Geotechnical Instrumentation NEWS

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John Dunnicliff

Introduction

This is the forty-first episode of GIN, with two articles. Thank you to the authors of both articles for sharing their innovations with us.

More about Heavy Rain and Landslides

The previous episode of GIN included and article by Beto Ortigao and Maria Justi about "Rio-Watch", the landslide warning system in Rio de Janeiro, Brazil. This current episode includes an article by R.K.S. Chan and W.K. Pun about the warning system in Hong Kong, which also experiences landslides during heavy rainfall, with major impact on the population. Both systems are results of major innovation.

Measurement of Dynamic Pore Water Pressures During Earthquakes

This is another topic involving major innovation. The article by Robert Farrell, Pedro de Alba and Jean Benoît describes the design, testing and installation of a piezometer for monitoring earthquake-induced pore water pressures in the field. Clearly this application requires a transducer with a much more rapid response than the ones most geotechnical engineers are familiar with, and it also requires comprehensive de-airing.

More on Measuring Pore Water Suction

In the next episode of GIN I'm expecting to have one more discussion of the September 2004 article, *"Some Experiences in Measuring Pore* Water *Suction in Dublin Glacial Till",* by Mike Long, Chris Menkiti and Ben Follett, and hope to have the authors' closure for the same episode.

Next Instrumentation Courses

This is a repeat of the announcement in the previous GIN. Two courses are planned. The first will be in Clearwater, Florida on March 13 thru 15, 2005 (*www.doce-conferences.ufl.edu/geotech/*). Please see page 39 for some details. The second will be in Delft, The Netherlands on June 1 thru 3, 2005 (*www.geodelftacademy.nl/nl/page161.asp).*

Some Anglo/American Questions and Answers

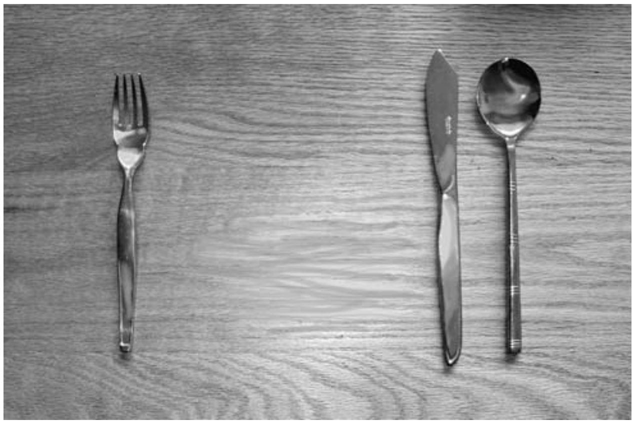
A few months ago some American geotechnical colleagues were staying with us here in rural England and, as engineers are wont to do, various analytical questions went back and forth. Here are three that I was asked to answer.

1. *Why do English people use fish knives and forks?*

These are different from normal knives and forks. The knives have a pointed end and the forks have an indentation at each side. There are two reasons. First, because when knives and forks were made of silver, fish stained the silver. By having separate tools, the staining was limited. Second, a fish knife has a pointed end, for use when removing bones. Very efficient too! As an aside, English people call knives, forks, and spoons "cutlery", as opposed to colonials who call them "silverware", and who may even go to the strange extreme of calling plastic ones "plastic silverware".

2. *Why do English people use soup spoons***?**

The bowl of the spoon is almost circular in plan. Because polite behaviour (please note the spelling) requires that the soup is conveyed to the mouth from the side of the spoon, not from the end. To do this, the spoon is rotated slightly about its long axis, towards the mouth. If you do that with a desert spoon, slurping usually occurs and the soup goes to your chin, and thence downward. As an aside, the soup should flow from the soup bowl into the spoon by moving the spoon away from the body towards the



far end of the bowl, with the bowl tilted slightly if necessary, away from the body. If it was tilted **towards** the body, the clothes might get wet. I don't know what the colonial word is for a soup bowl.

3. *Why do English people drive on the left side of the road?*

Because, well before the days of the automobile, while riding a horse the sword and right hand that held it needed to be on the side near the oncoming traffic, for defense purposes. So if a colonial contends that the right side is the "right" side, he or she had better think again and be more respectful of the Mother Country.

Here endeth the lesson for the day. The lesson is included here because my masters at *Geotechnical News* asked me to add some words to an unusually short 'column' so that the first article could start on this page and not near the bottom of the previous one. Now you know something about the logistics of writing material for a magazine!

Closure

Please send contributions to this column, or an article for GIN, to me as an e-mail attachment in MSWord, to *johndunnicliff@attglobal.net, or by fax or mail: Little Leat, Whisselwell, Bovey Tracey, Devon TQ13 9LA, England. Tel. and fax +44-1626-832919.*

Sherephey! (Turkey). *"To your honor"*. Thanks to Vahan Tanal for this.

Landslip Warning System in Hong Kong

R.K.S. Chan and W.K. Pun

Abstract

Hong Kong is a city with rugged topography. Landslides generally occur during periods of heavy rainfall. The Geotechnical Engineering Office (GEO) of the Civil Engineering and Development Department (CEDD) and the Hong Kong Observatory (HKO) of the Government of Hong Kong Special Administrative Region operate a Landslip Warning System to alert the public to landslide hazard. By using information on a combination of real-time measured rainfall and rainfall forecast, and based on our understanding of the rainfall-landslide relationship, the Hong Kong Government is able to issue Landslip Warnings as necessary. The GEO and the HKO manage a raingauge system of over 100 automatic raingauges distributed over Hong Kong that measures rainfall intensities at 5-minute intervals.

Introduction

Hong Kong has a long history of landslides, the majority of which are triggered by rainfall. The GEO of the CEDD and the HKO of the Government of Hong Kong Special Administrative Region operate a Landslip Warning System. Landslip Warnings are issued during times of heavy rainfall when it is predicted that numerous landslides will occur. The purposes of Landslip Warning are to alert the public to reduce their exposure to possible danger from landslides and to trigger the operation of an emergency system within government departments that mobilizes staff and resources to deal with landslide incidents.

The operation of the Landslip Warning System requires knowledge of the real-time and forecast of rainfall intensities, and a good understanding of the relationship between rainfall and landslides.

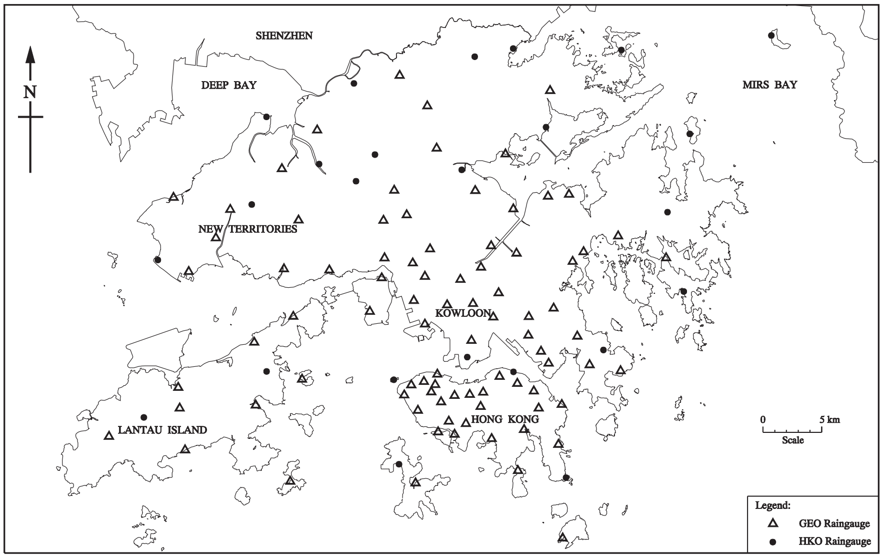


Figure 1. Locations of GEO and HKO Field Raingauge Stations.

The GEO Raingauge System

The GEO and the HKO operate an extensive network of automatic raingauges, providing real-time rainfall data to the Landslip Warning System. The locations of the raingauges are shown in Figure 1. The network comprises 86 raingauges operated by the GEO and 24 raingauges operated by the HKO.

The hardware for the GEO raingauge system comprises two main parts: (i) field raingauge stations and (ii) a Central Control Centre. Each field raingauge station comprises a Casella tipping bucket raingauge, a data logger module with a modem for data trans-

Figure 2. GEO Field Raingauge Station.

mission, and a rechargeable battery powered by a solar panel, as depicted in Figure 2. The Casella tipping bucket raingauge collects rainfall, and the data logger module records the corresponding measurement in real-time. Every 5-minute the modem transmits the total rainfall amount recorded in the last 5-minute by private telephone line to the data acquisition unit in the Central Control Centre, which is equipped with computers for receiving and processing the raw rainfall data. The data are also transmitted to the HKO in real-time using private telephone line.

Computer programs are developed and applied together with the proprietary software to acquire real-time rainfall data, display situation of rainfall development (such as rainfall contour maps), calculate the predicted number of landslides and check automatically the rainfall situation against the Landslip Warning criteria.

Issue and Cancellation of Landslip Warning

The first set of Landslip Warning criteria was established in 1977 based on the work of Lumb (1975). The criteria have been revised a number of times since then (Brand et al, 1984; Pun et al, 2003). The current criterion is based on the correlation between slope failure rate and maximum rolling 24-hour rainfall developed by Yu et al (2004). Landslip Warning would be issued when the estimated number of landslides exceeded a threshold value, currently set at 15. This value was adopted because past statistics showed that on average there was one major landslide (defined as a landslide with failure volume greater than 50 m³) in every 15 landslides.

For the estimation of the number of landslides, Hong Kong is divided into about 700 spatial grid cells, each having a plan area of 1.5 km by 1.2 km. When there is a rainstorm, the 24-hour rainfall is calculated for all spatial grid cells. The predicted number of landslides in each grid cell is obtained by multiplying the landslide frequency determined by the past 24-hour rainfall and the number of slopes within the grid cell, taking into account the distribution, the characteristics and the consequence (in case of a failure) of the registered slopes. The total number of predicted landslides in Hong Kong is the sum of predicted landslides of all the spatial grid cells.

Every 5 minutes, the GEO raingauge system automatically calculates the total predicted number of landslides. As the use of the Landslip Warning System is to issue timely warnings to the public and to mobilize Government staff and resources to deal with landslide incidents, Landslip Warning should be issued when the Landslip Warning Level (i.e. when the estimated number of landslide is 15 or more) is expected to be reached. Rainfall thus needs to be forecasted. Under the current system, the estimated total number of landslides is made up of two components (i) landslides calculated for the past 21-hours and (ii) landslides calculated for the next 3-hour rainfall forecast. With this approach, a 3-hour lead-time can be allowed for emergency preparedness.

When the Landslip Warning is issued, local radio and television stations are notified and are requested to broadcast the Warning to the public at regular intervals, together with advice on the precautions that should be taken.

To cancel a Landslip Warning, the number of landslides likely to occur after the cancellation should be small. Criteria for cancellation of Landslip Warnings have been developed based on the principles that (i) both the rainfall recorded in the past few hours and that forecast for the next few hours is small, and (ii) the time since the issue of the Landslip Warning should be sufficiently long such that the number of landslides likely to occur after the cancellation is small.

Conclusions

The GEO and the HKO operate an extensive network of automatic raingauges, providing real-time rainfall data to the Landslip Warning System. Landslip Warning criteria have been developed based on the relationship between rainfall and landslide using local data dated back to 1984. The data capture, control and processing and checking against the Landslip Warning criteria are all automated so that timely warning can be issued to the public and to mobilize Government staff and resources to deal with the aftermaths of landslide incidents.

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Acknowledgement

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Piezometer Design and Installation for Earthquake Pore Water Pressure Measurement

Robert Farrell
Pedro de Alba
Jean Benoît

Predicting the behavior of saturated sand deposits during earthquakes requires a forecast of how pore water pressures will rise as shaking continues. Mathematical models for this purpose should be calibrated by field observations; however, there have been only a few successful measurements of earthquake-induced pore water pressures in the field, and at least one of those caused a great deal of controversy because the records looked very different from what was expected.

Given the scarcity of data, there is general agreement that seismic instrumentation arrays for geotechnical earthquake measurements should include piezometers in potentially liquefiable deposits. Because of the nature of these observations, piezometers must be able to survive in the ground for long periods while waiting for the earthquake. Basically, the issues that have been raised in this respect center around (a) how to install them so that they can actually measure dynamic pore water pressure signals in the earthquake-frequency range (up to perhaps 25 Hz), and (b) how to verify that they are still working properly after several years in the ground.

Piezometer Design

The frequency range required means that an electronic transducer must be

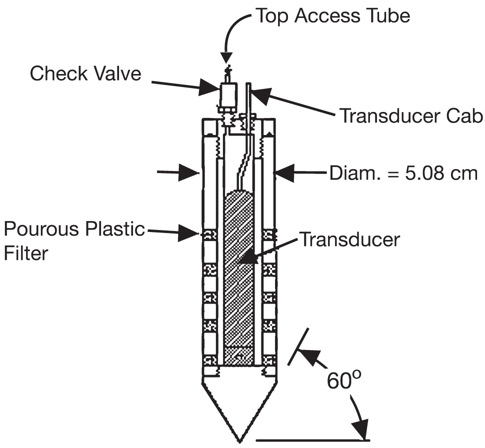

Figure 1. Section through piezometer tip.

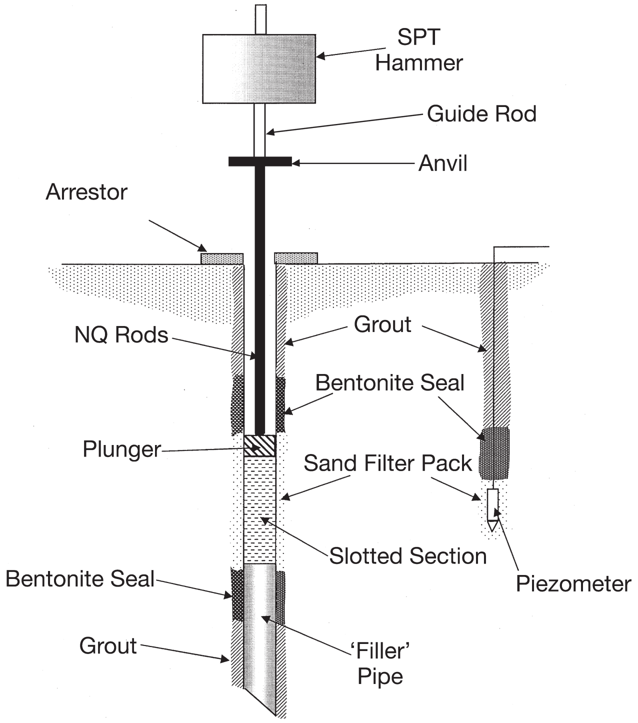

Figure 2. Schematic of Source/Piezometer System.

employed; the transducer of choice is configured as a metal housing forming a watertight cavity which interfaces with the pore water through an instrumented flexible diaphragm. The question is how to install it, undamaged, in the ground. It was originally thought by some researchers that the best way would be to place the transducer in a protective tip and push it a short distance into undisturbed material below the bottom of a borehole. This procedure was used in 1996 for the Treasure Island, California, geotechnical array (Faris and de Alba, 2000). Questions were raised, however, as to whether the presence of the protective tip itself, and the pushing procedure employed, would adversely affect the response of the piezometer, damping out the dynamic pore water pressure signal.

Consequently, a laboratory study was carried out in which a transducer in its protective tip was jacked into a confined deposit of saturated sand in a metal tank, and subjected to dynamic pore water pressure signals, which were compared to those received by a reference transducer in the wall of the tank. The transducer in its protective nylon tip is shown schematically in Figure 1. The tip consisted of a 5.08-cm diameter nylon sleeve with an array of 20, 0.5 cm-diameter, porous polypropylene filters which gave the transducer access to the pore water. The transducer was secured in the tip by removing its (factory-supplied) protective nose piece and screwing the body onto the conical nylon end (the significance of the access tube and check valve are explained later, in the section titled "Piezometer Tests."). We used two types of transducers in different phases of this study: the Druck PDCR-940 and the Keller 700-T. They have similar dimensions, being about 2.5 cm in diameter and 10 cm long. The hydraulic conductivity of the tip in water was about 3 x 10^{-2} cm/sec. Details of this study are reported in Farrell (2003) and Farrell et al. (2004); basically, we found that the tip was undamaged when subjected to jacking pressures of up to 4.5 kN over distances up to 30 cm. The laboratory signal-generation system could produce dynamic signals at frequencies up to 8 Hz; no significant difference was observed between the response of the jacked-in transducer and the reference transducer.

Dynamic Signal Generator

The issue of response after installation could only be addressed if it were possible to produce a hydraulic pulse in the right frequency range in the field. Heavy drop weights and small explosive charges had been used for this purpose by other workers, but these were found to damage the transducer itself and/or modify the source-path characteristics of the soil in such a way as to produce a decreasing response with each test. Consequently, a new signal-generation system was developed which basically consisted of a falling weight dropping on a plunger which would generate a dynamic signal in a water-filled 10-cm (4-inch) ID PVC casing. Piezometers would be installed around the signal well at different depths, and the signal well casing would be provided with 61-cm long slotted sections at the depth of each piezometer in the instrument array. The idea was to isolate each slotted section in turn, and produce a pressure pulse opposite the piezometer to be tested.

This system is shown schematically in Figure 2. A 0.62-kN SPT hammer was dropped 1.5 m onto an 'anvil' connected to a plunger by NQ-diameter rods. The plunger had previously been positioned above the slotted section of the casing at the depth of the transducer to be tested. Each slotted section was surrounded by a sand filter pack, and isolated by bentonite seals. The inside of the casing below the slotted section opposite the transducer to be tested was plugged by lowering a recoverable capped PVC pipe section ('filler' pipe, Figure 2) into the well, which was just long enough to reach from the bottom of the boring to the bottom of the slotted section selected.

We found that this system actually generated three types of waves; the fastest and most easily detectable was the compression wave (Type 1) produced directly by the impact of the falling hammer on the steel anvil; the second type of wave (Type 2) was produced as an initial response to the plunger acting on the (relatively incompressible) water volume in the slotted section of the pipe, and finally a third small signal was observed as the water flowed out of the slotted section into the aquifer.

An example of the initial (Type 1) compression wave, recorded at 50 cm from the signal well, is shown in Figure 3. The figure shows that actually two, and sometimes three, distinct pulses were often produced: when the hammer hit the anvil, when the hammer/anvil system hit its arrestor (bounce 1), and sometimes an additional rebound (bounce 2). The pulse frequency ranged from about 900 to 1000 Hz, and traveled at a velocity of approximately 1500 m/sec. Figure 4 shows the Type 2 wave; Videotapes of the hammer/plunger system showed that the Type 2 wave was produced just as the plunger started to move, and we assume it is an effect of injecting water from the well against the aquifer's resistance to flow (i.e. it behaves like a confined aquifer with a low storage coefficient). This signal was smaller in amplitude than the Type 1 wave and it was seen to slow down and shift its energy to lower frequencies as it moved away from the source, the predominant frequency dropping from 10 Hz near the source to about 0.25 Hz at 6 m; the example in Figure 4, recorded at 1.7 m from the signal well, had a predominant frequency of 0.5 Hz.

The signals were found to be quite reproducible over time; measurements six months apart at Treasure Island gave essentially the same results, showing that the sand deposit was not affected by these hydraulic pulses. Practically, we consider that if a piezometer is capable of measuring the higher-frequency, easily detectable, Type 1 wave, it can certainly detect waves in the earthquake range. The drawback is that the recording speed needs to be 5000 Hz for good detection, while the lower-frequency Type 2 wave requires a recording speed of only 500 Hz, and should indicate satisfactory piezometer response.

Piezometer Tests

This signal-generation system was tried out at two different sites: Camp Hedding, New Hampshire and Treasure Island, California. Both are silty sand sites; Camp Hedding is a glacial outwash deposit and Treasure Island is a hydraulic fill, so more heterogeneous and containing random lenses of clay.

Camp Hedding was used as an initial 'test bed' for the system, and we quickly learned that, if the piezometers were installed by pushing into undisturbed native material, there was a high probability that the filters would become sufficiently clogged with silt that they would not respond correctly to dynamic water pressure signals. They would respond to the static groundwater pressure, but could not detect any of the dynamic signals, even at a distance of about 2 m from the source. Consequently, we abandoned this installation method and installed the piezometers by placing them in a pre-bored hole, surrounded by a conventional filter pack and surmounted by a bentonite seal (Figure 2).

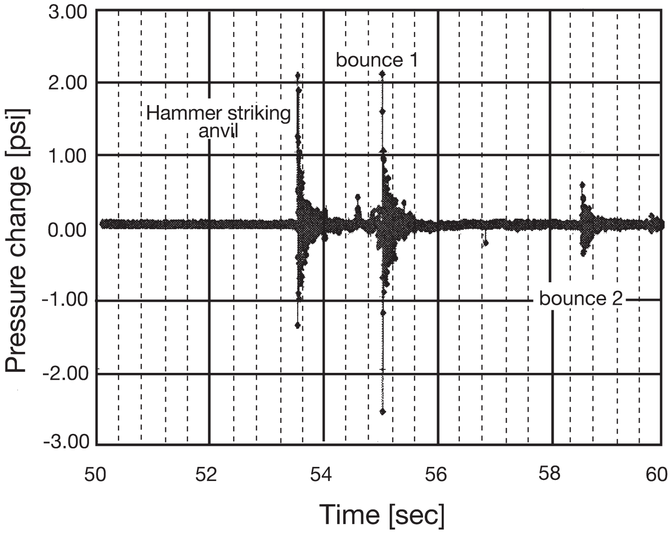

Figure 3. Type 1 compression wave recorded at 50 cm from the source. Predominant frequency: 900 Hz. One psi = 6.9 kPa.

The same behavior of pushed-in vs. filter-pack installation was seen at Treasure Island, where the pushed-in piezometers of the original 1996 installation could be compared with those placed in filter packs. As could be expected from the Camp Hedding experience, some of the original pushed-in piezometers could not detect dynamic signals, although they had been shown to respond correctly to the slow movement of the static groundwater level.

A second area of concern for the long-term measurement capability of the piezometers was the possibility that mineral deposits or biofouling would clog the filters, or that the filter pack itself would become clogged with fines. Consequently, the protective tip was fitted with a small-diameter flexible nylon access tube to the surface, connecting to the piezometer tip through a check valve, Figure 1. This allowed us to periodically check the slope of the transducer calibration curve and the hydraulic conductivity of the tip system.

Open observation wells had been drilled at both sites; an interesting and unexpected result found during the testing program was that a transducer lowered into one of these open water-filled casings could readily detect the Type 1 and Type 2 waves at distances to about 10 m from the source.

Recommended Layout for Future Installations

In order to check quickly if the piezometers are responding properly, they should be installed in a 3-m (approx.) circular array around a signal source well such as the one described above, with slotted sections provided at piezometer depths (although in our testing program we observed that piezometers 4 m below the slotted section of the signal well could still pick up satisfactory signals). A layout such as this will permit a quick and easy check of the whole installation. Further, the work of Mikkelsen and Green (2003) suggests that, in future installations, it would be sufficient to isolate the sand filters around the slotted sections (Figure 2) by surrounding the casing with cement/bentonite grout, thus eliminating the bentonite seals.

Every effort must be made to ensure that the piezometers are saturated; the tip assemblies should be left under vacuum in de-aired water for at least 24 hours before use, to saturate the filters. We produce de-aired water by atomizing tap water into a 2-m long column under 45 cm Hg vacuum, and curing it for 24 hr before use; a Nold DeAerator™ would certainly work as well. The saturated tips should be transported to the field in sealed water-filled containers, and assembled around the transducers under water. For installation, water-filled temporary casings should extend above the ground surface; these should be sufficiently large as to allow final assembly and insertion under water.

Survivability of the transducers remains a problem however; of the six piezometers installed at Treasure Island in 1996, possibly two are still responding properly; both transducers installed at Camp Hedding have died after four years. While in both cases transducers were factory-fitted with ‘integral’ cables molded into the transducer body, so preventing leaks at the connection, a weak point was found to be the factory-installed reference tube integrated with the transducer power cable to provide an atmospheric pressure reference; even when factory-sealed to produce an absolute pressure rather than gauge pressure transducer, we suspect that surface moisture eventually got past the seals and destroyed the electronics.

Replacement of transducers installed either in native soil or in a filter pack is a difficult and expensive operation; consequently, for future installations we recommend building on the fact that dynamic signals can be picked up in a standpipe, and installing the transducers in a slotted section at the bottom of a small-diameter water-filled PVC pipe. The slotted section of the pipe would be installed in a sand filter pack at the target depth, and the rest of the boring around the casing, above the filter, sealed off with a cement-bentonite grout The transducer would be positioned inside the casing, with its cable passing through a packer-type seal, which would allow the transducer to be easily retrieved for calibration or replacement. Some might object that the presence of the casings will affect the dynamic response of the groundwater; however, it is difficult to see how the presence of small-diameter flexible tubes would affect the global response of the stratum. It is worth noting that piezometers in flexible casings were recently installed at the Wildlife instrumented site in southern California (Youd et al. 2004), albeit without a signal-generating system to check response.

Either piezometer configuration (sealed in a borehole and provided with an access tube or, preferably, in a small-diameter casing) described in this article would have the additional important advantage of permitting the hydraulic conductivity of the filter pack to be checked, and redevelopment of the pack done as required by injection of water (and chemicals as required) , if the transducer is not seen to be responding properly to dynamic signals. We should re-emphasize that a piezometer which responds correctly to the slow fluctuations of the groundwater level will not necessarily pick up pressure pulses in the earthquake frequency range.

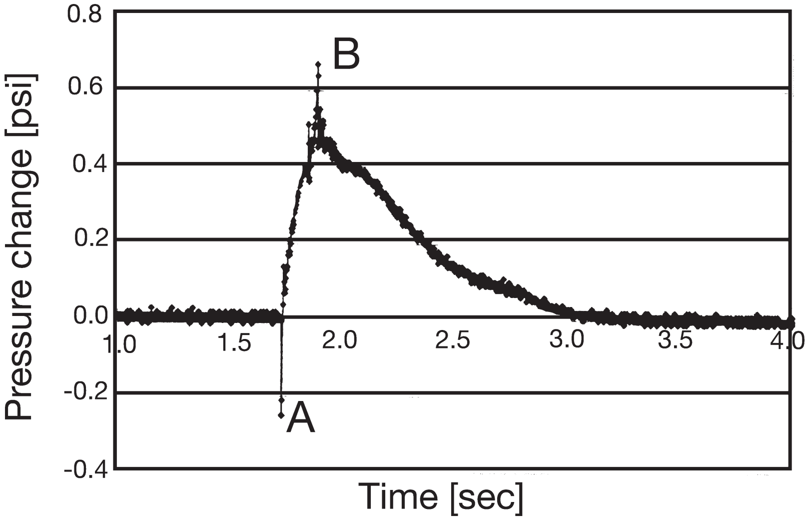

Figure 4. Type 2 wave recorded 1.7m from the source. Type 1 waves are seen as sharp peaks at points A and B. Predominant frequency: 0.5 Hz. One psi = 6.9 kPa.

Conclusions

The instrument layout proposed in the preceding section, with piezometers in small casings surrounding a signal-generation well, will get around many of the problems which were observed in the field; it provides a simple, non-destructive, way of checking the dynamic response of the piezometer installation, allows for correcting problems which may develop in the long term at the piezometer/soil interface, and eventually permits the easy replacement of the transducers themselves.

Acknowledgements

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Instrumentation Course Ad

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