Portable Crossings for Weak Soil Areas and Streams

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To access forest products, streams typically need to be crossed by heavy equipment. In many cases, the access is only needed for a short time. The cost and time involved to construct a permanent crossing exceeds the need. Also, permanent access into the area is unwanted, making it necessary to remove the crossing that closes the road. Removal may cause pollution to the stream and continuous erosion problems, especially when culverts are used. A possible solution would be portable, temporary, reusable crossings made of readily available, inexpensive materials. The U.S. Department of Agriculture Forest Service has investigated this type of crossing option. Several products were considered as potential crossings. Five crossings were chosen for field trials: pipe mats, gratings, Terra Mats, wood pallets, and wood mats. All five crossings work well, although each has different strong and weak points. Most of the work has been performed in Florida. Conditions in other states will require different design modifications and improvements. Although quantitative information is still being analyzed, qualitatively, the crossings greatly reduce impact to weak soils of stream beds. This impact was observed to be lower particularly when compared with using no crossing or removing a permanent crossing.

The U.S. Department of Agriculture Forest Service constructs many miles of low-volume roads. These are primarily single lane, unsurfaced roads that are often used to access forest products (*1*). In some cases, the roads are built in areas that already have a high road density, which is open to the public. Often, small, intermittent streams with little or no water and weak stream bed soils must be crossed. These minor stream crossings can present a formidable problem for engineers, who must consider the environmental aspects of the surrounding ecosystem.

The Forest Service has been trying to decrease the open-road density by closing roads after the timber sale. One closure solution involves the removal of culverts at stream crossings, making the stream impassable. Both installation and removal of a culvert adds unwanted fill material to the stream. After removal, continuous erosion can occur.

Intermittent stream beds often consist of soil with poor load-bearing capacity and high moisture content or standing water. When the soil is dry, it can support vehicular loads. As the moisture content increases, the soil can no longer carry the load without the possibility of erosion.

A better solution might be the use of portable crossing products that are temporary and reusable. These products should be

1. Able to handle the anticipated traffic loads,
2. Designed to be moved with available labor and equipment at the site and easy to remove with minimal erosive impact,
3. Designed with adequate traction to perform well while immersed in water or mud,
4. Durable enough to withstand transfer to another site, possibly as often as every 3 months, and
5. Cost-effective and readily available.

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It is also desirable to have a product capable of conforming to different lengths of a stream crossing.

Seeking to improve access while protecting streams, the San Dimas Technology and Development Center (SDTDC) began a study of portable crossings in 1990. The initial step was a literature review and market search, reported in the publication, *Portable Wetland Area and Stream Crossings* (*2*). The publication covers products available commercially and through the military. It includes a description of each product with photos and sketches; situations in which the product can be used; the testing and use that has been performed; and the potential problems that need to be addressed.

Over the past 4 years, some of the crossing products described in the publication have been field tested. For a product to be chosen for testing, it had to be new to this type of use, inexpensive, readily available, or any combination of these. Thus far, testing has entailed the crossing of three types of vehicles: log trucks (or similar heavy vehicles), light vehicles, and skidders. Testing began by locating possible sites, then determining which products would be the most suitable. Most of the field tests have been performed in the Osceola Ranger District (RD) near Jacksonville, Florida, where elevations are fairly constant and the soil is mainly a silty sand.

Before beginning the review of products, a word about the use of geotextiles is in order. Much literature currently exists on the use of geotextiles. Their connection with portable stream crossings relates to confinement of the material under the crossing product and its ease of removal. For most of the products tested, installation of geotextiles is recommended to limit the amount of local material permeating the installation. Geotextiles also facilitate the timely removal of the product.

Some concerns have been raised about leaving the geotextile behind. Ideally, an environmentally sensitive solution would require that the geotextile be removed or that a biodegradable type be used. The designer will need to determine the cost-effectiveness of the type of geotextile to use.

PORTABLE CROSSING PRODUCTS EXAMINED

Pipe Mat Crossing

One of the most interesting stream crossings found during the market search was the Pipe Fascine System (*3,4*). Designed by the British military, the system was specifically designed as a portable, reusable bridge for tank traps. Because of its design, logging equipment and loaders can easily install and retrieve the system. The Forestry Commission Kielder, United Kingdom, has performed field tests during timber harvests and intends to use the system on a regular basis. The system is excellent for alleviating the problem of one fixed bridging point because it is so easy to move. The Forestry Commission covers the system with logs or slash to protect it and provide a good running surface.

The SDTDC evaluated a pipe mat installation similar to the British Pipe Fascine System. The pipe mat crossing is constructed of schedule 40 polyvinyl chloride (PVC) pipes and steel wire rope (cable). Initial testing was conducted at SDTDC to verify adequate strength of the pipes under direct loading. A second set of loading tests was performed on pipes chilled to freezing temperatures. The pipe proved strong enough under direct loads up to 826 kPa (120 psi).

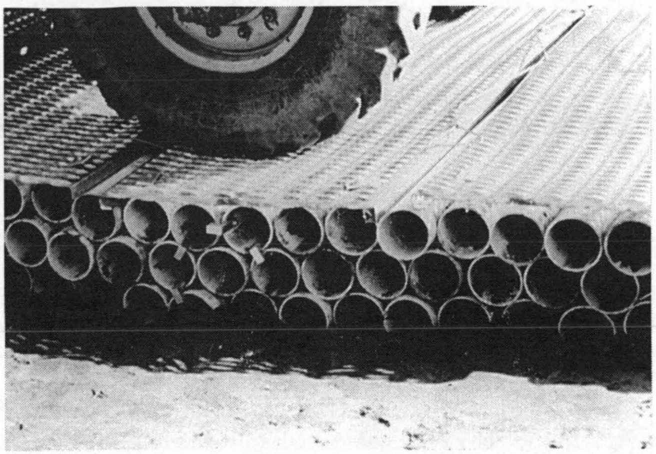

FIGURE 1 Pipe mat crossing with grating surface.

Field Tests

Field testing confirmed that connecting all of the pipe that comes in contact with vehicle tires is mandatory. Pipes are drilled at 0.3 m (1 ft) and 1.2 m (4 ft) from each end. Four 10-mm (3/8-in.) cables are threaded through the holes to connect the individual pipes. The cable ends are looped and secured with cable clamps to prevent individual pipes from rolling, shooting out the sides, or moving in other directions. This also reduces the time to install and retrieve the crossing. From field tests, 5-mm (3/16-in.) cable appeared to be sufficient, was much easier to work with, and was less costly than the larger-size cable.

Crossings were assembled into bundles made of 5.1-, 10.2-, 15.3-, and 20.4-cm (2-, 4-, 6-, and 8-in.) schedule 40 PVC pipe and proved very successful in crossing U-shaped channels. The main concern was damage to the banks due to gaps between the bank and the bundle. Because U-shaped channels are not typical, further testing was performed on broader, shallow channels. Bundles could not be placed to make an even surface. To alleviate this and completely fill the channel, thus reducing damage to the stream banks, loose pipe were placed in the channel. A single layer of pipe was connected along the surface, first using clamps, then cable. Sheets of grating were placed on top to protect the pipe and provide traction. The deck-span safety grating (described later) was placed with the 3.0-m (10-ft) edge perpendicular to the wheel lines and proved more stable than the expanded metal grating. The sheets were later connected to each other with 10-mm (3/8-in.) cable and clamped to the pipe (Figure 1). This crossing proved very successful with little pipe movement under a loaded log truck making 10 passes.

A field test on the Osceola RD was conducted at a site where a small, shallow stream required crossing by a skidder. Only a single layer of pipe connected to form a mat was needed. The mat was 2.7 m (9 ft) long by 6.1 m (20 ft) wide, providing the log skidder with plenty of maneuvering room. A nonwoven, needle-punched geotextile was placed along the stream bottom, with the crossing placed on top. Because of the short length, no additional surfacing material was needed for improvement of traction or protection of the crossing. The crossing materials cost approximately $602. Life expectancy is unknown. Construction and placement of the mat took approximately 3 hr. The skidder successfully completed 40 round trips with no movement or damage to the pipe mat crossing. Except for the slight indentation from the pipes, the stream showed no detrimental effects from the crossing. The only damage to the pipe mat crossing occurred after removal due to the skidder arm swinging back and hitting one pipe. The mat is still usable.

Another field test on the Osceola RD was conducted to measure changes to the stream bed and water quality. The channel was 10.6 m (35 ft) wide and 0.5 m (1.3 ft) deep at the center. A nonwoven, needle-punched geotextile was placed on the stream bottom followed by five loose pipes in the main channel used to even out the stream bottom. Then, two pipe mat crossings of 10.2-cm (4-in.) schedule 40 PVC and 5-mm (3/16-in.) cable were placed to cover 7.5 m (25 ft) of the span. A third 3.0-m-(10-ft-)long crossing was placed on top, at the center, to bring the crossing to the water surface level. Wood pallets (described later) were placed as the running surface. The entire crossing took approximately 1.5 hr to place. A loaded lowboy, 36 320 kg (80,000 lb), made a single pass. More passes were not attempted due to long stretches of weak soils on both sides.

Although test results are not yet available, several items appeared to affect water quality for the short duration of installation and removal. During installation, soil may be picked up with the crossing if the crossing has been stored directly on the ground. This soil is deposited in the stream with the pipes. Also, small fragments of pipe from cutting and drilling may remain inside the pipes and be deposited in the stream. With some care, both of these pollutants can be kept out of the stream.

During removal of the geotextile, sediment that had settled on the surface of the geotextile entered the stream mainly from disturbance when the fabric was dragged out. Care must be taken when placing and removing the crossing. Equipment can be a detriment to weak soils at the edges of streams. Measurements of changes to the stream bed are not yet completed, however, a slight indentation of approximately 12 mm (0.5 in.) was noticeable at the stream edges.

The pipe mat crossing has proven a very successful means of crossing a stream, provided the stream bottom has little, if any, grade. For all designs, it is important to place geotextile before pipe installation to ensure separation and prevent sinking, which causes impact to the stream and makes removal difficult. A layer of connected pipes should be placed along the stream bottom. If necessary, loose or connected pipes should then be placed to the desired height; then, a final layer of connected pipes should be placed. The top and bottom layers should be long enough to go beyond the stream edge to help protect the stream banks.

Typically, a tractive surface such as grating, Terra Mat, wood mats, or wood pallets should be connected to the top layer of pipe.

An important consideration is width. A 3.0-m (10-ft) width is too narrow for many vehicles, and 6.1 m (20 ft) (typical PVC length) may be excessive. It is possible to use shorter sections, end-to-end, between full length pipes making 4.2-m-(14-ft-)wide mats. This concept is shown in Figure 2.

Transport depends on the length and amount of pipe. In some cases, the drilled, individual pipes are transported by pickup truck and constructed on-site. Preconstructed mats may be too heavy for a pickup truck, requiring a lowboy or dump truck. Due to weight, equipment on-site (typically front-end loaders or skidders) is used to place the mats. Time to place depends on length and depth of the stream, amount of water, equipment available, and the amount of room needed for equipment to maneuver. The greatest consumption of time involves construction of the mat. To cut, drill, and cable together a 6.1-m-(20-ft-)long, 4.2-m-(14-ft-)wide mat can take three people about 3 hr.

The two main causes of pipe deterioration are impact (from dropping or hitting the mat) and ultraviolet (UV) light. Pipe with UV inhibitor is available, or the pipe may be kept covered as much as possible. The two main causes of vehicle damage occur when (a) loops at the end of the cables hook onto items on the underside of the vehicle and (b) the cross surfacing is not sufficiently connected to the pipe, possibly flipping up under the truck.

Grating

During the market search, placing steel grating over geotextile was considered. Two types of steel grating were suggested for the initial field tests. One is deck-span safety grating. Made from 10-gauge, pre-galvanized sheet metal, it is 0.9 m (3 ft) by 3.0 m (10 ft) by 3.3 cm (1-5/16 in.) with the edges flat instead of bent into a channel. The plank has an 8-diamond design with a diamond opening size of 9.8 cm (3-7/8 in.) by 3.2 cm (1-1/4 in.). The other is a 1.8 kg (4 lb) regular expanded metal grating. It is made of non-galvanized carbon steel. The size is 1.2 m (4 ft) by 3.0 m (10 ft) by 13.0 mm (0.6 in.) with a diamond opening of 3.2 cm (1.3 in.) by 13.4 cm (5.3 in.).

Field Tests

All the grating field tests were performed on the Osceola RD. The initial step was to smooth the area of rutting. The geotextile was then placed, followed by the grating. For one site, a woven, high-tensile strength geotextile was used. For the other tests, a standard nonwoven, needle-punched geotextile was used. For the other tests, a standard nonwoven, needle-punched geotextile was used. The woven geotextile has a slicker surface allowing more movement of the grating. The geotextile is critical to the success of this type of crossing and must be used.

Before placement of the grating, some of the deck-span safety grating was connected to reduce the amount of cold pressing. Cold pressing is the slow deformation (bowing) of the sheet metal over the 3.0-m (10-ft) length, which could catch under a vehicle, possibly damaging both. Cold pressing does not harm the grating, but would necessitate flipping the grating over occasionally. Connecting the grating was also considered to reduce installation time. Wing hinges were used to connect two sets of the grating. One set was connected along the 0.9-m (3-ft) edge, the other connected along the 3.0-m (10-ft) edge.

The grating was placed in the wheel paths with the 3.0-m (10-ft) edge parallel to the direction of travel. Only the set of safety grating connected along the 3.0-m (10-ft) edge was placed with the 3.0-m (10-ft) edge perpendicular to the direction of travel. The main problem with the connected grating during installation was its weight. It took six to eight people to lift, carry, and place the grating. Connecting did reduce bowing. Bowing is also reduced by placing the 3.0-m (10-ft) edge perpendicular to the direction of travel. The grating installation time was decreased very little, if any, by connecting the grating.

The initial use of the grating was for light-vehicle access through an intermittent stream with standing water. Only the two types of grating were used. Geotextile was not considered necessary. Approximately 200 vehicles traveled over the surfacing. It was very successful, with no problems or user complaints.

The first test with heavy vehicles occurred in March 1991. It took eight people 2 hr to place the geotextile and grating. After placement, an empty log truck made one round trip. Everything performed successfully, including a geotextile without grating section. Unfortunately, no further testing was performed at this site.

In March 1992, another opportunity arose when a 60-m (200-ft) section of continuously saturated soil conditions stopped timber harvesting. Four people installed the nonwoven, needle-punched geotextile and both types of grating in approximately 2 hr (Figure 3). The road was continuously used from March through May, equaling

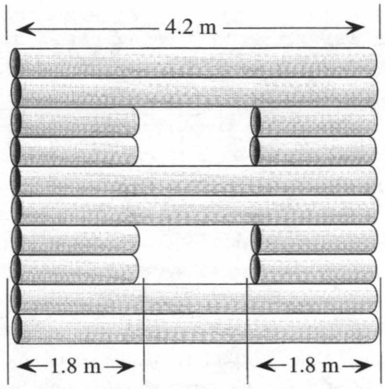

FIGURE 2 Using shorter pipe sections, end-to-end, between full length pipes, to make 4.2-m-(14-ft-)wide mats.

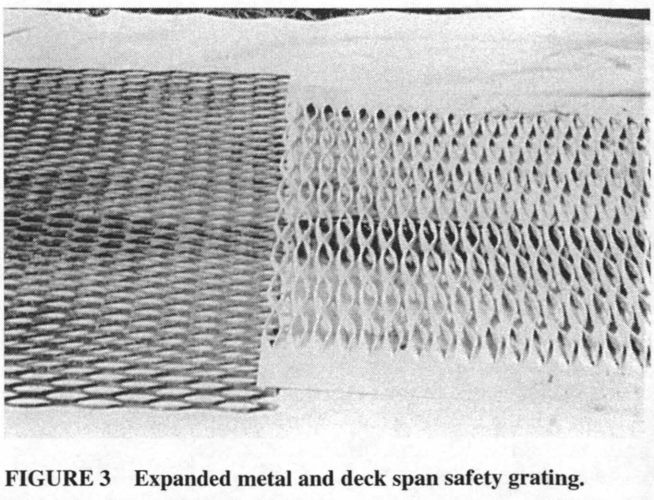

FIGURE 3 Expanded metal and deck span safety grating.

approximately 130 round trips of log trucks. The grating was quickly and easily removed by a nearby loader. The geotextile was still in good condition, however, it was saturated with water and sand. The weight of the fabric during removal resulted in fabric tears in several areas. A way to easily remove the fabric so it can be reused still needs to be determined.

The key to the system's success appears to be the geotextile. As the tires travel over the grating, the geotextile below it goes into tension, which helps distribute the load over the road surface between the tires. The geotextile allows the water to move to the surface while confining the sand beneath. The grating provides traction, keeps the geotextile from moving, and distributes the direct wheel load over a wider area of the geotextile.

A lower gauge (11-gauge) of expanded metal grating has also been used. It weighs less and costs only $32 for a 1.2-m (4-ft) by 2.4-m (8-ft) sheet. The problems with cold pressing of the deck-span safety grating and lateral movement of the expanded metal remain. Reinforcing bar, typically used in concrete, was shaped and used to anchor the grating. A 1.2-m (4-ft) section of 12.7-mm (0.5-in.) bar was bent into a U-shape. The center section would be 15.2 cm (6 in.) and the legs 0.5 m (1.7 ft) each. Thus far, it has worked well. It also helps reduce theft. Life expectancy information has been difficult to obtain due to theft of the grating before the end of its useful life.

Information concerning the reduction in surface impacts has been gathered and includes soil moisture content, strength, compaction, and surface deformation (mainly rutting). A comparison is made between two areas, one with the two types of grating and one without grating. The one with grating had about 1.3 to 2.5 cm (0.5 to 1 in) of deformation compared with up to 0.3 m (1 ft) of deformation in areas without grating (Figure 4). If the grating or other type crossing does not span the entire length of weak soil, deep rutting occurs at the ends. Vehicles begin to off-track, causing impact to the area.

Terra Mat

Disposal of rubber tires has become a growing problem due to the tires' slow rate of deterioration. Because old tires are readily available and inexpensive, companies are beginning to look for ways to use this material. Tires are very durable and have long-life attributes, which make them suitable for a portable, reusable crossing. Terra Mat was developed specifically to help logging trucks cross weak soils. The mats are made to be portable and reusable.

Terra Mat is made of interconnected tire sidewalls. Maintenance is minimal and typically consists of replacing connectors. Although it was developed specifically for logging trucks, only limited experimentation with Terra Mat had been performed on Forest Service roads. The product has performed well, but more experimentation is needed.

These mats come in a variety of sizes depending on the width of road, length of area to be covered, and weight that can be handled by on-site equipment. Variations include double layers of sidewalls or a layer of treads topped by sidewalls. The standard mat [2.7 m (9 ft) by 6.1 m (20 ft)] weighs 680 kg (1,500 lb) and costs $200 (Figure 5).

The other basic type of mat is narrower and should be placed only in the wheel tracks. These are typically 0.9 m (3 ft) wide and 3.0 m (10 ft) long. The design tested in the field has two layers of tire treads topped with tire sidewalls. This mat weighs 360 kg (800 lb) and costs $125 for two sections.

Field Tests

Several field tests have been performed, mainly with the standard and wheel track mats. In the Daniel Boone National Forest (NF), near Lexington, Kentucky, a standard mat was placed on a bridge deck. The timber bridge was being used by skidders. The surface had become slick due to rain and mud. The mat provided the necessary traction for the skidders to complete the remaining round trips over the bridge. It was transported by a pickup truck to the site. A skidder, chained to one end, dragged the mat into place, taking only a few minutes. By the end of the test, little remained of the mat. Trees dragged behind the skidders caught on the mat and pulled apart the center during the first pass. This continued throughout its use with only parts remaining along the deck edge in the wheel track areas.

A field test was performed on the Osceola RD using the wheel track mats. The site was for log truck use where no road previously existed. Using a feller buncher, trees and stumps were cleared. A nonwoven, needle-punched geotextile was placed over the existing

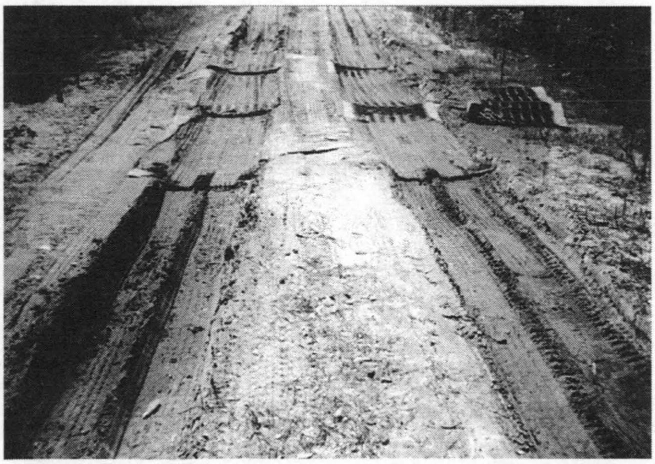

FIGURE 4 Comparison of wheel path deformation, grating versus untreated surface.

FIGURE 5 Interconnected rubber tire sidewalls, Terra Mat.

vegetation. A loader piled the Terra Mats for the skidder to drag to the road location. Each mat was then chained and placed by the feller buncher. The mats are heavy, very flexible, and have a tendency to curl under at the ends (Figure 6). Location of the chain is critical because people are not strong enough to help in placement. The mats took little time to place, 15 min per mat once on-site. Maneuvering room is critical to time of placement. Transport and chaining took the greatest amount of time. The mats performed successfully for 35 round trips. In the drier areas, without crossing materials, the trucks had to be assisted. Finally, due to the increased moisture conditions, the mats began moving out of place and the test ended. Impact to the crossing area was minimal when compared with the areas without crossings.

A field test was performed on the Apalachicola National Forest (NF) near Tallahassee, Florida. The site was a dry sand area with a grade of about 10 percent. The standard mat was placed directly on the sand. No means of holding the mat in place was used. A loaded log truck then tried to climb the grade. The mat was pulled out of place and the test was abandoned. This mat-crossing application may have been successful had the mat been anchored in place.

Without the proper equipment these mats are difficult to place. Because they are heavy, large, and very flexible, it can easily take an hour to place one mat. Although this makes them difficult to work with, they conform well to the area and their weight tends to keep them in place. With Terra Mat, use of geotextile is not as critical. Placement is easier without the geotextile because the mats can be dragged instead of lifted into place. Both are too narrow for typical forest road applications. Log trucks need at least 3.0 m (10 ft), preferably 3.6 m (12 ft) of width on straight stretches and more on curves. The 2.7-m (9-ft) by 6.1-m (20-ft) mat is too short in one direction and too long in the other. The 0.9-m (3-ft) mats can be spaced for the wheel tracks and are easy to drive off of. However, getting back on the mats can be difficult. Although the maximum grade has not yet been determined, anchorage of the Terra Mats should be considered for any grade greater than 5 percent. The Terra Mat does have a rough surface requiring a reduction in vehicle speed. Placement should be in areas where the speed is low or there is good visibility and plenty of distance to slow the vehicle. Their best quality is the very low cost.

The mats appear to cause little impact to the road surface. No direct measurements of the impact have yet been made. Unfortunately, the impact by the equipment placing the mats can be high and spread over a large area. This is mainly due to maneuvering to the side when lifting instead of dragging the mats into place. Proper equipment to handle the loads would help, and lighter mats would be desirable.

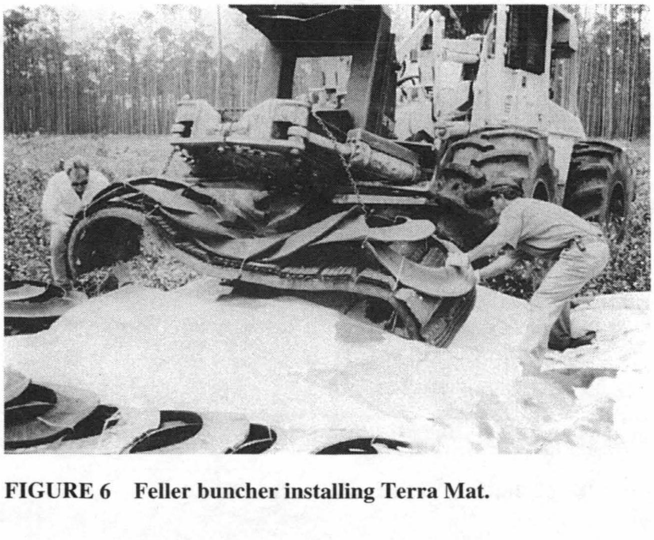

FIGURE 6 Feller buncher installing Terra Mat.

Wood Pallets

Supreme International is a Louisiana company that produces a sturdy variation of a wood pallet. They are made up of 7.6-cm (3-in.) by 20.3-cm (8-in.) hardwood planks, nailed together to make a three-ply pallet. They interconnect to make roads and platforms typically used in oil fields. The individual pallets range from 2.4 m (8 ft) by 3.6 to 4.8 m (12 to 16 ft). The prefabricated pallets are made from lumber weighing 1,000 kg (2,200 lb) with approximately 250 nails, and cost $370.

The pallets should last at least 2 years. No nail points can surface, which eliminates the possibility of tire puncture. The mats are reversible and broken planks can easily be replaced, prolonging their life. Each end has an overlap area for connection between pallets. In some areas, such as road intersections and curves, the panels are placed with the 4.8-m (16-ft) width, providing ample maneuvering room for log trucks.

Field Tests

A field test has been carried out on the Osceola RD. The area was near a culvert, which increased the moisture content of the silty sand soil to more than 30 percent. Although the area needs to be fairly smooth to obtain an even surface and reduce stresses to the pallets, 10.2 to 15.3-cm (4 to 6-in.) ruts were present at the time of placement. A nonwoven, needle-punched geotextile was placed under the pallets to reduce sinking and improve separation, reducing stresses to the planks during removal. The pallet was cut in half to make two 1.2-m (4-ft) by 4.2-m (14-ft) pallets. This helped reduce the weight and made them less cumbersome and easier to place. Each pallet was placed in a wheel track, providing proper road width. Soil was then placed on both ends to reduce the abrupt edges, which decreased roughness.

The geotextile was unrolled by two people and the pallets placed by a backhoe. Transporting was the most time-consuming process. Picking up pallets was somewhat difficult. The planks were too close together to use a chain. Making loops with cables through the center of the pallets could permit chain use. After 1 week and approximately 150 round trips, the pallets were holding up well. Some deflection occurred due to pre-existing ruts. One plank edge broke off and vehicles had to slow down at the crossing due to roughness (Figure 7). The pallets deformed the road surface by only 12.7 mm (0.5 in.).

Another field test was performed in Florida using the pallets as surfacing for the pipe mat crossing. Due to the small equipment available to handle the pallets, they were cut in half. They were placed by a front-end loader and truck with a winch (Figure 8). Placement took less than 15 min per pallet. No noticeable movement occurred under a loaded lowboy.

Wood Mats

Pallets work very well and have proven themselves in oil field applications. However, they are expensive, limited in size, and manu-

FIGURE 7 Wood pallet installation.

factured by only one company. Hence, they are not readily available and can be expensive to ship. As an alternative, wood mats using posts were constructed and tested. The posts were 10.2 cm (4 in.) by 10.2 cm (4 in.) and 15.3 cm (6 in.) by 15.3 cm (6 in.) in width and 3.6 to 4.2 m (12 to 14 ft) in length. Holes were drilled through each piece at 0.3 m (1 ft) and 1.5 m (5 ft) from each end. They were connected with 10-mm (3/8-in.) galvanized steel cable. Loops were made at the end of each cable and secured with cable clamps.

The connection between the lumber pieces was loose. Putting tension on the cable would help increase friction between the pieces so they would act as a unit and not individually. From the field tests, this does not appear to be necessary.

Field Test

A field test was performed in the same area and at the same time as the one for the wood pallets. Because the crossing area was large, both pallets and mats were needed to cover it. The existing rutting was smoothed by a small dozer. Unfortunately, most of the rutting reoccurred during placement from the backhoe and the need to allow log truck traffic to continue during installation. The geotextile was rolled out and the mats were emptied by the dump truck onto the ground. The backhoe picked up each mat by the loops and laid it in place. The mats were moved to better cover the weak soil area. It would be wise to flag where the mats should be placed, based on the length of mats and area to be covered, so extra moves are not necessary. The 15.3-cm (6-in.) mats were placed in the center with the 10.2-cm (4-in.) mats on each end as ramps. The length of each mat was 1.2 to 1.8 m (4 to 6 ft) to reduce weight and ease placement. The mats could be connected to each other on-site, but this was not done for this test. If the surface becomes slick, grating can be connected to the surface.

FIGURE 8 Front end loader installing wood mat.

During the first pass of a loaded log truck, a loop caught on the disconnect valve of the fuel line. It pulled the mat up out of position and disconnected the valve. Although inexpensive and easy to repair, this occurrence highlights the importance of making sure all loops are tucked under the mats. In the 150 round trips since, no other vehicle damage occurred. Impact to the site has been minimal. The pallets have settled about 12 mm (0.5 in.) and make for a smooth road surface.

The surface has not become wet or muddy to the point of becoming slick. Initially the moisture content of the soil was so high that pumping of water through the geotextile onto the mat surface was visible. The 10.2-cm (4-in.) mats were considered the most critical in terms of strength and have proven to work well, at a lower cost and lighter weight than the 15.3-cm (6-in.) mats.

Information was gathered at a pallet crossing site and at an area without pallet crossings. Moisture content, cone penetrometer, and shear vane data were gathered as well as surface deformation. Although further analysis of the information must be completed, the site without pallets had a moisture content typically 5 to 10 percent less than the crossing site. The rutting that occurred at the non-crossing site was 15.3 to 25.4 cm (6 to 10 in.). At the pallet crossing, settlement was only about 12 mm (0.5 in.). The addition of wood pallets left no specific areas to hold and channelize water or specific areas of high compaction (rutting).

Crossing Products Cost Comparison

Comparisons shown in Table 1 are made based on a crossing 4.3 m (14 ft) wide and 2.4 m (8 ft) long. Most of the crossings, except the 3-m-(10-ft-)long safety grating and Terra Mat, meet this criteria. For the pipe crossings, assume that the 6-m-(20-ft-)long pipes are cut to 4.3 m (14 ft) and that the extra 1.8-m (6-ft) pipes are used in the wheel tracks. None of the costs include labor to construct, install, or remove. Only the grating costs include the use of geotextile. No costs are included for surfacing over the pipe crossing. Shipping is not included in the costs (mainly for Terra Mat and wood pallets). Cost of rebar to pin down grating is not included.

CONCLUSION

A number of options exist for portable, reusable stream crossings. All of these options need further evaluation under conditions relevant to their operating environment. All of the options identified have positive as well as negative characteristics; some have a higher initial cost yet provide a longer life expectancy, while others can be

TABLE 1 Cost and Weight Comparisons of Various Products

Item		Cost	Approx. weight
Pipe mat	7.6 cm (3 in.)PVC 10.2 cm (4 in.)PVC	$331 $346	275 kg (605 lb) 295 kg (650 lb)
Terra mat		$250	815 kg (1,800 lb)
Wood pallet		$360	1 000 kg (2,200 lb)
Wood mat	10.2 cm x 10.2 cm (4 in.x 4 in.)	$220	700 kg (1,540 lb)
	15.3 cm x 15.3 cm (6 in.x 6 in.)	$340	950 kg (2,100 lb)
Grating	Expanded Safety	$74 $580	45 kg (100 lb) 80kg (180 lb)

used only under certain conditions. All of the products need various design improvements.

The goal is to devise short-term, portable crossings that allow temporary access, result in the least amount of damage to the environment, and remain cost-effective. This paper identifies a variety of temporary crossings that can be used during timber harvest; as pioneer and access roads during construction; and for other temporary applications including floods and fires. An alternative to building permanent stream crossings, these products have been proven to protect the environment while providing access without rutting. Research should continue, and testing of the various choices should be expanded to determine the most advantageous stream crossings.

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