Expedient Road Construction Methods for Sand and Soft Soil Subgrades

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Abstract
Recent military operations in the Balkans and Southwest Asia have demonstrated the need to develop solutions for rapidly constructing temporary roads in the theater of operations. Loose sands and very soft soils have historically provided obstacles to efficient military maneuver. The U.S. Army Engineer Research and Development Center (ERDC) has conducted a series of research projects over the last seven years to evaluate commercial-off-the-shelf technology for constructing temporary roads. These projects included two problematic subgrade types, loose sand and soft soil. These projects have evaluated a variety of products including geosynthetics, lightweight fill, and matting. This paper describes various systems for rapidly constructing temporary roads over loose sand or soft subgrade soils. This paper summarizes results from numerous full-scale test sections designed to evaluate the performance of expedient road systems under realistic traffic conditions. Each system's performance is summarized, and specific recommendations are provided for material use. A comparative analysis is included to present tradeoffs in performance, cost, weight, volume, and installation rate. This paper represents the state-of-the-art in temporary road construction for military applications.

INTRODUCTION

The U.S. military's policy shift from forward-deployed assets to power projection has generated requirements for improved asset deployability and a reduced logistical footprint. The ability of the military to rapidly project forces into a theater of operations is dependent upon the existence of an adequate transportation infrastructure to sustain enormous throughput requirements. The required transportation infrastructure includes airports/seaports of embarkation (APOEs/SPOEs), airports/seaports of debarkation (APODs/SPODs), and the Lines-of-Communication (LOCs) that connect the APODs/SPODs to tactical assembly areas (TAAs) within the theater of operation. Each link in the transportation infrastructure is equally important since a bottleneck in any segment restricts the throughput of supplies and materiel throughout the entire transportation system. Obviously, the enemy understands the strategic importance of transportation assets, and will likely mobilize to deny access or destroy critical facilities. Thus, the U.S. military will be required to rapidly develop new APODs, SPODs, and LOCs to effectively deploy its assets. Deployment via Logistics-Over-The-Shore (LOTS) operations, upgraded seaports, and austere airfields will require the rapid construction of temporary roads across the beach or over soft soils to connect to an existing transportation network. Additionally, bypasses around major bottlenecks, such as urban areas or damaged infrastructure, will be required to achieve desired throughput requirements. In some instances, the off-road mobility of the military's ground vehicles will be sufficient to maintain some level of throughput. However, the in situ soil strength in many regions of the world cannot support significant numbers of vehicle operations. Military engineers are continually faced with the task of quickly constructing roads in remote locations with minimal resources.

Traditional pavement design and construction practices require high-quality materials for fulfillment of construction standards. In many areas of the world, quality materials are unavailable or in short supply. Due to these constraints, engineers are often forced to seek alternative designs using substandard materials, commercial construction aids, and/or innovative design practices. The objective of this paper is to summarize innovative road systems for rapidly constructing temporary roads over loose sand and soft subgrade soils. This paper summarizes results from numerous full-scale test sections designed to evaluate the performance of expedient road systems under realistic traffic conditions. Each system's performance is summarized, and specific recommendations are provided for material use. A comparative analysis is included to present tradeoffs in performance, cost, weight, volume, and installation rate. The experiment results presented in this paper should not be confused with the multitude of individual ad hoc product demonstrations that plague the military's acquisition system. Each experiment described represents a controlled evaluation of individual products and an impartial quantitative evaluation of product performance. This paper represents the state-of-the-art in temporary road construction for military applications.

SUMMARY OF EXPERIMENTS

The following paragraphs briefly describe the experiments conducted to evaluate the temporary road systems presented in this paper. Each description includes the objective of the experiment, a brief summary of the experiment design, and a limited discussion of the results. All test items were trafficked with an M923 5-ton military truck at a speed of 5 to 10 mph loaded to a gross vehicle weight of 41.6 kips, which represents a 10-ton highway payload rating. The truck has a single front axle weight of 10.0 kips and a dual tandem rear axle assembly with approximately 31.6 kips on the rear tandem axles. The individual tires were inflated to a 75-psi tire pressure and a contact area of approximately 55.5 in^2. In all experiments presented, a failure criterion of 3 inches of rutting, including upheaval, was used. A comprehensive description of each experiment is beyond the scope of this paper, and the details of each experiment can be obtained from the references provided.

Webster and Santoni 1997 (1)
The objective of this study was to describe laboratory tests conducted to determine the optimum geofiber content for stabilization of coarse sand and to present the results of field tests conducted to evaluate geofiber stabilization for contingency roads and airfields. A limited laboratory experiment was conducted to determine the optimum dosage rate for 2-in. monofilament geofibers in coarse sand. Two full-scale field test sections were then constructed to evaluate various designs including geofiber-stabilized sand under simulated C-130 aircraft traffic and M923 5-ton truck traffic. A description of each test item of the test sections is provided in Table 1. The laboratory phase of the experiment produced an optimum geofiber dosage rate of 0.8 to 1.0 percent by dry weight of sand for the 2-in.-long monofilament fibers. The results indicate only minor amounts of rutting for the limited 5-ton truck traffic (120 to 1,000 passes) indicating excellent performance for all geofiber test items described.

Webster and Tingle 1998 (2)
The objective of this research was to evaluate new commercially available lightweight roadway matting materials for expedient road construction over loose sand subgrades. A six-item full-scale test section was constructed and trafficked to evaluate the individual roadway systems and compare them to an unreinforced control section. A description of each test item of the test section is provided in Table 1. The results indicate very poor performance of the control item (25 passes) and both Mobi-Mat test items (20 passes each). Both the reinforced and unreinforced Mobi-Mat items produced tears in the woven fabric, particularly around the reinforcing bars in the reinforced matting. The reinforced Mobi-Matting also produced a very rough driving surface due to the reinforcing bars, resulting in extreme discomfort of the driver. The aluminum hexagonal mat performed excellent, sustaining 5,000 truck passes with minimal rutting, while the plastic hexagonal mat performed very well sustaining 5,000 truck passes with 2.8 in. of rutting. The TracksPlus fiberglass-reinforced matting performed very well sustaining 5,000 truck passes with only 1.8 in. of rutting. However, the TracksPlus matting was difficult to handle without equipment and difficult to assemble due to sand entering the threaded bushings.

Tingle et al. 1999 (3)
The objective of the experiments was to determine the optimum mixture design for geofiber reinforced sands, validate performance in a variety of sand materials, and verify performance through full-scale field test sections. The laboratory study used unconfined compression testing to evaluate a test matrix including six sand types, four fiber types, five fiber lengths, six fiber deniers, and five dosage rates. The field experiments consisted of constructing and trafficking two full-scale test sections, each containing seven test items. The first test section provided a side-by-side comparison of fibrillated and monofilament fibers at three dosage rates versus a control item. The second test section evaluated the performance of 2- and 3-in. fibrillated, monofilament, and tape fibers at a single dosage rate of 0.8 percent by dry weight of sand. A

description of each test item of the test section is provided in Table 1. A total of 10,000 5-ton truck passes were applied over both test sections; however, maintenance techniques were evaluated after 5,000 passes. The results generally indicated that all of the fibers effectively stabilized the six different sand materials. Both the laboratory and field experiments demonstrated that a fiber content of 0.8 to 1.0 percent by dry weight was optimal for stabilizing the sand with 2-in.-long fibrillated or monofilament fibers. The field test sections also verified that 8 in. of the 0.8 percent geofiber-stabilized sand provided excellent load support for 5,000 5-ton truck passes.

Santoni 2003 (4)
The objective of this experiment was to evaluate geofiber-stabilized sand, Multi-Purpose (MP) matting, and GridTech plastic hexagonal matting for expedient road construction over loose sandy soils. A full-scale test track consisting of eight test items was constructed including straight and curved test items of each road system. The test section was constructed to evaluate road system performance, field construction procedures, and the effects of radius of curvature on performance. Figures 1 through 3 show a geofiber stabilized test item, a GridTech All-Around plastic hexagonal mat item, and a Multi-Purpose mat item, respectively. A description of each test item is provided in Table 1. The results generally indicate reduced performance of the curved test items compared to the straight test items for individual systems. The 50-ft radius curved section of the All-Around plastic hexagonal mat performed poorly and only sustained 165 5-ton truck passes. The straight test item consisting of the Special version of the plastic hexagonal matting, while sustaining 500 5-ton truck passes, performed worse than a comparable item composed of the All-Around plastic hexagonal matting in Webster and Tingle 1998 (2). The remaining test items all sustained 500 5-ton truck passes, with the Multi-Purpose matting providing excellent performance in both the straight and 50-ft radius test items. The geofiber-stabilized sand test items performed similarly with slightly worse rutting in the 50-ft radius curved item as compared to the 75-ft radius curved item and the straight item. The Multi-Purpose matting and geofiber-stabilized sand were deemed suitable for heavy traffic levels, while the plastic hexagonal mats were only recommended for light traffic and parking areas.

Santoni et al. 2001 (5)
The objective of this experiment was to demonstrate temporary road systems for bridging very soft subgrade soils to link LOTS debarkation sites to inland infrastructure. A full-scale test track with two traffic lanes at different subgrade strengths (CBR < 0.5 and 0.5 < CBR < 1.0) was constructed to evaluate conceptual road systems consisting of combinations of matting products, lightweight fill, and geosynthetics. A total of 13 different road systems were evaluated under 5-ton truck traffic, and a description of each test item is provided in Table 1. Figure 4 shows the site conditions prior to road construction. Figure 5 shows the construction of item T-2, and Figure 6 shows an overall view of items 1-1 through T-2 being trafficked with the 5-ton truck. The results show very poor performance in five of the 13 road systems. The eight successful road systems sustained up to 2,000 5-ton truck passes with acceptable levels of rutting. Five successful road systems were demonstrated for a subgrade CBR less than 0.5, and 3 successful road systems were demonstrated for the subgrade between 0.5 and 1 CBR.

Tingle and Webster 2003 (6)
The objective of this research was to validate existing Corps of Engineers (COE) criteria for geotextile-reinforced aggregate roads and to modify the criteria for the addition of stiff biaxial geogrids for reinforcement. A full-scale aggregate road test section was constructed over a very soft subgrade soil and trafficked with a 5-ton truck. The experiment was designed to compare the performance of various geosynthetic inclusions to each other and a control item that contained no reinforcement. All of the geosynthetics were placed at the base-subgrade interface. A description of each test item of the test section is provided in Table 1. The results indicate very good performance of all test items, sustaining 2,000 5-ton truck passes as the rutting in all items approached the 3-in. failure criteria. The comparable performance of the different test items indicates that the systems were roughly equivalent in terms of load bearing capacity and that the inclusion of geosynthetics can provide as much as a 50 percent reduction in aggregate thickness requirements. The results of this experiment were used to verify the existing criteria in TM 5-818-8 (7) and modify the criteria for the inclusion of stiff biaxial geogrids, as published in COE ETL 1110-1-189 (8).

Summary
The experiments summarized in this section represent the state-of-the-art in temporary road construction alternatives for military applications. The experiments described were controlled tests with impartial quantitative evaluations. This research should be distinguished from the typical product demonstrations performed by vendors for individual military units. Vendor demonstrations typically lack control of test variables, significant traffic volumes, and impartial quantification of results. These types of vendor demonstrations seek to bypass the military's rigorous product evaluation processes and jeopardize the military's acquisition program.

EXPERIMENT RESULTS

System Performance
The individual results from each experimental program were briefly summarized in the description provided in the previous section. The individual performance of various test items, in terms of rutting, is shown in Table 1. More detailed performance results are provided in the individual references associated with each experiment. In general, expedient road construction alternatives were presented with the capability of sustaining 500 to 10,000 military 5-ton truck passes, loaded to a 10-ton highway payload. For the loose sand subgrade condition, geofiber stabilization and Multi-Purpose matting demonstrated the best performance. While the GridTech aluminum hexagonal mat provided excellent performance, the cost is well beyond reasonable limits. The GridTech All-Around plastic hexagonal mat provided good performance for light traffic and parking areas. For the soft subgrade soil condition, many road systems performed well, sustaining up to 2,000 5-ton truck passes.

System Logistics
Each temporary road system must also be evaluated in terms of its logistical footprint. The logistical footprint includes the system's weight, volume, cost, and support requirements such as construction equipment and manpower. Table 2 provides a summary of all of the materials used in each of the experiments described in this paper, including material geometry for volume calculations, unit weight, and unit cost. The unit cost may vary depending upon the quantity of

product procured. Since relatively small purchases were made for the experiments described, it is anticipated that larger bulk purchases should result in a slightly lower unit cost for some products. The lightweight fill and aggregate unit costs will vary based upon availability of materials in a particular location. Since many of the road systems were composed of multiple products, care should be taken to compare actual systems rather than parts of systems.

Enabler Comparison

As noted in the previous sections, the experiments compared road systems often comprised of multiple materials. In addition, Table 2 provides a comparison of individual material geometry (volume), weight, and cost, but does not address the support requirements such as equipment, manpower, and time. Thus, a comparison of temporary road enabler alternatives is provided in Table 3 that attempts to quantify the composite system unit cost and installation rate for successful test items described previously. A subjective comparison in terms of qualitative performance, traffic suitability, overall logistical footprint, and equipment requirements is also provided in Table 3. The selection of an expedient road system must balance performance and logistics. For instance, the GridTech aluminum hexagonal mat provided excellent performance over sand subgrades, but the system cost is well beyond reason considering the alternative systems. Another example is the use of DURA-BASE matting for sand subgrades. Although the DURA-BASE would provide excellent performance over sands, as evidenced by its support over the more difficult soft subgrade, the product has a very large logistical footprint and cost compared to alternative road systems for sand subgrade conditions. One further example is the use of geosynthetic-aggregate systems that are low cost, but have significant logistical requirements. These geosynthetic-aggregate systems also depend upon indigenous aggregate availability and should be reserved for higher traffic sustainment levels or long-term use. Thus, military engineers must seek the "best" alternative for a particular scenario, considering the performance of road systems and their logistical footprint.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The results of six full-scale expedient road construction experiments were summarized to present alternatives for rapidly constructing temporary roads over loose sand or soft subgrade soil conditions. Comparisons of system performance in terms of resistance to rutting and system logistical footprint were made to differentiate between road construction alternatives. The following conclusions were derived from the compilation of experiment results:

1. Geofiber stabilization (0.8 percent of 2-in. fibers by dry weight of soil) and Multi-Purpose matting provided very good alternatives for expedient road construction over loose sand subgrades. The GridTech All-Around plastic hexagonal matting provided good support for light traffic areas and could serve a variety of temporary roles due to its rapid installation rate.
2. Both the unreinforced and reinforced Mobi-Mat systems are not suitable for sustaining significant numbers of military 5-ton traffic.
3. The Netlon mesh fibers failed to effectively stabilize the loose sand subgrade.
4. The Special version of GridTech's plastic hexagonal mat was inferior compared to the All-Around version.

5. For soft subgrades between 0.1 and 0.5 CBR, the combination of two layers of DURA-BASE, lightweight fill (wood chips/sand), and geosynthetics provided excellent support for sustaining significant 5-ton truck traffic. However, the 12-in. crushed stone/geogrid/wood chip/geogrid/geotextile road system performed almost as well and should be considered for systems that will be left in place.
6. For soft subgrades greater than 0.5 CBR, the 2-layer DURA-BASE system and geosynthetic-reinforced aggregate systems provided excellent capability to sustain military 5-ton truck traffic. Care must be taken with the geosynthetic-reinforced aggregate road systems to follow proper design procedures for aggregate thickness based upon the type(s) of geosynthetics used. Additionally, special construction procedures are described in COE ETL 1110-1-189 (8) to protect the geosynthetics during construction.
7. The geosynthetic-reinforced aggregate road test items demonstrated an aggregate savings ranging from 25 to 50 percent depending upon the type of reinforcement used.
8. The geofiber-stabilized and geofoam systems surfaced with Multi-Purpose matting did not provide adequate load support for sustaining significant 5-ton truck traffic.
9. The logistical footprint is much greater for road systems required to bridge soft subgrade soils compared to loose sand subgrades. This difference is due to the relatively strong load bearing capacity of sand once it has been confined. Thus, the loose sand road systems are only required to confine the sand, capitalizing on the stress dependent behavior of granular materials, rather than bridging over the soft subgrade soils.

Recommendation

The road construction alternatives presented in this paper should be incorporated into appropriate field and technical manuals, including detailed construction procedures. Additional reduced footprint alternatives should be evaluated to further reduce the amount of materials, equipment, and manpower required to effectively construct temporary military roads.

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Figure 1. Compaction of geofiber-stabilized sand

Figure 2. GridTech All-Around plastic hexagonal mat

Figure 3. Multi-Purpose mat

Figure 4. Very soft subgrade soil conditions (CBR < 0.5)

Figure 5. Construction of Item T-2 of soft subgrade test section Santoni et al. 2001 (5)

Figure 6. Military 5-ton truck traffic on soft subgrade soil test section (5)

Table 1. Experiment Summary

Experiment Title	Test Item	Test Item Description	Subgrade	Test Vehicle	Truck Passes	Rutting	System Failure
Loose Sand Subgrade Experiments							
Webster and Santoni (1997)	1A	4-in. Geofiber-Road Oyl over 8-in. Geofiber-stabilized sand	18-in. SP	5-Ton (41.6 kips)	1,000	Minimal	None
	2A	4-in. Geofiber-Road Oyl over 8-in. Geofiber in Geocell	18-in. SP	5-Ton (41.6 kips)	1,000	Minimal	None
	3A	4-in. Geofiber-Road Oyl over 8-in. sand in Geocell	18-in. SP	5-Ton (41.6 kips)	1,000	Minimal	None
	5	8-in. Geofiber in geocell with 1 gsy Road Oyl surfacing	18-in. SP	5-Ton (41.6 kips)	120	Minimal	None
	6	8-in. Geofiber -Road Oyl mix with 1 gsy Road Oyl surfacing	18-in. SP	5-Ton (41.6 kips)	120	Minimal	None
Webster and Tingle (1998)	1	GridTech Aluminum Hexagonal Mat	36-in. SP	5-Ton (41.6 kips)	5,000	1.1	None
	2	GridTech Plastic Hexagonal Mat	36-in. SP	5-Ton (41.6 kips)	5,000	2.8	Rutting
	3	TracksPlus Fiberglass-Reinforced Mat (Similar to MP Mat)	36-in. SP	5-Ton (41.6 kips)	5,000	1.8	None
	4	Polyester Rod Reinforced Mobi-Mat	36-in. SP	5-Ton (41.6 kips)	20	2.2	Fabric Tear
	5	Unreinforced Mobi-Mat	36-in. SP	5-Ton (41.6 kips)	20	3.3	Fabric Tear
	6	Control - No Matting	36-in. SP	5-Ton (41.6 kips)	25	8.0	Rutting
Tingle et al. (1999)	1-1	8-in. of mesh fiber stabilized sand (10 lbs/yd^3)	28-in. SP	5-Ton (41.6 kips)	800	3.0	Rutting
	1-2	0.6% 2-in. Fibrillated Fibers (1000 denier)	28-in. SP	5-Ton (41.6 kips)	3,000	3.2	Rutting
	1-3	0.6% 2-in. Monofilament Fibers (20 denier)	28-in. SP	5-Ton (41.6 kips)	3,000	3.0	Rutting
	1-4	0.8% 2-in. Fibrillated Fibers (1000 denier)	28-in. SP	5-Ton (41.6 kips)	10,000	3.0	Rutting
	1-5	0.8% 2-in. Monofilament Fibers (20 denier)	28-in. SP	5-Ton (41.6 kips)	5,000	3.2	Rutting
	1-6	1.0% 2-in. Fibrillated Fibers (1000 denier)	28-in. SP	5-Ton (41.6 kips)	10,000	2.8	Rutting
	1-7	1.0% 2-in. Monofilament Fibers (20 denier)	28-in. SP	5-Ton (41.6 kips)	10,000	3.2	Rutting
	2-1	0.8% 3-in. Fibrillated Fibers (360 denier) with Plastic Hex Mat	28-in. SP	5-Ton (41.6 kips)	5,000	2.8	Rutting
	2-2	0.8% 2-in. Tape Fibers (448 denier)	28-in. SP	5-Ton (41.6 kips)	3,000	3.0	Rutting
	2-3	0.8% 3-in. Tape Fibers (448 denier)	28-in. SP	5-Ton (41.6 kips)	5,000	3.1	Rutting
	2-4	0.8% 3-in. Fibrillated Fibers (360 denier)	28-in. SP	5-Ton (41.6 kips)	5,000	2.9	Rutting
	2-5	0.8% 2-in. Fibrillated Fibers (360 denier)	28-in. SP	5-Ton (41.6 kips)	5,000	2.9	Rutting
	2-6	0.8% 2-in. Monofilament Fibers (20 denier)	28-in. SP	5-Ton (41.6 kips)	5,000	3.4	Rutting
	2-7	0.8% 2-in. Monofilament Fibers (20 denier) in Yuma Sand	28-in. SP	5-Ton (41.6 kips)	5,000	2.2	Rutting

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Table 1. Experiment Summary (Continued)							
Experiment Title	**Test Item**	**Test Item Description**	**Subgrade**	**Test Vehicle**	**Truck Passes**	**Rutting (in.)**	**System Failure**
Loose Sand Subgrade Experiments							
Santoni (2003)	1-S	Straight Section of Multi-Purpose Mat (Fiberglass)	18-in. SP	5-Ton (41.6 kips)	500	1.3	Rutting
	1-C	50-ft Radius Curved Section of Multi-Purpose Mat (Fiberglass)	18-in. SP	5-Ton (41.6 kips)	500	1.3	Rutting
	2-C	50-ft Radius Curved Section of All-Around Plastic Hex Mat	18-in. SP	5-Ton (41.6 kips)	165	2.5	Rutting
	2-S	Straight Section of Special Plastic Hexagonal Mat	18-in. SP	5-Ton (41.6 kips)	500	3.1	Rutting
	3-CA	75-ft Radius of 8-in.Geofiber-Sand (0.8% of 2-in. Monofilament Fibers) Surfaced with 1gsy of Road Oyl	16-in. SP	5-Ton (41.6 kips)	500	1.6	Rutting
	3-CB	50-ft Radius of 8-in. Geofiber-Sand (0.8% of 2-in. Monofilament Fibers) Surfaced with 1 gsy of Road Oyl	16-in. SP	5-Ton (41.6 kips)	500	2.0	Rutting
	3-S	Straight Section of 8-in. Geofiber-Sand (0.8% of 2-in. Monofilament Fibers) Surfaced with 1 gsy of Road Oyl	16-in. SP	5-Ton (41.6 kips)	500	1.9	Rutting
	4	Control - No Matting	24-in. SP	5-Ton (41.6 kips)	25	10.0	Rutting
Soft Subgrade Soil Experiments							
Santoni et al. (2001)	1-1	Multi-Purpose Mat/EPS Geofoam/Geogrid/Geotextile	<0.5 CBR CL	5-Ton (41.6 kips)	50	3.0	Foam
	1-2	2 Layers of DURA-BASE Mat/28-in. Wood Chips/Geogrid/Geotextile	<0.5 CBR CL	5-Ton (41.6 kips)	2,000	2.2	Rutting
	1-3	2 Layers of DURA-BASE Mat/28-in. Sand/Geogrid/Geotextile	<0.5 CBR CL	5-Ton (41.6 kips)	2,000	2.9	Rutting
	1-4	2 Layers of SOLOCO Wood Mat/28-in. Sand/Geogrid/Geotextile	<0.5 CBR CL	5-Ton (41.6 kips)	2,000	1.4	Rutting
	1-5	2 Layers of SOLOCO Wood Mat/28-in. Wood Chips/Geogrid/Geotextile	<0.5 CBR CL	5-Ton (41.6 kips)	2,000	1.4	Rutting
	T-1	12-in. Crushed Limestone/24-in. Wood Chips/Geogrid/Geotextile	<0.5 CBR CL	5-Ton (41.6 kips)	100	3.0	Rutting
	T-2	12-in. Crushed Limestone/Geogrid/24-in.Wood Chips/Geogrid/Geotextile	<0.5 CBR CL	5-Ton (41.6 kips)	1,550	3.0	Rutting
	2-1	30-in. Crushed Limestone/Geogrid/Geotextile	<1.0 CBR CL	5-Ton (41.6 kips)	2,000	2.4	Rutting
	2-2	26-in. Crushed Limestone/Geocomposite (ECM)	<1.0 CBR CL	5-Ton (41.6 kips)	75	3.0	Rutting
	2-3	Multi-Purpose Mat/28-in. Geofiber-Sand/Geogrid/Geotextile	<1.0 CBR CL	5-Ton (41.6 kips)	300	3.1	Rutting
	2-4	Multi-Purpose Mat/28-in. Sand/Geogrid/Geotextile	<1.0 CBR CL	5-Ton (41.6 kips)	300	3.0	Rutting
	2-5	2 Layers of SOLOCO Wood Mat/ Geotextile	<1.0 CBR CL	5-Ton (41.6 kips)	2,000	2.8	Rutting
	2-6	2 Layers of DURA-BASE Mat/Geotextile	<1.0 CBR CL	5-Ton (41.6 kips)	2,000	2.1	Rutting
Tingle and Webster (2003)	1	20-in. Crushed Limestone Control - No Geosynthetics	0.8 CBR CH	5-Ton (41.6 kips)	2,000	2.4	Rutting
	2	15-in. Crushed Limestone Over 6-Oz. Woven Geotextile	0.8 CBR CH	5-Ton (41.6 kips)	2,000	3.0	Rutting
	3	15-in. Crushed Limestone Over 6-Oz. Nonwoven Geotextile	0.8 CBR CH	5-Ton (41.6 kips)	2,000	2.9	Rutting
	4	10-in. Crushed Limestone Over Geogrid/Nonwoven Geotextile	0.8 CBR CH	5-Ton (41.6 kips)	2,000	3.0	Rutting
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Table 2. Expedient Road Construction Materials

Product Name	Material Description	Geometry	Unit Weight	Unit Cost
Monofilament Geofibers	White Cylindrical Polypropylene Fiber	2-in.-long (20 Denier)	G_s=0.91	$1.40/lb
Fibrillated Geofibers	Beige Netlike Polypropylene Fiber	2- and 3-in.-long (360 Denier)	G_s=0.91	$1.40/lb
Tape Geofibers	Beige Wide, Flate Polypropylene Fiber	2- and 3-in.-long (448 Denier)	G_s=0.91	$1.40/lb
Netlon Mesh Elements	Brown Grid of Cylindrical Polypropylene Ribs	2-in. by 4-in. by 0.01-in.	G_s=0.91	--
Road Oyl	Nonwater Soluble Organic Tree Resin Emulsion	Viscous Liquid	G_s=0.91	$4.23/gal
Coarse Sand (SP)	River Deposited Coarse Sand	--	110 pcf	$7.00/yd^3
Geocell	High Density Polyethylene Cellular Confinement System	Collapsed 4-in. by 8-in. by 8-ft Expanded 8-in. by 8-ft by 20-ft	0.69 psf	$1.50/ft^2
Gridtech Plastic All-Around Hexagonal Mat	High Density Polyethylene Hexagon	2.9 ft^2 Hexagon (1.5-in.-thick)	2.12 psf	$7.20/ft^2
Gridtech Plastic Special Hexagonal Mat	High Density Polyethylene Hexagon	2.9 ft^2 Hexagon (1.5-in.-thick)	2.12 psf	$7.20/ft^2
Gridtech Aluminum Hexagonal Mat	Aluminum Hexagon	2.9 ft^2 Hexagon (1.5-in.-thick)	7.3 psf	$61.00/ft^2
TracksPlus Mat	Polyester Resin Reinforced with 4-Plies of Woven Chopped Fiberglass	5-ft by 12-ft by 0.70-in.	2.9 psf	$16.32/ft^2
Reinforced Mobi-Mat	Open Cross-Weave Polyester Mesh Reinforced with Polyester Rods	10-ft by 13.8-ft by 1.0-in.	0.72 psf	$49.80/ft^2
Unreinforced Mobi-Mat	Open Cross-Weave Polyester Mesh	10-ft by 13.8-ft by 0.50-in.	0.34 psf	$14.11/ft^2
Multi-Purpose Mat	Polyester Resin Reinforced with 4-Plies of Woven Chopped Fiberglass	6.67-ft by 6.67-ft by 0.70-in.	2.6 psf	$7.88/ft^2
DURA-BASE Mat	High Density Polyethylene Panels	8-ft by 14-ft by 4.25-in.	9.68 psf	$14.84/ft^2
SOLOCO Wood Mat	Interlocking Preassembled Hardwood Lumber Panels	8-ft by 14-ft by 4.0-in.	12.5 psf	$2.46/ft^2
Excogitated Composite Multifunctional (ECM)	Flexible Geocomposite of Geotextile and Geogrid with 3-D Nodules	3-ft by 60-ft by 0.3-in.	0.20 psf	$0.42/ft^2
EPS Geofoam Blocks	Prefabricated Expanded Polystyrene Foam	4-ft by 8-ft by 20-in.	1.8 pcf	$4.06/ft^2
Tensar BX1200 Geogrid	Polypropylene Biaxial Geogrid	13.1-ft by 164-ft by 0.15-in.	0.05 psf	$0.32/ft^2
AMOCO 2004	Woven Polypropylene	13.5-ft by 300-ft by 0.05-in.	0.10 psf	$0.08/ft^2
Geotex 801	Polypropylene Needle-Punched Nonwoven	15-ft by 300-ft by 0.1-in.	0.20 psf	$0.07/ft^2
Crushed Limestone (SM-SC)	Maximum Aggregate Size of 3/4-in. with 12% fines	--	135 pcf	$17.00/ton
Wood Chips	Nonuniform Scrap Pieces of Hardwood and Bark	Up to 2-in.-diameter by 8-in.-lon	--	$5.00/ton

Table 3. Expedient Road Construction Enabler Comparison

Enabler Description	System Cost	Installation Rate (ft^2/Man-Hours)	Qualitative Performance	Traffic Limits	Logistical Footprint	Equipment Required
Loose Sand Subgrade Enablers						
Sand-Grid or Geocell (Existing System)	$1.50/ft^2	65	Good	Medium	Small	Yes
4-in. Geofiber - Road Oyl over 8-in. Geofiber-Stabilized Sand (0.8%)	$2.06/ft^2	100	Excellent	Very Heavy	Small	Yes
8-in. of 0.8% 2-in. Geofibers (Fibrillated or Monofilament)	$1.59/ft^2	250	Excellent	Heavy	Small	Yes
GridTech Aluminum Hexagonal Mat	$61.00/ft^2	750	Excellent	Light	Moderate	No
GridTech Plastic Hexagonal Mat	$6.00/ft^2	750	Good	Light	Moderate	No
Polyester Rod Reinforced Mobi-Mat	$49.80/ft^2	100	Poor	Very Light	Small	No
Unreinforced Mobi-Mat	$14.11/ft^2	100	Poor	Very Light	Small	No
Multi-Purpose Mat (Fiberglass)	7.88/ft^2	400	Very Good	Heavy	Moderate	No
TracksPlus Fiberglass-Reinforced Mat (Similar to MP Mat)	$16.32/ft^2	40	Very Good	Heavy	Moderate	No
Soft Subgrade Enablers for CBR > 0.5						
2 Layers of DURA-BASE Mat/Geotextile	$29.75/ft^2	150	Excellent	Heavy	Large	Yes
2 Layers of SOLOCO Mat/Geotextile (No Longer Produced)	$4.99/ft^2	100	Very Good	Medium	Large	Yes
20-in. Crushed Limestone Control - No Geosynthetics	$1.92/ft^2	75	Excellent	Heavy	Very Large	Yes
15-in. Crushed Limestone Over 6-Oz. Woven Geotextile	$1.52/ft^2	75	Very Good	Heavy	Large	Yes
15-in. Crushed Limestone Over 6-Oz. Nonwoven Geotextile	$1.51/ft^2	75	Very Good	Heavy	Large	Yes
10-in. Crushed Limestone Over Geogrid/Nonwoven Geotextile	$1.35/ft^2	100	Very Good	Heavy	Large	Yes
Soft Subgrade Enablers for 0.1 < CBR < 0.5						
2 Layers of DURA-BASE Mat/28-in. Wood Chips/Geogrid/Geotextile	$30.57/ft^2	100	Excellent	Heavy	Very Large	Yes
2 Layers of DURA-BASE Mat/28-in. Sand/Geogrid/Geotextile	$30.77/ft^2	100	Very Good	Medium	Very Large	Yes
2 Layers of SOLOCO Wood Mat/28-in. Sand/Geogrid/Geotextile	$6.01/ft^2	75	Excellent	Heavy	Very Large	Yes
2 Layers of SOLOCO Wood Mat/28-in. Wood Chips/Geogrid/Geotextile	$5.81/ft^2	75	Excellent	Heavy	Very Large	Yes
12-in. Crushed Limestone/Geogrid/24-in.Wood Chips/Geogrid/Geotextile	$2.36/ft^2	50	Good	Medium	Very Large	Yes
30-in. Crushed Limestone/Geogrid/Geotextile	$3.27/ft^2	50	Excellent	Heavy	Very Large	Yes