Two New Specialty Geotechnical Processes for Slope Stabilization

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Abstract

The paper describes two newer specialist geotechnical construction techniques employed in slope stabilization. Case histories are used to illustrate contemporary practice in in situ earth reinforcement (Type A Walls) and large diameter deep drains (RODREN) The paper also touches upon the use of various alternative contracting procedures to facilitate the introduction of these recent techniques to maximum mutual benefit.

1. Introduction

The solution of the problems inherent with slope instability remains a fundamental challenge to the geotechnical community. Indeed, the increasingly onerous demands placed by developers ensure that the community must continue to evolve technically despite the vast store of knowledge and expertise already accumulated. This evolution is reflected dramatically in the sophistication of methods of design and analysi now employed by designers. Equally dynamic, however, are the developments being made by specialty geotechnical contractors, in order to fulfill the developers' and designers' concepts.

These developments are taking several forms such as

- refinements of existing techniques, such as anchored earth retaining structures (e.g., Reference 2);

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- new applications for existing techniques, such as diaphragm walls (e.g., References 3 and 15);
- resurrection of older techniques previously underexploited, such as certain types of in situ reinforcement; and
- importation of new techniques, such as RODREN.

This paper focuses on the other latter two methods, which may be less well known to readers in North America than the former pair.

2. In Situ Earth Reinforcement: Type A Wall

Background

In the last decade or so in the United States, there has been increasing use of small diameter cast-in-place bored inclusions. Most have been designed to act as conventional load bearing piles, commonly known as pinpiles (References 4 and 6). However, these elements (100-250 mm in diameter) are finding growing popularity in the field of slope stabilization, where, installed in densely spaced patterns (Figure 1), they act as in situ reinforcement (Reference 9). The concept of their performance is that they form a composite structure with the included soil: this structure then constitutes an in situ barrier to arrest actual or potential slope movements.

General Features

Early applications of conventional, axially loaded pinpiles indicated, surprisingly, a positive "group effect", thought to be due to beneficial soil-structure interaction (Reference 5). This advantage was then exploited in slope stability applications in Western Europe and then latterly - but infrequently -in the United States. In urban environments similar groups of pinpiles (or "INSERTS" in this context) can be used in cut and cover, as well as bored tunnel, construction. There the concept is to create protective structures in the ground to separate the foundation soil of the building from the zones that are potentially subject to disturbance (Figure 2). All these INSERT structures rely for their effectiveness on soil/pile interaction, and not intergranular soil cementation. This composite structure - referred to as a "Type A Wall" because of its distinctive cross sectional appearance - is intended to stop loss of soil from behind it, and to prevent sliding along potential failure planes passing through it.

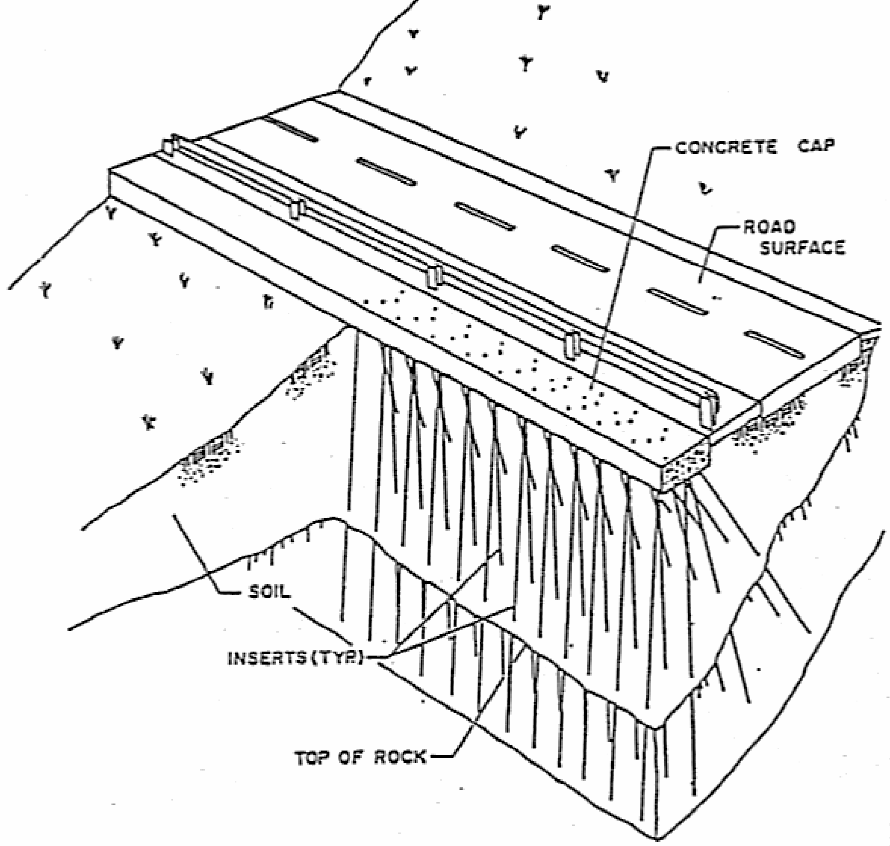

Figure 1. Typical arrangement of INSERTS (Reference 10)

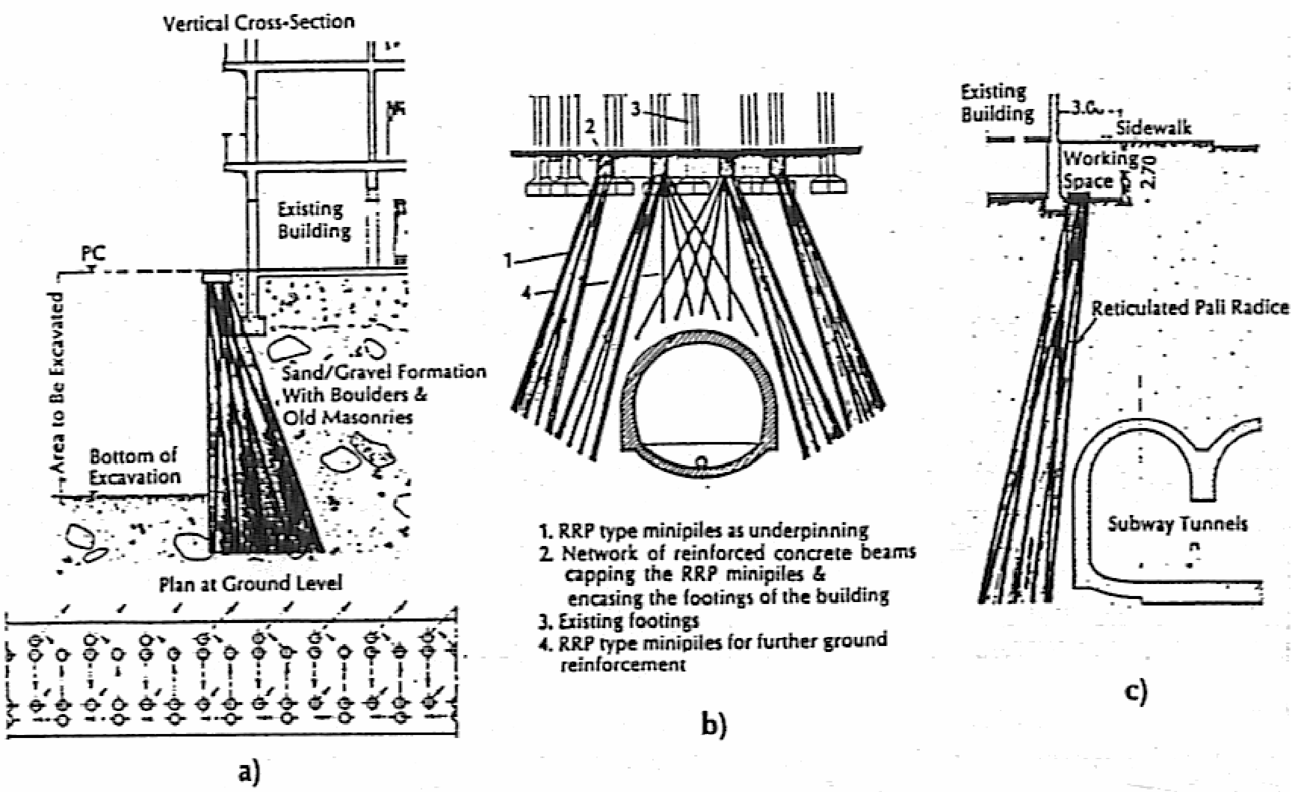

Figure 2. Applications of INSERTS a) for cut and cover and b) and c) around bored tunnels (Reference 6)

Design approaches do continue to lag behind other aspects of the technology, but several instrumented field programs have confirmed that reinforcement stresses and overall wall movements in service are minimal, and that most probably designs have been highly conservative. Even the original proponent - Fernando Lizzi - confirmed in 1982 (Reference 12) that "it is not yet possible to have at our disposal an exhaustive means of calculation ready to be applied with safety and completeness." In addition, the ASCE Committee (Reference 1) also alluded to the great reliance placed on soil/pile interaction, the safe exploitation of "which is still subject to experience and intuition".

The typical approach to design is, of course, relatively simple, and involves standard basic steps:

- estimating loads (active and passive) on the wall;
- conducting a stability analysis to determine the shear force needed to maintain a required factor of safety;
- determining the number of inserts needed to provide the required shear resistance;
- calculatons (similar to those for a conventional gravity wall) to check stability against overturning, sliding and bearing failure at the base of the wall.

Usually the INSERTS are extended into bedrock where economically possible (and always below the failure plane). INSERT Walls can be constructed in close proximity to existing buildings in relatively tight access locations without the need to excavate or underpin, and without causing any decompression of the foundation soil. Given their mode of construction, as detailed below, they can be installed in any type of ground, including through boulders, old foundations or any other obstructions with no constructional limitation on hole inclination or orientation.

Construction Aspects

The successive steps involved in the construction of a Type A Wall are illustrated in Figure 3. The capping beam may be installed before or after the INSERTS are formed although field evidence does suggest that the latter option allows for an earlier effectiveness by the reinforcement. The drilling method is chosen to ensure minimal disturbance or upheaval to the soil. Of all the seven generic methods of overburden drilling (Reference 7), the most common method is rotary drilling with water flush, either via a single casing or by the duplex method, depending on

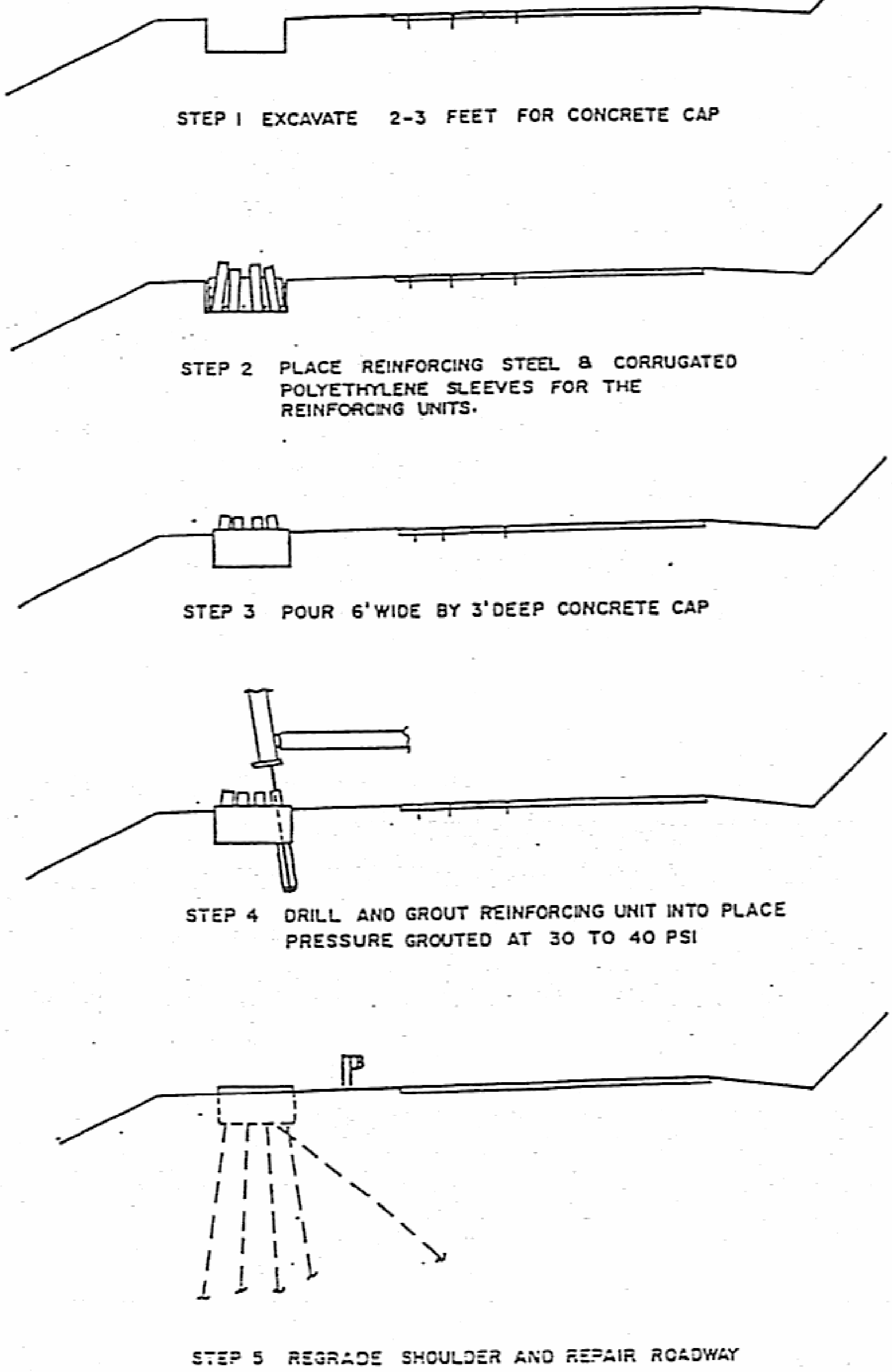

Figure 3. Typical steps in INSERT Wall construction (Reference 10)

ground conditions. Once the casing has been advanced to target depth it is filled with a stable, high strength cementitious grout, and the permanent reinforcement is placed. This may be a solid high strength steel bar, typically 25-50 mm in diameter, or a steel pipe of suitable dimensions, as dictated by the structural design requirements. The drill casing is then withdrawn from the hole as grout continues to be injected under pressure. The effect of the pressure grouting is three-fold in most conditions:

- it ensures all voids or drilling related disturbances to the soil are filled;
- it permeates a little into sands and gravels;
- it compacts somewhat the soil around the pile, too fine to be permeated.

Individual piles are oriented in different directions in each plane to promote the most effective soil/pile network. After installation of the INSERTS, the capping beam is simply graded over, or it can form the base of a guard rail or similar: the whole wall is thus wholly out of sight and maintenance free.

Case History: Armstrong County, PA

Portions of State Route 4023 (S.R. 4023) north of Kittanning, Pennsylvania, were constructed on a slope adjacent to the Allegheny River. A 73 m. long section of the two-lane road, and the railroad tracks located upslope, experienced damage caused by slope movements toward the river. In June, 1988, and January and February, 1989, the owner conducted a subsurface exploration program and installed slope inclinometer casings to monitor the slope movements. The inclinometers indicated that a slip-plane was located approximately 8 to 11 m. below the roadway and that the slope was moving at a rate of up to 18 mm per month toward the river.

Boreholes showed that a significant amount (6-9 m.) of fill had been placed at the site apparently during the construction of the roadway and/or railroad tracks. The fill consisted of intermixed loose to medium dense rock fragments and medium stiff silty clay. Underlying the fill was a 1.5-3 m. thick layer of stiff colluvial clay with rock fragments, in turn overlying a 1-6 m. layer of weathered claystone. Competent rock was encountered at about 15 m. below the roadway, and generally consisted of medium hard siltstones and sandstones.

The owner designed a repair of the failed section using an anchored caisson wall extending into competent rock. The earth pressures used for the design were based on the results of stability analyses, for which the soil along the slip-plane was assigned a residual friction angle of 17°. This design provided a minimum factor of safety with regard to the overall slope stability equal to 1.5 and 1.2 for the normal and rapid drawdown conditions, respectively. In general, the design consisted of a row of 0.9 m. diameter caissons at a center-to-center spacing of 1.4 m. immediately downhill of the roadway. The caissons were to be connected at the top by a cast-in-place reinforced concrete cap which was to have 27 m. long prestressed rock anchors extending underneath the roadway at 2.1 m. lateral intervals.

In 1989, Nicholson Construction proposed and the owner accepted an alternative design employing an INSERT Type "A" Wall. The wall consisted of four rows of pinpiles extending across the slip-plane and into competent bedrock. It comprised two equal length sections designated as WALL A and WALL B. WALL A contained a higher density of piles than WALL B, because the top of weathered rock dipped to a lower elevation in the area of WALL A which resulted in a larger volume of soil to be stabilized in this area. In general, WALL A contained 4 piles per lineal meter, and WALL B contained 3 piles per lineal meter. Besides providing a significant economic savings over the original design, the selection of the INSERT Wall allowed for one lane of roadway to remain open during construction (February to May, 1989). The wall was constructed as described above, with the cap poured after pinpile installation for practical reasons.

To monitor the INSERT Wall performance, two sections of the wall were instrumented with strain gauges, inclinometers, telltales, and survey pins. The inclinometers yielded the most useful information regarding the performance of the wall. The data for inclinometers located relatively close to and within the wall indicated that up to 38 mm of horizontal movement occurred during the 75-day construction period, and up to 8 mm of movement occurred in the 7-month period following the completion of the wall.

Overall, the inclinometer data indicated that the wall performed as expected, and had effectively stopped the slope movements at the site. It also indicated that some deflection of the relatively flexible INSERTS may be required to mobilize their lateral resistance.

Final Remarks

Two major restrictions have so far limited the popularity of this type of in situ reinforcement in the United States. Firstly, there remains no rigorous design methodology and, secondly, often as a direct consequence, the high density of INSERTS required has often compromised the cost effectiveness of this novel method. However, fundamental research is underway to try to better understand the basic soil-structure phenomenon, while intensive field monitoring of installations is also clearly increasing knowledge. With a more precise design rationale, and more cost effective solutions, this technique offers a very potent option in combatting slope instability.

3. Large Diameter Deep Drainage Wells

Background

Drainage has long been recognized as a most effective method to stabilize landslides in saturated soil slopes. A valuable new technique introduced recently in Italy extends this potential. It basically features deep large diameter drainage wells, interconnected at their toes by a small diameter discharge pipe. The technique - registered as RODREN - had its first applications to stabilize several landslides affecting urban areas and other important structures, principally along the A1 Motorway, between Bologna and Florence, in the Tuscan-Emilian Apennines zone. The effectiveness of RODREN, and its favorable cost/benefit ratio, have encouraged several further uses in other regions with different geological conditions but similar problems.

General Features

RODREN consists of alignments of separate vertical drainage wells, 1200-1500 mm in diameter and 5-7 m. apart, but connected near their toes by a pipe, 76-100 mm in diameter. This collector pipe transfers by gravity the water intercepted by each well, and eventually leads to a convenient discharge or pump out location. The depth of the wells depends on the geological features of the slope; it is important that the discharge pipe is located below the slip surface. The depth of RODREN is normally limited to about 30 m., although, in favorable geological conditions, wells of 2 m. diameter, 20 m. apart, have been drilled to over 50 m. deep (Reference 8).

As the system is not structurally continuous, say like a drainage trench, it is particularly convenient when shallow obstructions are present, typically in urban areas. Other advantages of the system are that it is:

- highly efficient and effective, especially in restricted areas;
- environmentally compatible and safe;
- cost effective, in comparison with equivalent drainage systems, such as continuous drainage trenches;
- possible to adapt the layout to the actual geometry and geology of the unstable slope, as revealed during construction.

Another important technical feature of RODREN reflects the flow rate conditions: the discharge reacts to the actual natural hydraulic conditions, depending on external factors such as rainfall, and the effectiveness of any pre-existing surface collector systems. It is not an active pumpout system in which the piezometric level is reduced through the action of electric submersible pumps in deep, cased boreholes.

<u>Construction Aspects</u>

Shafts are drilled using the standard equipment commonly employed for bored piles with temporary steel casing. Before backfilling and withdrawal of the casing, each shaft is connected to the adjacent wells by a horizontal hole, drilled just above the shaft toe (<u>Figure 4</u>). The wells are backfilled using a selected drainage filter material, graded according to the surrounding soil grain-size characteristics. Generally the grain size distribution of the filter is between 3 and 20 mm, with no more than 3% passing the 200 ASTM sieve. Several types of wells can be constructed:

- standard drainage wells, as just described;
- inspection drainage wells, having a permanent steel inner casing, for inspection and maintenance purposes (1500 mm outside diameter);
- structural drainage wells, having a reinforced concrete liner of minimum thickness 300 mm.

For these three types, the following steps are taken:

a) Vertical drilling operation: wells are drilled using a temporary casing. The thickness and the strength of the casing is chosen to guarantee adequate safety for the operators.
b) Horizontal drilling operation: the hole for the horizontal pipe is drilled by means of a special rig having a circular frame sized to operate inside

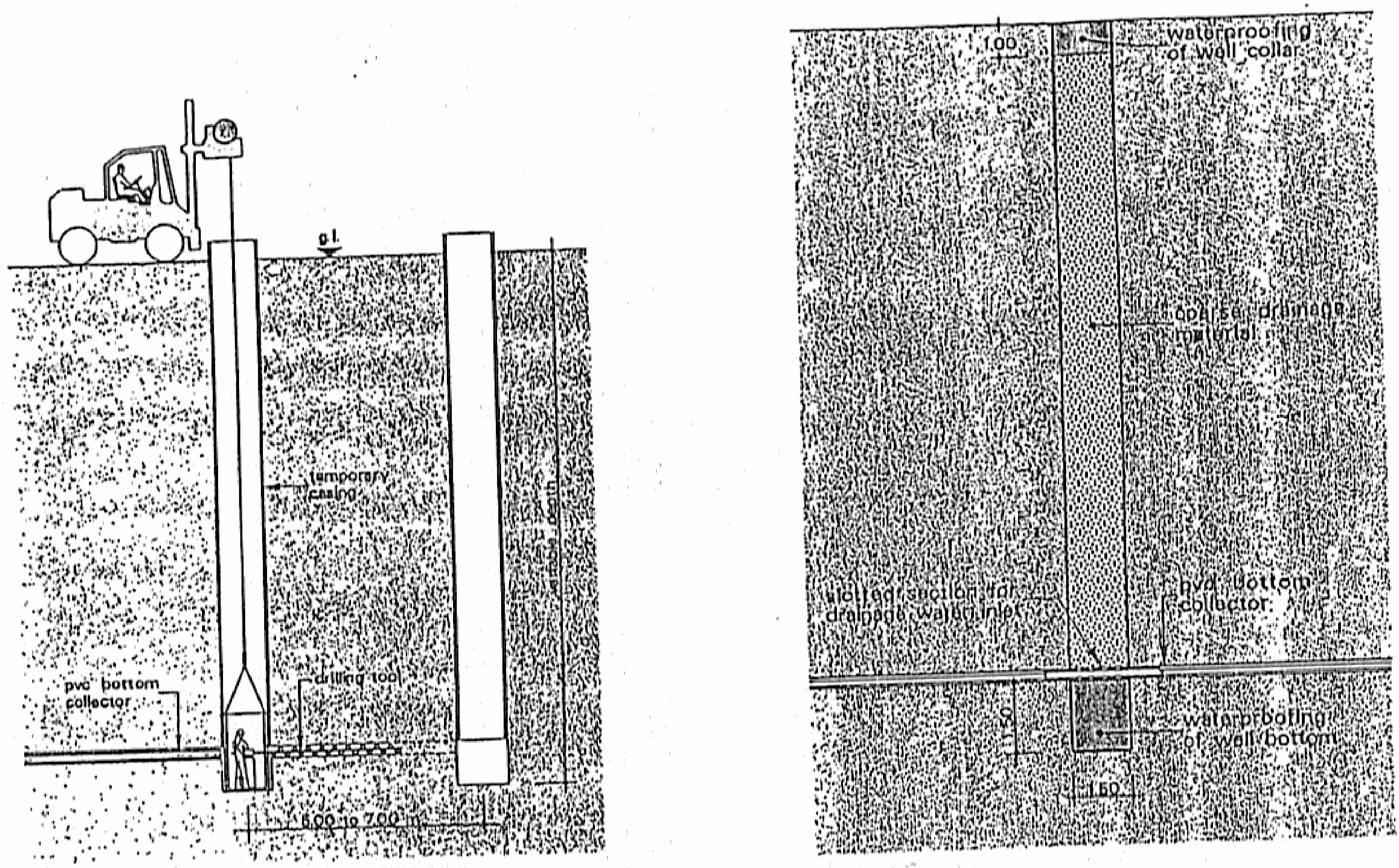

Figure 4. a) Schematic of horizontal drilling, and b) standard RODREN drainage well (Reference 8)

the vertical steel liner and to safeguard the operator. All engines and power packs are placed outside the shaft.

c) Waterproofing of the bottom of each well and the pipe connection with concrete.

d) Well completion: depending on the type of well, different procedures are applied:
   1) standard drainage wells: the drain material is poured into the well, and the temporary casing then removed.
   2) inspection wells: a permanent steel casing, having a smaller diameter (generally 1200 mm), is installed inside the temporary casing. The drain filter material is then placed around it in the annulus and the temporary drill casing is then removed as before.
   3) structural wells: in this case the diameter of the wells is increased to a minimum of 2 m. A drain filter is first placed, applying the same procedure as the inspection wells (permanent casing of 1800 mm diameter). Then a second steel liner, 1200 mm in diameter, is placed and the annular space concreted. If necessary, the concrete liner may be reinforced by means of a steel cage.

e) Waterproofing of the top and, for inspection and structural wells, closing of the wells by steel covers, completes the operation.

All construction steps, and particularly the horizontal drilling, are conducted with special safety measures, such as forced fresh air supply, safety belts and cables, phone, dewatering pipes, and remote TV survey of horizontal drilling.

Case History: Ancona Palombella, Italy

In December, 1982, a suburban area of Ancona, the District capital of the Marche region in central Italy, was affected by a catastrophic landslide involving more than 3,000,000 sq. m. of surface area (Reference 11). Geologically, this area features a Pliocene basement (grey overconsolidated clay), with several thin sandy layers, covered by a silty-clayey stratum, from 10 to 40 m. thick. In the upper part of the slope a large Pleistocene sandy stratum is confined between these two principal formations. At the toe of the slope the Adriatic Sea produces a progressive erosion. The unfavorable hydrogeological conditions of the slope, named the Balducci Landslide, were known for centuries, and so the expansion of the city had been limited to other areas. However, as the Balducci Landslide is close to Ancona Harbour, some important elements of the infrastructure, such as railways and highways, are now located on the lower part of the slope, along the coast.

To permit improvements to the coastal highway, it was therefore necessary to execute a significant stabilization of the east side of the slipped area (Palombella). In Figure 5, one typical group of wells is shown. Due to the unfavorable stratigraphy, the wells were drilled to depths of over 50 m. for which it was necessary to resolve many technological problems, such as tolerance in vertical and horizontal drilling, the power required to drill very competent bedrock, hydraulic and earth pressures on permanent casing, backfilling operations, and so on. For this reason, it was decided to increase the standard well dimensions of the RODREN system to a diameter of 2.0 m., and a spacing of 15-20 m. To check the accuracy of drilling operations, the verticality of the wells was measured combining displacements and rotations (polar coordinates). For the alignments completed to date, deviations of about 1% have been recorded.

The work is currently still in progress, but already very positive piezometric and inclinometric data have been recorded. As the well drilling has been carried out starting from the toe of the slope, the flow discharge of each alignment increases progressively. A significant change in flow rate is obtained when each well group intercepts the Pleistocene sandy formation present in the upper part of the slope. For Alignment B, the flow increased from 10 to 30 liters/min.

Final Remarks

The RODREN technique of providing slope stability through water table lowering is clearly a proven success when applied in the appropriate set of hydrogeological conditions. Recent steps have been taken to guarantee the personal safety of the operators who must drill the horizontal connecting paths from well to well. Increasing experience with the method is reflected in a confident flexibility in the design-build process to optimize technical and economic return. One of the main attractions of the method is its environmental compatibility. It is not a forced drawdown dewatering system requiring active pumping: rather it is a maintenance free, gravity driven interceptor array, responding directly to the ambient conditions. The advantages of RODREN are being exploited in Italy and are currently favored for stabilizing very sensitive environmental and urban

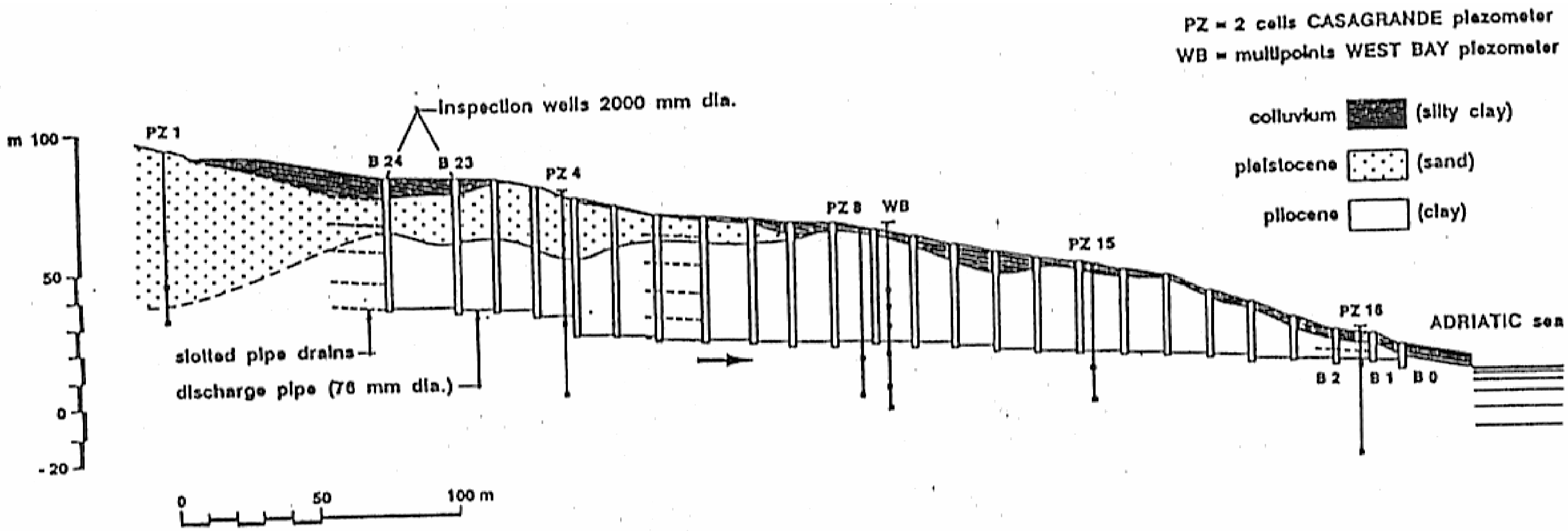

Figure 5. Cross section through RODREN Alignment B.
Ancona, Italy
(Reference 9)

areas in Spain and Southern California. An expansion of the technique into other areas with similar problems and restraints would appear most likely.

4. Conclusions

This paper illustrates two entirely different specialist geotechnical techniques of great technological potential in landslide stabilization. One owes its roots to drilling and grouting principles while the other is a novel application of well established drainage techniques. However, such new ideas can only be applied if the type of contracting practices adopted by the owner are sympathetic. This has been discussed at length by Wolosick (Reference 14) and Nicholson (Reference 13), who identified several contract specification options available.

Many of these options, such as open specifications, performance specifications, prebid designs and post-bid designs are excellent vehicles for introducing new cost effective techniques. For example, the advantages to owners of such options relative to "closed" specifications (wherein everything is designed by the owner from the onset) include:

- They allow for innovative designs, resulting in lower construction costs.
- The specialty contractor shares in the responsibility for the design, construction, and performance of the completed wall.
- The engineer has the opportunity to review each contractor's design and to critique the various design elements, thus enabling him to incorporate necessary revisions into each design prior to bidding. This procedure eliminates confusion or misinterpretation that often results in design changes after the bid that could adversely affect construction costs.
- They allow the owner to take full advantage of the experience of qualified specialty contractors.
- Design costs are minimized.
- They allow value engineering to be utilized more effectively since the value engineering is essentially performed prior to contract award and the start of construction. The owner retains one hundred percent of the value engineering savings rather than sharing the savings.
- They minimize change orders and contract disputes.

Assuming owners are willing to adopt these variations as the standard theme, the novel techniques outlined in this paper have an excellent chance to gain national application.

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