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THE EVOLUTION OF LAUNCHED SOIL NAILS

A 30-Year Retrospective

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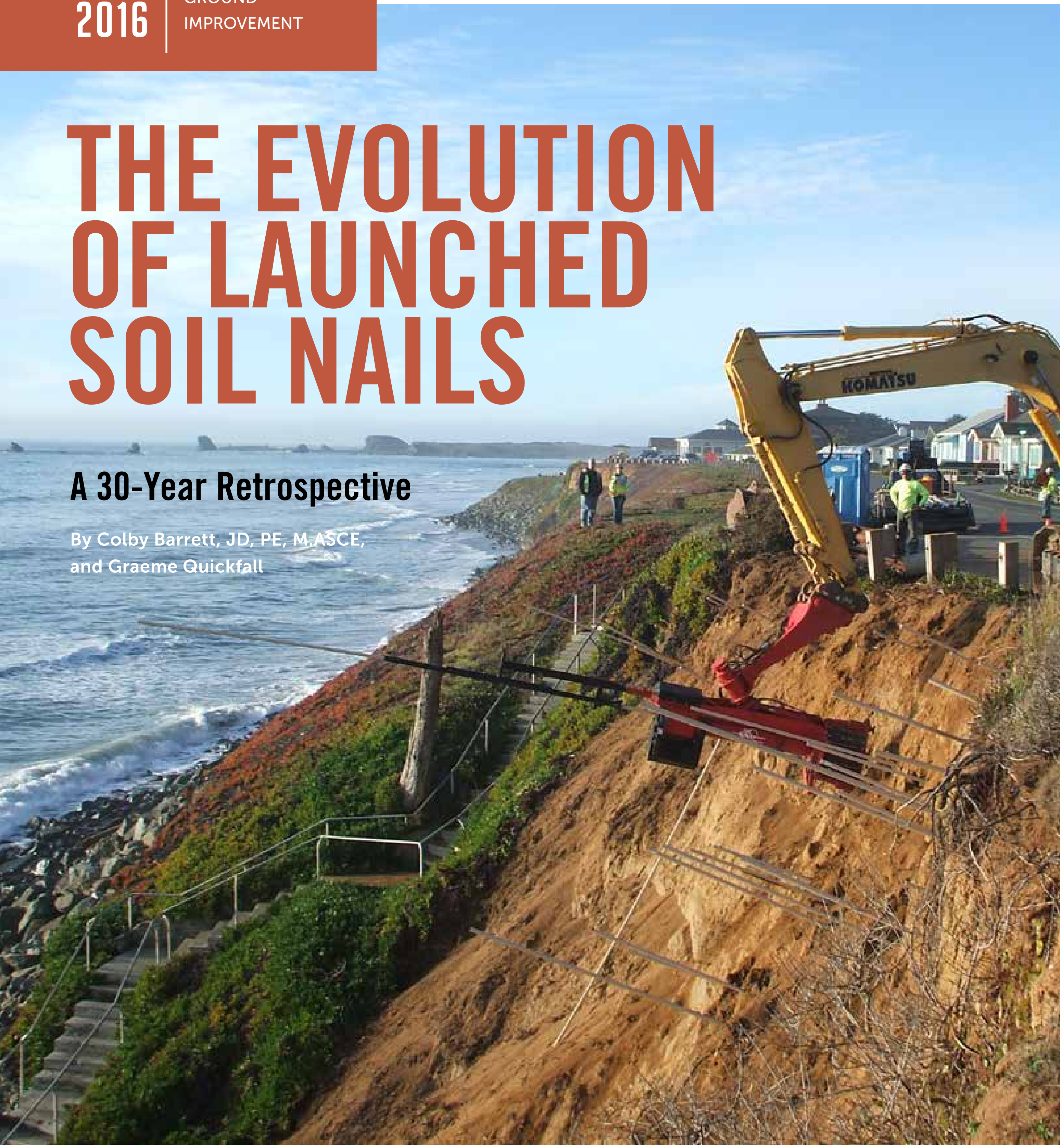


Fiberglass launched soil nails used for bluff stabilization in Northern California.

Launched soil nails are a unique remedial technology in the geotechnical construction toolbox. These 20-ft-long, 1.5-in.-diameter nails are installed in a single shot using a compressed air “cannon” at velocities of up to 250 miles/hour, and at rates approaching 250 nails/day. The nails reinforce an unstable or potentially unstable soil mass by transferring the nail’s tensile and shear capacity into the sliding soil. However, at least as interesting as the tool itself, is the story behind the development of launched soil nail technology over the past 30 years.

This story is not just one of technological innovation, advancement, and refinement of a specific piece of construction equipment. It stands as a testament of the innovative, bold, and resourceful character of engineers and practitioners in the geotechnical construction industry. It’s also an insight into how engineers from three continents — often working independently — responded to challenges as diverse as national tragedy, shrinking infrastructure budgets, and the challenges posed by geohazards across the globe, to create a powerful new tool that continues to be refined, updated, and improved to the present day.

Impetus and Early Development (1966-1989)

On Friday, October 21, 1966, after several days of rain, more than 150,000 cy of waste spoils from a local coal mine liquefied and surged toward Aberfan, Wales, burying much of the village, including the Pantglas Junior School, in up to 30 ft of soil and spoil debris, killing 116 children and 28 adults. Soon afterward, the concept of soil nailing started to emerge in Europe and beyond, and engineers began to investigate how nails could be installed most efficiently. Groups from the U.K., Germany, and France independently developed installation methods that included driving, drilling, driving with simultaneous jet grouting, and even chemical explosive actuated firing systems. One group, which included Bernard Myles, an engineer from the defense industry, and the Industry Center at Cardiff University in Wales, developed the first version of the “soil nail launcher” that is still used today.

Riparian landslide repair using pressure-grouted launched soil nails for Western Federal Lands Highway Department.

Stories from those early days are colorful, full of intrigue and details about classified technology. They even include unconfirmed rumors that Gerald Bull, the artillery engineer best known for positing that large guns could be used to launch satellites into space and who assisted Saddam Hussein with his "Babylon Supergun" project, had a hand in the early development of the technology as well. Rumors aside, it's true that Myles' group based its invention on declassified British military technology originally developed to propel chemical weapons munitions using compressed air. They likely saw the benefits of a technology that could rapidly and economically install many soil nails to stabilize a slope, especially in areas prone to conditions like those that precipitated the 1966 Aberfan disaster. By 1989, Myles had formed Soil Nailing Limited in the United Kingdom and began the first successful application of air-launched nails for rail, highway, and commercial clients in the U.K.

The First Shots in North America (1992-1994)

At the 1989 Transportation Research Board (TRB) Annual Meeting in Washington, DC, a chance meeting between Myles and John Steward, then the Pacific Northwest geotechnical engineer for the U.S. Forest Service, led to a joint USFS/FHWA demonstration project of the launcher technology using soil nails to repair landslides at eight sites in four western states and three western U.S. Forest Service (USFS) regions in the early 1990s. The nails used at the time were galvanized, solid steel bars. The cannon was mounted on a tracked excavator. The project produced a video, a report, design methodology, and an application guide. But the project did not produce what Myles had sought — a completed sale of the launched soil nail technology to American owner-operators. State and federal agencies could not justify the purchase of a very expensive piece of equipment to repair just the 10-15 applicable sites likely to need it each year in their regions, and the researchers were unable to entice a private contractor to purchase the technology to cover a larger, and therefore commercially viable, geographic area. After the demonstration, the launcher and Myles returned to the U.K.

Rapid Fire in North America and Australasia (2001- Present)

This story could have ended there. But in 2000, Bob Barrett, a former Colorado DOT geologist and an original member of the USFS project team, and his business partner, Al Ruckman, contacted Myles about buying the launcher technology. The timing couldn't have been better. The technology had been purchased by a European conglomerate, but was shelved because they thought it would disrupt their other soil stabilization business lines, and perhaps even compete with them. After a series of mergers and acquisitions, the launcher technology was mothballed in a warehouse in England. After stretching their personal credit and borrowing to their limits, promising U.K. officials to only use the cannons for "non-military" applications, and convincing U.S. customs officers that importing 150-caliber guns from overseas immediately after 9/11 was a good idea, Barrett and Ruckman were finally able to begin business in North America.

The cannon units weigh over 6,000 lbs and are typically mounted on a tracked excavator that has been converted to carry a specialized compressor unit rather than a rear counterweight. The units may also be suspended from a crane or mounted on a long-reach excavator for greater range. Initial firings used 1.5-in.-diameter, 20-ft–long, galvanized solid steel bars. These solid bars were both costly and heavy, so in early 2002, galvanized steel tubes were introduced. Research conducted at project sites confirmed that the lighter tubes could be advanced up to 12 in. farther into similar soils than the heavier solid bars. The tubes could also be perforated to act as drains, or later pressure grouted to improve bond strength, corrosion protection, and capacity. The typical launched soil nail soon became a three-step process:

1. A perforated, galvanized outer tube would be launched to full depth at pressures between 800-4,500 psi.
2. The hollow tube would be pressure grouted with neat cement grout.
3. A #6 epoxy-coated inner bar would be inserted before the grout set.

Fiberglass outer tubes have also been installed in corrosive soil environments, and many projects have been completed where pressure-grouted, launched soil nails were installed in combination with ungrouted, perforated launched drains.

As of 2016, tens of thousands of launched soil nails and drains have been installed in the U.S., Canada, U.K., New Zealand, and Australia. Primary applications have been to stabilize shallow landslides, although the technology has been used to stabilize failing sheet/H-pile walls, for temporary shoring, for pipeline stabilization, and as micropile foundation supports for retaining walls. Launched soil nails have been used in a variety of soil and slope conditions, especially in mountainous areas, where rugged terrain limits construction options. They are primarily fired into sand, silt, clay, and even soils with some cobbles or boulders. Launched nails are not suitable for sites with large/frequent boulders or very hard, shallow bedrock, in very stiff clays, or in areas where failure surfaces exceed 17 ft deep. Launched soil nails have also been specified on sensitive riparian projects where drill cuttings/grout spoils and excavations often associated with traditional drilled and grouted soil nails would not meet environmental mandates.

Project Applications

Launched soil nails have been used on many notable projects and are credited with saving I-75 in Northern Tennessee from total collapse in 2005 and again in 2012 due to their speed of installation and ability to provide immediate structural contribution. In 2005, the use of launched soil nails for temporary embankment shoring prevented slope failure during excavation for the emergency installation of a rock buttress. Because the nails are effective seconds after installation, with no delay required for grout set, shoring of the slope could be conducted at the same rate as the slope excavation advanced without compromising worker safety. A few miles down the road in 2012, large cracks had developed in the southbound lanes as part of a large, active landslide. Within hours, both southbound lanes had failed and cracks were progressing into the northbound lanes. Emergency stabilization work commenced, and

Launched soil nail shoring to support a roadway in Northland, New Zealand. (Photo courtesy Hiway Geotechnical Ltd.)

The group that developed the first version of the “soil nail launcher” based its invention on declassified British military technology originally developed to propel chemical weapons munitions using compressed air.

within 48 hours, over 250 launched soil nails were installed into the northbound lane and pressure grouted, which prevented scarp regression of the large landslide. With traffic on the northbound lanes safely restored, the southbound lanes could be stabilized with post-tensioned strand anchors and then reconstructed using a large rock buttress.

Launched soil nail technology has been used in New Zealand since 2006, primarily on the subtropical North Island, which features steep terrain and numerous landslides. In 2009, launched soil nail technology was introduced to Australia, starting in the far North region of Queensland, near Cairns. On sites where roadway width had been lost, launched nails were combined with geosynthetically confined soil retaining walls with aesthetically pleasing and erosion-resistant vegetated facing. This combination proved to be particularly effective in environmentally sensitive tropical and high-rainfall regions. Several other launched soil nail/vegetated face retaining wall projects have been completed on roads within Australian tropical wetlands national parks and also in New Zealand’s national parks, often using native plantings to blend in with the natural bush and surroundings.

Installation Theory and Corrosion Protection

The compressed air cannon induces tensile stresses in each tube as it penetrates the ground. This tension counteracts the compressive stresses induced by the displaced soil and thereby prevents nail buckling. The single impulse, high-installation velocity creates a shock wave at the nail tip, which displaces the adjacent soil as the nail penetrates. It’s important to note that during the majority of the nail’s flight into the soil, the

Completed launched soil nail geosynthetically confined soil wall in Cairns, Australia (l) immediately after wall construction, and (r) vegetated-face 18 months later. (Photo courtesy Hiway Geotechnical Ltd.)

Launched soil nails used to prevent the regression of a large landslide in northern Tennessee (2012). Note the launcher at the top of the photo for scale. (Photo courtesy Tennessee DOT.)

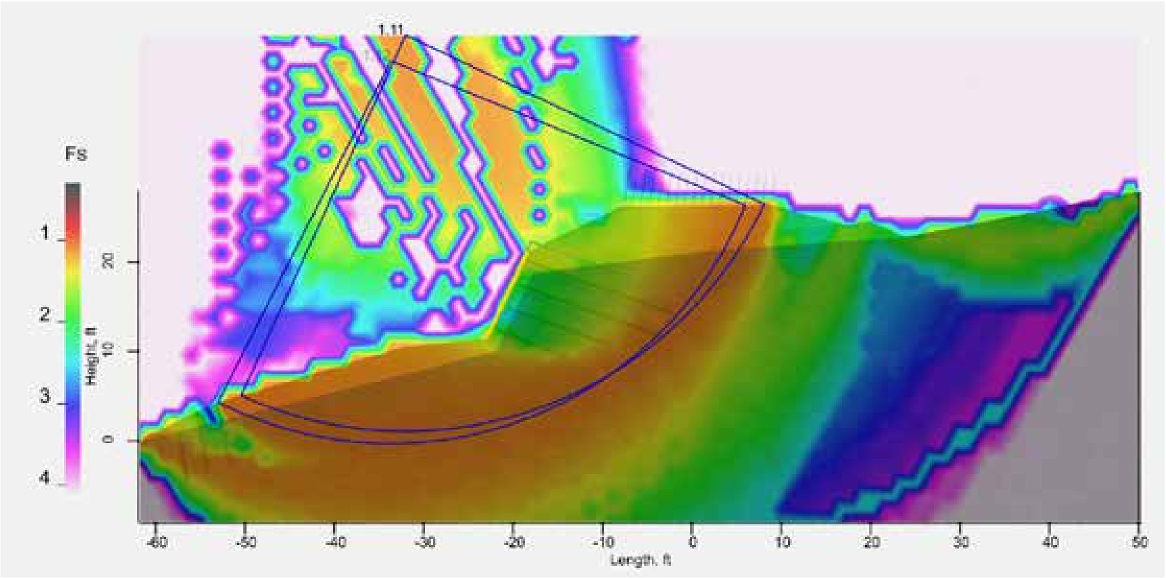
main frictional resistance occurs at the nail tip (not along its length) due to the elastic over-deformation of the soil induced by the rapid impulse.

To demonstrate this phenomena, paper stickers were placed on the outside of nails that were launched into a gravel pile, then later carefully exhumed. The stickers remained unabraded even after traveling up to 17 ft into the gravel. This phenomena also explains the higher-than-expected bond strengths seen in launched soil nails versus driven soil nails. Like driven nails, the soil displaced by the nail densified (thus creating higher normal stresses along the nail shaft), but unlike driven nails, launched soil nails create minimal disturbance to the surrounding soil because of the rapidity of the single impulse. Consequently, launched soil nail unit bond strengths always exceed those of driven nails, and often exceed those of conventional drilled soil nails using open-hole drilling techniques. Launched soil nail bond stresses also tend to increase over time, with studies showing up to 30 percent increases over a 3-year period. Experts theorize that the mechanism for this time-dependent bond strength increase is due to excess pore water dissipation and soil/nail cohesion increase over time.

Launched Soil Nail Design

Launched soil nail design methodology is outlined in the joint USFS/FHWA *Application Guide for Launched Soil Nails*, and relies on the theory that launched soil nails resist soil movement by acting in both tension and shear. In a drilled and grouted nail, by contrast, nail shear contributions are typically ignored. To understand this difference in design assumption, it is important to understand that unlike traditional drilled and grouted soil nails, launched soil nails have a much higher shear capacity to axial capacity ratio. Shear capacities of up to 20 percent or more of axial pullout capacity have been observed in launched soil nails (compared with typical values well below 5 percent for traditional drilled and grouted nails). Because of this difference, the shear component of a launched soil nail is not ignored as it would be in traditional drilled and grouted soil nail design. The ultimate shear resistance of the nail is not controlled by the shear strength of the nail material, but by the ultimate bearing capacity of the soil in a localized area near the active failure surface. This localized bearing failure develops over a short section of the nail on either side of the failure plane, typically 3 ft or less. Typical shear resistance values range from 300-1,200 lbf.

Although the USFS/FHWA manual provides a detailed discussion of the equations and mechanisms behind launched soil nail capacity, the manual models shallow landslides and embankment failures as a planar sliding wedge, ultimately presenting simplified charts to determine nail spacing for various slopes. These charts, however, do not allow for non-uniform slopes, water tables, or slopes with non-uniform materials. Between 1994 and 2013, if designers wished to model a slope that did not fit neatly into the charts, they were forced to employ a more tedious design method using nail input parameters from the USFS/FHWA manual. In 2013, the programmers who developed FHWA's SNAP (Soil Nail Analysis Program) and



LSNAP screenshot for a multi-tiered launched soil nail slope stabilization.

SNAP-2 created the free program LSNAP (Launched Soil Nail Analysis Program). This software allows designers to quickly perform calculations that previously required many hours. In addition, designs can be produced using either ASD or LRFD formats, with both static and dynamic loading, and with highly complex soil geometries.

Launched soil nails have also been mentioned in other federal design documents. In the 2003 version of *Geotechnical Engineering Circular (GEC) No. 7 – Soil Nail Walls*, FHWA noted that launched soil nails were "bare bars" that were "only used for temporary nails" and that the method was "not currently used in FHWA projects." Twelve years and many federally-funded, permanent launched soil nail projects later, the 2015 rewrite of *GEC #7* eliminated the "temporary" restriction and noted that the "technique is applicable to landslide repairs, and to roadway and embankment widening." Perhaps the most accurate federal guidance on the technology since the publication of the USFS/FHWA manual in 1994 can be found at *geotechtools.org* (see "GeoTech Tools – Your Ground Modification Website" in the November/December 2015 issue of *GEOSTRATA*, pp. 38-42, 44). The GeoTech Tools website contains case studies, cost data, and other useful information on launched soil nails and myriad other innovative, geotechnical construction technologies, and notes that the advantages of launched soil nails "include rapid construction, easy monitoring and testing, construction with limited headroom and right-of-way, and ability to withstand large deformations."

New Applications and the Future

Because of their speed of installation, technical characteristics, and relative cost compared to drilled soil nails, novel applications for launched soil nails continue to be developed. From foundation supports for solar farms to gas vents for landfills, new non-slope stabilization ideas for the technology may serve to be quite viable in the future. Perhaps the most interesting application developed in the last few years is for permafrost preservation. Engineers in the Yukon are currently investigating whether hollow, launched steel tubes can be installed vertically into or around roadways overlying permafrost to stabilize melting northern roads. In the winter, air currents would transmit heat from the soil to the atmosphere, solidly freezing, and therefore stabilizing, the permafrost. In the summer, the currents naturally shut off, preventing convection-based energy transfer. From slope stabilization to natural radiators, there's seemingly no end to the possibilities that innovative engineers may find when utilizing launched soil nail technology. GS

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