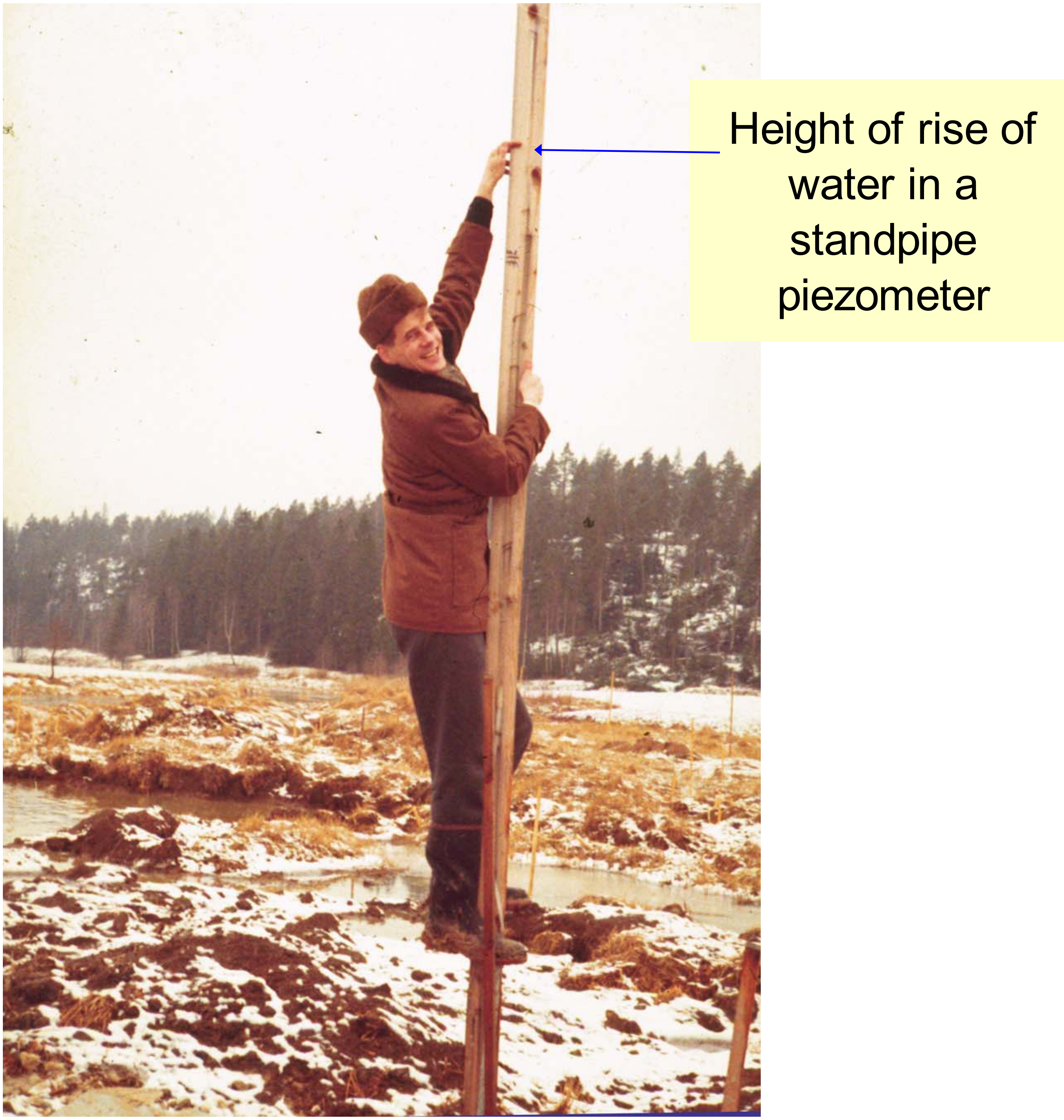

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A New Technique for Reduction of Excess Pore Pressures During Pile Driving

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A new technique is described whereby excess pore pressures induced during pile driving in soft, varved silts and clays were economically reduced to a safe level. The technique was applied to piles at a bridge site south of Stockholm, Sweden, where a small slide had occurred during pile driving. A new paper–plastic drain was attached to the wood piles during driving, and two pulling tests indicated that the drain was undamaged under normal driving conditions. The excess pore pressure generated during the driving of some 13 test piles without drains and 48 piles with drains was measured. The data indicated at least a 50% relative reduction in excess pore pressure when the drain was used. In addition, the cost of the technique was considerably less than alternative methods for dealing with dangerous excess pore water pressures resulting from piling in similar soils. The technique has been successfully applied at two other piling sites in Sweden.

Une nouvelle technique est décrite grâce à laquelle les surpressions interstitielles, induites par le battage de pieux dans des argiles et silts varvés mous, ont été réduites à des valeurs admissibles de façon économique. La technique a été appliquée aux pieux d'un pont au sud de Stockholm, Suède, où un petit glissement s'était produit durant le battage des pieux. Un nouveau drain de papier–plastique a été fixé aux pieux de bois durant le battage et deux essais d'arrachement ont indiqué que le drain n'était pas endommagé lors d'un battage dans des conditions normales. Les surpressions interstitielles générées pendant le battage de quelques 13 pieux d'essais sans drain et de 48 pieux avec drains ont été mesurées. Les observations indiquent une réduction relative d'au moins 50% des surpressions interstitielles lorsque le drain était utilisé. De plus, le coût de cette technique était considérablement moindre que celui de méthodes alternatives permettant de traiter des surpressions interstitielles dangereuses résultant du battage de pieux dans des sols similaires. La technique a été utilisée avec succès sur deux autres chantiers de pieux en Suède. [Traduit par le journal]

Pile driving in slopes of soft clays and silts, which often occur along rivers and lakes, presents difficult problems to the geotechnician. The stress–strain characteristics of these soils are such that sometimes only small deformations are required to exceed the peak shear strength, and thus the factor of safety of the slope may be markedly reduced. Broms and Bennermark (1967), for example, cited a case wherein down-slope deformations due to piling decreased the shear strength sufficiently to cause a failure.

An additional contributing factor to slope instability is the high excess pore pressures generated during pile driving in soft clays. Bjerrum and Johannessen (1960) described the reduction in safety factor due to piling at a bridge site in Norway. They used pore pressure measurements made during pile driving operations together with the results of effective

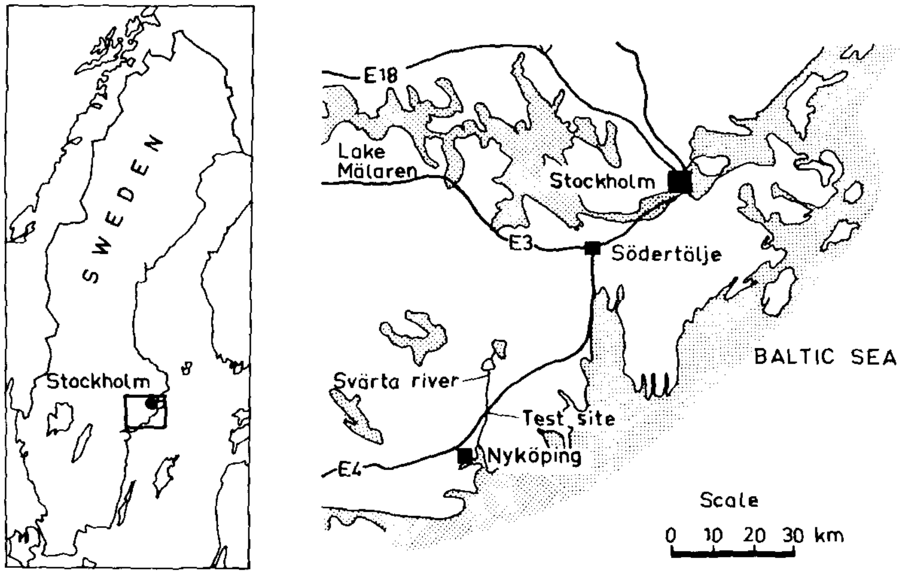

FIG. 1. Test location.

stress triaxial tests to compute the stability of two slopes during construction. This procedure, while theoretically correct, is not followed in Sweden, primarily for economic reasons. Additional factors working against its general acceptance include the uncertainties in sampling, triaxial testing, and piezometric measurements, and the unknown effects of clay disturbance due to piling.

Typically, only simple measurements of surface movements are made by the construction engineer at a piling site. If they become 'excessive', he calls in a geotechnician who bases his determination of what is 'excessive' almost entirely on intuition and experience. About all a contractor can do when faced with 'excessive' movements is: (1) remove a core of the clay from the top few meters where the pile is to be driven, and/or (2) slow down his operations significantly so that high excess pore pressures will have time to dissipate. Both procedures are expensive. Because of the low permeability of Swedish clays, the times required for dissipation are often on the order of weeks and months (Orrje and Broms 1967). If piezometers are installed, the driving rates can be controlled by observations of the excess pore pressures—otherwise a very conservative driving rate, often allowing only a few piles per week, is followed.

Recently, a practical solution to the problem of excess pore pressures generated during pile driving has been tried in Sweden and found to be quite satisfactory. The technique involved attaching a newly developed paper–plastic drain, known as the Geodrain, to the pile as it was being driven. The efficiency of the drain is such that a significant reduction in excess pore pressures was observed when the drain was employed on some wood piles at a bridge site about 100 km southwest of Stockholm, Sweden (Fig. 1). Here, a new location of the E4 motorway crosses the Svärta River on a reinforced concrete bridge 62 m long. The area is geotechnically rather well-known because of a major landslide which occurred in 1938 during road construction only a few kilometers away from the present site (Fagerström 1972).

Site Description

After the retreat of the last glacier, the relatively thick deposits in the Svärta river valley were formed by sedimentation in the Baltic Sea, which at that time covered a large part of central Sweden. At the same time the Scandinavian peninsula started to rise, but as late as in the fifteenth century, the valley still was covered with water from the Baltic.

In the early twentieth century, attempts were made to lower the groundwater table in the valley for agricultural purposes, and many small slides occurred along the riverbanks. There is, for instance, evidence of such a small slide at the construction site itself.

The results of site investigations for the bridge are shown in Fig. 2. Since the clays in the valley are so young, they are unusually soft below the dry crust, even for Swedish conditions. Otherwise, the geotechnical profile is rather typical for this part of central Sweden.

The bridge has four piers, each supported by 30

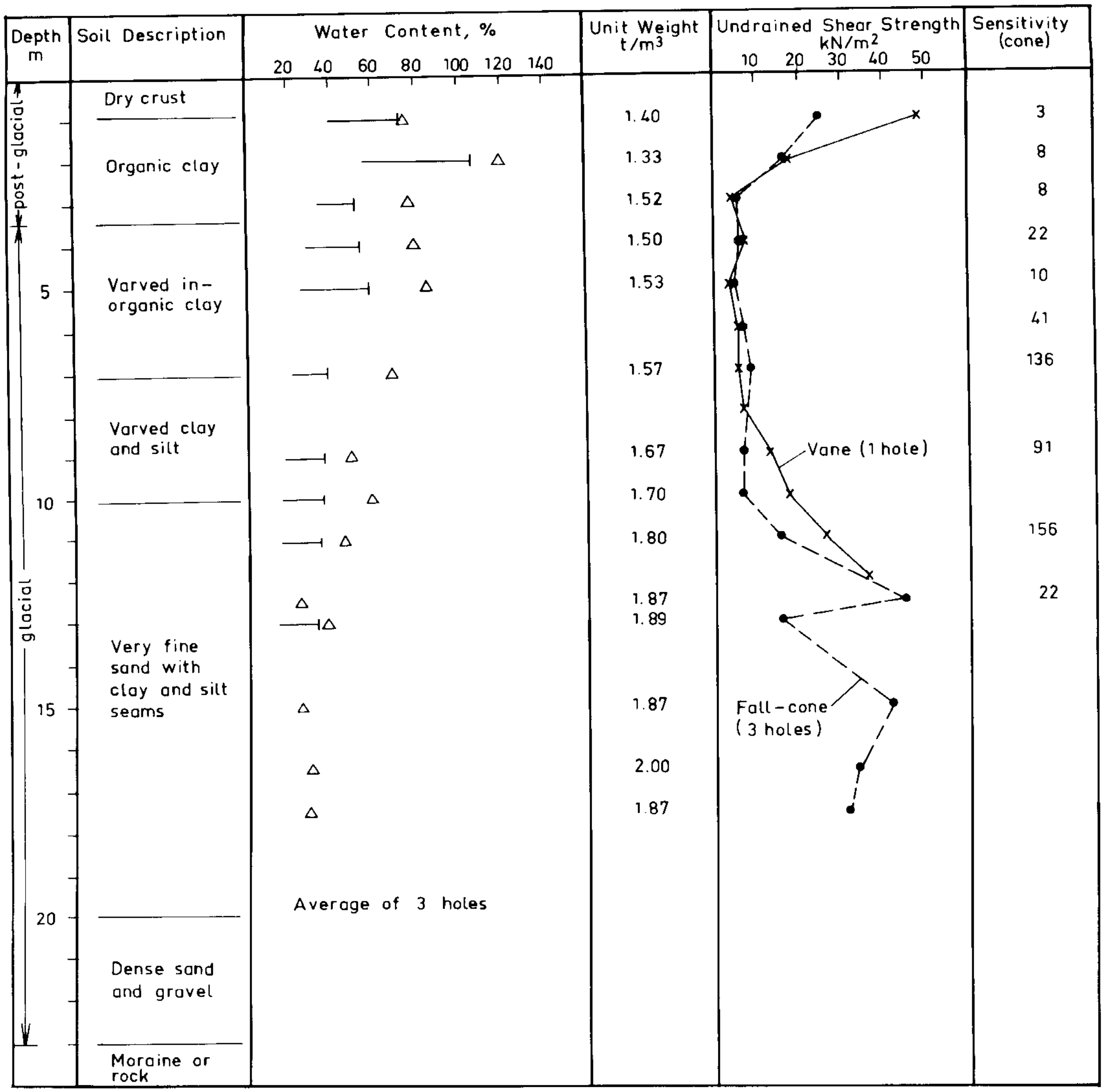

FIG. 2. Geotechnical profile. See Fig. 3 for location of bore holes.

× 30 cm precast reinforced concrete piles. Because of poor stability conditions and potentially excessive settlements, the approach embankments were founded on wood piles, and temporary wood piles were even required to support the form work for the bridge girders. The designers suspected that there might be problems during pile driving because of the poor subsurface conditions, and the contractor was instructed to observe movements of the ground during driving and notify a geotechnician should any occur.

Problem and Solution

Most of the concrete piles for the piers had been driven when a small slide occurred on the east bank of the river and slightly downstream of the site (Fig. 3). Piezometers were installed at the suggestion of geotechnicians from the National Swedish Road Board, and the measurements indicated rather high artesian pore water pressures in the silt and sand layers underlying the soft clays (Fig. 2). These excess pressures ranged from about 1 m to about 2.5 m above the ground surface.

The consensus was that further piling, required for the temporary form work, would be inadvisable as originally planned. An attempt was made to remove clay cores prior to driving these piles, but in general it was unsuc-

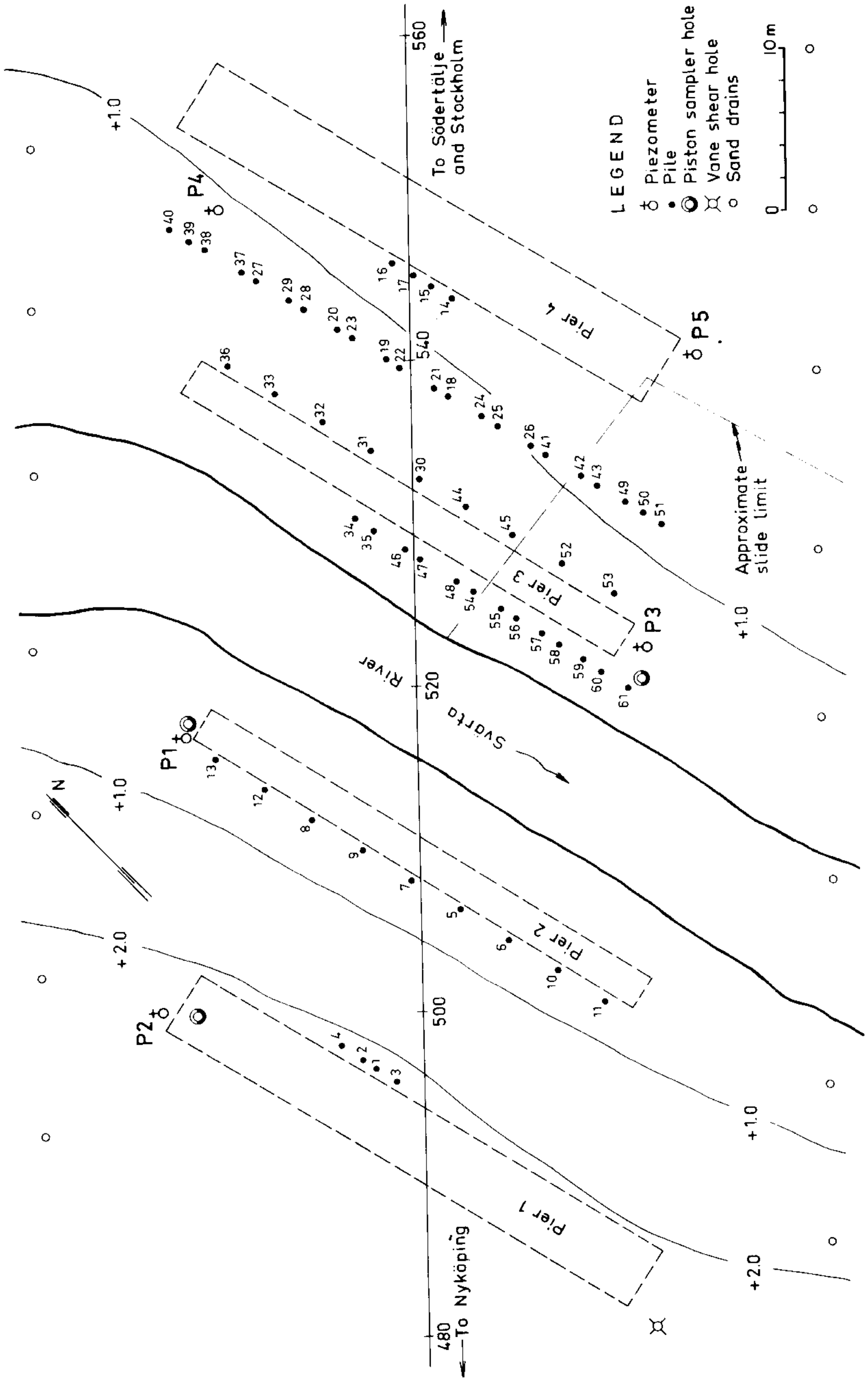

FIG. 3. Site plan showing test piles and piezometers.

cessful due to the soft and sensitive nature of the clay. Most of the core simply did not remain in the open pipe long enough to be removed. The only alternative left to the contractor was to markedly reduce the rate of piling and wait for dissipation of the excess pore water pressures—obviously a very expensive proposition.

At this point, geotechnicians at the Road Board suggested the contractor try the new paper–plastic drain to accelerate dissipation of excess pore pressures, and a test program was arranged. The first question concerned whether or not the drain would remain on the pile during driving, especially when the pile passed through sand and silt seams. A trial was made wherein two piles, which were driven with the drain attached, were pulled and the drain inspected. In both cases, the drain was intact and undamaged by either driving or pulling.

The Geodrain, invented by O. Wager of the Swedish Geotechnical Institute, is an improvement of the Kjellman (1948) paper drain. The new drain was, however, originally intended to not only replace paper and sand drains, but also for draining clay embankments. It consists of a grooved plastic core, 10 cm wide and 0.4 cm thick with a coarse paper wrapping. The paper acts as a filter and its permeability is on the order of 10^{-3} cm/s. It comes in 150 m rolls, is tough and lightweight, and experience at the Svärta site showed that it was very easily handled in the field.

Test Program

Since the results of the initial driving test were encouraging, a program was set up to measure the induced pore pressures during driving of piles with the drain attached. As a control, these results would be compared with the excess pore pressures generated during driving of some 13 wood piles, which remained to be driven on the west bank of the river. Figure 3 shows the locations of both groups of piles and the piezometers, which were simply open tube standpipes attached to a filter stone pushed into the silt and sand layers below the clays.

All test piles were wood with an 18 cm tip diameter, and they had lengths ranging from 16 to 25 m depending on the depth to firm bottom. All piles were vertically driven with a pneumatic hammer. For the piles with drains, driving was temporarily stopped every couple of meters and the drain was simply nailed to the pile. Figure 4 shows a partially driven pile with the drain attached. Both the drain and the pile were cut off at the ground surface after the pile was driven to the desired depth.

FIG. 4. Partially driven pile with drain attached.

Discussion of Results

The results of the measurements are summarized in Fig. 5. The schedule of test piles driven is shown at the top where the pile numbers refer to the location as given by Fig. 3.

Since the piezometers were the open standpipe type and were read only once per day, the measurements can only be considered to be relative. Although no separate measurement was made of the groundwater table, or in this case the artesian pressure level at some distance from the piling, it is assumed that this level remained essentially constant during the measurement period. For example, piezometer No. 4 was almost constant for the first 6 weeks of the test program, and the other piezometers

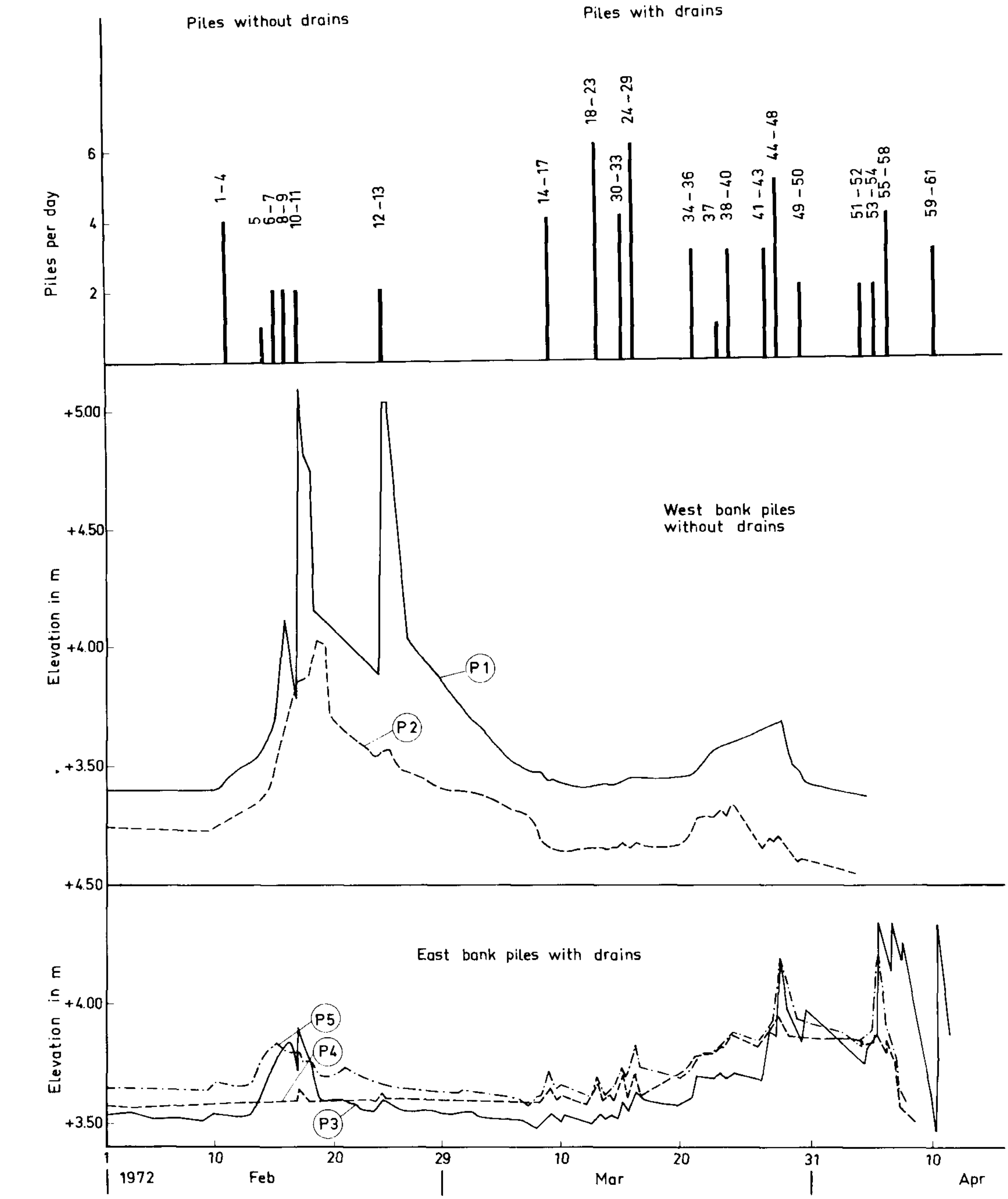

FIG. 5. Record of piles driven and piezometer observations. Piezometers designated P1, P2, etc. correspond to locations shown on Fig. 3.

returned to about their initial level after a number of piles were driven.

In general, the response of the piezometers correlates quite well with the occurrence of piling. There is some time lag due to the open measurement system, and it is quite likely that the peak pore pressures greatly exceeded those measured, especially temporarily.

It is obvious that the excess pore pressures induced by piling on the east bank where the drains were used is significantly less than on the west bank where no drains were used. For example, the maximum pressure recorded by piezometer P3, even when piles were driven very close to the piezometer, is about half the maximum given by P1.

It is interesting to note that piezometers P3 and P5, on the east bank some 15 to 40 m away from the west bank piles, responded to the driving of those piles, probably because of the fine sand and silt seams. Similarly, P1 and P2 responded slightly to piling on the east bank.

It should be mentioned parenthetically that towards the end of the test program, 150 mm diameter sand drain wells to help stabilize the site were installed at approximately 10 m spacings in two rows 23 m north and 25 m south of the bridge center line (Fig. 3). This work (ordered before the new technique was considered) was started at the northwest corner of the site on March 20, 1972, or after all the west bank piles and some 22 east bank piles had been driven. The authors visited the site on March 28, after the first four north row wells had been installed, and observations of the completed wells and the piezometers indicated that no reduction of the artesian pressures had yet occurred. Thus, the wells could not have affected significantly the measured pore pressures up to this date, and in fact it is doubtful that any of the measurements were affected before April 5 (piles 53 and 54, Fig. 5) when the last north row well was installed. Since only three east bank south row wells were installed before April 10 when the test program was completed, it is possible, though doubtful, that the peak pore pressures measured during driving of piles 55–61 may have been reduced somewhat because of the wells. Clearly, however, the response of the east bank piezometers to the driving of the east bank piles prior to April 6 demonstrates that the Geodrains on the piles helped to dissipate the excess pore pressures.

Costs and Comments on Future Applications

The cost of the technique described herein was significantly less than the alternatives the contractor had available. As mentioned, the removal of clay cores prior to driving was unsuccessful, so slowing down the rate of driving was the only conventional alternative remaining. The extra cost of the new technique was about three swedish crowns per meter ($0.25 per foot) of pile, including the drain, or for typical jobs in Sweden, about 20% of the cost of the piles. As a comparison, successful removal of cores of clay might increase the piling costs about 50%, excluding the cost of the delays.

A still cheaper and probably better procedure would involve installation of the drains at a site prior to piling. This might result in greater efficiency especially in varved soils because insertion of a drain alone would cause less disturbance than a pile. It is, of course, possible to attach the drain to the pile prior to, rather than during driving, and it could be attached to concrete and steel piles as well as wood piles. When applied to cohesion (friction) piles in clays, the drain should greatly accelerate the dissipation of induced excess pore pressures, and thus increase the rate of strength increase. Some investigations of the drain on cohesion piles are currently underway in Sweden.

Conclusion

Use of a new paper–plastic drain on timber piles driven into a very soft varved clay overlying a fine sand with clay and silt seams resulted in at least a 50% relative reduction in the excess pore pressures induced by the piling. The cost of the technique was significantly less than the cost of the only other practical alternative available to the contractor at this particular site.

Acknowledgments

The National Swedish Road Board kindly granted permission to publish the data reported herein. Engineer I. Åberg, who supervised the piezometric measurements, was particularly helpful in supplying additional details about the project. S. Johansson made the drawings, and J. Wait typed the manuscript.

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A New Technique for Reduction of Excess Pore Pressure during Pile Driving:[1] Discussion

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The authors are to be complimented on an interesting case history presenting an original method of solving the commonly occurring problem of development of excess pore pressures, when driving piles in soft clays. In Fig. 5, the authors present the measured pore pressures and number of piles driven on specific days. This figure indicates that the developed pore pressures were considerably smaller after the installation of the Geodrain on the piles, as compared with the measurements before the drain application. However, as the magnitude of the measured pore pressures is less dependent on the number of piles driven per day and more on the distance from the piles to the piezometers, a different plotting of the results gives a better basis for the conclusions drawn by the authors.

In Fig. 1, the writer has plotted for each driven pile the distance against time to two piezometers, numbers P-1 and P-3. A black dot shows the distance (and date) of a pile relative to piezometer number P-1 and an open dot that of the same pile relative to piezometer number P-3. The lower diagram in Fig. 1 shows the piezometric elevations measured in piezometer numbers P-1 and P-3.

A study of the measurements taken before March 10 shows that already when driving piles more than 20 m away from the piezometers, a small increase of pore pressures occurred (piezometer P-3). When piles were driven at a distance of less than 20 m to the piezometers, considerable increase of the pore pressure was measured, which is shown from the plot of measurements from piezometer number P-1. After March 10, when the Geodrain was applied on each new pile, the piles were driven closer to piezometer number P-3 and Fig. 1 shows also that despite the fact that a larger number of piles were driven, the developed excess pore pressures were 50% smaller than measured in piezometer number P-1 before the drain application.

Figure 2 presents a plot of the same data, where the axis of increasing distance goes downward, which from a visual point of view better shows the effect of distance on the measured pore pressures.

The writer agrees with the conclusions drawn by the authors. The authors' discussion that the sandwells have a negligible influence can be strengthened by the fact that the few wells, which were installed during the last 6 days of the measurement period, were located 35 to 40 m away from piezometer number P-3 and the piles driven close to this piezometer. This distance is too large to have influenced the measurements.

[1]Paper by Holtz, R.D., and Boman, P. Can. Geotech. J. **11**(3), pp. 423–430.

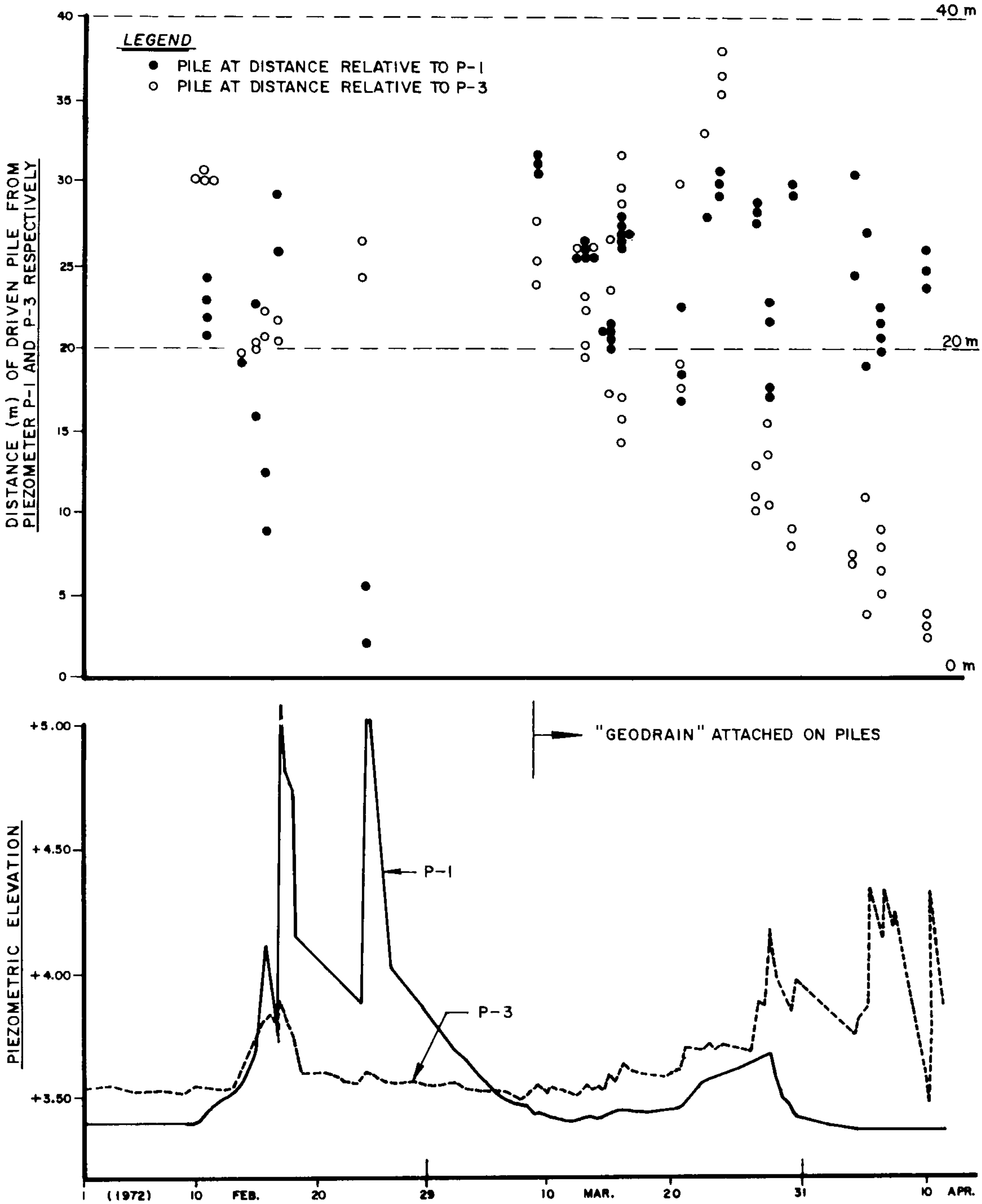

FIG. 1. Upper. Record of piles driven against time (date) and distance to piezometer (numbers P-1 and P-3). Lower. Piezometric elevations measured in piezometer numbers P-1 and P-3.

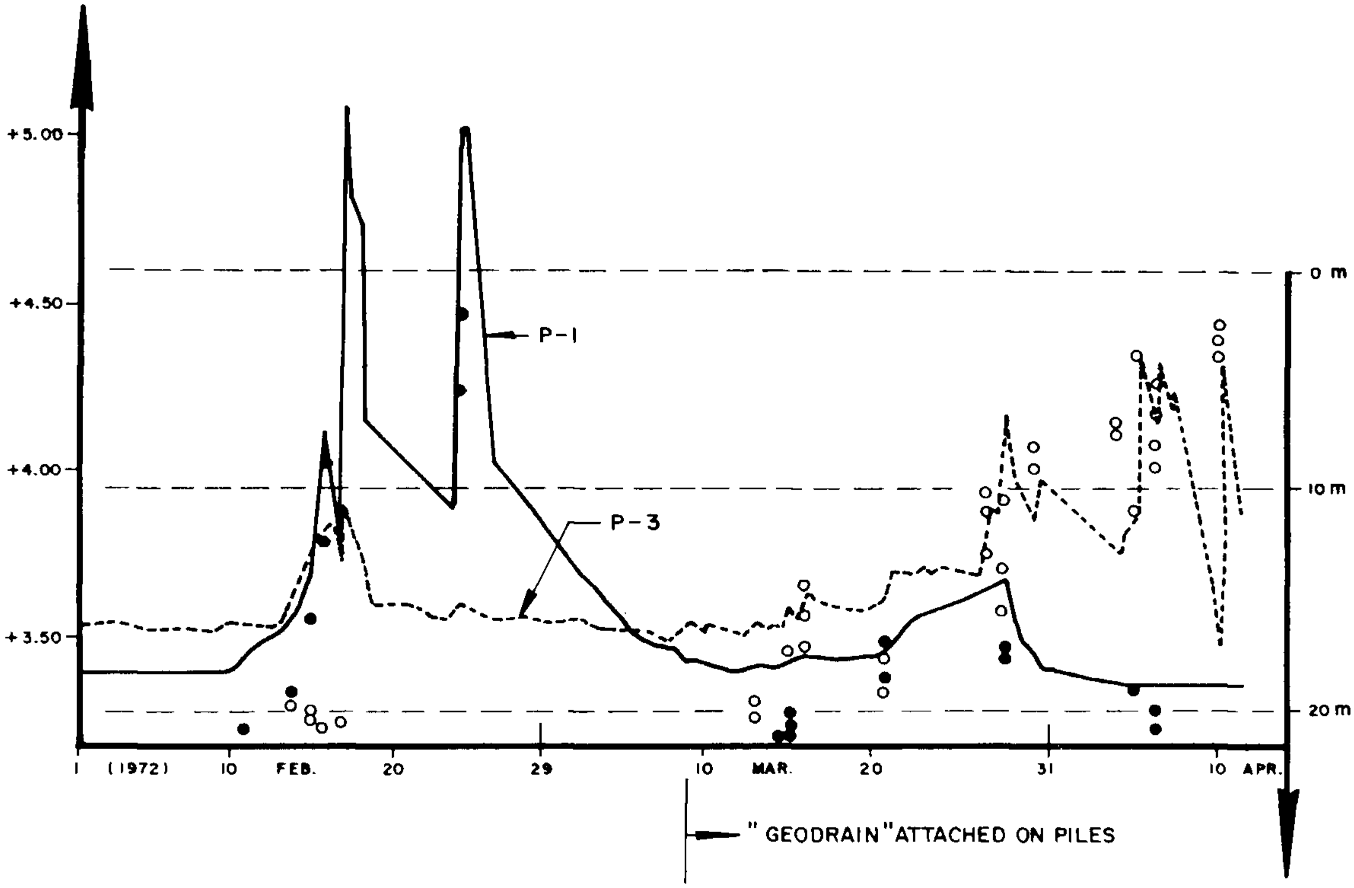

FIG. 2. Combination of the data shown in Fig. 1. Piles driven at greater distance than 22 m are excluded.