LARGE LANDSLIDE STABILIZATION BY DEEP DRAINAGE WELLS

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The principle of enhancing slope stability by draining the ground-water has been applied for decades. However traditional solutions, such as small diameter drains and dewatering wells, are not generally practical or economic where unstable masses are deep and cover large areas, or where sensitive urban developments and underground services preclude their use. In the past few years, a new technique has been applied with great success to stabilize urban areas catastrophically threatened by deep active slide zones in Italy. Large diameter (up to 2 m) shafts are drilled vertically, at centers of 5 to 20 m. Each shaft is connected to its neighbour by a horizontal drill hole, drilled just above the shaft base. Thus, all water attracted and intercepted by these large drainage columns is transmitted by gravity to a convenient draw off point.
This system has major operational, environmental, technical and cost advantages, and has been used to depths of over 50 m. A key feature is that the array geometry can be readily modified and adapted to the geology, structure and permeability of the unstable mass revealed during construction.

1. INTRODUCTION

Commonly, drainage is the most effective method to stabilize landslides in saturated soil slopes. In this field, a valuable new technique has been introduced recently by the authors' company. It basically features deep large diameter drainage wells, interconnected at the toe by means of a small diameter discharge pipe (fig. 1).
The technique - registered as RODREN - had its first applications in Italy to stabilize several landslides affecting urban areas (ref. 2) and other important structures, principally along the A1 Italian Motorway, between Bologna and Florence, in the Tuscan-Emilian Apennines zone (fig. 2). The effectiveness of RODREN, and its favourable cost/benefit ratio, have encouraged several further uses in other regions with different geological conditions and difficulties.

The paper presents a review of the RODREN technique, and describes details from two significant case histories at Perugia and Ancona.

2. GENERAL FEATURES OF THE RODREN TECHNIQUE

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 drilled below the slip surface.

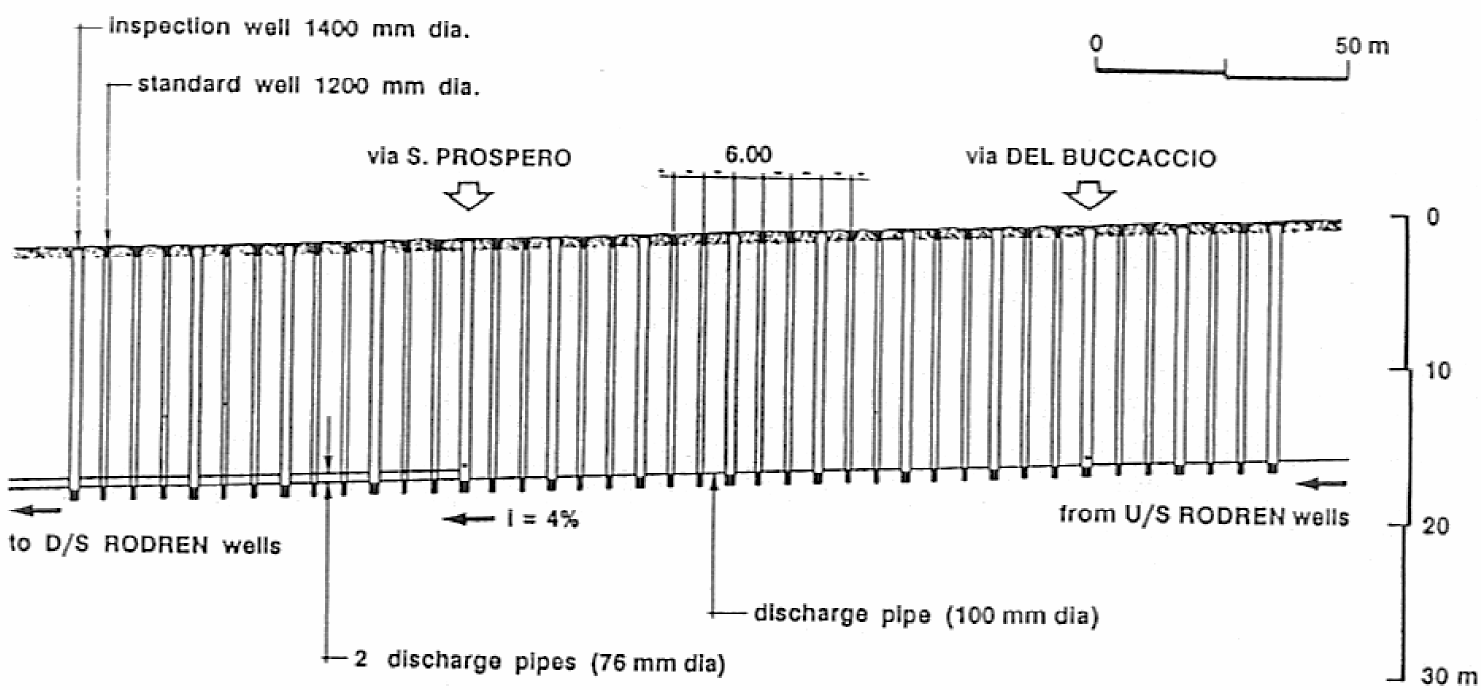

fig. 1 Perugia landslide stabilization by a curtain of RODREN wells. Cross section along Via XX Settembre, Perugia [after (3)]

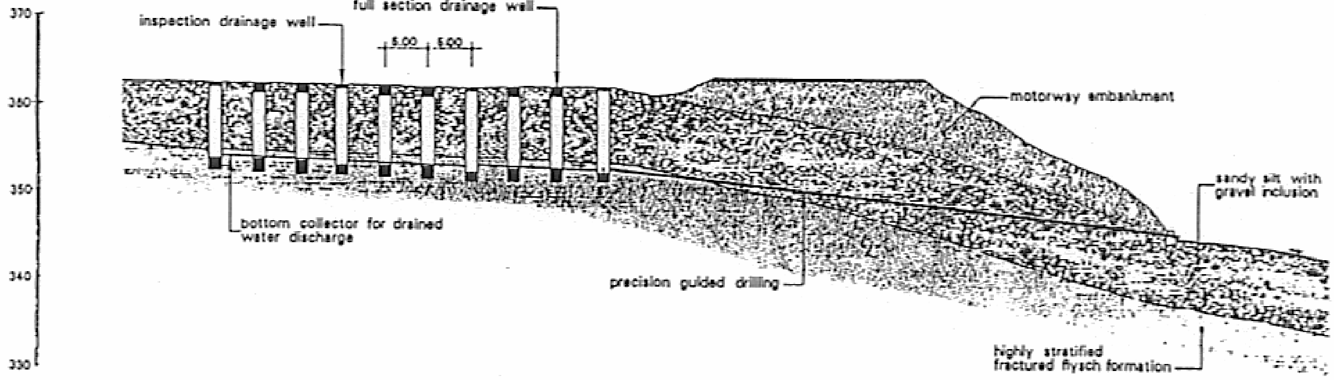

fig. 2 Bologna - Florence A1 Motorway. The cross section shows part of the RODREN system installed upstream of the Motorway and the by-pass under the embankment to discharge the drained water [after (5)]

Generally, the depth of RODREN wells is normally limited to about 30 m. In favourable geological conditions, wells of 2 m diameter, 20 m apart, have been drilled to over 50 m (ref. 4).
As the system is not 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 (fig. 3)
- possible to adapt the layout to the actual geometry and geology of the unstable slope, as revealed during construction.

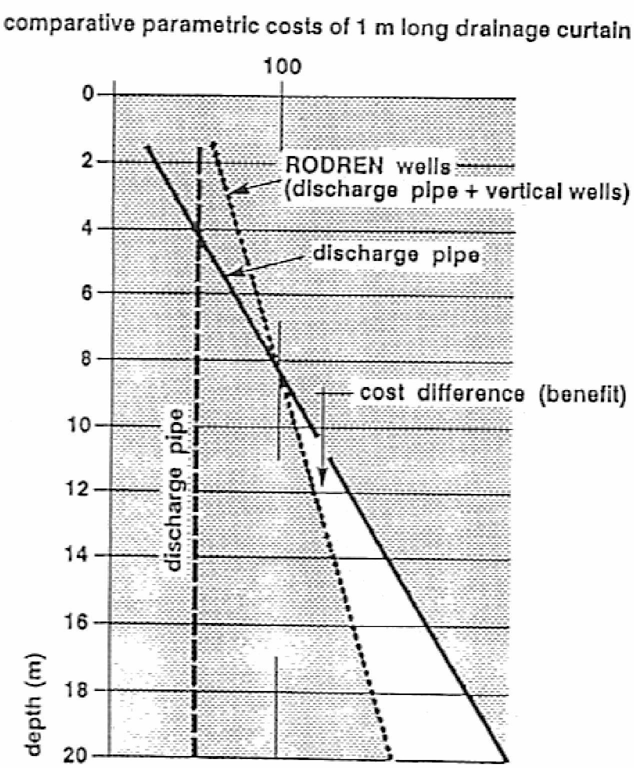

fig. 3 Cost of RODREN system, in comparison with a standard drainage trench. Below about 10 m the higher costs of the trench, due to the increase of excavation quantities and backfilling materials, supersedes the total costs of RODREN wells, resulting from the connecting pipe cost, constant with depth, and the vertical well cost which depends on the depth [after (2)]

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 meteorological phenomena, and the effectiveness of any preexisting surface collector systems. It is not a positive pumpout system in which the piezometric level is reduced through the action of electric submersible pumps in deep, cased, boreholes.

3. CONSTRUCTION ASPECTS

Shafts are drilled using the standard equipment for bored piles with temporary casing. Before backfilling and withdrawal of the temporary steel casing, each shaft is connected to the adjacent wells by a horizontal hole, drilled just above the shaft toe (fig. 4).
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 (fig. 5)
- inspection drainage wells, having a permanent steel inner casing, for inspection and maintenance purposes (fig. 6)
- structural drainage wells, having a reinforced concrete liner of minimum thickness 300 mm (fig. 7)

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 operations (fig. 8)
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 the vertical steel liner and to safeguard the operator (fig. 9). All engines and power packs are placed outside the shaft (fig. 10)
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:
   d1) standard drainage wells: the drain material is poured into the well, and the temporary casing then removed
   d2) inspection wells: a permanent steel casing, having a smaller diameter (generally 1200 mm), is installed inside the temporary casing. The

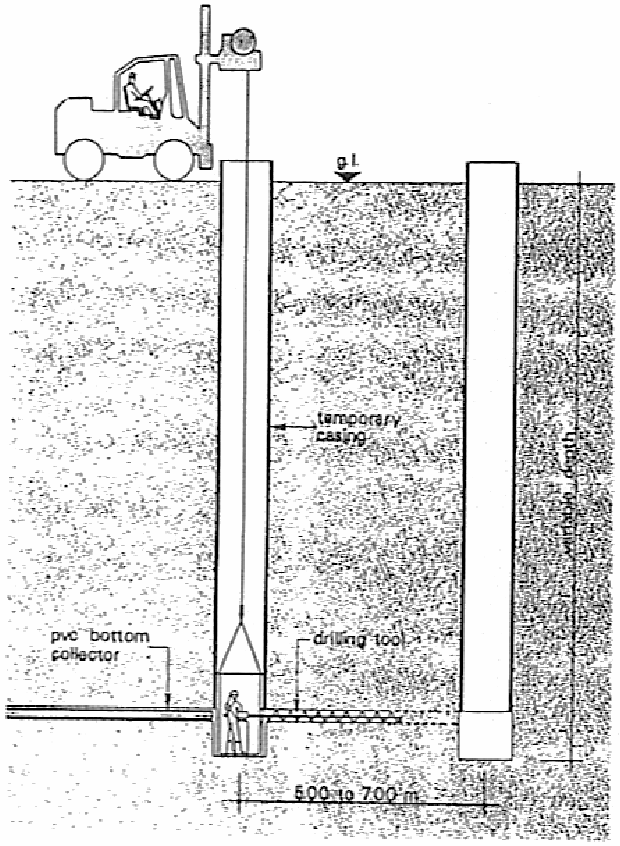

fig. 4 Schematic of horizontal drilling operations [after (5)]

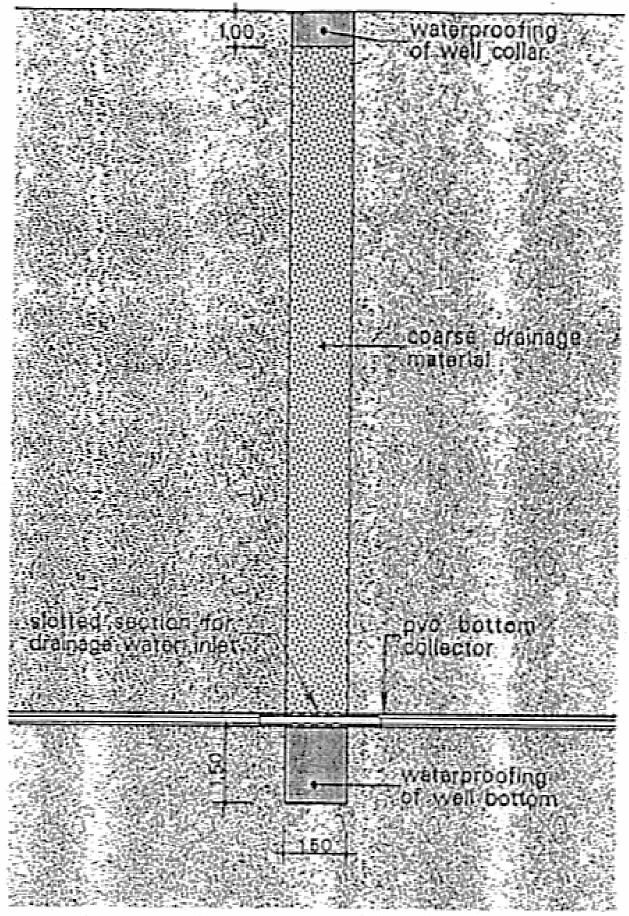

fig. 5 Standard RODREN drainage well [after (5)]

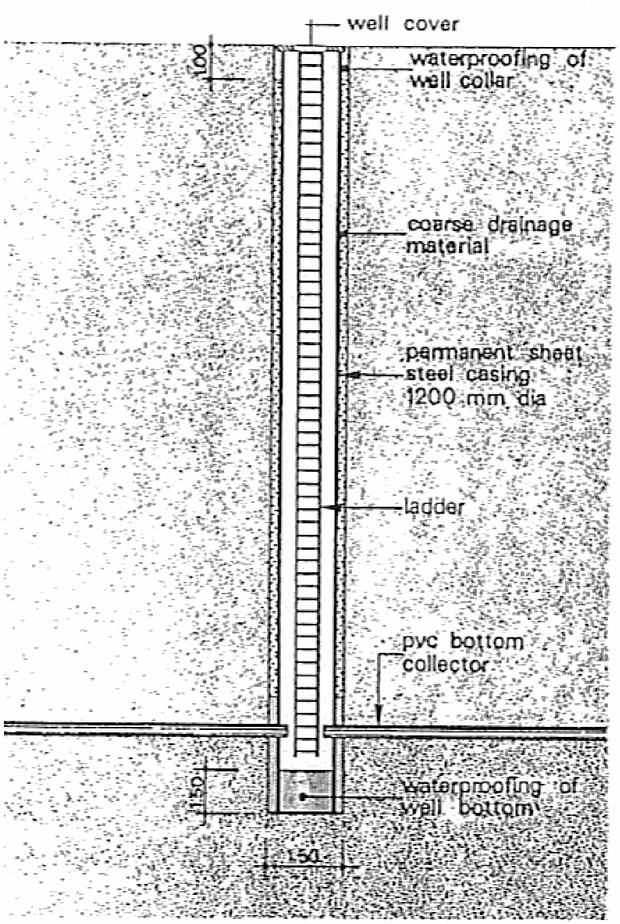

fig. 6 Inspection RODREN drainage well [after (5)]

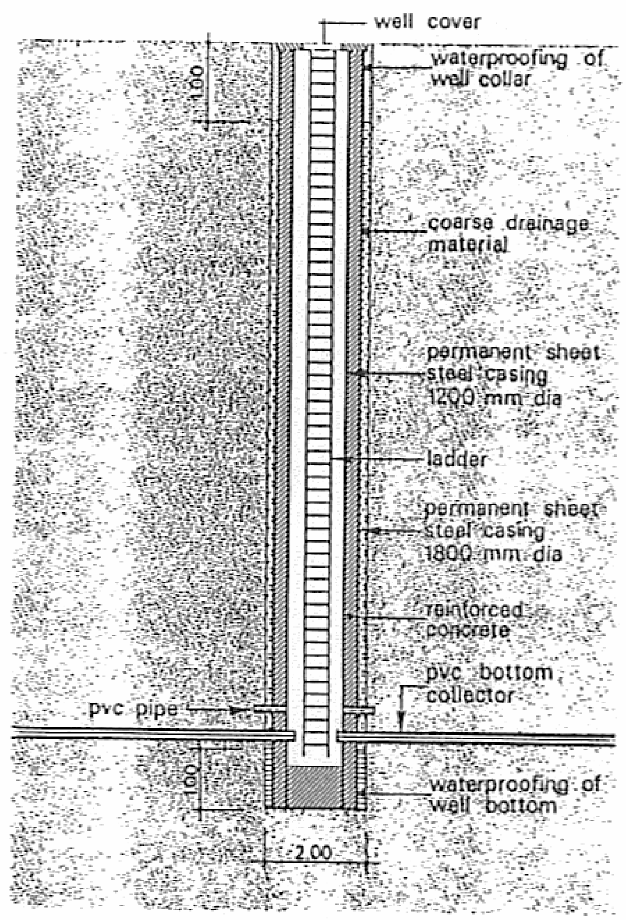

fig. 7 Structural RODREN drainage well [after (5)]

drain filter material is then placed around it in the annulus and the temporary drill casing is then removed as before

d3) structural wells: in this case the diameter of the wells is increased (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 operations, 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.

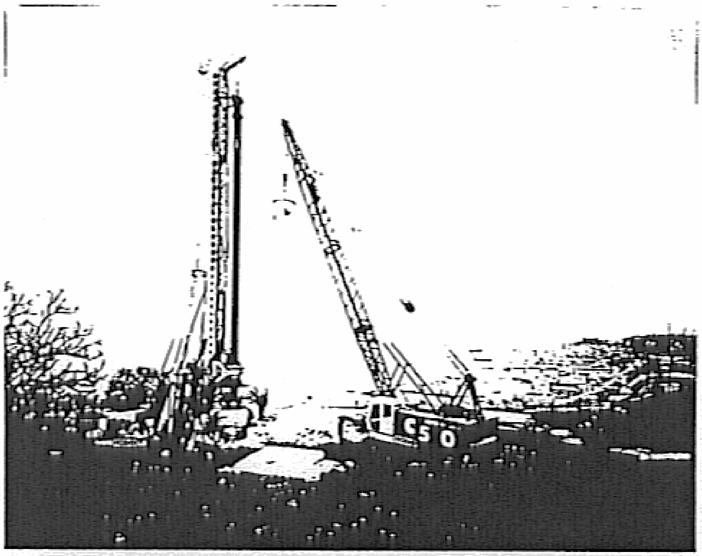

fig. 8 Installation of permanent steel liner for inspection RODREN drainage well

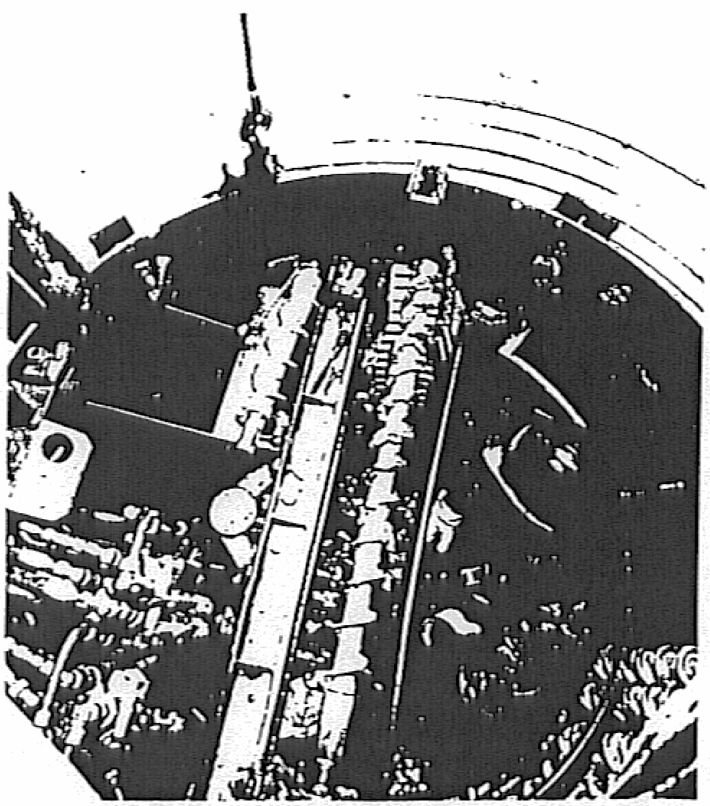

fig. 9 Drilling of the horizontal hole between wells to accept the connector (discharge) pipe

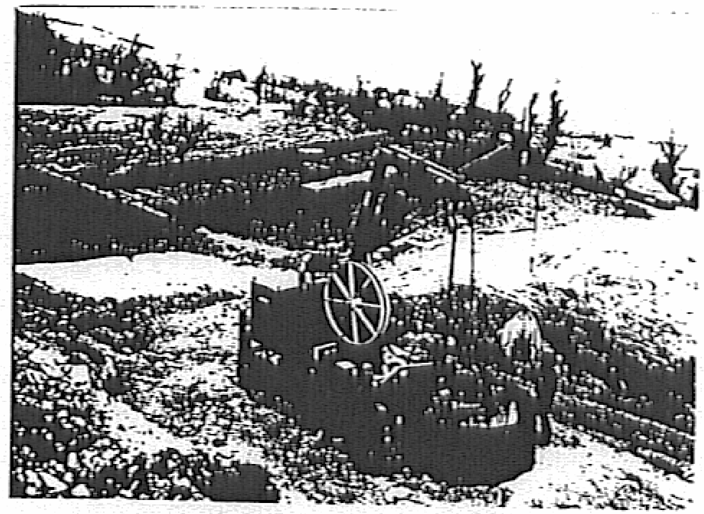

fig. 10 Lifting of the special rig having external engine and power pack

4. LANDSLIDE STABILIZATION CASE HISTORY 1 : PERUGIA

Perugia is a historic town, famous for its churches, museums, and ancient villas, situated on a hill in the Apennines region. In the last few years the west side of the city, expanding into the medium and lower parts of the slope, has been affected by a very large landslide. Studies show that the instability of the slope has been caused by the modifications carried out to build roads, buildings, a new commercial centre and the relevant infrastructures.

With the hydrogeological conditions of the site particularly unfavourable, in 1982 during the winter season a large landslide occurred and several buildings were seriously damaged. Strata having different consistencies and permeability constituted the upper unstable mass (ref. 7):

- made ground
- very soft yellow silty clay and clayey silt
- sand and silty sand, with a few sandstone boulders
- grey-blue hard clay, including a few thin conglomeratic layers

The strata are irregularly laid on a deep sandstone-limestone bedrock (Marnoso-Arenacea).

The permeabilities of these strata are very variable and their thicknesses are not uniform. The hydrology is affected by a very shallow phreatic watertable, present in the upper soil layers, and by some irregular artesian phenomena, arising from the confined groundwater of the lower strata. A few springs were known in the site before the urban development, the most important being Fonte di Veggio (Old Man Spring), giving rise to the site name, Fontivegge.

From 1984 to 1985 the landslide was stabilized by the RODREN system, comprising 400 wells approximately 20-25 m deep (fig. 11). On the basis of the geotechnical studies and of the results of stability analyses, at least 4 m of drawdown was required. The values of the actual drawdowns are greater than this target, so that the stability of the slope has been guaranteed. On the basis of the piezometric monitoring, it has been possible to plot the final isophreatic lines. The magnitude of the groundwater drawdown depends on the closeness of the RODREN wells. In fact the actual drawdown ranged from 20 m close to the well groups, to a minimum of 6 m further away.

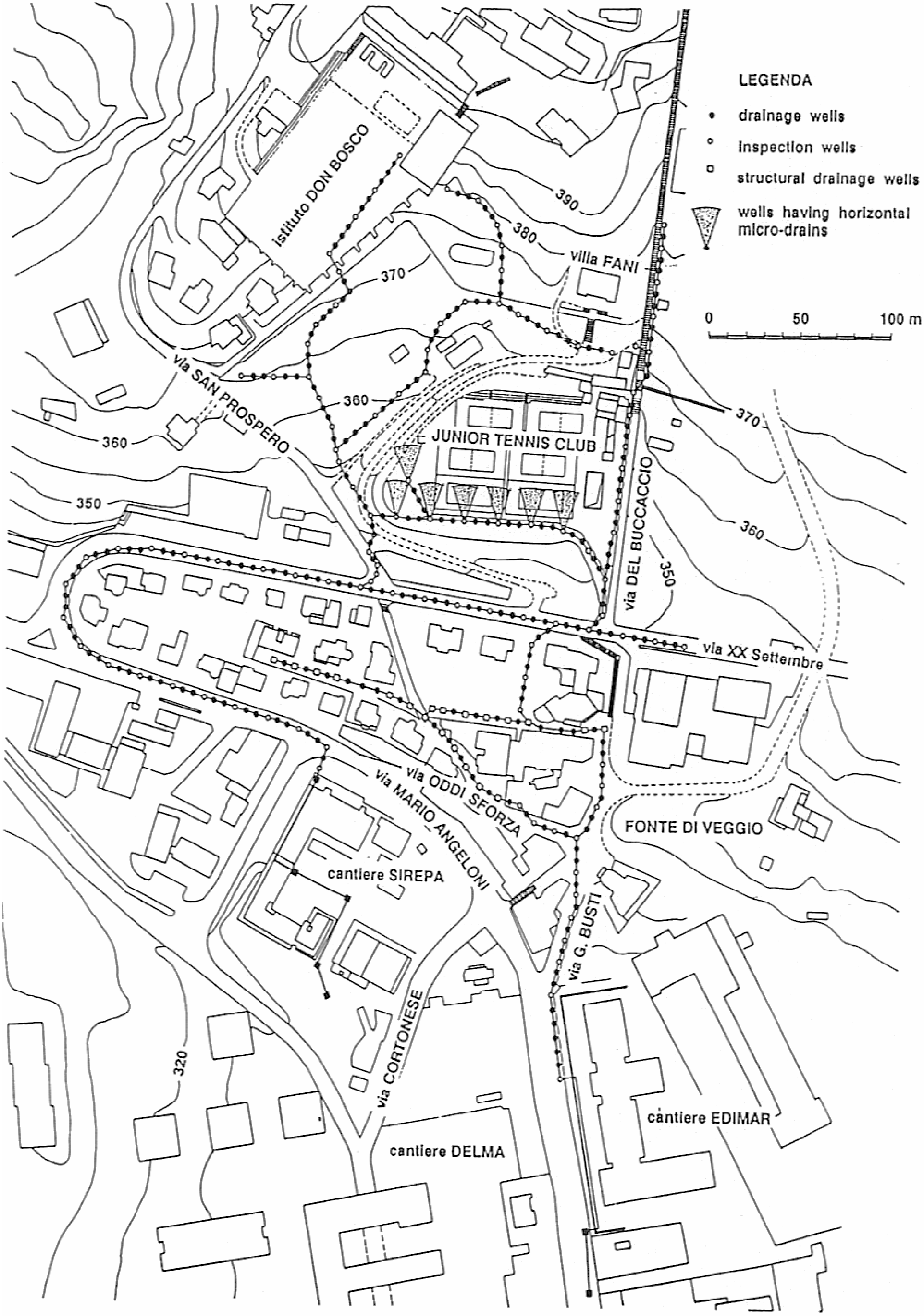

fig. 11 Plan of Perugia landslide showing the arrangement of the RODREN wells [after (3)]

Two draw off points were provided. The total discharge was about 300 l/min. at the start of the dewatering, decreasing to about 150 l/min. in later service.
Thereafter, a small scatter (±30 l/min.) has been revealed, related to seasonal variations. A finite response can also be noted in relation to major periods of rainfall. Overall, however, the maximum increase of piezometric levels has not exceeded 2 m.

The stability of the slope has been confirmed by all the inclinometer readings carried out after the completion of the drainage system (ref. 1).
Recently, the Technical Department of the Perugia Public Administration has prepared an updated report on the results obtained from the geotechnical monitoring system and this confirms the positive results of the drainage.

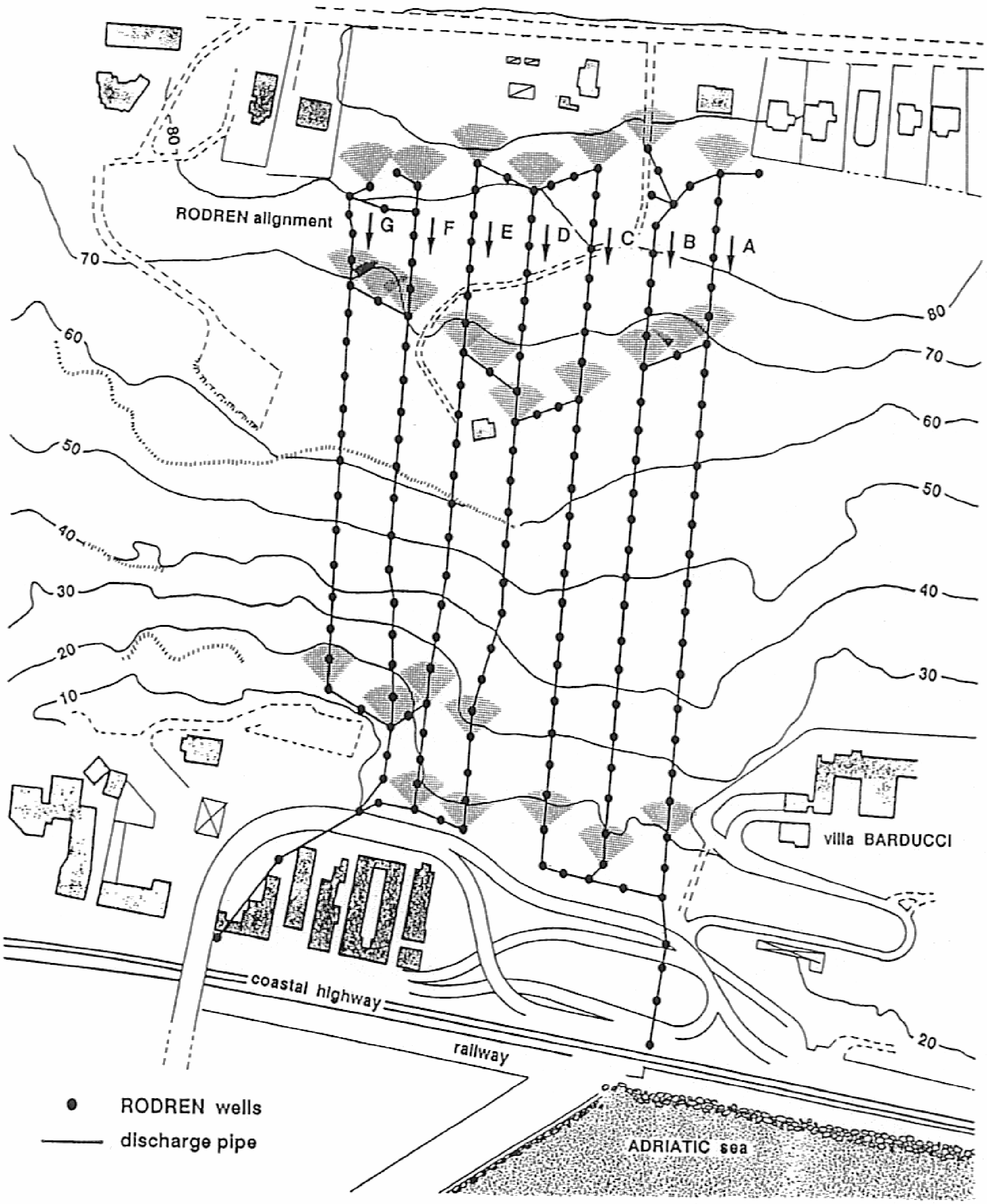

fig. 12 Plan of Palombella (Ancona) landslide showing the RODREN wells [after (4)]

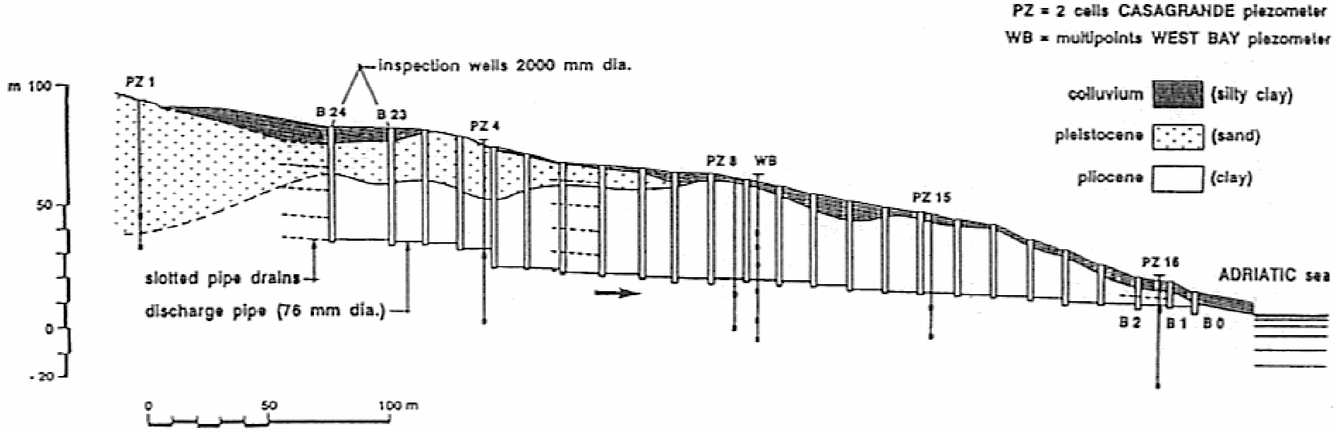

fig. 13 RODREN alignment B cross section, with the geological profile and the location of slotted pipe, Casagrande and West-Bay piezometers shown. Ancona

5. LANDSLIDE STABILIZATION CASE HISTORY 2 : ANCONA PALOMBELLA

On 12 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 (ref. 6).
The geological features of this area consist of a Pliocene basement (grey overconsolidated clay), having 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 unfavourable 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). Figure 12 shows the arrangement of the RODREN wells for this portion of the slope. In figure 13, shafts of Group B are shown on the relevant geological cross sections of the slope. The piezometric monitoring network, consisting of slotted pipes, Casagrande and West-Bay piezometers, is also indicated. Due to the unfavourable stratigraphy, the wells were drilled to depths of over 50 m (alignment B cross section, fig. 13). In order to reach this depth, 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). Figure 14 shows the data for Well B21 - the maximum deviation was 231 mm at 48.7 m depth. The largest deviation was recorded in drilling Well B16, where a 1.37 m deviation at 49 m depth was measured.
For the alignments already completed the following average deviations have been obtained:

Group of wells (fig. 9)	Average value of deviation (%)
B	1.29
D	1.16
F	1.18

The work is still in progress and, as planned, will be completed (Alignments A, C, E and G) at the end of 1991. The landslide monitoring is already giving favourable data regarding piezometric and inclinometric values. 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 l/min.

Figure 15 shows the flow rate at the discharge point of Group B shafts, in the period September-April 1989, compared with the corresponding rainfall records. Figure 16 shows the piezometric levels measured in the same period in the piezometers PZ1 and PZ4. The phreatic level is slightly decreasing; the pressure of deeper artesian groundwater confined into the Pliocene bedrock has been notably reduced.
The monitoring of the slope has been completed by inclinometer and geodetic controls. These confirm there are no appreciable movements in the area of the site.

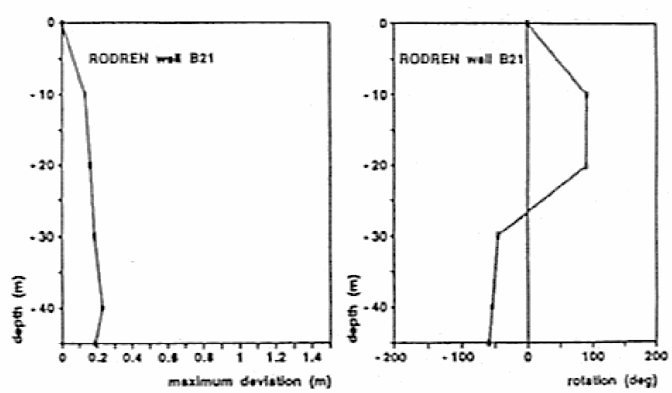

fig. 14 Accuracy of drilling operations of well B21 in polar coordinates. Ancona

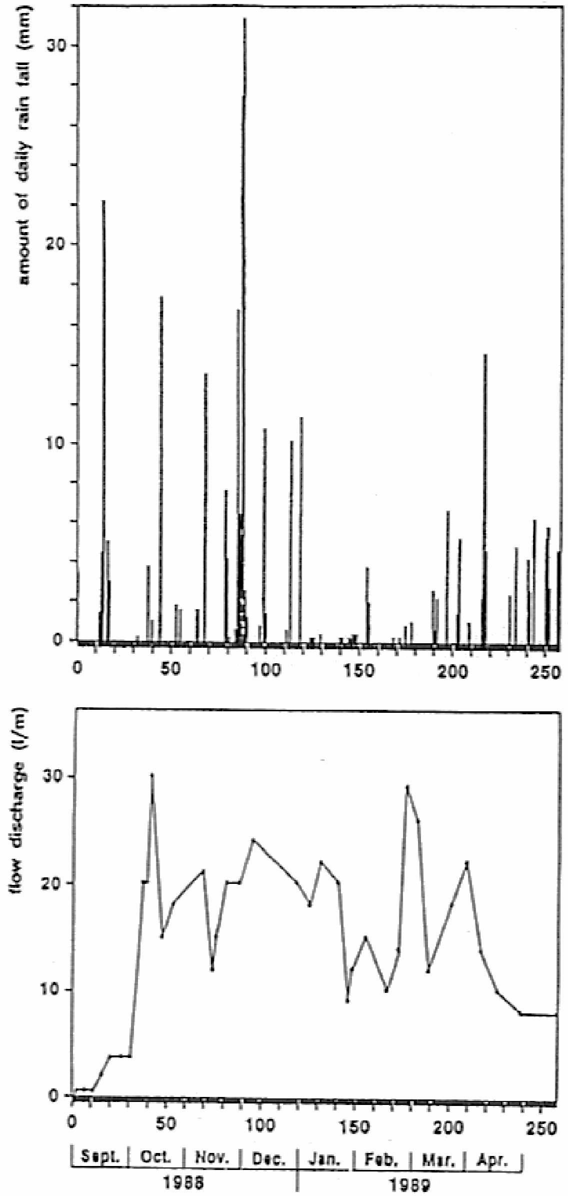

fig. 15 Flow rate at the discharge point of group B wells, in the period September-April 1989 compared to rainfall in the same period. Ancona

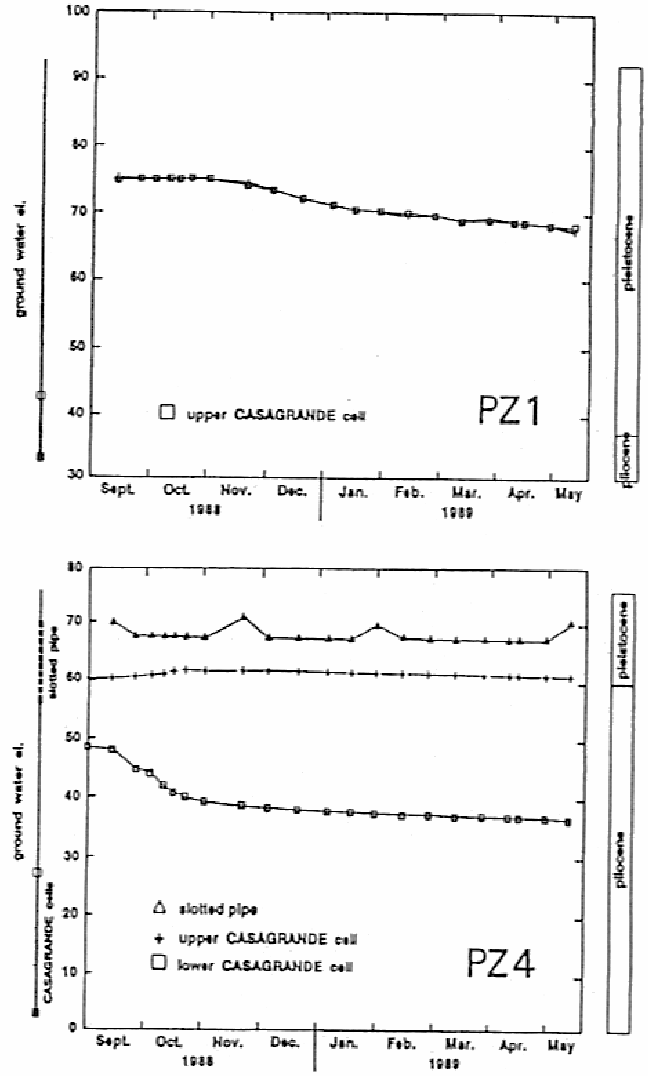

fig. 16 PZ1 and PZ4 piezometric levels in the period September-April 1989. Ancona

6. 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 favoured for stabilizing very sensitive environmental and urban areas in Spain and Southern California. An expansion of the technique into other areas with similar problems and restraints would appear most likely.

REFERENCES

1. BALDUCCI M. Misure di controllo sulla frana di Fontivegge (Perugia). Discussione, Proc. 16th Geotechnical Nat. Symp. on Landslides Stabilization, Bologna (Italy), 1986.
2. BIANCO B., BELIGNI D. Deep Drainage for Landslides Stabilization in Built-up Areas, L'Industria delle costruzioni, Dec. 1983.
3. BIANCO B. Il consolidamento della frana di Fontivegge in Perugia. Problemi tecnico esecutivi, Proc. 16th Geotechnical Nat. Symp. on Landslides Stabilization, Bologna (Italy), 1986.
4. BIANCO B. Pozos drenantes profundos para la estabilizacion de deslizamientos, Simposio El agua y el terreno en las infraestructuras viarias, Torremolinos (Spain) 1989.
5. COLLOTTA T., MANASSERO V., MORETTI P.C. An advanced Technology in Deep Drainage of Slopes, 5th Int. Symp. on Landslides, Lausanne (Switzerland) 1988.
6. HEGG U. Case History of a Large Coastal Landslide in Pliocenic Clays, Proc. 4th Int. Symp. on Landslides, Toronto (Canada) 1985.
7. RIGHI P.V., MARCHI G., DONDI G. Stabilizzazione mediante pozzi drenanti di un movimento franoso nella città di Perugia, Proc. 16th Geotechnical Nat. Symp. on Landslides Stabilization, Bologna (Italy), 1986.