Using Confined Aggregate Concrete to Reduce Erosion on Unpaved Shoulders, Roads and Trails, and other Venues

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Abstract: Pavement shoulders are a key element in the design of safe and efficient highways. The problem of erosion of unpaved road shoulders and of unpaved rural roads is a major ongoing, costly safety and maintenance challenge in every nation. This article looks at erosion as basically caused by limited and/or inadequate lateral support for soils and aggregates as they resist the flowing water's kinetic energy. It articulates the mechanism of failure and offers an economical method for providing permanent direct lateral support for aggregates and soils that form the unpaved traffic way or other natural or man made soil or stone structures.

Overview

Pavement shoulders are a key element in the design of safe and efficient highways. The most significant benefit of the pavement shoulder is its role in highway safety. Properly designed, constructed and maintained highway shoulders provide the driver with a margin of safety when the vehicle wanders out of the main travel lane. In today's world of increasing driver distractions due to information technology and lifestyle the shoulders role in safety is of increasing importance. While high volume roads often have paved shoulders, most medium and lower volume roads have granular, unpaved shoulders which are subject to erosion.

The development of the first paved roadways quickly highlighted the problem of erosion of unpaved shoulders and embankments caused by direct runoff from the impervious pavement. Shoulder washout and its associated drop off has always been a widespread problem in every nation with paved roads and granular shoulders. Unpaved highway shoulders are vulnerable to erosion as soon as the paving is completed. This persistent storm water source further complicates watershed management on highway corridors. Storm water generated soil erosion is also the primary global maintenance challenge for unpaved rural roadways.

Highway Safety and Drainage

Paved highway surfaces are designed to shed all intercepted precipitation onto roadside shoulders. There it flows over the shoulder as rainwater or snowmelt. Without vegetative groundcover or other treatments, these regular water discharges begin a process of shoulder soil erosion. This process not only has the potential to washout the shoulder but it also undercut the paved surface as it collects and carries silts and fine soil particles into the roadside drainages and culverts. These roadside flows in turn grow into larger and faster flows that carry heavier particles that accelerate erosion and scouring, ending at some point with a discharge into a stream, wash area, wetland, lake or reservoir.

Primarily as a matter of main paved travel lane safety, water drainage velocities from the travel surface must be maintained. This is to ensure that water retention on paved road surfaces is prevented to avoid reducing tire friction resulting in hydroplaning during the spring and summer storm season or ice formation during the winter months. However, serious shoulder erosion generates another driver control safety problem when a car at road way speed accidentally wanders from the paved surface and enters the shoulder. The presence of shoulder washouts and/or drop offs caused by storm water erosion create serious driver control problems which often result in accidents. Since shoulder condition is construed as a maintenance issue, washouts and drop offs also generate a ongoing liability issue for the highway agency. This liability problem is significant for West Virginia and other states in the Appalachian region because of large numbers of steep grades, sharp curves and narrow lanes.

The Challenge

So, we acknowledge highway shoulder soil erosion as a fact of life. Further, we know repeated high velocity/energy storm water from rain storms and runoff is the principal cause of washouts to unpaved highway shoulders, unpaved rural roads, unpaved industrial roads, and other unpaved trails, paths and bikeways. Ditches and well established shoulder vegetation can only limit normal run-off from normal rains and storms. So the challenge is to find a solution from a construction engineering perspective to reduce the impact of this naturally recurring erosion problem. A clear understanding of the erosion failure mechanism is necessary to assess potential solutions. In the US during the post interstate era, many primary and secondary highway shoulders are have been paved at significant cost to address this safety issue. And while paved shoulders do improve pavement performance, they don't eliminate the erosion problem; but merely transfer it to a new 'edge-of-pavement'.

Friction Basis of Traditional Construction

Modern and historic shoulder and unpaved roadway and trail construction techniques rely primarily on soil compaction methods to generate sufficient internal friction between soil particles to hold the soil-particle mass together laterally. Large collections of graded aggregate particles are combined with smaller binder particles to enable construction of a relatively dense, uniform compacted mixture with adequate internal friction between soil particles..

A survey of soil erosion control and mitigation measures show that modern approaches to addressing erosion problems involve three techniques; 1. using water barriers, 2. using natural or man-made tensile fibers and mats to reinforce the soil and 3. providing direct lateral support for soil and aggregate particles.

Erosion Failure Mechanism

The erosion failure mechanism for spoil particle, P, involves two active water generated forces and the basic action of gravity forces parallel to the soil surface. These forces are from 1. water velocity, 2, the buoyancy force of the water acting against gravity and 3. from gravity on the soil particle of weight, $\mathbf{w_g}$. In a traditional compacted sloped shoulder and those with barriers or tensile reinforcement these three lateral forces are resisted through the internal friction of the compacted mass.

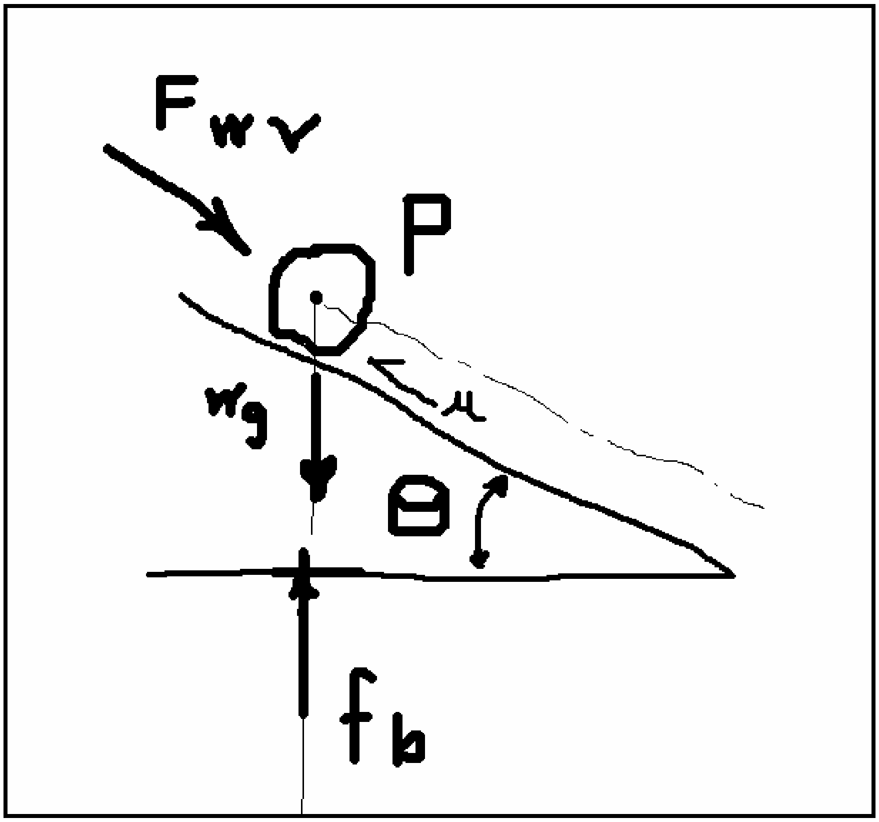

Figure 1 Erosion forces on soil particles

The first lateral force parallel to the surface is the lateral component of the particle, **P**, of weight, $\mathbf{w_g}$, the gravity force, and is created by the existence of a gradient of angle **θ.** This gradient is used to direct the water's flow away from the roadway centerline and along the shoulder.

The second lateral force also parallel to the surface, $\mathbf{F_{wv}}$, is generated by the velocity of the flowing water parallel to the surface of the soil. This is usually the most significant erosion force since its energy increases in proportion to the square of the water's velocity.

The introduction of water into the compacted soil system eventually saturates and fills the voids with water which tends to reduce the friction bond between the particles. This generates the third force, $\mathbf{f_b}$, the buoyancy force, which further reduces friction between particles. The combined operation of these three collected forces represents the general mechanics of the erosion process which must be resisted by the internal soil friction force, **μ**.

The constant action of storm water eventually erodes large portions of the compacted soil mass into a natural, gravity-designed drainage way. One place this erosion failure mechanism is readily observable is in eroded lane shoulder drop offs at the edge of paved roadways. This usually occurs on steeper and longer grades and creates severe driver control safety hazards for cars which accidentally wander from the paved surface at normal roadway speeds. Shoulder drop-offs are responsible for a wide variety of auto accidents.

Historic Solutions

Two of the erosion reduction solutions involve using additional friction and/or increased mass to resist the erosion forces. These solutions resist $\mathbf{F_{wv}}$ the water velocity generated force and $\mathbf{f_g}$ the slope generated gravity force. They don't offer resistance to the buoyancy force $\mathbf{f_b}$ or the tendency of water to reduce internal soil friction. These solutions offer a limited capacity to absorb the water's erosion energy by reducing the water velocity and allowing it to percolate into the underlying soil. Various types of bio-barriers offer mass resistance as do numerous special vegetation planting methods. These are often combined with tensile soil reinforcing mats and meshes to provide additional internal friction and can accomplish many of the erosion reduction goals. However, these are not appropriate or economical in all locations particularly unpaved highway shoulders and roads. These methods are still subject to high velocity water damage since they provide only limited direct lateral support for the soil particles and internal ability to reduce water velocity energy.

The use of rip rap and other larger diameter stones to reduce water velocity is currently the most effective method due to the mass of the rock particles. However, rip rap is generally limited to off-road drainage, river bank stabilization and trail drainage applications away from the unpaved shoulder.

Other erosion approaches are to chemically increase the friction between the particles. Soil stabilization using resins, hydraulic cement and other products are also ways of increasing the chemical friction bond between particles. Hot asphalt liquid sprayed over aggregates achieves a similar result. However, even these higher cost chemical approaches to stabilizing shoulders can be eroded by high velocity storm water run off.

An economical method of laterally confining and holding the stone and soil particle in place has the potential of offering a long term solution to this historic road safety, maintenance and liability challenge.

A New Erosion Reduction Solution

The discovery of confined aggregate concrete offers the potential of a new, relatively permanent, long term, economical solution to this universal roadway problem. This material is made using a thin-walled cylinder to confined soil, crushed stone or man-made aggregates. The thin walled cylinder functions similar the hydraulic cylinder; by confining a compressive material, the aggregates or soil particles, within its boundary. With a minimum of soil compaction energy, the thin-walled cylinder provides direct lateral support and holds the aggregates laterally in place. It does not depend on internal friction. This significantly increases the vertical load-bearing capacity and lateral strength of loose or compacted natural and man-made aggregates even when saturated. By confining the soil particle mass, the cylinder transfers its support to each particle within the cylinder. The cylinder thus physically restricts the stone's lateral movement when it is subject to internal or external, natural or man-made lateral forces such as tire loads, water velocity energy or gravity forces.

Mechanical Concrete® and *Mechanical Cement®*

In the U.S.A. Mechanical Concrete® is the trade name for permeable, confined-aggregate-concrete and *Mechanical Cement®* is the trade name for the thin-walled cylinder used to confine the stone or soil particles. For ease and speed of construction and maximum erosion protection in civil engineering uses the specified aggregates are of generally similar diameter and size and thus flow together with minimal compaction energy required. Any common aggregate of uniform size gradation such as AASHTO # 57 or #3 meet this specification criteria for use in confined-aggregate-concrete. Mechanical Concrete® is a patented technology of The Reinforced Aggregates Company, **www.mechanicalconcrete.com**

Mechanical Concrete® is an engineered material like steel or hydraulic cement concrete. It requires knowledge of physics, material behavior and engineering principles to use effectively and safely.

Tire Derived Cylinders, TDC

Used auto tires are a ubiquitous waste material of modern societies and are uniformly distributed based on human population and the auto. A used auto tire with both sidewalls removed makes a readily available, low-cost, rugged cylinder for highway, heavy and site construction. It is known as a tire-derived-cylinder, TDC. Mechanical Concrete® using a tire derived cylinder, TDC, is rugged since it has the ability to absorb large amounts of energy and has an overall design factor in excess of 3.0. Photos below show this simple, easy-to-construct technology.

Mechanical Cement®
Figure 2

Mechanical Concrete®
Figure 3

Mechanical Concrete®, using TDC, is a new, economical, green, material-reuse alternative structural solution to a wide variety of soil erosion, river bank and beach erosion and soil stabilization challenges. It is simple and economical to use and construct and requires limited training and equipment. The tire-derived-cylinders, TDC, have an indefinite life when used below the soil surface. The TDC offers a structural cylinder of steel and polyester fibers surrounded and protected from deterioration by a matrix of inert environmentally benign hydrocarbon rubber.

Lab and Field Tests

Mechanical Concrete® has been extensively tested for its structural properties in in the structures labs at West Virginia University and its functionality and constructability in the field. The detailed test information is available in other papers available at the website, **www.mechanicalconcrete.com** . A summary of the structural test is that a single TDC Mechanical Concrete® cylinder or a stacked column of TDC cylinders derived from a standard auto tires and aggregates similar to AASHTO #57 limestone behave linearly under load and can support a standard AASHTO truck wheel load, 16,000 lbs, (approx 200psi) with a minimum design factor of three against failure. Functionality and constructability tests show uniformly high levels of performance, economy and productivity.

Morgan Run Road—A Full Scale Erosion Test

The primary field test for erosion is currently in place on an unpaved rural road, Morgan Run Road, in Doddridge County WV. The Doddridge County WVDOH constructed a 140 foot long section of Mechanical Concrete® one lane road way in 2006 using 350 cylinders of Mechanical Concrete® filled with AASHTO #57 limestone aggregate and finished the surface with 6inches of compacted ¾ inch crusher run limestone. The cylinders were laid directly on the existing road base and were not connected to each other.

Morgan Run Road Construction Doddridge County WV, USA

Figure 4 Mechanical Concrete® Base

Figure 5 Wearing Surface

This roadway section was chosen because of its soft subgrade and its location next to a stream which flooded frequently and the associated high maintenance needs. Since the installation in 2006 the road way has continued to flood an average of 3-4 times per year with as much as 24 inches of flood water running across the surface. During these frequent floods the Mechanical Concrete® base has remained basically in tact, with less than 5 cylinders being moved or raised by the storm water.

More importantly the AASHTO #57 limestone base has remained stable and in place and the ditch line of gabion size stone has stayed in place. According to WVDOH personnel, maintenance of this section after flooding has been reduced by over 50% in labor and materials over pre Mechanical Concrete® basic rural, unpaved conditions. This road is frequently used by logging trucks, oil and gas rigs, and other industrial loads.

Figure 6 Morgan Run Road Flooding on Mechanical Concrete® Roadway

Figure 7 Morgan Run Road Mechanical Concrete® Test Section March, 2010

Conclusion

Cylinder-confined-aggregate concrete offers a new engineering method to directly resist erosion forces by having a collection of discrete structural cylinders filled with stone absorb the waters dynamic energy. Mechanical Concrete® reuses a chemically inert, tire-derived-cylinder, TDC, to confine stone aggregates and thus provides a low cost, green, reuse technology in this application. A three year test section of confined-aggregate-concrete roadway in Doddridge County WV demonstrates that Mechanical Concrete® using TDC can be very effective in reducing erosion damage to unpaved roads, shoulders and trails and also reducing post flood maintenance costs.

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