Construction Methods for Slope Stabilization with Recycled Plastic Pins

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A new method for reinforcement of surficial slope failures is currently being developed that utilizes reinforcing elements, similar to soil nails, manufactured from recycled plastics and other waste materials. Using recycled plastics has the advantage of providing reinforcing members with high resistance to degradation while providing a market for materials that might otherwise be landfilled. A key aspect of development of the new stabilization scheme is development and evaluation of equipment and methods for installing the plastic reinforcing members. In this paper, results of a series of laboratory and field tests performed to evaluate alternative installation techniques are presented and installation activities performed to construct a full-scale field demonstration are described. Results of development activities to date indicate that recycled plastic members can be reliably and efficiently installed to produce a cost-effective alternative to more conventional slope stabilization techniques. Evaluation of the suitability of recycled plastic pin stabilization schemes for effecting long-term stabilization is ongoing.
Key words: slope stabilization, recycled plastic, construction methods, soil improvement.

INTRODUCTION

Maintenance costs due to slope failures on public and private transportation routes amount to a significant portion of yearly expenditures for infrastructure maintenance programs. Costs for repair and maintenance of slope failures for U.S. highways alone have been estimated to exceed $100 million annually (*1*). A new technique for stabilizing slopes is being developed that uses Recycled Plastic Pins (RPPs) in procedures comparable to soil nailing and conventional piling (Figure 1) that will offer a cost-effective alternative to current slope repair techniques. RPPs are composite members of plastic, wood, and other waste products. RPPs are lightweight, can be produced in various sizes, are easily modified with conventional construction equipment, and have excellent resistance against chemical and biological attack as shown by laboratory testing summarized in Table 1.

A critical component for development of the technique is development of construction equipment and methods for cost-effective and reliable installation of the plastic members. While equipment for installation of reinforcing elements is available, the unique characteristics of recycled plastic pins as compared to more conventional reinforcing elements necessitates adapting currently available equipment for the purpose of installing plastic members. The criteria on which alternative construction methods and equipment were considered and evaluated for this work include:

- equipment must be simple, robust, and operable with typical construction labor,
- equipment must be readily available with minor changes to conventional equipment,
- installation rates must be sufficient to be cost effective,
- equipment must have versatility and mobility to access potentially difficult sites, and
- installation must occur with minimal damage to recycled plastic members.

The efforts undertaken to develop and evaluate potential installation methods are described in this paper. These activities were accomplished in two phases. Phase one consisted of a series of small-scale laboratory and field tests using both impact and pseudo vibratory driving methods to install reduced-scale RPPs. In phase two, full-scale 10 cm by 10 cm by 2.5 m RPPs were driven in field trials and at a demonstration site using variations of the pseudo vibratory installation method developed during small-scale testing.

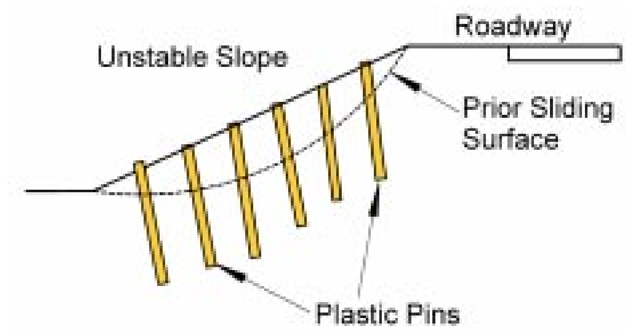

FIGURE 1 Reinforcement of unstable slope with recycled plastic pins

REDUCED-SCALE INSTALLATION TESTS

A series of laboratory and field tests were performed on reduced-scale versions of the RPPs in order to evaluate alternative installation methods with minimal cost. Both impact and vibratory methods were evaluated in this phase of development. Impact driving was evaluated in the laboratory using a simple drop weight driving mechanism to drive 4 cm by 4 cm pins into a soil filled drum. Results of these tests showed the recycled material to be extremely resilient to driving stresses. However, installation rates were generally unacceptable. Vibratory driving was evaluated using a slightly

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TABLE 1 Summary of the Material Properties of the RPPs Under Various Environmental Conditions Determined from Laboratory Tests (*2*)

	Tension Tests				Compression Tests				Shear Tests		Bending Tests	
	Young's Modulus (MPa)		Peak Stress (MPa)		Young's Modulus (MPa)		Peak Stress (MPa)		Peak Stress (MPa)		Peak Moment (kN-m)	
Exposure Environment	Avg.	Std. Dev.	Avg.	Std. Dev.	Avg.	Std. Dev.	Avg.	Std. Dev.	Avg.	Std. Dev.	Avg.	Std. Dev.
No Exposure (Control)	906	108	13	1.4	749	43	21	2.1	8.7	1.7	1.5	0.3
Acid (pH=5)	924	148	12	0.7	877	74	18	1.4	—	—	—	—
UV	822	79	9	0.5	642	25	15	3.5	—	—	—	—
Water	925	148	12	0.7	680	21	18	2.1	—	—	—	—
Kerosene	767	92	10	1.4	668	88	19	1.2	—	—	—	—
Freeze\Thaw	791	80	11	2.1	702	18	19	1.4	—	—	—	—

modified 27 kg (60 lb) pavement breaker to drive reduced-scale pins at a field test site near Columbia, Missouri (Figure 2). These tests again demonstrated the resilience of the plastic members. In addition, penetration rates for the pseudo vibratory method far exceeded those observed in tests using the drop hammer system. The pseudo vibratory method was thus selected for subsequent trials on full-scale RPPs.

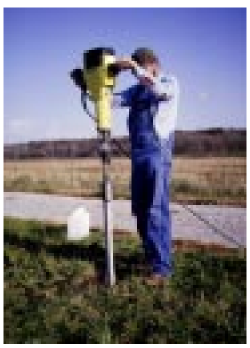

FIGURE 2 Modified pavement breaker used for preliminary evaluation of vibratory installation methods

FULL-SCALE FIELD DRIVING TRIALS

Based on the success of the small-scale tests, a series of full-scale driving trials were conducted at a site near St. Joseph, Missouri using a scaled-up version of the pseudo vibratory mechanism. The site, which is located in the flood plain of the 102 River, is generally stratified into two strata. The upper layer consists of approximately 1.5 m (5 ft) of compacted low plasticity (CL) clay. This material overlies a natural alluvial deposit of highly plastic (CH) clay. The in-place dry densities of the site soils ranged from 1.4 ton/m^3 to 1.7 ton/m^3 (86 lbs/ft^3 to107 lbs/ft^3). A total of seven 10 cm by 10 cm square pins of 1.2 m and 2.4 m length were driven at the site.

The driving mechanism used for the full-scale trials consisted of a modified Indeco MES 351 hydraulic breaker mounted on a rubber-tired 835 Bobcat® skid loader as shown in Figure 3. The hydraulic breaker was adapted by machining the breaker tool to create a 4 degree taper that would fit into a drive head adapter to form a compression fitting. The drive head adapter was machined from 152 mm (6 in) diameter round steel stock to form a 127 mm (5 in) receiver on one end to hold the end of the RPPs and a 4-degree tapered hole on the opposite end to accept the breaker tool.

FIGURE 3 Pseudo vibratory driving system used for full-scale field driving trials

Penetration rates observed during the field trials varied from a maximum of 3.7 m/min (12 ft/min) to a minimum of 0.24 m/min (0.8 ft/min) due to varying soil conditions at the locations of the test drives. The highest penetration rates were observed in the soft, highly plastic alluvial deposits with an average dry density of 1.4 ton/m^3 (86 lbs/ft^3). The lowest penetration rates were observed in locations of the dense, highly compacted clays of low plasticity with dry densities of up to 1.7 ton/m^3 (107 lbs/ft^3). Penetration rates more typically ranged from 0.31 to 1.2 m/min (1 to 4 ft/min) which was considered acceptable for cost effective installation.

The skid loader used for the field driving trials performed adequately for preliminary testing but had inherent limitations that preclude use of similar equipment for more typical applications. The relative short wheelbase of the skid loader makes it unstable and prone to rolling when working on slopes, particularly when operating the boom and hydraulic hammer at maximum height. In addition, the skid loader lacks sufficient headroom to drive full length (2.4 m) RPPs without pre-boring, which would add additional costs to installation.

INSTALLATION AT FIELD DEMONSTRATION SITE

A field demonstration site north of Emma, Missouri was selected to demonstrate the constructability and evaluate the effectiveness of the RPP stabilization technique. The site is the embankment for the eastbound entrance ramp to Interstate 70 located approximately 60 miles west of Columbia, Missouri. The embankment slopes vary from 2.5:1 (horiz.:vert.) to 2:1 and have repeatedly failed for over a decade, requiring periodic repair up to five times annually. The embankment soils generally consist of alternating layers of soft to very stiff lean and fat clays intermixed with localized pockets of concrete rubble that has been deposited via side cast over several years in an attempt to stabilize the slope.

Four general slide areas were observed in the embankment just prior to the field demonstration as shown in Figure 4. Three slide areas, denoted S1, S2, and S3, are located along the south side of the embankment with an additional slide, denoted S4, on the north side of the embankment. Slide areas S1 and S2 were selected as test areas for installation of RPPs; slide area S3 will be used as a control section.

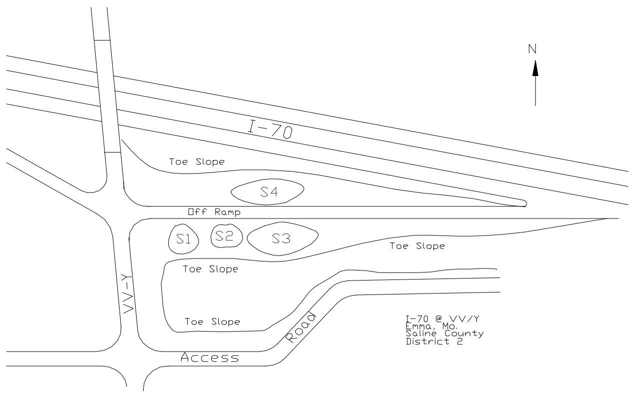

FIGURE 4 Plan view of the demonstration site located north of Emma, Missouri with the four slope failures designated as S1 through S4

A total of 317 RPPs were installed in slides S1 and S2 during October and November 1999. The pins were installed in a 0.91 m (3 ft) staggered grid with every other row offset by 0.46 m (1.5 ft) as shown in Figure 5. Pins were driven perpendicular to the face of the slope in slide S1; pins were driven vertically in slide S2. Not all of the RPPs could be driven to the full 2.4 m (8 ft) length due to the presence of concrete rubble from previous repair attempts (Figure 5). Conditions at the site were generally dry throughout construction allowing for maximum traction and maneuverability.

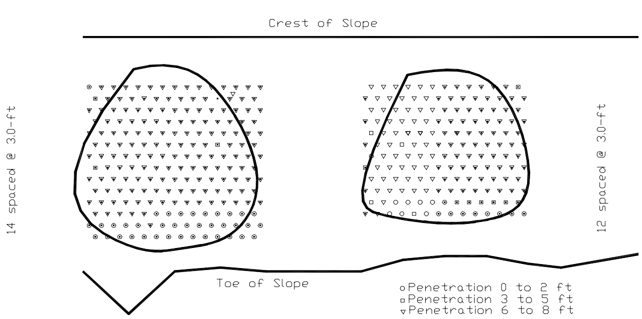

FIGURE 5 Layout of the RPPs at the Emma demonstration site showing the varying penetration depths

Pin installation activities at the field demonstration site were initiated in October 1999. The initial installation equipment used at the site consisted of an Okada OKB 305 1695 N-m (1250 ft-lb.) energy class hydraulic hammer mounted on a Case 580 backhoe as shown in Figure 6. This equipment proved unsuccessful for several reasons. The rubber-tired backhoe was difficult to maneuver on the slope and caused excessive rutting while trying to reach the top of the slope. Maintaining a fixed position during driving also proved difficult with the backhoe tending to slide down slope even with the outriggers placed thereby further damaging the slope and making driving pins with the correct alignment and placement extremely difficult. The average penetration rate obtained using this equipment was 0.7 m/min, which was significantly less than that obtained during the field trails. In addition, play in the backhoe boom and the inability to maintain precise alignment of the hammer and pin during driving resulted in numerous pins being broken during installation. Set-up time between installation of pins was also excessive due to difficulty in navigating the slope and the need to constantly reposition the equipment. As a result of these problems, the rate of installation (including time for set-up and repositioning) averaged only 10 m/hr. This rate was deemed unacceptable and installation was halted.

FIGURE 6 Hydraulic hammer and backhoe system used for initial installation of recycled plastic pins at the Emma field demonstration site

Installation at the field demonstration site resumed in early November 1999, using a Davey-Kent DK 100B crawler mounted drilling rig supplied by the Judy Company of Kansas City, Kansas as shown in Figure 7. The rig is equipped with a mast capable of 50-degree tilt from vertical forward, 105-degree tilt backward, and side-to-side tilt of 32 degrees from vertical. This rig offered numerous advantages over previously used equipment in that the drilling mast ensures that the hammer and pin remain aligned during driving without requiring any movement of the chassis. In addition, the crawler-mounted rig was much easier to maneuver on the slope, thereby reducing set up time between pins. The rig was equipped with a Krupp HB28A hydraulic hammer drill attached to the mast providing a maximum of 400 N-m (295 ft-lbs) of energy at a maximum frequency of 1,800 blows/min. The hammer energy is further augmented by a push/pull of 8,165 kg (18,000 lbs) supplied by the drill mast.

FIGURE 7 Drill rig and mast system used for installation of recycled plastic pins at the Emma field demonstration site

Penetration rates (not including set-up time) and installation rates (including set-up time) measured during installation using the mast-mounted system are summarized in Table 2. The mast-mounted hammer clearly outperformed all previous installation equipment that was evaluated. Penetration rates for pins driven perpendicular to the slope reached 3.0 m/min (10 ft/min) and averaged 1.6 m/min (5.2 ft/min). Penetration rates for pins driven vertically were only slightly lower reaching a maximum of 2.9 m/min (9.6 ft/min) and averaging 1.3 m/min (4.1 ft/min). Installation rates were also dramatically faster than observed previously because of reduced set-up times, reaching a maximum of 37.8 m/hour (124.0 ft/hour) at peak production. The average installation rate for installation of all pins was 25 m/hour (80 ft/hour). Installation rates generally increased during installation of pins for each slide as experience was developed indicating that installation rates for future installations may be closer to the maximum rates achieved for the field demonstration.

TABLE 2 Summary of the Penetration and Installation Rates for Mast-Mounted Hammer on Slope Failures S1 and S2

	S1		S2	
	Penetration Rate m/min (ft/min)	Installation Rate m/hr (ft/hr)	Penetration Rate m/min (ft/min)	Installation Rate m/hr (ft/hr)
Average Rate	1.58 (5.18)	29.26 (96.0)	1.25 (4.10)	20.73 (68.0)
Maximum Rate	3.05 (10.0)	37.80 (124.0)	2.93 (9.60)	29.87 (98.0)
Minimum Rate	0.04 (0.12)	18.0 (59.0)	0.16 (0.53)	10.06 (33.0)

Limitations of the Davey-Kent drilling rig necessitated that pins installed in a vertical alignment were driven with the rig being backed up the slope. While not critical, this feature did result in slightly lower installation rates for pins driven vertically as compared to pins driven perpendicular to the face of the slope (Table 2). An alternative rig, the Crawlair ECM-350 extendible boom rig manufactured by Ingersoll-Rand, capable of driving pins vertically from a forward position was also used at the site. The Crawlair rig was equipped with an EVL-130 195-kg air hammer operating at a maximum frequency of 2100-blows/min attached to a chain drive capable of 1362 kg (3000 lb.) of down force. While the rig was much more maneuverable than the Davey-Kent rig, the hammer and drive system lacked the power and down force necessary to achieve acceptable penetration rates and its use was discontinued after a few attempts.

Overall, installation of the recycled plastic pins using the mast-mounted hammer system worked extremely well and the total cost of installation was competitive with other slope stabilization methods. A total of 317 pins were driven in slightly over four days for a total installation cost of $5,250 including labor. Comparison of the drill mast system verses the backhoe-mounted system revealed the mast system was much more effective and accurate and required less skill to operate. The crawler system also caused much less damage to the slope than the rubber-tired equipment. The crawler system did become marginally stable when operating on the steepest parts of the embankment and had to be tethered to the top of the slope in some locations.

FUTURE ENHANCEMENTS TO DRIVING SYSTEM

Several enhancements of the installation equipment are currently being considered. One alternative being considered is to mount the mast system on equipment with booms to expand the reach of the driving system. Candidate equipment for this purpose includes crawler-mounted excavators (track-hoes) and extendible boom excavators (grade-alls). The additional reach provided by such equipment will allow the equipment to remain off of the slope during installation which will further limit damage to the slope and reduce set-up time. An excavator/grade-all mounted mast system will also have greater swing range than the track mounted system allowing a larger number of pins to be driven without movement of equipment.

Several mechanical problems slowed progress during installation at the demonstration site. The connection between the hammer and the pins proved particularly troublesome as several different connections failed during installation. In the early stages of installation with the mast-mounted hammers, a welded drive head was used to receive the drill bit connector allowing the transfer of energy from the hammer to the RPPs. The repetitive impacts from the hammer inevitably caused the welded connections to fail. While several spare connectors were kept on site, construction was stopped on two occasions to permit re-welding of the connectors. In the latter stages of installation, the connection used during the field driving trials was adapted for use with the mast-mounted hammers. This connection performed much better than the welded connections but eventually failed due to incompatibility between the steel used for the connection and the steel used in the hammer. Modifications are currently in progress developing a more reliable drive head connector.

Extensive instrumentation was installed during construction to permit the performance of the slope to be monitored over time to establish the effectiveness of the plastic reinforcing members for stabilizing the slope. Instrumentation monitoring is expected to continue for several years. Results of instrumentation measurements will be presented in forthcoming papers.

SUMMARY

A new technique for slope stabilization is being developed that used Recycled Plastic Pins (RPPs) for reinforcement of unstable slopes. A particularly important part of this development has been consideration and evaluation of methods and equipment for installation of recycled plastic members into slopes. Activities undertaken in this work include a series of reduced-scale laboratory and field tests to evaluate the performance of both impact and pseudo vibratory driving mechanisms, a full-scale field driving trial, and installation of over three hundred plastic pins at a field demonstration site. The results of this evaluation indicate that a mast-mounted vibratory hammer system can produce efficient, reliable, and cost effective installation of recycled plastic members. The mast-mounted driving system was clearly superior to the other installation techniques evaluated to date.

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