they are comprised of discrete particles of varying sizes that can roll, or slide, over one another. They have relatively low shear resistance and will eventually fail as a result of single or multiple load applications. However, this *weak link* property also makes these natural construction materials easily workable relative to stockpiling, transporting and placing over large areas or long roadways.

Asphalt cement and Portland cement are commonly used to improve the stability of aggregate materials to make them suitable for the wearing course of load support structures. In addition, most load support structures also require a good base and/or subbase layer to distribute surface loads over the subgrade. Unbound aggregate materials are ideal for this purpose because they are easy to place, are flexible and improve the ride quality of the structure. However, because of their inherent weakness, road builders have long sought new ways to increase the long-term stability of unbound aggregate materials. Many products have been developed and tested to bind together or reinforce aggregate materials but often with limited success.

Fine and uniformly graded sands best exemplify the inherent weakness of granular materials. Desert sands and dry beach sands cannot support channelized traffic loading without significant rutting occurring due to localized shear failure of the near surface material. For this reason, the U.S. Army Corps of Engineers, Waterways Experiment Station, began a research project in the mid 1970's to investigate methods for rapid construction of sand roads for beach landings and desert operations. In order to achieve surface stability without the requirement for chemical additives, mixing and curing time, three-dimensional cellular confinement of loose sands was determined to be the most practical alternative. Through field trials and experimentation, the optimum cell depth to diameter ratio was determined to be approximately 1.0 for heavy military and civilian wheel loads. In the late 1970's Presto Products Company developed the Geoweb cellular confinement system, based on the Corps of Engineers research, as a commercial product to stabilize unbound aggregate materials. The Geoweb system consists of an assembly of polyethylene sheet strips connected in a series of off-set, full-depth ultrasonic welded seams, aligned perpendicular to the longitudinal axis of the strips. When expanded, the interconnected strips form the walls of the cellular confinement structure into which granular fill materials can be placed. Various cell depths have been developed to satisfy load and subgrade strength design criteria based on optimum cell to diameter ratios. Recent improvements to the Geoweb system include surface texturization and cell wall perforations for improved frictional resistance and lateral drainage.

Examples of Geoweb Load-Support System Applications

Granular Access Roads	Parking Lots	Retaining Wall Spread Footings
Grass Access Roads	Storage Yards	Foundation Mattresses
Porous Pavements	Intermodal and Port Facilities	Trench Invert Stabilization
Pavement Subbases	Boat Ramps / Low Level Crossings	Stabilized Drainage Layer

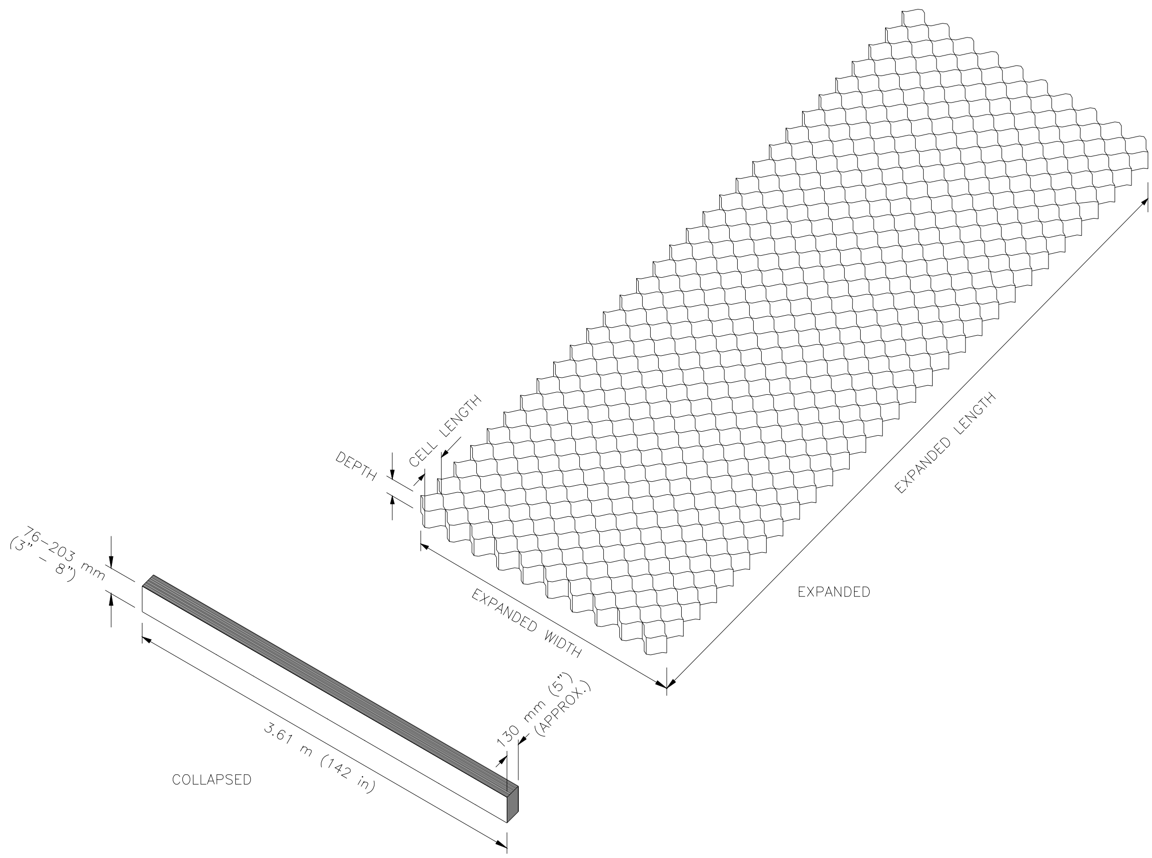

Figure 1 Typical Geoweb Sections

Features and Benefits of the Geoweb Cellular Confinement System

The Geoweb cellular confinement system improves the load-deformation performance of granular infill materials due to the hoop strength of individual cells, the passive resistance of infill material in adjacent cells and vertical stress transfer to adjoining cells. When compared to 2-dimensional sheet reinforcement materials, the stiffness of the 3-dimensional Geoweb system is significantly greater and does not require initial deformation to support the design load.

The Geoweb cellular confinement system dramatically increases the shear resistance of granular infill materials allowing the use of lower quality aggregates (e.g. sand, gravel) to carry concentrated loads that would otherwise require crushed stone or bituminous mixes to prevent localized, near-surface, shear failure. The cellular structure also distributes concentrated loads to surrounding cells thus reducing the stress on the subgrade directly beneath the load and the required total thickness of the structure.

The Geoweb load support system can offer several advantages over conventional solutions and alternative systems. When very soft soils and/or heavy loads are a factor, the system can reduce costs by reducing the required section thickness. Where aggregate materials are expensive or unavailable, the system can reduce costs by incorporating locally available materials. Since Geoweb sections are very compact for shipping and reduce total thickness requirements, a small quantity can be used to replace truckloads of imported aggregate that may have to be hauled over long distances. Finally, when extended pavement life and/or low maintenance requirements are desired, the Geoweb system can ensure that the integrity of granular infill materials will be maintained indefinitely.

Identifying Load Support Problems and Geoweb Solutions

Load support design problems most commonly arise when:

- soft subgrade soils are encountered,
- surface soils are unstable, (i.e. good quality aggregates are locally unavailable or uneconomical) or,
- there are aesthetic and/or environmental consideration.

To identify load support problems where Geoweb cellular confinement should be considered, the following questions should be asked.

Soft Subgrades Problems

Are there any constraints on undercutting or designing a thick structure? If yes, consider the Geoweb cellular confinement system to reduce the section thickness.

Is it impossible to build a stable foundation mattress below the load structure because of a very soft, unstable subgrade condition? If yes, consider the Geoweb cellular confinement system, with a geotextile underlayer, to bridge over the soft soil and support construction equipment while using a minimum thickness of cover material.

Conventional, non-Geoweb solutions to soft subgrades problems, may include:

- excavation of the soft soil and replacement with imported fill (usually granular),
- chemical stabilization of the subgrade soil, or
- design of a thick, multi-layered structure which may include high quality aggregate materials, asphaltic concrete and/or Portland cement concrete.

Thick pavement structures and/or deep excavation may not always be possible due to existing curbs and buried utilities in existing roads.

Surface Stability Problems

Do the locally available soils (e.g. sands and gravels) have adequate shear strength to be used as a wearing surface for a temporary or low-volume access road? If not, confinement of the local materials in the Geoweb system should be weighed against the cost of importing higher quality aggregate materials.

Will aggregate degradation and lateral spreading of the pavement base course result in rutting and premature failure of the pavement structure? If the subgrade is relatively competent, deformation and rutting of the base course is likely to be the cause of maintenance problems and reduce the potential life of the pavement structure. Using the Geoweb system to confine the base course will totally restrict lateral movement that causes rutting and will minimize abrasion and wear on the aggregate infill material.

Few, if any, conventional solutions exist for this problem.

Aesthetic / Environmental Problems

Would a grass surfaced, low volume access road for maintenance vehicles be more aesthetically pleasing than a gravel or asphalt concrete surfaced pavement? If yes, the Geoweb cellular confinement system infilled with an aggregate/topsoil mix and vegetated is an attractive solution.

Is a porous pavement required for groundwater regeneration? If yes, the Geoweb cellular confinement system infilled with porous stone should definitely be considered. However, without confinement, porous aggregates are inherently unstable as surface materials.

Geoweb Load Support Systems - The Key Components

Textured Geoweb system

Engineered surface-textured polyethylene strips used in manufacturing Geoweb sections improve the frictional interaction between the Geoweb cell walls and granular infill materials. The increase in cell-wall / infill-interface friction provides structural benefits in certain Geoweb applications.

In load support applications, the higher cell wall/infill interface friction increases the resistance to vertical deformation of the infill soil relative to the cellular structure. Therefore, a more efficient transfer of vertical stress is provided to the surrounding cells. The result is a further reduction in vertical stress on the subgrade compared to a smooth walled geocell. For certain combinations of wheel loads and infill material properties, the surface texture makes it possible to further reduce the total required thickness of granular pavement over smooth-walled geocells.

Results of small and large scale shear box tests on sand and stone materials with textured Geoweb materials have demonstrated that Peak Coefficient Ratios (i.e. peak interface friction coefficient of textured Geoweb sections divided by the peak interface friction coefficient of granular infill soil in-isolation) varied from 0.63 (crushed stone materials) to 0.81 (coarse sand materials) compared to 0.64 (crushed stone materials) and 0.61 (coarse sand materials) with smooth Geoweb materials. Note that texturization does not increase the interface friction with some crushed stone infills. The Peak Coefficient Ratio should not be confused with the Peak Friction Angle Ratio defined in the section titled Geoweb Cell Wall/Infill Friction Angle Ratio

Perforated Geoweb system

Similar tests using sand and stone materials with the perforated Geoweb material demonstrated that the interface frictional characteristics are similar, or in some cases better, than those with surface textured Geoweb cells. Specifically, the Peak Coefficient Ratios of perforated Geoweb materials with crushed stone and coarse sand infills were found to be 0.75 and 0.89 respectively.

The latter test results indicate that perforated cell walls can be as effective as textured cell walls in increasing the interface friction. Therefore, the structural capacity of the perforated Geoweb load support system with certain sand/gravel infills is more effective than the textured Geoweb system. Since perforations also offer the advantage of lateral drainage, which is particularly useful over impermeable subgrades, the perforated Geoweb system is the recommended choice for many pavement applications. Refer to Table 1 for an illustration of the significance of the performance advantage using textured and perforated cell wall type.

Infill materials

Infill materials for Geoweb load support applications should always be predominately granular with a maximum particle size of 50 mm (2 in). For best performance, the fines fraction (i.e. material passing the #200 sieve - 75 μm) should not be greater than 10%. Soils with greater than 10% fines have low permeability and lose strength dramatically when they become wet. Pure granular materials are not affected by moisture fluctuations but are not as stable as granular materials with 5% - 10% fines. A small fraction of fines will increase stability by reducing the voids ratio and binding the soil.

The Geoweb cellular confinement system is effective in increasing the stability of lower quality granular infill materials such as poorly graded sands and gravels. With cellular confinement, poor quality granular infills can be used as the surface or near-surface material of access roads where driving speeds are relatively slow and ride quality is not a major concern. Higher quality aggregates are recommended for granular surfaced pavements where traffic speeds are higher and a smoother riding surface is required. Good quality aggregates typically include well graded crushed stones or gravels with a maximum particle size of 40 mm (1.5 in) and less than 8%, by weight, passing the #200 sieve. For long-term durability, the coarse fraction of the aggregate should have a Los Angeles Abrasion test wear less than 50%. The fines fraction (i.e. passing the #200 sieve) should not be greater than two-thirds of the fraction passing the #40 sieve and the fraction passing the #40 sieve should have a liquid limit no greater than 25%. The plasticity index should be less than 6%.

Table 1 Total Thickness of Coarse Sand / Gravel Base Including Geoweb Section

Subgrade CBR	Wheel Load		Smooth Cell	Textured Cell	Perforated Cell	Unconfined Gravel
%	kN	(lbf)	Relative Total Thickness of Road Base			
0.2	**27**	**(6,000)**	32%	28%	27%	100%
	53	**(12,000)**	59%	25%	25%	100%
	111	**(25,000)**	72%	23%	23%	100%
	222	**(50,000)**	80%	22%	22%	100%
0.5	**27**	**(6,000)**	46%	40%	40%	100%
	53	**(12,000)**	43%	38%	37%	100%
	111	**(25,000)**	40%	35%	34%	100%
	222	**(50,000)**	38%	33%	32%	100%
1.0	**27**	**(6,000)**	58%	54%	54%	100%
	53	**(12,000)**	55%	49%	48%	100%
	111	**(25,000)**	52%	45%	44%	100%
	222	**(50,000)**	49%	43%	42%	100%
2.0	**27**	**(6,000)**	81%	81%	81%	100%
	53	**(12,000)**	65%	58%	58%	100%
	111	**(25,000)**	59%	52%	51%	100%
	222	**(50,000)**	60%	52%	51%	100%
NOTE: **This table is based on theoretical methodologies outlined herein. Values are for comparative purposes only and are not a substitute for project specific design.**						

Geotextile underlayer

When the Geoweb section is to be placed directly above a fine-grained or cohesive soil subgrade, a nonwoven geotextile is typically recommended for separation of the native soil and the granular infill. Separation is important to prevent contamination and loss of shear strength of the granular infill and to prevent punching or migration of the infill material into the subgrade. With a geotextile underlayer, the infill material is totally confined on all sides and at the bottom of individual cells.

When specific designs require a granular subbase below the Geoweb section, a woven or nonwoven geotextile may be recommended for separation as well as temporary load support during placement of the subbase layer. If the subbase is a well-compacted granular material, a geotextile separator is not typically required between the subbase and Geoweb infill.

Surface materials

In order to prevent trafficking directly on top of the Geoweb cell walls, it is generally recommended to place a minimum 50 mm (2 in) of granular cover (i.e. overtopping) above the Geoweb cell walls. The surface material should be dense-graded crushed stone that is resistant to surface rutting. If traffic volumes are high, a bituminous surface treatment can increase the stability of the riding surface.

If an asphalt concrete base or surface layer is to be placed over the infilled Geoweb base, the depth of granular cover above the cell walls should be at least 25 mm (1 in) to allow for minor consolidation of the infill material and to insulate the polyethylene from direct contact with the hot mix asphalt concrete.

Design Considerations and Methods

There is no single design method that encompasses the full range of Geoweb load support applications. A theoretical design method, based on empirically derived design methods for unpaved roads over soft soils, has been developed for the Geoweb granular pavement system. Design methods for flexible pavements, spread footings, and granular pavements with unstable infill soils have yet to be developed. However, it was this latter function for which Geoweb was originally invented and developed and has proven effective, particularly with sand infill materials.

Recent results of large scale triaxial compression testing of the Geoweb cell infilled with granular materials demonstrate that the Geoweb system imparts an apparent cohesion of approximately 150 kPa (3000 psf) to the confined material. This effective cohesion is in addition to the natural frictional shear strength of the granular material. Presto Geosystems is currently using this information to develop bearing-capacity design procedures for Geoweb load support structures that takes into account the additional shear strength provided by the apparent cohesion. These design procedures will apply to large spread footing and granular pavement applications with poor-quality infill materials.

A discussion of currently available design procedures follows for Geoweb granular pavement systems and the design approaches used for other Geoweb load support applications.

Flexible Pavements

Conventional flexible pavement design methods (e.g. AASHTO, Asphalt Institute, Caltrans, etc.) are all based on empirical data collected from either full-scale road tests or ongoing testing and monitoring of pavement performance within various geographical areas. Structural values of conventional road construction materials (e.g. crushed stone, gravel, asphalt concrete, etc.) have been determined by federal and local agencies based on years of in-service performance history. While many new materials (e.g. stabilizers, geosynthetics, etc.) have been introduced in recent years to enhance the structural value of conventional construction materials, it is difficult and can take several years to obtain structural values for these components to use with existing design methods. For this reason, there are no agency-accepted structural values or equivalencies that can be used with current pavement design methods for the Geoweb system.

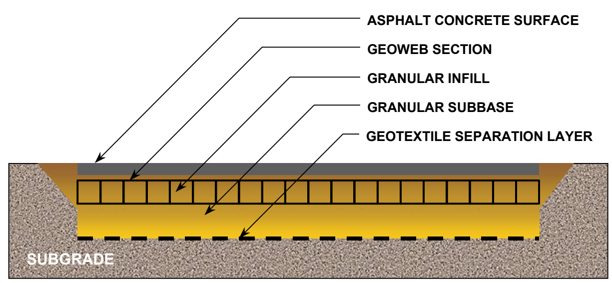

Figure 2 Flexible Pavement Detail

By combining conventional pavement design methods with a theoretical method for determining the structural equivalency of a confined pavement layer, it is possible to design pavement structures that incorporate the Geoweb system.

Granular Pavements

Design of Geoweb confined granular pavements (e.g. access roads) over soft soils is relatively straight forward and has been well documented for general design purposes. Refer to the Design Parameters – Granular Pavements and Design Calculations Granular Pavements sections of this document for specific details about the required design input data and the design calculations.

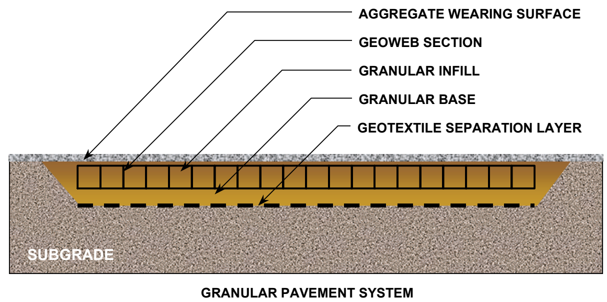

Figure 3 Granular Pavement Detail

Spread Footings

Geoweb spread footings may be considered for a wide range of load support applications such as building footings, buried pipes and segmental retaining walls. They may also be considered for a variety of soil problems such as low bearing capacity, settlement and inadequate shear resistance of near surface foundation soils. Footing loads may be relatively large or small with respect to individual cell or section size of Geoweb spread footings. Due to the versatility of the Geoweb cellular confinement system, the function and design method may change with varying combinations of application, problem and footing loads. In some cases the governing design factor may be:

- the overall shear resistance of the Geoweb spread footing,
- the redistribution of stresses within individual Geoweb cells or
- the increase in bearing area provided by a Geoweb spread footing.

The design approach used for granular pavement structures can also be used for design of Geoweb spread footings with relatively small rigid footing loads by modifying the design criteria for bearing capacity from local shear failure mode to general shear failure mode. For conventional bearing capacity and settlement calculations of larger footing loads, the recommended effective bearing area of a Geoweb mattress should extend no more than 500 mm (18 in) beyond the edges of the rigid footing. In most cases, this will provide a significant decrease in the calculated bearing pressure without compromising the basic assumption that the Geoweb mattress will be effectively rigid.

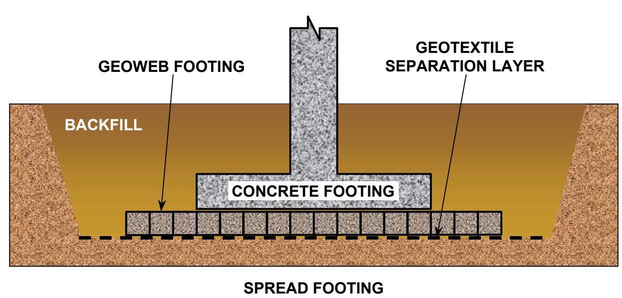

Figure 4 Spread Footing Detail

As stated above, development of a design method for Geoweb spread footings, which will take into account the effective cohesion of the cellular structure, is currently underway.

Design Parameters - Granular Pavements

The following information and input parameters are required for design of the Geoweb load support system for granular pavements.

Wheel Load

The design wheel load is the heaviest single or dual wheel load that the granular pavement will be required to support over the proposed life of the structure.

Tire Pressure

The tire pressure is the tire inflation pressure of the design wheel load and is approximately equal to the ground contact pressure. An input value is required for determination of the effective contact radius of the design wheel load.

Bearing Capacity Coefficient

Bearing capacity coefficients are mathematically or empirically derived coefficients used within standard equations for determination of the bearing capacity of a soil. For unpaved roads over soft cohesive soils, the US Forest Service and others have developed bearing capacity coefficients for determination of the bearing capacity of soils subjected to dynamic loading wherein punching (local) shear failure is more prevalent than general shear failure. The US Forest Service developed the following bearing coefficients for unpaved haul roads for two broad ranges of traffic loading.

$N_c = 2.8$ High traffic with little rutting (i.e. > 1000, < 10000)

$N_c = 3.3$ Low traffic with significant rutting (i.e. < 1000)

Depth to Top of Geoweb section

The depth of placement of the Geoweb layer influences the distribution of stresses through the system and has a significant effect on the design. Since vertical stresses are higher near the surface, optimum performance and maximum thickness reduction are obtained by placing the Geoweb as close to the surface as possible. However, in order to protect the top of the Geoweb cell walls, a 25 mm - 50 mm (1 in - 2 in) aggregate wearing surface is typically recommended.

Subgrade Strength

There are several laboratory and field test methods available to determine the strength of subgrade soils for design purposes. The calculations require soil strength to be expressed in terms of shear strength or cohesion. Shear strength can be determined in the field by the vane shear test or in the laboratory by the shear box or triaxial compression tests. Soil strength is also commonly determined by the Standard Penetration Test and the California Bearing Ratio (CBR) test. For cohesive soils, shear strength of a soil can be estimated from the standard penetration resistance (N) or the California Bearing Ratio (CBR). In the absence of field or laboratory test data, the strength of the subgrade soil can be estimated by it's consistency (see the Field Identification section of Table 4). When estimating a soil's strength by it's consistency, the soil sample should be taken from a test pit which is deep enough to ensure it's properties have not been affected by changing surface conditions (e.g. rain water, hot dry weather, etc.).

Brief descriptions of the most common test methods for determining the strength of subgrade soils are given below.

California Bearing Ratio (CBR) Test

The California Bearing Ratio test is an index test used to determine the relative strength of a soil compared to a standard high-quality crushed stone material. The test specimen is prepared by compacting a sample of the soil, in multiple lifts, into a 6 inch diameter cylinder, applying a surcharge in the form of circular plates to approximate the confining stress of the final pavement on the soil and soaking the entire sample for a period of 4 days. The test consists of loading the soil sample with a 3 square inch (1935 square mm) circular piston, through holes in the surcharge plates, at a rate of 0.10 inch (2.54 mm)/minute up to a maximum of 0.5 inches (13 mm). The CBR value is the ratio of the unit load at 0.10 inch (2.54 mm) or 0.20 inch (5.04 mm) to that of the standard crushed stone material at the same depth of penetration (whichever is higher). The unit loads are given in Table 2.

Table 2 Unit Loads for Standard Crushed Stone Material

0.1 inch penetration	1000 psi
0.2 inch penetration	1500 psi
0.3 inch penetration	1900 psi
0.4 inch penetration	2300 psi
0.5 inch penetration	2600 psi

Standard Penetration Test

The standard penetration test provides an indication of the density, and the angle of internal friction of cohesionless soils and the shear strength of cohesive soils. The tests consists of driving a split spoon sampler, equipped with a cutting shoe and attached to the end of a drill rod, into a soil by dropping a 140 lb (63.6 kg) hammer a distance of 30 inches (0.76 m). A split spoon sampler is a thick-walled steel tube, split lengthwise, used to obtain undisturbed samples of soil from drill holes. The number of blows required for each 6 inches (150 mm) of penetration of the split spoon sampler is recorded. The standard penetration resistance is the sum of the blows for the second and third increments of 6 inches (150 mm) and is termed N in blows/ft (blows/300 mm).

Shear Strength Tests

The shear strength of a soil is the stress at which the soil fails in shear. It can be calculated by dividing the shear force at which a soil fails by the cross-sectional area of shear or, if the cohesion and angle of internal friction are known, by the general Coulomb equation.

$$s = c + \sigma \tan \phi$$

where c is the soil's cohesion (i.e. interparticle attraction) expressed in terms of force per unit area

σ is the overburden or surcharge pressure in terms of force per unit area

ϕ is the soil's angle of internal friction (i.e. resistance to interparticle slip) in degrees

Granular soils do not have cohesion and therefore shear strength is governed by overburden pressure that explains why granular pavement surface materials are inherently unstable. Undrained cohesive soils (e.g. soft and saturated clays) do not have internal friction and therefore shear strength is governed by cohesion that can vary with moisture content. Drained cohesive soils can have both cohesion and internal friction.

The shear strength of granular soils can be measured in a laboratory by the shear box test. Cohesion and the angle of internal friction of cohesive soils can be measured in a laboratory for drained and undrained conditions by triaxial compression tests. In the field, shear strength can be measured by the field vane shear test. Refer to a textbook on soil mechanics or geotechnical engineering for more information about the shear strength of soils and test methods.

Angle of Internal Friction - Geoweb Infill Material

The angle of internal friction of a cohesionless granular soil can be determined by measuring the maximum shear stress at failure over a range of normal stresses (i.e. confining pressures) and plotting the results on a graph. The angle formed by the best-fit straight line through the origin and the horizontal axis is a close approximation of the angle of internal friction. See Figure 5. For compacted granular materials, the angle of internal friction is typically within a range of 30° to 40°. The higher the quality of the granular material (e.g. angularity, gradation, hardness, etc.) the higher the angle of internal friction.

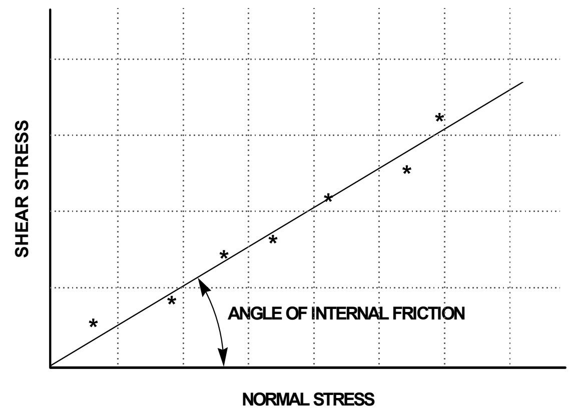

Figure 5 Angle of Internal Friction

Geoweb Cell Wall/Infill Friction Angle Ratio

The Geoweb cell wall/infill material friction angle ratio is the ratio of angle of shearing resistance between the infill material and the Geoweb cell wall over the peak friction angle of the infill soil in-isolation. It will vary depending upon the gradation and particle angularity of the infill material and the roughness of the cell wall or the size and spacing of perforations in the cell wall.

Shear box tests have been carried out to determine angles of shearing resistance between standard Geoweb cell wall treatments and typical granular materials. The results were expressed in terms of peak friction angle ratios (or Geoweb Cell Wall/Infill Friction Angle Ratio), where Peak Friction Angle Ratio is defined as the angle of shearing resistance between the granular infill and the Geoweb cell wall divided by the peak friction angle of the infill material in-isolation. Geoweb Cell Wall/Infill Friction Ratios for standard cell wall treatments and typical compacted granular materials are given in Table 3. The values presented in Table 3 are used to develop the relationships in Table 1 and base thickness in Table 5.

Table 3 Recommended Peak Friction Angle Ratio

Granular Infill Material	Cell Wall Type	$r = \delta/\phi$
Coarse Sand / Gravel	Smooth	0.71
	Textured	0.88
	Textured - Perforated	0.90
#40 Silica Sand	Smooth	0.78
	Textured	0.90
	Textured - Perforated	0.90
Crushed Stone	Smooth	0.72
	Textured	0.72
	Textured - Perforated	0.83

Design Calculations Granular Pavements

Illustrated here are the design procedures and calculations for determining aggregate thickness requirements for granular-surfaced pavements (e.g. access, utility and haul roads) both with and without the Geoweb cellular confinement system. Empirically derived bearing capacity coefficients are first used to determine the maximum allowable stress on a subgrade with either known or estimated shear strength. The maximum allowable stress is that stress which would cause local punching / shear failure of the subgrade under sustained loading conditions. Since granular pavement loads are transient, the effective strength of the soil is typically higher than it would be under static loading. Therefore, the maximum allowable stress is the limiting stress for design purposes. Boussinesq theory is then used to determine the required depth of granular cover beneath the design wheel load to ensure that the maximum allowable stress is not exceeded. The calculations outlined herein are intended for low volume roads where minor deformations are tolerable or for design of pavement subbase layers over soft soils. They are not intended for design of flexible pavement structures with paved surfaces. The calculations are only valid for granular pavement design over cohesive subgrade soils with CBR values less than 5.

Variable Names

c_u	Subgrade shear strength
N_c	Bearing capacity coefficient - based on design traffic - see below
P	Design wheel load
p	Contact pressure
r	Geoweb cell wall/Infill peak friction angle ratio
δ	Angle of shear resistance between the granular infill and Geoweb cell wall
ϕ	Angle of internal friction of the Geoweb infill material
z_t	Depth from surface to top of Geoweb cell walls
z_b	Depth from surface to bottom of Geoweb cell walls

Calculations

Determine the subgrade shear strength. Refer to Table 4 if the subgrade strength is reported in terms of Standard Penetration Resistance, CBR or by Field Identification.

Determine the maximum allowable stress on the subgrade, q_a

$$q_a = N_c c_u$$

where N_C = 2.8 (High Traffic, Low Rutting - from U.S. Forest Service guidelines)

N_C = 3.3 Low Traffic, High Rutting - from U.S. Forest Service guidelines)

Determine the required thickness of granular pavement, z_U, without the Geoweb cellular confinement system using the following equation (Boussinesq equation for estimating vertical stress at a given depth below a circular load re-written to calculate the depth of cover above a given vertical stress, q_a).

$$z_U = \frac{R}{\sqrt{\dfrac{1}{\left(1 - \dfrac{q_a}{p}\right)^{2/3}} - 1}}$$

where R = Radius of loaded area (i.e. effective radius of single or dual tires)

$$R = \sqrt{\frac{P}{p\pi}}$$

Determine the required thickness of granular pavement, z_G, with the Geoweb cellular confinement system.

Table 4 Correlation of Subgrade Soil Strength Parameters for Cohesive (Fine-Grained) Soils

California Bearing Ratio CBR (%)	**Undrained Shear Strength** c_u kPa (psi)	**Standard Penetration Resistance** SPT (blows/ft)	**Field Identification**
< 0.4	< 11.7 (1.7)	< 2	Very soft (extruded between fingers when squeezed)
0.4 - 0.8	11.7 - 24.1 (1.7) - (3.5)	2 - 4	Soft (molded by light finger pressure)
0.8 - 1.6	24.1 - 47.6 (3.5) - (6.9)	4 - 8	Medium (molded by strong finger pressure)
1.6 - 3.2	47.6 - 95.8 (6.9) - (13.9)	8 - 15	Stiff (readily indented by thumb but penetrated with great effort)
3.2 - 6.4	95.8 - 191 (13.9) - (27.7)	15 - 30	Very stiff (readily indented by thumbnail)
> 6.4	> 191 (27.7)	> 30	Hard (indented with difficulty by thumbnail)

The total required thickness of granular pavement with the Geoweb cellular confinement system is a function of the Geoweb cell depth, the depth of placement below the applied load, the wheel load and tire pressure and the infill material properties. Surface stress (i.e. wheel load contact pressure) is distributed both vertically and horizontally through the Geoweb cellular structure. Horizontal stresses, in turn, are converted into vertical resisting stresses along the cell walls thus reducing the total vertical stress directly beneath the center of the loaded area. The total resisting stress provided by the Geoweb cell structure is calculated and added to the maximum allowable stress on the subgrade for determination of the total required thickness of granular pavement with the Geoweb cellular confinement system.

The first step is to select the Geoweb section placement depth, z_t within the granular pavement structure. Since vertical stresses are higher near the surface, optimum performance and maximum thickness reduction are obtained by placing the Geoweb as close to the surface as possible. However, to protect the top of the Geoweb cell walls, a 25 mm to 50 mm (1 in to 2 in) aggregate wearing surface is typically recommended.

After selecting a trial depth of placement, calculate the vertical stress, σ_{vt}, at the top of the Geoweb section using the following equation.

$$\sigma_{vt} = p\left[1 - \left(\frac{1}{1 + \left(\frac{R}{z_t}\right)^2}\right)^{3/2}\right]$$

Next, calculate the vertical stress, σ_{vb}, at the bottom of the Geoweb section. The bottom depth, z_b, is the top depth, z_t, plus the thickness (or depth) of the Geoweb section.

$$\sigma_{vb} = p\left[1 - \left(\frac{1}{1 + \left(\frac{R}{z_b}\right)^2}\right)^{3/2}\right]$$

Calculate the horizontal stress at the top, σ_{ht}, and bottom, σ_{hb}, of the Geoweb section using the following equations.

$$\sigma_h = K_a \sigma_v$$

where K_a is the coefficient of active earth pressure.

$$K_a = \tan^2\left(45 - \phi/2\right)$$

Horizontal stress at the top of the Geoweb section, σ_{ht}

$$\sigma_{ht} = K_a \sigma_{vt}$$

Horizontal stress at the bottom of the Geoweb section, σ_{hb}.

$$\sigma_{hb} = K_a \sigma_{vb}$$

The average horizontal stress on the Geoweb cell walls is then determined as follows.

$$\sigma_{avge} = \frac{(\sigma_{ht} + \sigma_{hb})}{2}$$

Next, calculate the reduction in stress, σ_r, directly beneath the center of the loaded area due to stress transfer to the Geoweb cell walls using the following equation.

$$\sigma_r = 2\left(\frac{H}{D}\right)\sigma_{avge}\tan\delta$$

where H = Geoweb cell depth in mm (in)

D = Effective Geoweb cell diameter = 190 mm (7.5 in)

δ = Angle of shearing resistance between granular infill material and Geoweb cell walls.

$\delta = r\phi$ (obtain test data or estimate r from Table 3)

Determine the design allowable stress, q_G, on the subgrade with the Geoweb cellular confinement system using the following equation.

$$q_G = q_a + \sigma_r$$

Determine the total required thickness of granular pavement, z_G, with the Geoweb cellular confinement system.

$$z_G = \frac{R}{\sqrt{\dfrac{1}{\left(1 - \dfrac{q_G}{p}\right)^{2/3}} - 1}}$$

If the total required thickness is greater than the surface thickness (i.e. depth to the top of the Geoweb section); in addition, the depth of the Geoweb section, a subbase layer is required. The thickness of the subbase layer must be equal to the total required thickness minus the surface thickness and the Geoweb section depth.

Using the equations presented herein, Table 5 gives base/subbase thickness requirements vs. cell wall type for the Geoweb load support system, under the following load condition:

- 203 mm (8 in) depth of Geoweb section,
- crushed stone infill,
- 38 degree friction angle,
- 690 kPa (100 psi) tire pressure,
- 25 mm (1 in) depth of cover over the Geoweb section,
- 2.8 bearing capacity coefficient.

Table 5 Total Thickness of Coarse Sand / Gravel Base Including Geoweb Section

Subgrade CBR	Wheel Load		Smooth r = 0.71		Textured r = 0.88		Textured - Perforated r = 0.90		Unconfined Stone	
%	kN	(lbf)	mm	(in)	mm	(in)	mm	(in)	mm	(in)
0.2	**27**	**(6,000)**	277	(10.9)	241	(9.5)	236	(9.3)	876	(34.5)
	53	**(12,000)**	366	(14.4)	315	(12.4)	310	(12.2)	1240	(48.8)
	111	**(25,000)**	490	(19.3)	419	(16.5)	411	(16.2)	1788	(70.4)
	222	**(50,000)**	655	(25.8)	556	(21.9)	546	(21.5)	2527	(99.5)
0.5	**27**	**(6,000)**	251	(9.9)	221	(8.7)	218	(8.6)	546	(21.5)
	53	**(12,000)**	335	(13.2)	292	(11.5)	287	(11.3)	772	(30.4)
	111	**(25,000)**	450	(17.7)	389	(15.3)	384	(15.1)	1113	(43.8)
	222	**(50,000)**	605	(23.8)	518	(20.4)	511	(20.1)	1575	(62.0)
1.0	**27**	**(6,000)**	218	(8.6)	203	(8.0)	203	(8.0)	376	(14.8)
	53	**(12,000)**	292	(11.5)	257	(10.1)	254	(10.0)	531	(20.9)
	111	**(25,000)**	396	(15.6)	345	(13.6)	340	(13.4)	767	(30.2)
	222	**(50,000)**	536	(21.1)	465	(18.3)	457	(18.0)	1085	(42.7)
2.0	**27**	**(6,000)**	203	(8.0)	203	(8.0)	203	(8.0)	251	(9.9)
	53	**(12,000)**	231	(9.1)	206	(8.1)	203	(8.0)	353	(13.9)
	111	**(25,000)**	315	(12.4)	279	(11.0)	274	(10.8)	536	(21.1)
	222	**(50,000)**	429	(16.9)	376	(14.8)	368	(14.5)	721	(28.4)

NOTE: The above wheel load values are from either single or dual wheels. For axle loads multiply by 2. **This table is based on theoretical methodologies outlined herein. Values are for comparative purposes only and are not a substitute for project specific design.**

Available Tools & Services

Presto and Presto's authorized distributors and representatives offer assistance to anyone interested in evaluating, designing, building or purchasing a **Geoweb Load Support System**. You may access these services by calling 800-548-3424 or 920-738-1707. In addition to working directly with you, the following design and construction resources are available for your use with the **Geoweb Load Support System**.

Design	Material and CSI-format Specifications, System Components Guideline, Request for Project Evaluation, AutoCAD® Drawings, SPECMaker® Specification Development Tool, Technical Resources Library CD, videos
Construction	Installation Guidelines, SPECMaker® Specification Development Tool, Technical Resources Library CD, videos

Disclaimer

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