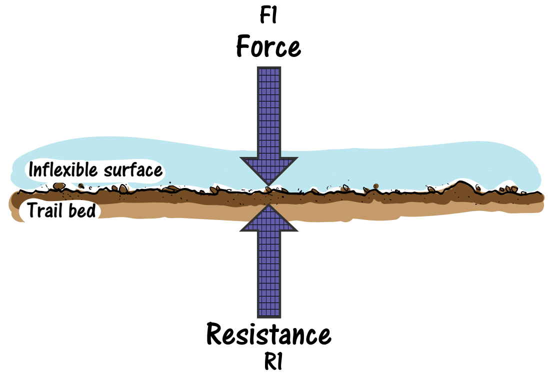
Chapter Six

Tools in the Toolbox: Soil Stabilization and Trail Hardening

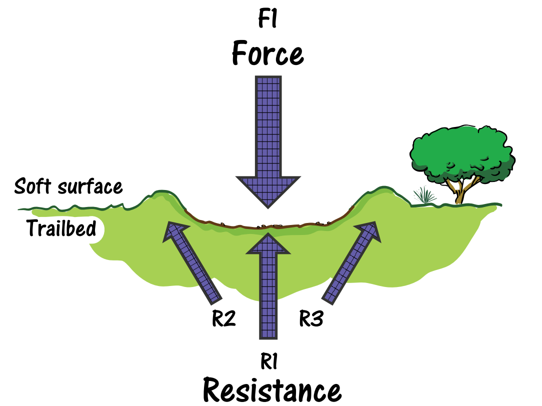
There are times when trails must go through wet areas or soft soils, and there are times it is desirable to have them there to enhance the scenic quality, variety, and rider experience. There are times when no matter how good the soil is, it can't withstand the vehicle volume of use or weight. There are also places, as in road and structure crossings, where the approaches need to be enhanced to ensure smooth transitions. All of these scenarios require some type of tread reinforcement.

Chapter 4 discussed the physical forces and the fact that for every force down, there is an equal and opposite force up. On a hard surface, the upward force is equal to and directly opposite the downward force. As the surface softens, the vertical upward force decreases and lateral upward forces increase resulting in soil displacement and berms. A goal for a durable trail is to minimize displacement, and one way to accomplish that is to increase the strength of the tread surface.

There are two ways to increase the strength of the tread: stabilization, where another material is mixed into the soil, and trail hardening, where another material is added on top of the soil. Before discussing these two methods, Section 1 explains geosynthetics, which are often used in both soil stabilization and trail hardening.



Resistance = Force (R1=F1)

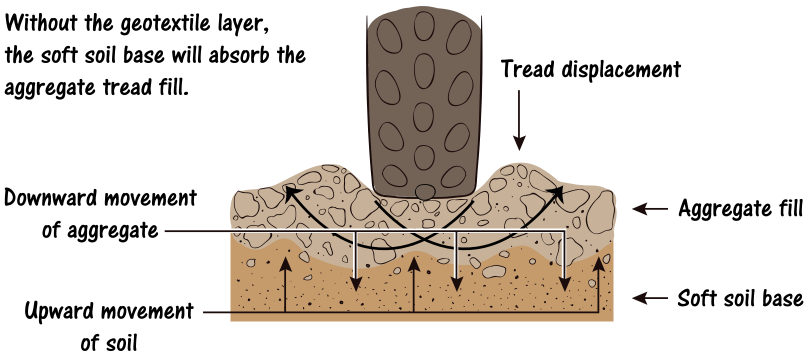


Resistance = Force (R1+R2+R3=F1)

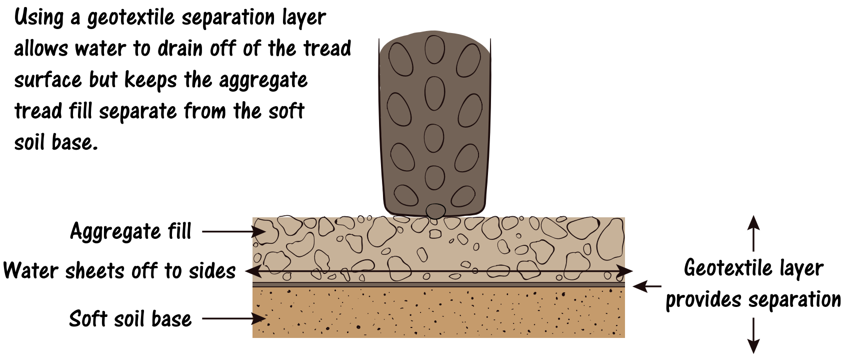
Section 1: Geosynthetics 101

Geosynthetics Defined

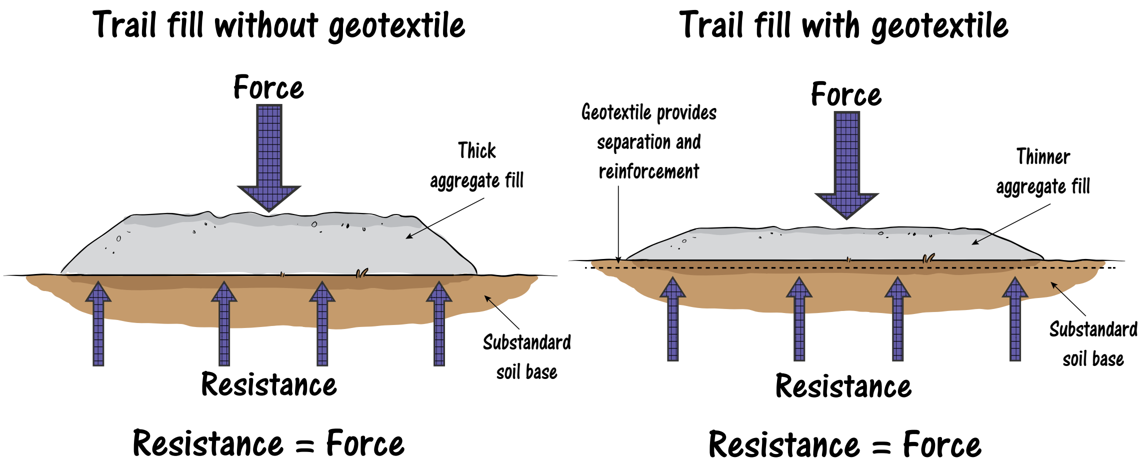
Geosynthetics are synthetic polymers that are woven or formed into a variety of shapes. These materials perform six major functions: reinforcement, separation, drainage, filtration, containment, and erosion control. The first four functions are most commonly used for trails and are explained below.



The tough polymer fibers give the geosynthetics lateral and longitudinal tensile strength, which provides reinforcement and helps prevent deformation under a load. This tensile strength distributes the load over a wider area reducing the PSI of the load and improves the weight-bearing capacity of the material above it. Since the geosynthetic supports much of the load with little deformation, less force is directed down into the layer of soft soil resulting in less displacement and less subsoil pumping. The geosynthetic acts as a structural bond between the good upper layer and the poor lower layer, which increases the weight-bearing capacity of both layers. Using a geosynthetic or a geosynthetic layer can reduce the amount of fill needed on a tread surface, saving costs and maintenance in the long-term.



A layer of geosynthetics is used for separation and prevents good material, like crushed rock, from intermixing with poor material, like soft or saturated soil. For example, many times rock is placed in a mud hole but in a couple of years it has disappeared. When moisture conditions are right, the rock gets pushed into and absorbed by the soft soil. Geosynthetics provide important separation of and reinforcement between the layers of rock and soil.



Some geosynthetics are used for drainage and designed to allow water to drain laterally across them so water is diverted off to the sides rather than down, which reduces the saturation of the subsoil and increases its strength.

Some geosynthetics are used for filtration and designed to allow water, but not soil, to pass through their pores. It is this filtration property that makes silt fence and French drains so effective.

Common Geosynthetics Shapes

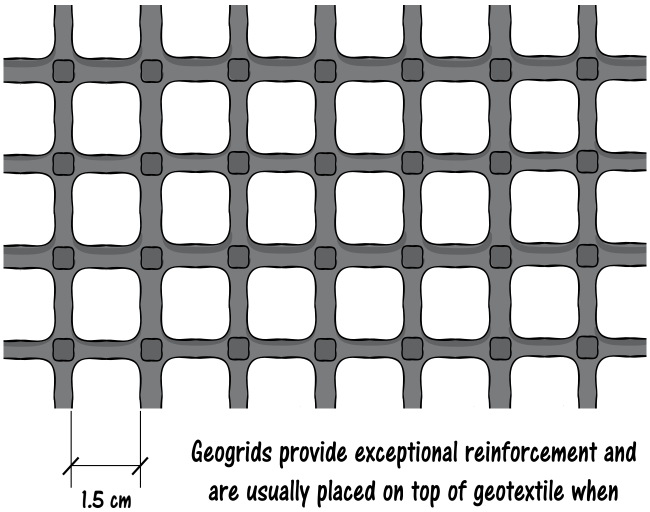
The most common geosynthetics shapes are: geotextiles, geogrids, geonets, geocells, grass pavers, and geocomposites.

Geotextiles are synthetic fabrics that are most commonly used for separation, reinforcement, and filtration. These are great for OHV trails because they allow water but not soil to seep through and their tensile strength can support heavier loads.

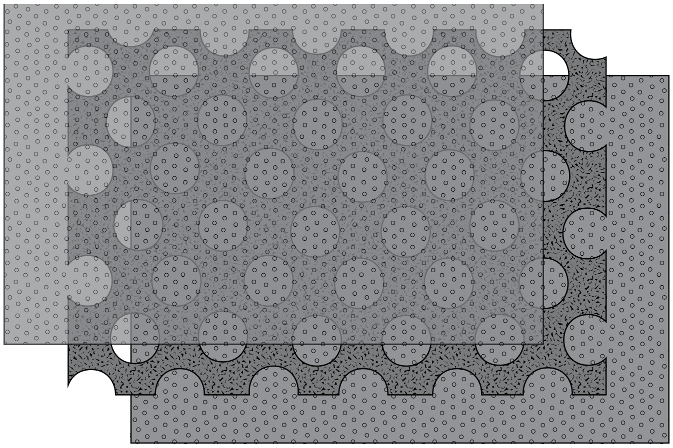
Felt like products are easier to use than slick products because they are easier to cut and place on curved trail sections.

Geogrids are polyethylene strands that are bonded into a grid pattern like a fish net. They are heavier and less flexible than geotextiles and therefore provide a higher level of reinforcement. They are often used in retaining walls and buttresses for added strength and shear resistance. For OHV trails in wet areas, geogrid is often put down over a layer of geotextile fabric and topped with a layer of coarse rock. This combination provides a superior level of separation and reinforcement.

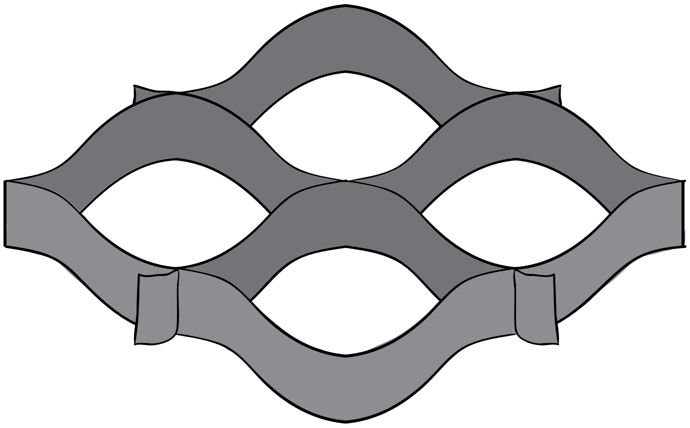
Geonets are a composite consisting of a thick geogrid sandwiched between two layers of geotextile. Because there are two layers of fabric, they provide excellent separation and reinforcement, but they are primarily designed to allow water to flow through the center grid and off to the side of the trail.



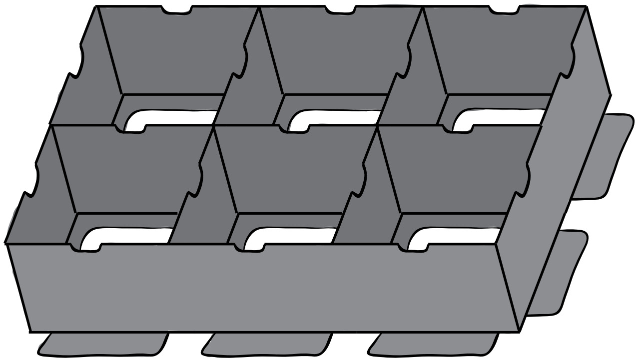
Geogrids provide exceptional reinforcement and are usually placed on top of geotextile when separation is also needed.



Geonets are considered a geocomposite because they incorporate more than one type of geosynthetic.



Geocells open up like an accordian and provide great lateral containment. The fill material needs to drain well so it doesn't squish out of the cells.



Grass paver is tough and rigid which provides excellent reinforcement while allowing for direct tire contact.

Geocells are polyethylene strips that are bonded into a honeycomb shape. They come in a variety of thicknesses, and are shipped flat for easy transport and then expanded on site. Once expanded, the honeycomb is filled with good soil, rock, or a mixture, which is then compacted. The cells contain the material so it can't displace out to the sides and each cell provides increased load-bearing and rigidity. The primary function of geocell is to provide reinforcement, not separation, so when it is used in a wet area with saturated soils, a layer of geotextile is put down first to provide the necessary separation.

Grass paver is a category of very stiff panels that can provide cellular containment like geocell but has a partial bottom that gives it excellent reinforcement properties. The panels interlock, which helps to distribute the load, reduce PSI, and stabilize the structure. Lightweight and easy to use, this is the one category of geosynthetic that is designed for direct tire contact.

Geocomposites such as sheet drains have a large cross section that allows drainage. If geotextiles are placed under the trail tread, the sheet drain should be oriented with the geotextile on the bottom and the plastic core on top. This orientation reduces the amount of fill needed.

Tip, Trick or Trap?

Trap: Installing only geotextile under a non-cohesive soil is not a quick fix

Why? Because the tires will quickly displace the soil cover and expose the geotextile. Once that occurs, the integrity of the structure will be compromised and it will rapidly deteriorate.

This is an excellent example of boxing in the trail hardening to provide lateral and longitudinal support. Unfortunately, the cover over this geocell has been lost and the structure is rapidly degrading. The large cobble rock in the center section is actually holding up better.

Here are some key points on geosynthetics:

- The need for any structure requiring a geosynthetic is a potential red flag indicator of poor trail location. Explore other options first, if available.
- Some geosynthetics are not UV stabilized so they deteriorate when exposed to the sun. Check specifications before purchasing and store them in their original wrappers out of sunlight.
- Ensure that the fill material covers the entire top and sides of these UV sensitive geosynthetics and is maintained at this level. Geosynthetics are tough, but most are not designed or intended to be used as the tread surface. Forces from the tires will quickly break down the material, tear it, and displace it.
- When used for trail hardening, the geosynthetic installation must be wider than the designed trail width. The more the load is centered, the more effective the weight-bearing will be. This keeps the tires off the shoulders of the installation, which protects them from displacement.
- Because of its reinforcing property, less fill is needed with a geosynthetic to attain the same weight-bearing capacity as a fill without it. This reduces the amount of material that needs to be hauled in and reduces the cost of the installation.

Tires and geotextile do not mix.

Section 2: Soil Stabilization Techniques

Just as gardeners treat the soil to add nutrients and organic matter, trail designers can fortify some soils to add structural strength. The intent is to give the soil the ideal clay content for binding and the ideal rock content for loadbearing strength. Benefits include increased strength to withstand heavy traffic pressure (reduced displacement), reduced sedimentation (soil loss), and increased intervals between heavy maintenance operations. Another advantage of stabilization is that in most cases, the trail retains its natural appearance and character, which enhances the rider experience. Designers should consult with an engineer, geologist, or soil scientist to determine the best treatment for a particular soil. The amendment process is simple: excavate the top layer of the tread, mix in the amendments usually with a rototiller or similar machine, spread the mixture back out onto the tread, add water if available, and compact it with a roller. Adding a layer of geosynthetics between the original soil and the treated soil will further increase the durability of the trail.

Tip, Trick or Trap?

Tip: The fist test: a simple field test for assessing water content and soil strength

Put a sample of soil about the size of a golf ball in the palm of the hand and make a tight fist. If the mass easily flakes apart, it is dry and below the Optimum Moisture Content. If the mass is firm and resists breaking apart, it is at or near the OMC. If water squeezes out of the soil, it is wet and above the OMC.

Soil Stabilization Materials

There are five common types of soil stabilization materials: clay, lime, aggregate, mix, and chemical.

A non-cohesive soil is one that has a low clay content. One way to remedy that is to add clay as a binder. This will not work for fine-grained soils like sand because the clay adds binder, but not load-bearing capacity. However, if the soil is course-grained with a high rock content, just adding clay can work quite well. There can be a fine line between not enough and too much clay, so getting the right mix is important but hard to control in the field.

Above, a rototiller on a 3-point tractor hitch makes an effective mixing implement. Below, an adjustable spreader box towed behind an ATV was used to measure out bentonite clay. The clay was too fine and the spreader box did not work well.

Lime has long been used to stabilize wet soils, especially wet clay soils. It dries the soil, bonds it together, and increases its load-bearing capacity. It has been successfully used under roads, runways, and building foundations, but there is little documentation on its use on motorized trails.

Some soils have a high clay content, but not a high rock content. Adding aggregate, which binds with the clay, increases the structural strength of the soil. Crushed rock works the best because it is highly angular and the rock points tend to lock the rock in place, but other rock can work also.

For non-cohesive fine-grained soils like sand or pumice, the soil lacks clay and rock content, so amending the soil with a mixture of clay and aggregate can work quite well.

Bentonite clay being rototilled into non-cohesive pumice soil.

A variety of chemical products are available which provide dust abatement by stabilizing the tread surface. Some are salts like magnesium chloride and calcium chloride and some are polymers like Road Oyl®, Soiltac®, Envirotac®, and Soil-Sement®. To be effective on trails, these products cannot be applied topically and must be disked or rototilled in for deep penetration. While there have been some studies of chemical stabilization for accessible trails, there has been limited testing of its use for OHV trails.

As an experiment, a section of this heavily used trail was stabilized with crusher reject (often called dirty rock, it has a lot of fines and angular material which can bind up like concrete). The rock was rototilled into the non-cohesive soil in an attempt to reduce displacement and mogulling. It worked. Ten years later, the stabilized section is firm and has retained its original prism while both ends have heavily displaced and moguled.

Tip, Trick or Trap?

Tip: The ribbon test: a simple field test for assessing the clay content of the soil

Add water to a sample of soil until it is at its optimum moisture content. Then take a small sample of soil about the size of a golf ball and squeeze it into a ribbon between thumb and forefinger. If the ribbon breaks apart in <1” sections, the soil is sandy. If the ribbon breaks in <2” sections, the soil is a clay loam. If the ribbon is >2” sections, the soil has a high clay content.

For some soil types, a variety of chemical dust abatement treatments can help stabilize the soil as well as prevent dust.

Here are some points regarding soil stabilization:

- Even with a mix design from a specialist, field application and mixing methods are crude at best and consistency is difficult to attain.
- The application and mixing is labor and equipment intensive and thus expensive.
- Because of the cost, a common mistake is making the stabilized soil layer too thin. Tire action can quickly break through it creating potholes and maintenance equipment can quickly wear it away. Minimizing the design to save money is a false economy.
- Unlike a road, runway base, or building foundation, trails have roots and rocks. In order to obtain a uniform depth and consistent mix, those need to be taken out, which adds to the cost and detracts from the naturalness of the trail.
- If chemicals are being considered, check for regulations that prohibit or restrict their use. A permit may also be required.
- When considering a project, check with local road or trail authorities to see what their experience has been. There may be a local mix or a local material that has exceptional qualities.
- Don’t be afraid to experiment.

When the spreader box plugged up, the eyeball measuring and hand distribution methods were used.

Section 3: Trail Hardening Techniques

Gravel and Stoning Reinforcement

This trail has been hardened with open graded crushed limestone from a nearby source. The trail drops into a sensitive watershed and hardening was required as a mitigation to reduce potential sedimentation. Though the rock was inexpensive due to its proximity, the poor gradation does not provide sufficient binding to prevent moguls on this grade, so maintenance costs are high.

Often the easiest and cheapest way to harden a wet spot or a soft spot is to simply add rock to it. A well-graded crushed rock works the best since the fine components fill in the voids between rocks and the crushed angles lock the whole mass together. Because crushed rock binds together so well, it is more impervious to water, which helps prevent the further saturation of the underlying soil layer. Most times people use whatever material is readily available to save cost. That's okay, try it and see how it works. Typically, the rock should be 3 - 4" or less. Anything larger than that can be too rough to comfortably ride with a motorcycle, but may be okay for ATVs, ROVs, and 4WDs.

With a nice serpentine alignment, this hardened trail harmonizes with the landscape. Notice the tightly compacted densely-graded aggregate.

Stoning works well in soft non-cohesive soils and in seasonal wet areas. It does not work in perpetually saturated soils. Stoning provides a host of benefits: a) it provides both bearing and binding for increased weight capacity and decreased rutting and displacement; b) it reduces or eliminates trail widening or braiding by creating a firm trail tread; c) it protects the underlying soil layer from erosion thus reducing sedimentation; d) it has a rough surface and doesn't form rills so it reduces the velocity of the surface water, which makes it easier to drain water off the trail; and e) being more durable, it increases the interval between required tread maintenance.

On the negative side, stoning: a) reduces the naturalness of the trail and detracts from the rider experience; b) can conflict with the aesthetics of the setting, especially if the rock color does not harmonize with the landscape; c) can cover up roots and rocks that are challenge features; d) can increase speed and therefore decrease seat time; and e) in wet or clay soils, can gradually sink in and need replacement.

This straighter alignment and light color aggregate makes the installation more visually intrusive.

This rock is almost uniform-graded. While it will reduce the velocity of water running down this trail, it has no binder to hold it together. Given the steep grade, this rock will quickly displace and form wheel ruts as the tires seek firm ground to gain traction.

A Closer Look...

Rock mixtures like crushed aggregate are categorized by the size of the largest rock size and the mix of progressively smaller particle sizes. There are three main categories:

- Uniform-Graded. This is rock where all the particle sizes are about the same. A 4" UG would have all rocks about 4" in diameter. There are no fines to fill the voids, so the rock does not compact or bind together well, but it does allow water to drain through it.
- Open or Poorly-Graded. This has a mix of particle sizes, but they may not be progressively smaller. PG will bind together better that UG, but will not stay compacted and will not drain water as well.
- Dense or Well-Graded. This rock has progressively smaller particle sizes so that all voids between the particles are filled. WG compacts tightly, stays bonded together, and has the best weight-bearing capacity. Water will run off the surface rather than drain down through it.

Due to a lack of load bearing, tire ruts have developed as this fine rock has been pushed into the mud.

Other Trail Hardening Materials

There are seven other commonly used materials for trail hardening: cobble reinforcement, geotextile fabric, grass pavers, geocell, pavers, slab rock armoring, and tire mats. There are also inventive materials or "others".

Cobble reinforcement is similar to stoning except it uses rock that is 6 to 10" or less in size. Cobbles work well because they have a large surface area for increased load-bearing and that surface area also reduces the tendency of wet soils to suck the rock down into oblivion. Because cobble rock is usually uniform-graded, the voids between the rocks allow water to run through them, thus providing load-bearing as well as drainage. This is why cobble rock is used in drains.

In wet, mucky areas, cobble rock is often put down first, worked into the ground, and then covered with a layer of smaller-sized gravel. This allows water to drain through the rock subsurface, but the tread surface is smoother. The combination has less displacement since a mix of particle sizes holds the tread surface together.

When soils are wet more frequently than seasonally or if they are saturated, any applied gravel or cobble will eventually get sucked down into the soil and disappear. In this case, a layer of geotextile fabric will provide separation of the wet and dry layers and provide reinforcement by distributing the load over a wider surface area. This technique is simple, effective, and probably the most widely used trail hardening method.

This mixture of cobble and smaller rock is being spread over a layer of geotextile to provide load bearing for this ROV trail.

The trail through this draw used to be a mudhole in the spring. A layer of 8-10" cobble rock was put down and then topped with a layer of finer 4-6" cobble rock. It has not displaced after four years of heavy use. Even in a wet year, the cobble provides bearing while allowing water to run through it and over it.

Geotextile Fabric. When soils are wet more frequently than seasonally or if they are saturated, applying gravel or cobble won't be a long-term fix. Eventually, the stones will sink into the soil and disappear. In these cases, a layer of geotextile fabric will provide separation of the wet and dry layers. It will also provide reinforcement by distributing the load over a wider surface area. This technique is simple, effective, and possibly the most widely used trail hardening method.

Note the flared inlets on the culverts. These not only funnel the water into the culvert, but also retain fill material to keep it from sloughing off into the culvert.

Geotextile is being put down to provide separation and reinforcement on this Alaska trail.

Grass pavers can be placed directly on the surface with sandy or wet soils or placed on a layer of geotextile in saturated soils. The geotextile provides separation and additional reinforcement. Some varieties of grass pavers are the only geosynthetic that can take direct tire contact. It can be used as is or covered with a layer of fill for additional support and a more natural appearance. When placed directly on the surface with no geotextile or fill layer, the holes in the bottom of the panel allow vegetation to grow up through the panel. This results in less site disturbance, increased soil stability since the root zone is not disturbed, and increased visual appeal. The panels can be easily cut in the field to create curves or irregular shapes. Geoblock® is a grass paver often utilized for OHV trail hardening.

This is a good installation that is confined on the sides and segmented into blocks with treated timbers. However, water has not been managed and the cover of fill is being eroded away. Over time, this will weaken the structure and make it more slippery to ride. Tire impact forces on the timber may cause it to dislodge resulting in potential movement of the grass paver panels.

If only dual-track vehicles use this trail, why armor the entire width? The geotrack installation uses two rows of grass pavers attached to plastic timbers. Note how the grass pavers have been cut to form an angle. The entire installation was then covered with soil and rock.

Though able to withstand tire contact, grass pavers will break down under repeated tire impact. This end panel should have been angled down into the soil to provide a shallower impact angle. It could also be protected with a log or treated timber pinned into place. The left side has been dug down and is confined and protected, but the right side is vulnerable to damage by tires and should have been framed in or protected by fill. It appears that riders are avoiding the approach impact and are riding off to the right.

Grass pavers makes an excellent hardened approach to this bridge installation.

They did a nice job of making a circular curve on this installation, but a poor job of confining it. Unfortunately, riders are short-cutting it either to avoid the structure or to take a quicker path and the edges of the GeoBlock will start to break down. Strategically placed debris or a barrier would remedy this.

Notice how the installation was excavated down below natural ground elevation. This provides containment and support for the structure. The cells were filled with uniform graded rock and then everything was covered with fill layer of soil and rock. Maintaining an adequate cover layer is critical to ensure the integrity and longevity of the structure.

Geocell is commonly used for retaining walls and other support structures like bridge abutments. It is available with perforated or non-perforated cell walls. It has been used for trail hardening, but many of those installations have failed due to the lack of maintaining an adequate layer of fill. Geocell will disintegrate if exposed to direct tire contact.

One advantage of geocell is that it is easy to make curves. In this installation, geotextile has been placed under the geocell to provide separation and additional support.

The fill for this bridge approach and bridge abutments has been constructed in layers of geocell filled with a good soil and rock mix. Note the grass paver panels to insure a smooth transition onto the bridge deck.

The fill layer over this installation was not maintained. Direct tire impact displaced the material in the cells and destroyed the integrity of the structure.

This geocell bridge approach is in the process of disintegrating. Bridges and other structures can be very slippery. Having an approach on a curve is not desirable since the vehicles are still on the curve once they hit the bridge deck which increases the risk of losing control and sliding into the railing. The curve also creates more lateral tire forces which act to increase displacement on the geocell and deck approach. Note the lip on the bridge abutment (arrow). This will bounce a motorcycle tire off the ground and increase the risk of sliding on the bridge deck.

Tip, Trick or Trap?

Trap: Never assume that the pavers will stay in place because they are heavy concrete with edges that will bite in

Anchor or confine the pavers. OHVs exert tremendous rotational and lateral forces that must be counteracted by strong anchors.

This is an excellent example of a trail hardening installation that will likely fail. On the plus side, the material is framed into sections which help prevent movement. The gap between these two sections (yellow arrow) serves as a log culvert. On the minus side, this cobble surface is rough to ride on and the rotation action of the tires will displace the rocks out of the Geocell (red arrow) and the exposed cells will start to break down. The life and functionality of this structure could have been extended if it had been covered with a layer of well-graded aggregate.

Both of these pavers are designed to interlock. These are easier to install and they allow for flex, but they resist lateral movement. The ones on the right are pre-formed with holes so they can be tied together which further inhibits movement.

Pavers include concrete blocks and cinder blocks. When installed properly, these are tough, durable, and can withstand direct tire contact. The concrete edges provide traction, so pavers can be used on very steep grades. They are heavy, so transport into the site can be a challenge, and their installation is labor intensive, but pavers are one of the most commonly used trail hardening methods.

There are as many examples of poor installations using pavers as there are of good installations, but here are three points to ensure success with pavers:

1. The pavers must lay on a smooth, even surface. The bedding could be compacted native soil if it is a cohesive soil that won't displace. Compacted gravel will provide a firm bedding and bearing for the pavers. If the soil is always wet, a layer of geotextile can be put down under the bedding material to provide separation and reinforcement. Roots, rocks, or any surface protrusions can cause a paver to break or move.

2. When pavers are allowed to move, the installation will be doomed to failure. They must be thoroughly anchored or confined in place to prevent movement. It is easy to assume that since they are so heavy, they will never move.

3. In some soils, such as non-cohesive soils like sand, pumice, or wet muddy soils, the pavers are likely to move even if they are pinned. Also, factors like the grade and alignment can affect the forces being placed on the installation. A 100' stretch of pavers on a 35% grade exerts huge downward forces on the bottom pavers and enough force for the installation to eventually blow out at the bottom. The best, most durable, and longest lasting installations are divided into sections and are confined on all sides with logs or preferably 4x4 or 6x6 treated timber that is pinned in place. Each section performs independently and has no impact on the others. Downward and lateral forces are controlled and contained and the pavers cannot move. An additional benefit of framing is that the edges are supported and protected. This helps prevent breakage. As soon as breakage starts to occur, movement will soon follow.

A Closer Look...

A key consideration in the design of any trail hardening, but especially rigid structures like pavers and slab rock, is the forces being applied to them. Vehicle size and weight are factors, but more important is the vehicle width. Vehicles with solid axles or locked axles have different rates of rotation between the inside wheel and the outside wheel. The wider the axle, the bigger the rotational difference. This results in the exertion of twisting forces that cause either the tire to spin and hop, or the tread surface to twist and move, or both. Structures that are poorly bedded and confined can be displaced and destroyed by these forces. Acceleration will compound the forces, so where possible minimize grades or grade changes on hardening structures. Also, the larger the turning radius, the less rotational difference between the inner and outer tire, so larger radius turns will have less impact than small radius turns. This is especially important on climbing turns, which combine grade changes with the directional changes. Interlocking pavers or structures that are confined with frames will help resist these forces.

Depending on the availability of materials or access to the site, flat flagstone-type rocks or other materials can be used to harden short sections of trail. As with pavers, proper bedding and prevention of movement are essential.

The approach to this technical step-up is being armored to prevent the step from getting higher and eventually becoming unrideable.

These rock slabs are well-placed and keyed together, but they lack confinement. Rotational and centrifugal forces will gradually displace them.

Recycled tire mats have been available in some fashion for many years. Though using recycled material is good for the environment, the mats to date have not held up well to the forces of OHV use.

Right and above, once again, the key to success is keeping the material anchored. Once it is allowed to move, it will self-destruct.

Trail hardening can be expensive, but there may be local sources of materials available for free that might work quite well. Don't be afraid to experiment. Trying something and having it fail may be disappointing, but it's probably still better than doing nothing at all.

This hardening installation is composed of chunks of sidewalk that was headed for the landfill. Being heavy and angular, the pieces should key together very well. Notice that they have been embedded so that the edges are contained by the natural soil.

This hardening installation is another recycling project. A brick and concrete high school was being torn down and was headed for the landfill, but a heads-up project planner thought to grind it up and try it for trail hardening. The material was free, it worked, and it set up like concrete due to a good mix of particle sizes. This was a win-win for the project, the community, and the environment.

Here are some things to consider about trail hardening:

- Product manufacturers can assist in product selection, application, and design specifications.
- A key consideration before installing any trail hardening is how it will be maintained. A relatively thin layer of fill over a structure requires awareness and a light touch by maintenance workers, especially when using equipment.
- It is also critical that the layer of fill over a structure be maintained at the designed depth to prevent exposure and damage to the material underneath.
- In areas with limited trail access points, another consideration is how maintenance equipment will be able to get from one end of the installation to the other without damaging the structure. If the maintenance equipment is a trail dozer with steel tracks, what will that do to pavers or grass pavers without a layer of fill?
- Placing heavy angular material directly on top of geotextile can tear the fabric and affect the integrity of the structure.
- Don't be afraid to experiment with unusual or locally available materials or methods.
- Trail hardening projects can be labor and equipment intensive so they can provide great opportunities for volunteer work parties or for creatively seeking new partnerships for the task and project.
- Depending on the soils, reducing speed and increasing the flow of the trail by changing the alignment can reduce the need for hardening in some situations.
- Trail hardening is often seen as a "fix" for steep grades and excessive erosion, but the forces at work need to be understood. Tire action and displacement is one, but water volume and velocity is the other. Hardening does little to manage the water, so it is essential that as much water be removed from the trail as possible before the water gets to the installation.
- It may be better and less expensive in the long run to move a trail instead of hardening it.

The Good...

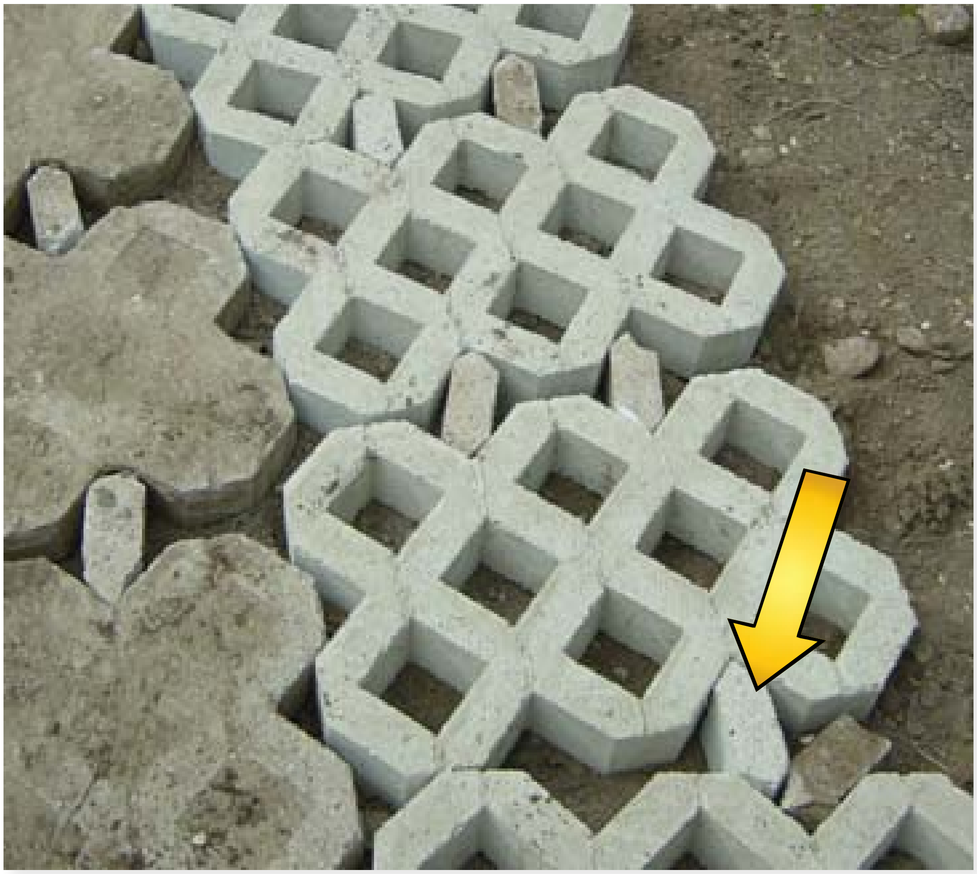
This installation has been framed in which not only resists movement, but provides lateral support and decreases the chance of breakage.

The eroded trench of this site provides natural containment for the blocks. The fill is a densly-graded aggregate that is holding together nicely.

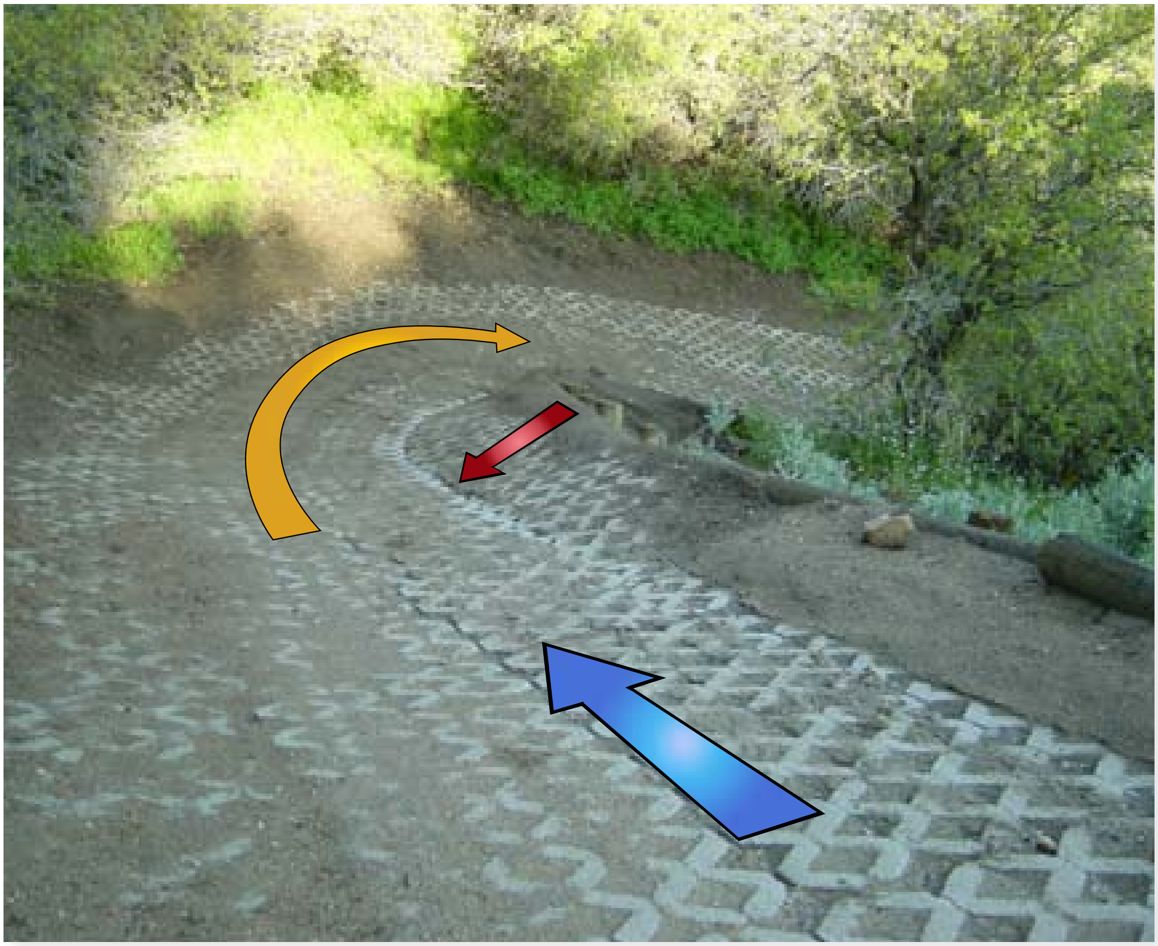
To help manage tire forces, it is important to have a smooth transition onto any structure. Here, the last four end blocks are angled down into the soil. This also helps anchor the structure and resist movement.

Not contained or framed, but this soil binds like concrete. The logs are pinned in a wishbone pattern to help drain water off to the sides and to force riders to stay on the structure. This is a nice touch.

Well contained, these blocks make a beautiful and functional approach to this bridge deck.



These blocks are being laid to form a curve. Notice how spacers have been placed to maintain the shape and resist movement.



This is a beautifully hardened climbing turn. The edges have been embedded and are well protected. The curve is super-elevated so speed is easily carried through the turn and lateral forces are reduced which helps to minimize the risk of block movement. Riders hug the inside edge, so the inside is armored which keeps riders on the structure and resists breakage of the edges. The V on the inside edge also keeps water on the structure and resists erosion.

This steep grade approaches 30%. The sides are contained by the shape of the site and the installation is framed to absorb the downward forces. Nicely done. It is essential that the water be effectively managed before it reaches the top of this slope.

These interlocking blocks are being tied together to build this ford. This design resists movement from the lateral forces of the water, but still allows a little flex in the structure. Any non-interlocking blocks would not stay in place and would soon fail in this situation.

The Bad...

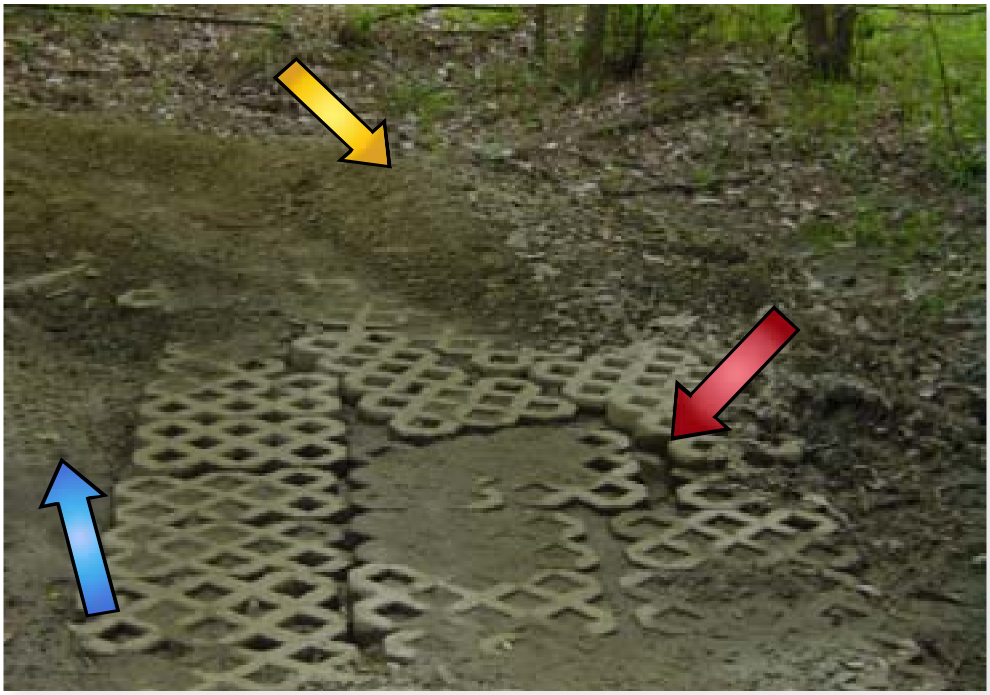
This armored drain dip is a great idea, but is subject to failure. Why?

1. The curve in front of the bike will exert lateral forces on the single row of blocks and they will be subject to movement.
2. The sharp angles of the blocks armoring the crest will receive increased impact forces from the tires which will result in movement.
3. The right edges of the blocks on the crest are poorly supported and these blocks will likely slough off to the right as the fill softens and erodes.
4. Riders will tend to use this as a jump which will increase the forces imposed on the structure.

The edges are not contained and will be subject to movement and breakage (yellow arrow). The blocks were poorly bedded (red arrow) creating an irregular surface which will result in movement and breakage. Water has been poorly managed (blue arrows). Soils saturated by the pond will allow the blocks to sink, deflect, and eventually break. A lead-off ditch should have been constructed on the left to drain the low area (maybe it was, but poorly maintained). The log on the right actually inhibits water flow into the grass behind it and deflects the water onto the trail which increases ponding.

For the most part, these pavers have been embedded to resist movement. The leading edge (blue arrow) should have been angled down for a smooth transition or otherwise protected with a treated timber. Without frontal support, the leading edges will be subject to breakage. All of the roots were not removed (yellow arrow) so there is irregular bedding which will result in movement and eventual breakage and failure. As the trees grow and roots expand, they will pop out the pavers.

It looks like this structure had a cover of fill at one time. The curve has caused displacement of the material and has formed a berm on the outside edge (yellow arrow). Water apparently drains across the middle which has washed away the fill material there. Due to the curve, the lateral forces are starting to move the blocks. Notice the increased gap (red arrow) between the outside blocks and the inside blocks. Riders are also being allowed to short-cut the structure (blue arrow) and ride off the inside edge. This will lead to block breakage and movement.



What's wrong here?

1. The steep uphill road approach does not allow riders a place to easily stop and start up again, so they probably won't stop at all.
2. The stop sign nailed to a tree is obscured by vegetation and does not allow adequate sight or reaction time. It should be on a post within 24" of the trail.
3. Concrete blocks have a taller profile than other blocks. This makes them more prone to movement and breakage, so it is more critical that they be confined.
4. Water draining off the road (arrows) is eroding the right edge of the blocks which will increase the risk of movement and failure.

Bedding and containment are important because concrete blocks are brittle. Note the broken blocks (yellow arrows) on this relatively new installation. The wide gap between these blocks (red arrow) will invite movement. The railroad tie provides a strong anchor for the bottom of the structure.

Tip, Trick or Trap?

Trap: Manage your risk

Poor construction + poor maintenance + poor management = Increased tort claim risk.

The Ugly...

Poor bedding + no containment + movement = failure. You can see (arrows) where riders are going up the right side to avoid this installation.

No containment, no protection for any of the edges, and uneven surfaces. Note the settling that has occurred (arrow) between the two rows of blocks. Given a choice, which there is, any rider would avoid this.

Pavers poorly bedded and placed on an uneven surface of rocks will move and fail.

The results of a poor installation: broken pavers, two eroded trenches instead of one, risk, resource impacts, and a mess.

Poor paver installation in this stream crossing resulted in resource impacts. Cobble stone would have been a better choice.

Need more? Learn more here…

Geosynthetics for Trails in Wet Areas: 2008 Edition, USDA Forest Service, Technology & Development Program, 0823-2813-MTDC, April 2008

Managing Degraded Off-Highway Vehicle Trails in Wet, Unstable, and Sensitive Environments, USDA Forest Service, Technology & Development Program, 0223-2821-MTDC, October 2002

Wetland Trail Design and Construction, USDA Forest Service, Technology and Development Program, 0123-2833-MTDC, September 2001

Having an army of volunteers certainly helps with a trail hardening project.

A Look Back…

Here are some of the elements discussed in this chapter:

- Soil stabilization and trail hardening are primarily needed in:
  - Soft soils
  - Wet soils
  - Any soil that cannot support the vehicle volume or weight
  - Structure approaches (including roads)
- Stabilization is mixed into the existing soil, trail hardening is placed on top of the existing soil
- The need for stabilization and hardening can be a red flag indicator of poor trail location, excessive grade, or poor soils. Look for alternatives where appropriate
- Geosynthetics provide reinforcement, separation, drainage, and filtration
- Except for grass pavers, tire contact with geosynthetics must be avoided
- When applying stabilization products, it is difficult to attain a consistent mix design in the field
- Stabilization and hardening methods are expensive and labor-intensive. Cutting corners in the design or installation will affect the longevity and integrity of the structure.
- Hardening products need to be properly bedded, confined, and anchored to resist movement.
- Don't be afraid to experiment such as using local material sources or seeking local expertise
- For installations that have been designed and built with a fill layer, it is critical that the depth of that fill is maintained over time. If that isn't likely to happen, consider another option.
- Engineers, geologists, soil scientists, etc. can have valuable insight. Consult them during the planning.
- While planning hardening and repairs, consider the largest and heaviest vehicles using the trails including reconstruction equipment; especially steel tracked equipment
- Hardening is a manmade structure that is added onto the trail. Manage your risk through proper design, installation, maintenance, and management.