

Launched Soil Nails – Theory and Practice

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Abstract

Soil nailing has now gained acceptance as a tool to enable the construction of oversteep excavations in soils, or the remediation of failing oversteep slopes. The methodology could have wider applications if it were able to be rapidly mobilised, was easier to establish, quicker to construct, had nails ready for service sooner, and didn't cost any more. A new tool that has these attributes has been developed - the soil nail launcher.

A British military invention has been turned to civilian use. Six metre long nails are able to be fired into the ground, in a single shot, using high pressure compressed air.

The design and construction expertise is being transferred to New Zealand via a technology agreement with a specialist geotechnical contractor from the USA.

The European, UK, and USA track record has demonstrated that launched soil nails are suitable for temporary or permanent works on the construction or remediation of steep slopes.

Four case studies from the USA that have similar characteristics to potential uses in New Zealand are presented.

Launched soil nails are a serious tool that geotechnical engineers in New Zealand will find many and varied uses for, not just in the obvious area of steep slope problems.

Launched Nails – The Difference

As the name suggests, the most obvious difference between these nails and traditional nails is the method used to install them. They are not drilled, driven, or grouted – they are launched. The launching mechanism is not too dissimilar to that of a builders nail gun – it's just supersized as shown in Figure 1.



Figure 1. A supersized nail gun.

Patented British Invention

The British military developed the technology to launch nerve gas canisters. Canisters weighing just over a kilogram were thrown up to 10km in field demonstrations. After ideas of military deployment were abandoned, British engineers adapted and patented the technology for this civilian application.

European and USA Track Record

Two launchers were built and used in the United Kingdom and Europe under a world wide licence from 1989. The majority of that work was on road and rail related landslides.

Complicated business developments resulted in the two launchers lying idle for a period of time before being purchased by Soil Nail Launcher Inc (SNL) in 2002 and moved to the USA.

Proven Technology Transfer to New Zealand

The only two launchers using this patented technology are now operated in the United States by SNL – a specialist, design and build geotechnical contractor. The two principals of SNL (one of them being author Barrett) have over 50 years of geotechnical experience in the USA. Prior to SNL, author Barrett was Manager of Geotechnical Research for the Colorado DOT and for the Colorado Transportation Institute. SNL have used their nail launchers (often affectionately referred to as cannons) on a large number of jobs in a broad range of geotechnical environments. This successful track record and knowledge is being tapped into by Hiway Stabilizers Environmental Ltd (HSE) through their licence agreement with SNL to transfer the proven technology into New Zealand.

Launched Soil Nails

Launching Mechanism

The launching method enables a 40mm diameter solid bar or pipe of 6m length to be installed into suitable soils in a single shot. Figure 2 shows a diagrammatic representation of the launching mechanism. The release of the high pressure compressed air into the breech provides enough energy to accelerate the nail to over 300km/hr.

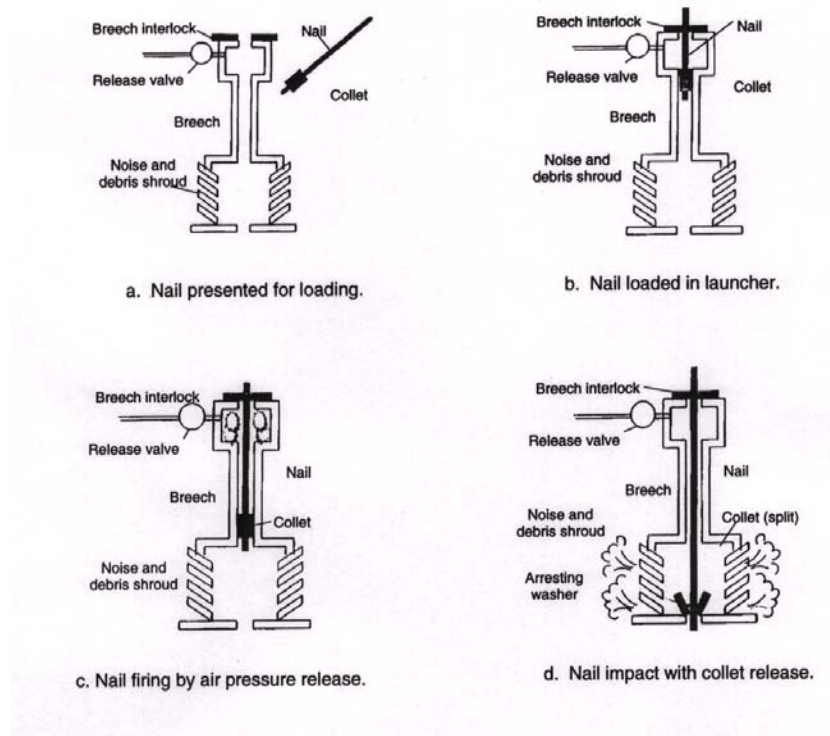


Figure 2. Diagram of launching mechanism.

A disposable collet is used to enable the mobilising force to be transferred to the head of the nail. Figure 3 shows the machined nail tip and Figure 4 the collet fitted to the tip.



Figure 3. Machined nail tip



Figure 4. Fitted collet

Nail Material

The vast majority of applications use a 40mm hollow steel pipe as the nail. Drilled holes along the length of each pipe means that they can act as subsoil drains and reduce peak ground water levels. Where corrosion is of concern, galvanised pipe can be used. Exhumed galvanised nails show that the coating is typically not abraded during installation. A number of proprietary systems rely on galvanised strips and wire to reinforce soil in works designed to last forever. The much larger cross sections of launched nails would, by definition, mean longer life than that accepted by these proprietary system uses.

Soil Entry

Application of the energy to the head of the nail means that the nail is placed in tension, resulting in a straight trajectory into the soil. It is theorised that the shock wave created by the high nail velocity causes the soil to elastically deform, creating a clear path for the entry of the bar. The soil rebounds and grasps the bar with a strong bond.

Excavator Carrier

HSE's launcher uses an 18 Tonne tracked excavator as carrier. Modifications have been made to accommodate compressors, air storage, and electronic safety controls. The launcher is fixed to a rotary head and mounted onto the excavator via a quickhitch attachment. The rotary head enables the launcher to be tilted to almost any desired angle.



Figure 5. Rotary head enables tilting launcher at any angle.

Facings

A variety of facings can be used where lateral confinement of surface soils is required. Shotcrete, the most traditional of soil nail facings, is easily incorporated into a launched soil nail construction. Lighter and less expensive materials are able to be used imaginatively where lighter loads, shallower slopes, or aesthetic criteria are encountered.

New Zealand Applications

The application of launched soil nails in New Zealand will be many and varied. As confidence and familiarity with the system grow, so will the list of inventive uses.

Benefits

The following benefits will support the favourable consideration of launched nails in many circumstances;

- quick installation
- functionality after installation - instant
- access – no scaffolding required
- cost – competitive with other systems

Functions and applications

Launched nails can have the following applications:

- horizontal drainage – installation of perforated nails will help reduce peak ground water levels
- vertical gas venting – useful to vent methane from landfills
- wall strengthening – existing walls that have deteriorating tiebacks, increased external loading, or ageing components can be remediated by launched nails
- ground anchors and tiebacks
- temporary excavation support – speed of installation means that excavation and launched nails can work together at the same time
- steep slope stabilization – in either new works or old slopes that have started to fail

Launched soil nails will have application on a range of infrastructure and markets;

- earthworks
- roading
- rail
- residential

Suitable Ground Conditions and Geometry

Launching nails into clays, silts, sands and gravels, or mixtures of these, is not a problem. The soil should not contain a high percentage of cobbles or boulders to ensure full design embedment. The presence of some of these is not a problem, as embedment can still be achieved when the nail is deflected slightly. Repositioning of the launcher and installing a replacement nail is an easy solution where refusal is met by subsurface objects.

Design

Simplified Wedge Analysis

Designs for simple locations follow the US Forest Services simplified wedge design analysis method (FHWA-FPL-93-003). This method follows the Clouterre (Clouterre, 1991) design principles of nails with moderate stiffness resisting the forces both in tension, shear and bending. The number of nails for per unit area of treated slope is determined by inputting

the slope geometry, determining critical wedge geometry and assumed soil properties. Careful use of this approach by experienced practitioners in appropriate circumstances can avoid the relatively high cost of investigatory drilling.

It is not unusual to deal with any element of uncertainty on relatively small projects by simply installing additional nails.

Two Dimensional Analysis

Standard slope stability software can be used where slope geometry and material types vary. However, standard two dimensional analytical models do not provide an accurate model of a large body of soil yielding in an unstable slope. All limit equilibrium techniques require an oversimplification of soil properties and completely miss the beneficial effects and contribution provided to the overall stability by the interaction of closely spaced inclusions.

Decades of research has shown that adding internal reinforcement to a soil mass dramatically increases its composite strength properties. A close array of launched soil nails going past the ends of a hypothetical slide surface make a significant contribution to the strength and stiffness properties that are not acknowledged or recognised in standard limit equilibrium slope stability software.

For complex or critical slopes, analysis utilising finite element software to model soil strength, stiffness and composite material behaviours is preferred.

Construction

Mobilisation

Support equipment required for the soil nail launcher is minimal. For a small 30m long job, the whole crew and equipment could be moved on site, the job completed, and the crew moved onto the next site in 1 day.

Access

Any site that a mid-sized excavator can get onto is suitable for launched soil nails. Excavation for a working bench is not usually required. For sites where it is too steep for the excavator to safely work on the slope, the reach of excavator can launch nails;

- 7.5m above its tracks, or 6.0m below, on an 80° slope
- 5.5m above its tracks, or 4.5m below, on a 45° slope

Only one lane will be required when working from a road.

Preparation

The amount of site preparation will depend on the design details of the total solution. For jobs that don't require any facing, preparation may be non-existent.

Safety

Documented operating procedures ensure that all team members and the public are not exposed to safety risks. They ensure that all people, apart from the operator, are outside of defined zone at the time of firing.

Installation

Nails are generally installed sequentially from the top of the slope down while working progressively from one end to the other.

The operator is able to adjust pressure settings to ensure that design nail embedment is achieved. Where the presence of cobbles or boulders prevents satisfactory embedment, extra nails are launched in the vicinity.

Finishing and facing

Surplus nail length is cut off at ground level where no facings are required.

Where the design includes facings, construction of these can commence immediately after nail installation.

Case Histories

Steep Landslide Scarps

Where a landslide has moved catastrophically, exposing a near vertical headscarp, the shape of the next failure plane can be defined by a classic Rankine Wedge and the first concern is to preserve the steep backslope that remains. Observation shows that these Rankine failures often begin as a series of thin slabs near the upper scarp face. Thus, even 3m of penetration can be effective in preventing failures and saving the remaining platform. An example of this type of failure is shown in Figure 6.



Figure 6. Near vertical slope suitable for launched soil nail repair.

An array of launched nails into the face of the scarp will confine the soil, maintaining equilibrium, and preventing the development of the most critical Rankine Failure. This can be accomplished expeditiously with the launched nail and is effective immediately since a large exposed scarp can be nailed in a day or less.

Experience has shown that preventing the initiation of shallow Rankine failures appears to prevent or significantly delay development of the maximum potential failure.

Permanent preservation can be achieved by attaching a reinforced concrete facade onto the launched nails. This is accomplished by placing steel mesh over the slope and attaching it to the nails via steel plates. Shotcrete is then applied on this steel reinforcement – see Figure 7. A variety of architectural finishes can be applied if required.



Figure 7. Mesh and shotcrete after nailing
Tennessee Department of Transport (DOT)



Figure 8. Excavation and nail launching working in sync.

The Tennessee Department of Transportation discovered a major slide on Interstate 75 north of Knoxville. The road was on a bifurcated section and the lower two lanes were beginning to slide down hill. Traffic was shifted to the northbound (uphill) lanes and the slide was surveyed, drilled and instrumented. The solution designed by the DOT geotechnical group included a 30m high excavation on a 1:1 slope in order to construct a keyway for a rock buttress. It was decided that the excavation should be temporarily shored. Tennessee DOT estimated that traditional nailing would take perhaps a month to complete due to the constraints of the site.



Figure 9. Excavating trying to keep ahead of launched nailing.

Also, with traditional nailing, there is a delay until the grout sets to begin the next bench of excavation. They elected to use launched nails. The work was completed in 4 days and

within the active excavation. No delays were reported by the contractor. Total savings were reported to exceed half a million dollars, and the value of time was very important.

North Carolina DOT

North Carolina DOT (NCDOT) lost a section of roadway on Dogwood Drive near Maggie Valley due to a rupture in a major water service line that was located in the roadway platform. A fatality resulted from the debris overtopping a house below.



Figure 10. Failure caused by water service leak.

NCDOT engineers considered several traditional alternatives including rock buttresses, piling, caissons and a bridge. None of these fit the location, site geometry or access.

SNL personnel and the NCDOT staff designed a solution that included launched soil nails and a modern Geosynthetically Reinforced Soil (GRS) wall founded on launched nail micropiles. This was a first for bringing together all these new tools, concepts and technologies. Savings was estimated at nearly \$150,000 and time for this construction was about half of any of the other choices.



Figure 11. Launched soil nails and micropiles.

Also important was that the low volume paved streets were not damaged with the heavy traffic that would have been included in other options.



Figure 12. GRS wall being constructed on launched micropiles

These modern GRS walls are easy to build. NCDOT has built several now with their own forces and with their prison inmate labour.

Pennsylvania DOT

The Pennsylvania Department of Transportation lost an embankment on Route 31 near the village of Bedrock during a flood event. The stream undercut the embankment and precipitated a rotational landslide. The headscarp developed along the post line for the safety railing. Soon the cracking regressed to the asphalt edge.

The slide was declared an emergency and the plan was to install caissons. It was not possible to simply replace the embankment with rock due to water quality regulations. The caisson design would have included geotechnical borings and taken a few weeks to complete. The other real problem was an important overhead wire array that could not be moved in a timely manner.

Cost estimates for that ranged to over \$500,000 and it would take 3-6 months to complete the investigations, design and construction. SNL repaired the slide in 3 days for about 15% of the cost of a traditional solution. The road was made safe again, and much quicker than any other option.



Figure 13. First soil nails launched.



Figure 14. Shotcrete facing after launched soil nails.

Ohio DOT

Ohio Department of Transportation awarded an embankment slide repair contract that included excavation of the slide mass and replacement with angular rock contract to Savage Construction of Wheeling. As the excavation neared completion, a tension crack developed in the pavement above half of the cut. Traffic was being maintained at the top of the excavation, and there was concern that the excavation slope would fail before the contractor reached planned depth.

The DOT instructed the contractor to immediately replace some of the excavated material and halted the project. It was decided that temporary shoring was required to prevent the tension crack from developing into a full blown slide and taking the road out of service. The temporary shoring design for this project was estimated to cost over \$200,000 and take 3-4 weeks to complete.

The ODOT Geotechnical Engineer contacted SNL and requested a proposal to provide emergency shoring service. SNL completed the project in 4 days. Cost was about \$60,000. The project schedule was kept on track. Launched nails can save both time and money. Unlike traditional nails, launched nails are effective immediately.



Figure 15. Launched soil nailing keeping ahead of embankment reconstruction.

Conclusions

Launched soil nails have a proven track record in Europe, the UK, and the USA that demonstrates that launched soil nails are suitable for temporary or permanent works on the construction or remediation of steep slopes.

The transfer of design and construction expertise to New Zealand via a technology agreement with a specialist design and build geotechnical contractor from the USA will give New Zealand geotechnical practitioners the confidence to use launched soil nails as one of their tools for the construction or remediation of steep slopes. In addition to these obvious areas of use, New Zealand engineers will find further innovative uses for launched soil nails that harness the unique attributes of rapid mobilisation, easy establishment, quick construction, and instant readiness for service.

References

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