Geotechnical Instrumentation News

Tenth Anniversary Episode

John Dunnicliff

Introduction

This is the fortieth episode of GIN. After ten years of writing these columns, please allow me a bit of a break from geotechnical instrumentation, and tolerate the telling of two recent experiences that I've found very satisfying – one about my favorite composer, and one about linguistics.

However, there **are** two articles about instrumentation, and a discussion.

More on Measuring Pore Water Suctions

There have been several articles in previous episodes of GIN on measurement of pore water suctions (negative pore water pressures):

- Penman, "*Measurement of Pore Water Pressures in Embankment Dams",* December 2002.
- Ridley, "*Recent Development in the Measurement of Pore Water Pressure and Suction",* March 2003.
- Thomann, Goldberg and Napolitano, *"Are those pore pressure readings correct?",* March 2003.
- Sellers, Dunnicliff, Mikkelsen, Beth, Penman, "*Discussions and Author's Reply. Measurement of Pore Water Pressures in Embankment Dams",* June 2003.

I said earlier that I'd solicited another case history on this subject – here it is – *"Some Experience in Measuring Pore Water Suction in Dublin Glacial Till"* by Michael Long, Chris Menkiti and Ben Follett.

I've written a discussion of this article, which immediately follows it. **Other discussions of this or any other article are welcome** – the deadline for the next episode of GIN is September 30, 2004.

A Brazilian Tale about Heavy Rain and Landslides

When I was I in Brazil a few years ago I was very impressed by a demonstration of an innovative landslide warning system. Most landslides in Rio de Janeiro are triggered by heavy rain, and conventional instruments for monitoring deformation and groundwater pressure are of limited use for landslide alarm purposes because they can't provide an early enough warning. Here's an article about the system, *"Rio-Watch: the Rio de Janeiro Landslide Alarm System"* by Beto Ortigao and Maria Justi.

While on this subject, why is 3D modeling of ground behavior not used in Madrid*? (Answer at the end of the 'column').*

Next Instrumentation Courses

Two are planned. I gave dates in the previous episode of GIN, but both have been changed. The first will be in Clearwater, Florida on March 13 thru 15, 2005 *(www.doce-conferences.ufl.edu/geotech/).*
Please see page 32 for some details. The second will be in Delft, The Netherlands on May 31 through June 2, 2005 *(www.geodelftacademy.nl/nl/page161.asp).*

Instrumentation and Resignation

I recently participated in a week-long "Johann Sebastian Bach Journey", a musical journey through the primary

places in Germany where Bach lived, composed and played. The program included nine concerts, performed in Bach's 'places' with period instruments. A truly memorable experience. I can't share the music with you, but I **can** share a letter that Bach wrote to his patron when resigning his post in Mühlhausen.

I recommend that you use this wording as a model when telling your boss that you no longer want to work for him/her!

> *"The manner in which Your Magnificence and my Most Respected Patrons most graciously engaged my humble self for the post of organist of the Church of St Blasius when it became vacant a year ago, and your graciousness in permitting me to enjoy a better living, I must ever acknowledge with obedient thanks.*

Even though I should always have liked to work toward the goal, namely, a well-regulated church music … yet it has not been possible to accomplish all this without hindrance, and there are, at present, hardly any signs that in the future a change may take place … to which I should humbly add that, however simple my manner of living, I can live but poorly, considering the house rent and other most necessary expenses.

Now God has brought it to pass that an unexpected change should offer itself to me, in which I see the possibility of a more adequate living and the achievement of my goal of a well-regulated church music without further vexation, since I have received the gracious admission of His Serene Highness of Saxe-Weimar into his Court Capelle and Chamber Music".

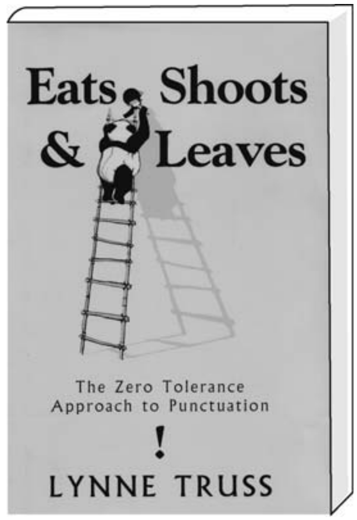
For information on this and other well-planned tours relating to art, music, architecture, archeology and history, visit *www.martinrandall.com.*

How are Your Punctuation Skills?

Can you imagine that a book about punctuation has become a best-seller in England? True! *"Eats, Shoots and Leaves – The Zero Tolerance Approach to Punctuation"* by Lynne Truss (ISBN 1-86197-612-7).

On the back cover is an explanation of the title:

A panda walks into a café. He orders a sandwich, eats it, then draws a gun and fires two shots in the air.



"Why?" asks the confused waiter, as the panda makes towards the exit. The panda produces a badly punctured wildlife manual and tosses it over his shoulder.

"I'm a panda," he says, at the door. "Look it up."

The waiter turns to the relevant entry and, sure enough, finds an explanation.

*"**Panda**. Large black-and-white bear-like animal, native to China. Eats, shoots and leaves."*

There are numerous anecdotes about the use of apostrophes, commas ("*the friendly little tadpoley number-nine dot-with-a-tail that today we know and love*" – oh, I've just remembered, readers from the Colonies call them pollywogs!), dashes and other "traffic signals of language".

Apparently punctuation marks didn't see major use until the 16th century. So who decided whether it should be:

"Verily, I say unto thee, this day thou shalt be with me in paradise."

or:

"Verily, I say unto thee this day, thou shalt be with me in paradise."?

Another:

"Comfort ye my people" (please go out and comfort my people)

or:

"Comfort ye, my people" (just cheer up, you lot; it might never happen)?

Enough! Lotsa fun! And very helpful for editors of GIN, and for those many of you 'out there' who are going to respond to my plea in the last episode of GIN for articles – **PLEASE!** As the author cries, "sticklers unite".

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.

Answer to the question about 3D modeling: *because the strain in Spain stays mainly in one plane.* Ouch! We should always acknowledge our sources, and check with them that it's okay to do so: Dave Druss of Parsons Brinckerhoff.

Bonne foi! (Haiti). Literally, in French, "Good faith". In Haiti's vernacular Creole, it's a sincere parting remark of friends or close working partners. Thanks to Marshall Metcalf for this.

RST AD pick up from page 27, June 2004

4 colour, full bleed

Some Experience in Measuring Pore Water Suction in Dublin Glacial Till

Michael Long, Chris Menkiti and Ben Follett

Several recent articles and discussions in GIN, by Penman (2002), Thomann et al. (2003), Ridley (2003) and Sellers et al. (2003) highlight the importance of pore water pressure and suctions and in particular the difficulties associated with measuring suction. This article outlines some recent experience in measuring suctions, which were developed in cut slopes in a very stiff glacial till during the Dublin Port Tunnel (DPT) project in Ireland. A particular feature of the project was the execution of a fully instrumented 12 m deep trial excavation (Menkiti et al., 2004).

Figure 1. Northern cut and cover section of Dublin Port Tunnel.

Initially some background to the project and to the problem will be given. Then some details of the specification, installation technique and some examples of the measurements obtained will be outlined. Finally some conclusions will be made on the lessons learned and recommendations will be made for future similar applications.

Dublin Port Tunnel – Northern Cut and Cover Section

Further details of this project can be found in the papers by Long et al. (2003) and Menkiti et al. (2004). This article focuses on the works within the 800 m long northern cut and cover section, where the following design constraints apply (Figure 1):

- Very tight limitations on land take exist.
- This section of tunnel runs along the footprint of the existing M1 Motorway, now diverted to run 2m from the slope crest. The diverted motorway (and adjacent properties and homes) must be protected throughout construction work.
- Tight costs and programme constraints also apply.

Tender stage site investigations suggested the general presence of competent Dublin Boulder Clay (DBC), which is a very stiff to hard, dark grey, slightly sandy clay, with some gravel and cobbles. Local experience (Long et al., 2003) confirmed that steep excavations, up to 8 m or so, could stand unsupported for periods of three to four months. Since temporary support is only required for a period of three to six months and the excavation depth is 12m or less, it was decided right from tender stage to construct the works within steep cuts supported by soil nails where appropriate. The basic design solution required nails installed over the full slope height. However an observational approach was developed whereby rows of nails are omitted unless required by adverse geology or unsatisfactory monitored performance. By partially utilizing the excavation induced soil suctions, the partly nailed slopes were specifically designed to have a limited "stand up" time of about 12 months in order to match construction requirements plus an adequate margin of safety.

The adopted solution is an application of the observational method originally codified by Ralph Peck in his Rankine lecture (Peck, 1969). He stated, "*Inherent in the use of instrumentation for construction purposes is*

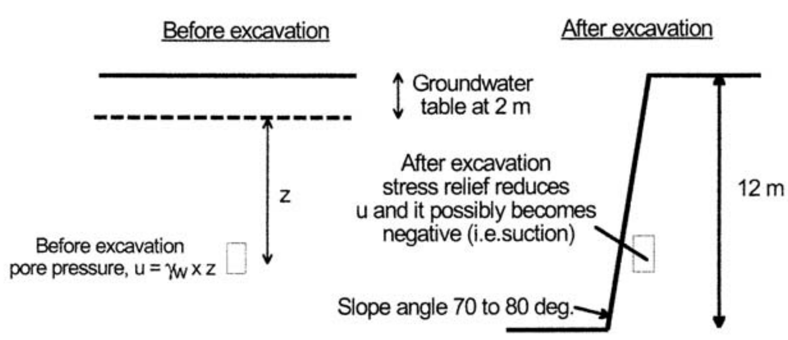


Figure 2. Pore water pressure reduction in cut slopes.

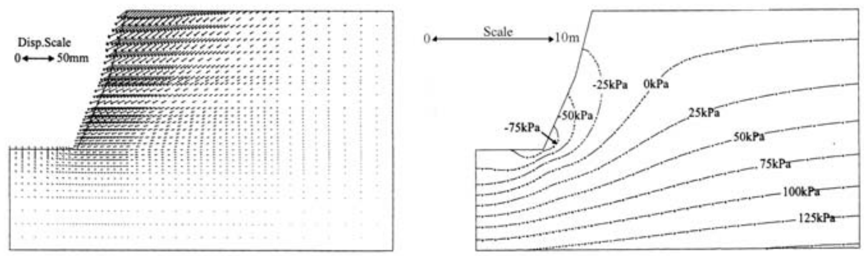


Figure 3. Finite element output for trial trench (assumes homogenous clay slope).

the absolute necessity for deciding, in advance, a positive means for solving any problems that may be disclosed by the results of the observations. If the observations should demonstrate that remedial action is needed, that action must be based on appropriate, previously anticipated plans". In our case history, as a key aspect of the design submission, a series of appropriate contingency measures were developed for each stage of the works, and time interval for their implemented on site justified. Further details of the design and construction of this case history can be obtained from (Milligan et al., 2004).

This observational approach relied on thorough logging of the excavated materials as well as a daily review of readings from instruments, which included inclinometers, piezometers with a suction measuring capability, precise leveling and conventional geodetic surveying.

Pore Water Pressure in Cut Slopes

The pore water pressure conditions in the slope before and after excavation are shown diagrammatically on Figure 2. Before excavation the pore water pressure (u) is simply given by the hydrostatic head below the groundwater table, which is at about 2 m depth, i.e.

$$u = \gamma_w z$$

The change in u caused by the excavation can be determined (approximately at least) from Skempton's (1954) classical equation for pore water pressure change:

$$\Delta u = B\left[\Delta\sigma_3 + A\left(\Delta\sigma_1 - \Delta\sigma_3\right)\right]$$

In this case both the all round pressure ($\Delta\sigma_3$) and the deviator stress ($\Delta\sigma_1$-$\Delta\sigma_3$) reduce due to the excavation-induced stress relief. This means that u reduces and, depending on its initial value, could become negative. If u reduces then the effective stress increases, thus improving, in the short term, the stability of the slope. The length of time over which this reduced pore water pressure can be sustained is a complex issue and depends on the soil type, its fabric, permeability, the sequence of construction, slope protection, weather, etc.

Calculation of Reduced Pore Water Pressures / Suctions

As can be seen from Skempton's formula above it is necessary to determine $\Delta\sigma_3$ and $\Delta\sigma_1$-$\Delta\sigma_3$ in order to calculate the pore water pressure after excavation. This is not a trivial matter. Some elastic based solutions exist. However in this project use was made of the finite element approach. Further details of these analyses can be found in Menkiti et al. (2004). This work was carried out by the Geotechnical Consulting Group (GCG), who made use of the Imperial College, London, geotechnical finite element code called ICFEP.

Initially, a full-scale monitored trial excavation was carried out to accurately calibrate the numerical model, and to develop procedures for safely implementing the observational method in the main excavation. No soil nails were used in the trial excavation. Then, various analyses were carried out with the calibrated model to investigate the influence of the excavation slope, slope protection measures, granular lenses in the till (which encourage recharge and suction dissipation), the presence of soil nails etc. (Menkiti et al, 2004). Some typical output for a homogenous clay till, without any permeable lenses or horizons, and with no soil nails (i.e. similar to the trial excavation) is shown on Figure 3.

A maximum horizontal movement of 15mm is predicted near the slope crest due to essentially undrained excavation. The induced stress changes depress the pore water pressures as discussed earlier to give high suctions of various intensities, up to -75kPa (-10.9 psi) at the slope toe. In the analyses, it is these suctions that maintain the stability of the slope.

Specification for Piezometers

In view of the above it was clear that the pore water pressure sensors to be used in the project had to have a suction measuring capability. The following parameters were included in the specification, which was sent to the tendering instrumentation contractors both for the trial trench and for the main works. Tendering was for a "supply and installation of instrumentation" to be carried out by a subcontractor to the general contractor. Separate tenders / contracts were used for the trial trench (which was part of the design development) and later for the main works.

- Direct measuring piezometers are required. Indirect measuring systems, such as thermal conductivity and electrical resistivity sensors, are not acceptable.
- The piezometer shall be calibrated and be able to operate in the range -85kPa to + 250kPa (-12.3psi to +36.3psi).
- They shall have an output resolution of 0.025% full scale (FS) and an accuracy of 0.1% FS. Resolution, meaning the smallest division on the readout scale, was specified to give the designers confidence that the accuracy can be achieved. If a resolution of 25% of the required accuracy cannot be achieved, then the system must very closely examined.
- Each piezometer shall be installed in a separate borehole and the measur-

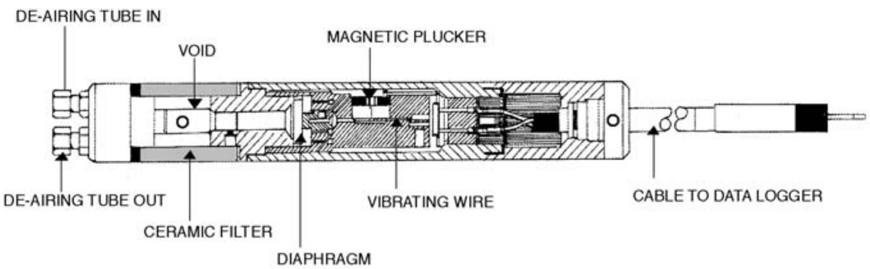


Figure 4. Section through de-airable, flushable, vibrating wire piezometer.

ing unit inserted, into a cleaned smaller diameter hole at the base of the main borehole, so as to fit as tightly as possible against the natural ground. (However, as a result of budgetary constraints during tender negotiations for the main works, this technical requirement was relaxed so that up to three piezometers could be installed in a single borehole. The relaxation was coupled with stringent requirements to prevent vertical hydraulic connectivity between instruments in the same borehole.)

- It is then sealed into the hole using plaster of Paris before the borehole is grouted up using a bentonite / cement mix.
- The piezometer should have the facility to be de-aired, prior to reading, e.g. by flushing with de-aired water.
- Output from the piezometers shall be logged at 15-minute intervals. Sufficient data logging capability should be provided to permit downloading weekly.

Why Use a Plaster of Paris Seal?

Installing piezometers in boreholes and completely surrounding them with grout (of permeability higher than that of the ground) is not a new idea. This technique was used for the instrumentation of embankment dams in the 1960s. Vaughan (1969) describes some experience at Balderhead Dam in the UK. He developed an approximate relationship between the error in the piezometer reading and the relative permeabilities of the ground and the grout. Vaughan also showed that the grout must have permeability considerably higher than the ground for the piezometer reading to have a significant error.

Subsequently experience in Europe had shown that plaster of Paris is a rigid but permeable material that can provide a good snug seal around the piezometer, without trapping air voids. Depending on the adopted mix, the permeability of the set plaster of Paris is similar to that of a fine sand / silt (i.e. of the order of 10^{-7} to 10^{-6} m/s). This is many orders of magnitude higher than the permeability of the cohesive glacial till (which has a permeability of the order of 10^{-9} to 10^{-10} m/s). In essence, the plaster of Paris performs the same function as filter sand commonly used in the response zones of standpipe piezometers, except that the plaster of Paris arrangement gives a system that is capable of rapidly transmitting the local ground water pressures to the instrument for measurement. Furthermore, the whole piezometer-plaster of Paris tip arrangement is easy to keep saturated.

The plaster of Paris is only used over a short length of borehole around the piezometer (typically 0.5m long). Above this, the borehole is filled with low-permeability cement-bentonite grout to avoid hydraulic connectivity vertically along the borehole.

Details of Piezometers Actually Used

The piezometers used in the works were supplied by ITM Ltd. and comprised the Soil Instruments, de-airable vibrating wire, 3 bar (43.5 psi), piezometer, which was fitted with flushing lines. A section through and a photograph of the instrument are shown on Figures 4 and 5 respectively.

Some special and particular features of the piezometer are as follows:

1. Unit is approximately 50mm diameter, 300mm long and with a 50mm long filter
2. The filter unit is constructed with 1 bar high air entry (i.e. high resistance to air entry) value porcelain, supplied by Fairey Industrial Ceramics Ltd. It has maximum pore size of 1 µm and an apparent porosity of 40% to 45%.

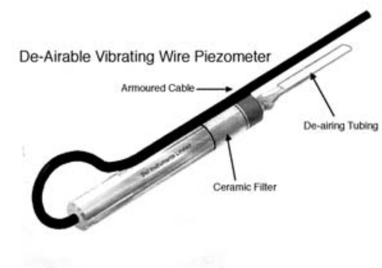


Figure 5. Photograph of piezometer.

3. The volume of water in the chamber between the filter unit and the pressure measuring diaphragm is approximately 12.5 cm^3.
4. The de-airing flushing lines consist of two 3.7mm internal diameter tubes (one marked in and one marked out).

Alternative Proposal

As the works are approximately 800 m long with monitoring being required at about 20 m intervals on both sides of the excavation, and with up to three pore water pressure instruments at each location, economic factors significantly influenced the choice of instrument used.

An alternative, but significantly more expensive, instrument was also suggested by one of the tendering contractors. This comprised low air entry filters with solenoid or hydraulic valves at the tip to be installed in a fully-grouted borehole. The chief advantage of this system is in the ease of installation, i.e. only one medium is needed for the installation. However there were concerns about some aspects of the system, which was still under development at the time. For example there was a much higher risk of vertical connectivity between the three instruments if all were installed in a single hole, particularly in the case of a perched water table within the surface made ground. These concerns, together with cost considerations, led to the selection of the chosen solution.

Installation of Instruments

Prior to installation, several small scale tests were conducted under laboratory conditions, in which trials were made of the powder / water ratios required for the grout and the plaster of Paris, setting times required and optimum sequence of installation. It was also found that, due to the low permeability of the till, in general the boreholes were dry. This allowed all three instruments to be installed in a single borehole in most cases (see "Specification for Piezometers" above). For these conditions, the liquid plaster of Paris mix could be tremied straight to the bottom of the dry hole. However if the hole is flooded, the liquid plaster of Paris tends to dissociate in the borehole water into a thin colloidal mix that coats the side of the borehole over the wetted perimeter. This tends to generate unacceptable hydraulic connectivity over the flooded section of borehole. The following procedure was therefore adopted, as shown on Figure 6.

1. Assemble piezometer and pre-saturated ceramic filter tip. Cut cables and tubes to required length.
2. Encase piezometer tip in plaster of Paris using a mould.
3. Once set, saturate the piezometer tip and keep under water until installation.
4. Drill a 146mm borehole using Geobore 'S' tools to a point 300 mm deeper than the installation depth of lowest instrument. Dip the hole to check that it is dry.
5. Tremie a pre-measured volume of thoroughly mixed plaster of Paris into the borehole.
6. Insert the piezometer into the plaster of Paris and leave for at least 10 minutes to set.
7. Carefully tremie well mixed cement / bentonite grout into the borehole to within 1 m of next installation tip and allow 10 minutes to settle down.
8. Thereafter, add the required amount to bentonite pellets to bring the level up to 0.3m below next installation. Bentonite pellets were used in combination with cement / bentonite grout for the following reasons: (i) it was found from lab trials that this combination gave the best seal around multiple cables and tubes; (ii) bentonite pellets also provided a stable platform for installation of the next piezometer, and (iii) the bentonite pellets prevent intermixing plaster of Paris with the cement / bentonite grout.
9. Tremie water onto the bentonite pellets until water level is level with top of pellets (using a dip meter). Allow 20 minutes for pellets to go off by expanding and absorbing all the free water.
10. Repeat steps 5 to 9 with remaining instruments.
11. Once last instrument is in place, and the plaster has set, bring the remaining level up to 0.4m below ground level with cement / bentonite grout.
12. Concrete headworks (plastic covers with caps) into the ground. Insulate de-airing tubes against frost.
13. Wire up to datalogger
14. After 24 hours, de-air instruments.

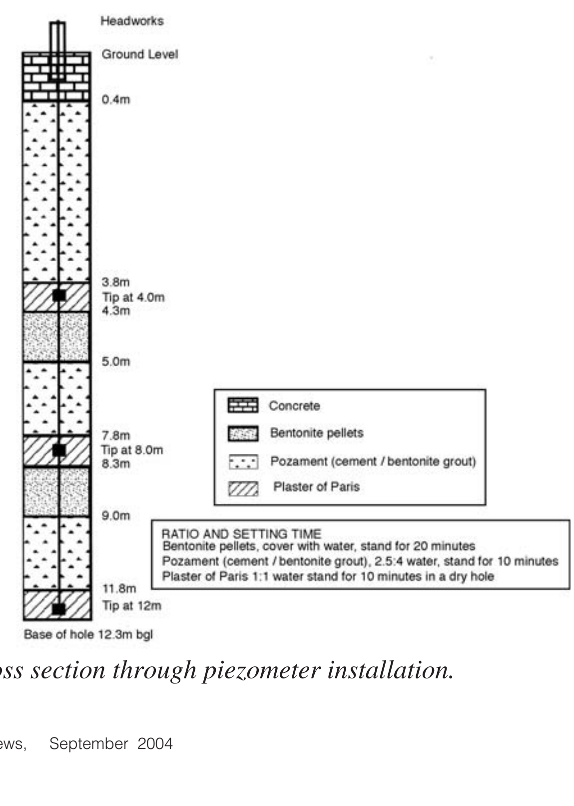


Figure 6. Cross section through piezometer installation.

Commissioning Procedure

The following procedure was adopted to de-air and commission the instruments and to check whether there was any connectivity between each separate installation.

1. Connect the de-airing equipment to the piezometer "in" valve. Keep the piezometer "out" valve closed. The de-airing equipment consists of a system of foot pump, pressure gauge and collection chambers. The system is used for driving de-aired water through the piezometer installation while measuring the volume of water circulated through the piezometer. A system by ITM was used for supplying de-aired water. This was produced by boiling water in a reinforced chamber with a one way outlet valve. Boiling was maintained for a minimum of 10 minutes, preferably much longer, to de-air the water and drive out any air in the chamber. Then, the valve was closed and the system allowed cool.
2. Set the data logger to log at the highest frequency.
3. Using the foot pump and pressure gauge pressurize the lowest piezometer first, taking care not to exceed the pressure limits for the instrument.

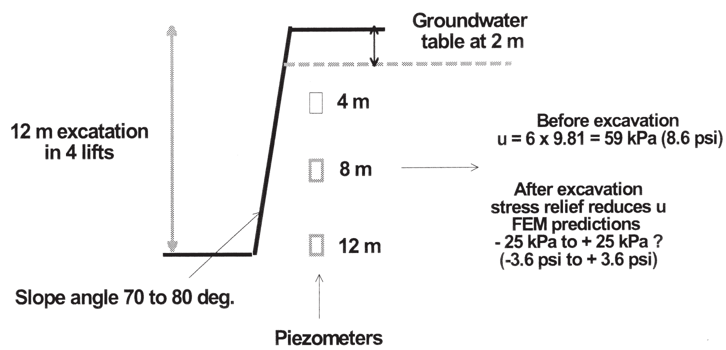


Figure 7. Typical cross section - Main works (Chainage 1320 W).

4. Once at a reasonable pressure (150 - 200 kPa) (22 - 29 psi) is attained, lock off and maintain that pressure for 30 minutes, periodically introducing more pressurised water as the pressure dissipates.
5. Gently release the pressure applied to the piezometer to complete the connectivity test. Then, de-air the instrument by circulating de-aired water through the piezometer to complete the commissioning process. The volume of de-aired water circulated through the piezometer should be several times the volume of the piezometer chamber and connecting tubes.
6. Repeat steps 1 to 5 for the other piezometers in the borehole, working upwards.
7. Download data logger and analyse results, pressure peaks should only occur at one instrument at a time.

Typical Measured Data – Main Works

A cross section at a typical location (Chainage 1320W) on the main works is shown on Figure 7. Piezometers were installed in relatively homogenous low permeability clayey till at 4 m, 8 m and 12 m and the ground water table was at about 2 m. Taking the 8 m piezometer, for example, initially the pore water pressure should respond to the ground water table 6 m above it (i.e. 58.9 kPa or 8.5 psi). Subsequently it was expected, from the finite element analyses, that the excavation induced stress relief would reduce the pore water pressure to a value in the range –25 kPa to +25 kPa (- 3.6 psi to + 3.6 psi), with a "best guess" being about – 10 kPa (–1.5 psi).

Recorded data for the three piezometers at Ch. 1320W is shown on Figure 8. As was expected the 8 m piezometer initially recorded a pressure of about +58 kPa (+8.4 psi). The effect of the four stages of the excavation can be clearly seen with the final stage having the most pronounced influence. The lowest value recorded in this piezometer was about +5 kPa (+0.7 psi), a value consistent with the finite element prediction.

The lowest values of pore water pressure were recorded by the 12 m piezometer, with a minimum value of about –8 kPa (-1.2 psi). This instrument was de-aired a few occasions and the effect of the de-airing process can be easily seen in the data. It can be seen that the readings recorded by the piezometer recovered rapidly following de-airing and thus the length of time during which the piezometer was out of commission was very small.

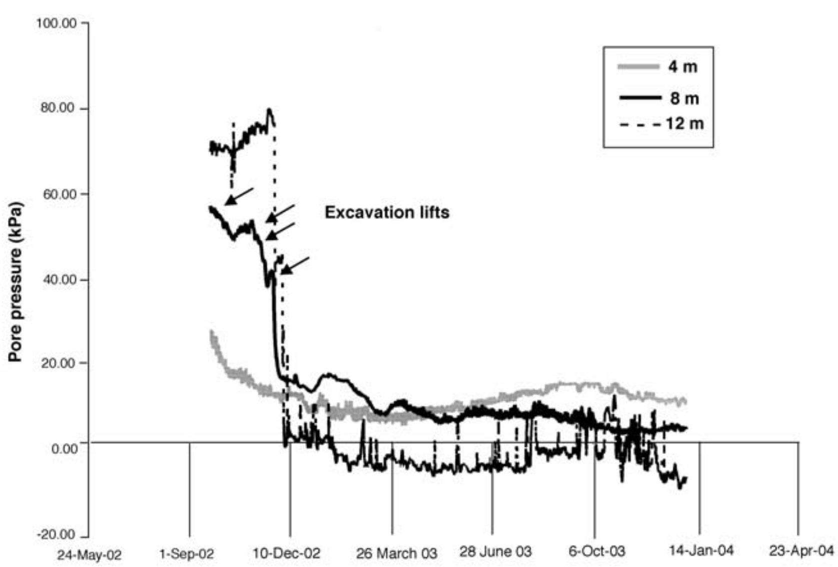


Figure 8. Pore water pressure data - Main works Ch. 1320 W (Note y-axis range of -20 kPa to +100 kPa = -2.9 psi to +14.5 psi).

Typical Measured Data – Trial Excavation

Output for all of the instruments, located within 0.5 m of the slope crest, in Zone 2 of the trial excavation is shown on Figure 9. At this location, the slope was protected by a geotextile. A local failure occurred about 35 days after excavation. The failure was attributed to persistent high rainfall which occurred for several days preceding the slip and the presence of a high permeability lens at about 5 m depth (Menkiti et al., 2004).

The finite element analyses predicted that suctions of about –20 kPa or –2.9 psi (2.5 m) and –10 kPa or –1.5 psi (5.5 m) would be induced by the excavation in the upper two piezometers and that the 7.5 m piezometer should indicate pore water pressures of about zero. In actual practice it can be seen that all the recorded values were more positive than the predictions. Only the 2.5 m deep instrument recorded negative values of about –10 kPa (-1.5 psi).

Subsequently it can be seen that this piezometer (P2A at 2.5m depth) responded to the persistent rainfall which eliminated all of the suction. As it was located on the failure surface, negative pore water pressures were induced due to dilation on shearing until cavitation occurred at about -15 kPa (-2.2 psi).

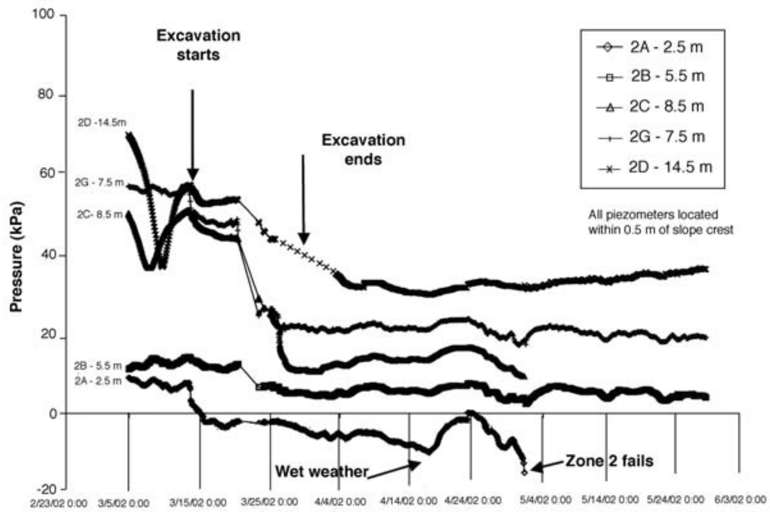


Figure 9. Pore water pressure data - trial excavation Zone 2 (Note y-axis range of -20 kPa to +100 kPa = -2.9 psi to +14.5 psi).

Conclusions and Discussion on Measured Values

Some conclusions on the measured piezometer data are as follows:

- The excavation-induced suctions were modest and the instruments generally successfully recorded these.
- These suction values were lower (i.e. closer to zero) than predicted by finite element analyses, probably due to local higher permeability zones in the microfabric, not accounted for in the analyses.
- The installation procedure adopted, including the use of plaster of Paris to encase the piezometer tips, was successful. However a high level of engineering supervision is essential.
- The piezometers responded very well and rapidly to routine de-airing.
- Some instances of cavitation were noted at suctions in the range –20 kPa to –30 kPa (-2.9 psi to –4.4 psi).
- Site experience suggests that although de-saturation of the filter tip and the relatively large body of water within the piezometer may have contributed to the instances of cavitation, these were not the major factor.
- It is likely that the most significant contributing factor to the instances of cavitation was the length of the de-airing lines. Occasionally when the valves at the top of the lines were opened for de-airing air bubbles emerged from the water body.

Lessons Learned / Proposal for Future Works

- Very significant cost and time savings were enjoyed in the case history described by applying the observational method with controlled use of induced soil suctions. This illustrates the potential benefits that could be accrued, for temporary works in particular, by taking induced soil suction into account in a quantitative manner. However, the design and implementation of these procedures requires careful thought.
- For this reason the trend is increasingly for the contribution of soil suction to be taken into account in design work. In parallel, it is likely that there will be increased demand for suction measurement instruments. Consequently more work is needed to develop reliable and cheaper instruments for suction measurement in the ground.
- The piezometers in the case study described were found to be suitable and cost effective for suctions up to about –20kPa (-2.9 psi).
- In cases where it is essential to measure higher suctions, other piezometers that contain a smaller volume of water would be more appropriate. However, these are generally more expensive.
- For similar work in Dublin Boulder Clay, sufficient experience has now been gained to warrant substantial reduction in instrumentation quantities to say half of those used for the initial application of the novel design. For application to different ground conditions instrument numbers should be selected based on careful consideration of: (i) sensitivity of the design to measured suctions; (ii) consequences of collapse; (iii) variability of the ground conditions, etc

Acknowledgements

The design and site supervision of the work described was carried out by Haswell Consulting Engineers, Geotechnical Consulting Group and University College Dublin. The Contractor is Nishimatsu-Mowlem-Irishenco Joint Venture. The DPT Project is funded by the NRA (National Roads Authority) Dublin City Council is the Employer. The authors would like to thank all these parties.

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Discussion of “Some Experience in Measuring Pore Water Suction in Dublin Glacial Till”

Michael Long, Chris Menkiti and Ben Follett

Geotechnical News, Vol. 22, No. 3, September 2004

John Dunnicliff

The article by Long et al. is a very valuable addition to the previous articles and discussions in GIN that *“highlight the importance of pore water pressure and suctions*”, and is a welcome, practical and detailed contribution The authors list those previous articles and discussions in the first paragraph of their article.

This discussion relates to the “*Alternative Proposal*”, because in my view this should be considered as one option by anyone who plans future similar measurements. Elaborating on the authors' section on the alternative proposal, its characteristics were:

- Vibrating wire piezometers with low air entry (coarse) filters. The authors used high air entry filters, which necessitate a special and rigorous procedure for saturation. In the alternative, the grout surrounding the filter acts as the equivalent of a high air entry filter.
- Solenoid valves in the flushing lines at the head of the piezometer. The purpose of these was to have them open only during de-airing. With them closed during normal operation there would be no column of water acting on the vibrating wire transducer, as is the case with the chosen option. The response time during normal operation would have been faster, as would have been the recovery time after de-airing.
- Installation by the fully-grouted method (Mikkelsen and Green, 2003). This would allow several piezometers to be installed in a single borehole, with the grout acting as the high air entry filter (Mikkelsen, 2003 and Penman, 2003).
- Installation in a borehole with a diameter significantly smaller than the 146 mm used for the chosen option.

Contrary to the view of the authors, I believe that “*the chief advantage of this* [alternative] *system”* in not only in the ease of installation, but is:

- Ease of installation.
- Ease of saturating the filters.

- Reduced need for such a *"high level of engineering supervision"* during installation.
- Reduced cost of borings, because of the smaller diameter. I understand that the authors opted for 146 mm diameter boreholes because of sampling needs, but future installations might not have those needs.
- Ability to install several piezometers in a single borehole by using the fully-grouted method (yes, I appreciate that this was eventually done at DPT, but it was not a consideration at the time when the option was selected).
- No use of those annoying bentonite pellets, which tend to bridge before they reach their intended destination. Use of 146 mm diameter boreholes is likely to have overcome that problem. However, it is very real in smaller diameter boreholes, therefore the concern would apply to future installations if the diameter was not dictated by sampling needs.
- Because of the solenoid valves, reduced response time under normal operation, and reduced recovery time after de-airing (yes, I appreciate that in the main works *"the readings recorded … recovered rapidly following de-airing"*, but was this known at the time when the option was selected?).

The authors were concerned about risk of vertical connectivity between instruments installed in a single hole, and also that the alternative *"was still under development at the time"*.

I believe that a careful reading of Mikkelsen and Green (2003), together with the references cited in that paper, and of Beth (2003), Mikkelsen (2003) and Penman (2003) leads to the view that the "alternative proposal" should be considered as one option by anyone who plans future similar measurements.

On the important issue of cost, the authors say, (1) *"An alternative, but significantly more expensive instrument ..."*, (2) *"These concerns, together with cost considerations, led to the selection of the chosen solution"*, (3) *"… more work is needed to develop … cheaper instruments"*. It should not be forgotten that when evaluating cost among various options, it is not the cost of the instrument itself that governs, but the total cost of buying the instruments, installing them, and performing all the tasks that follow.

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Rio-Watch: the Rio de Janeiro Landslide Alarm System

Beto Ortigao and Maria G Justi

Abstract

In 1996 the City of Rio de Janeiro, Brazil, installed the *Rio-Watch* system for warning of landslides triggered by severe rainfall. The system consisted of a raingauge network and one automatically instrumented slope. In 1999 the system was enhanced by a meteorological Doppler radar, operated by meteorologists. This is part of a 10-year long project conducted by *GeoRio*, the Rio de Janeiro Geotechnical Engineering Office. This article describes the Rio-Watch project, which is aimed at giving an early warning some two hours in advance of a risk of landslides.

Introduction

The City of Rio de Janeiro presents unique fascinating scenery due to the contrast of high steep slopes and beaches. Many of its six million inhabitants live on the lower slopes where they are exposed to a high risk of landslides and slope failures.

The catastrophes striking Rio in 1966, 1967 and 1988, and more recently in 1996, are vivid reminders of the seriousness of landslides triggered by severe rainfall. To keep landslide risk within an acceptable level the Government's policy has been to carry out a large number of slope stabilisation works and risk mapping (Ortigao and Sayao, 2004). The work described in this article started in 1991 with a pilot automatic instrumentation project, consisting of three instrumented slopes with piezometers and raingauges (Ortigao et al. 1994). The data were transmitted and analysed at GeoRio. The success of the pilot project led GeoRio to deploy the full raingauge network for the Rio-Watch alarm system (d'Orsi et al. 1997). The aim of this programme was an early warning system for heavy rains and its potential landslip consequences. The project included a fully automatic instrumented slope (Ortigao et al. 1997). In 1999, Rio-Watch was significantly enhanced by the addition of a meteorological Doppler radar with a team of meteorologists to analyse the data and issue warnings two hours before heavy rain. In 2003 numerical modelling of the atmosphere on a regional (small) scale has proved to be an accurate tool, being able to predict the weather conditions up to four days in advance. The radar, on the other hand, can be used to follow up the atmosphere during the event and compare with numerical predictions. Based on GeoRio's experience, guidelines for risk mapping, design of stabilisation works and slope instrumentation have been recently published in the form of a handbook of slope stabilisation (Ortigao & Sayao, 2004).

This article presents the development and implementation of the Rio-Watch system.

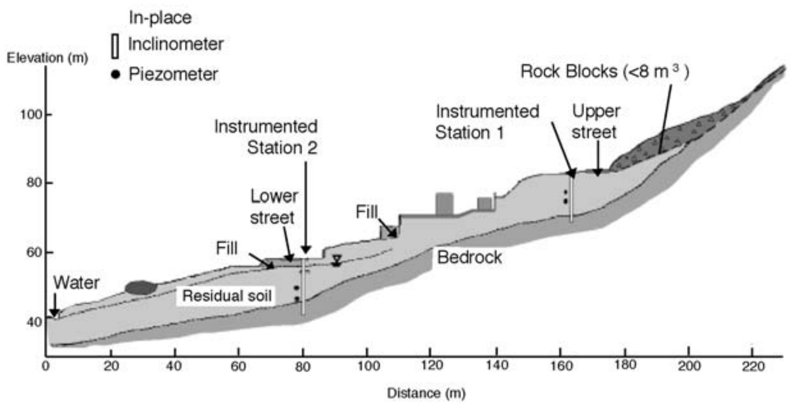

Figure 1. Instrumented slope at the Itanhanga Hill (Ortigao et al. 1997).

Alarm System Concepts

Landslip alarm systems based on slope instrumentation is an accepted concept in the geotechnical profession. This idea has been applied successfully on man-made slopes, such as dams or embankments. Geotechnical engineers are able to assess the margin of slope safety by analysing trends shown by the instrumentation. However, most natural slopes in residual and other tropical soils may not show any obvious signs of an incipient failure condition until the slope fails under a severe rainstorm. Therefore, the concept applied to the design of *Rio-Watch* was based on:

- A few specific instrumented slopes, for research and to gain insight into the phenomena.
- A raingauge network which, instead of measuring the *effect*, measures the main landslip *cause*.
- In 1999 this system was enhanced with a meteorological radar and meteorological analyses, to predict heavy rainfall a few hours in advance.

Figure 1 shows an example of a fully automated instrumented slope in Rio de Janeiro (Ortigao et al. 1997) with piezometers and in-place inclinometers. This slope was instrumented because soil movements occurred in the past and damaged several houses, and because it is very gentle, unlike many slopes in Rio.

Such automated slope instrumentation is aimed at understanding what is controlling slope stability. It cannot be regarded as a practical advance warning tool for a large area such as Rio. It would be too expensive to have a hundred instrumented slopes and the cost of data analysis and interpretation would be enormous. Therefore, the concept of measuring the cause of the landslip, *i.e.,* rainfall, and not the effect, came into play.

The Raingauge Network

The raingauge network in Rio de Janeiro consists of 30 automatic raingauges of the type shown in Figure 2. Figure 3 shows the locations of the raingauges. This network became operational in December 1996. The data are transmitted at 15 minutes intervals to a Central Station fitted with a microcomputer network to handle the data.

Critical Precipitation Levels

D'Orsi et al. (1997) presented a comprehensive study of the relationship between rainfall and landslips for Rio de Janeiro based on 65 landslips and precipitation data from five rain gauges. This preliminary study led to GeoRio's criteria for the landslip risk level. The criteria relate daily or hourly precipitation to 4-day antecedent rainfall. They disregard several important variables such as: accumulated antecedent rainfall in different time windows, slope and ground characteristics. Therefore, these empirical relationships are rather limited in scope, but they constitute a preliminary approach for Rio de Janeiro.

This work was reassessed in 2000 (Ortigao et al, 2001) using new landslip and rainfall data from the raingauge network and the results are given in Figure 4. The maximum daily precipitation level is about 180 mm/day, decaying as a function of the antecedent 4-day rainfall.

Weather Forecast

In 1999 GeoRio decided to enhance the Rio-Watch system by using a team of meteorologists and a digital Doppler radar to obtain early warnings of heavy precipitation.

Meteorological analyses consist of three phases: *regional scale*, preliminary analyses of data available at the Internet, *mesoscale* which is based on the radar imagery and finally a compari-

Figure 2. The automatic raingauge.

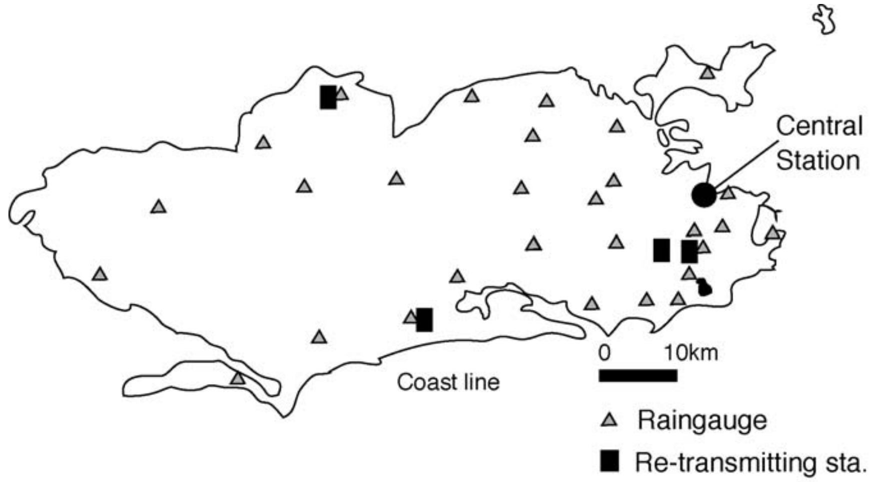

Figure 3. Location of raingauges, metropolitan area of Rio de Janeiro.

son between prediction and actual rainfall measurements through the raingauge network.

Regional Scale Analysis

Rio-Watch staff receives twice a day the results of numerical weather predictions of the CPTEC, the Brazilian Centre for Weather Forecasting and Climate Studies. Weather data on surface and upper-air measurements of temperature, pressure, moisture, winds and air density are gathered by many stations and fed into high speed computers running numerical models of the atmosphere. Regional scale numerical models became available in 2003 and run the atmospheric models on small or regional scale. As numerical predictions of weather conditions have proven to be reasonably accurate, this reduces the role intended for the rain gauge network.

Meteorological Doppler Radar

A digital Doppler radar is used to investigate mesoscale weather systems, within 300 km radius from the radar antenna. It gathers information about storms and precipitation in previously inaccessible regions. Meteorologists use weather radar to examine inside of a cloud much like physicians using X-rays to examine the inside of a human body. Certain kinds of weather storms, like squall lines, mesoscale convective systems and severe thunderstorms, are more easily studied and followed by means of radar.

The radar screen shows not only where the precipitation is occurring but also how intense it is. In recent years, the radar image has been displayed using various colours to denote the intensity of precipitation within the range of radar unit. Figure 5 shows a set of images obtained on 25 January 2000 at several times from 14:11*Z* to 22:11*Z*, where *Z* stands for GMT (Greenwich Mean Time).

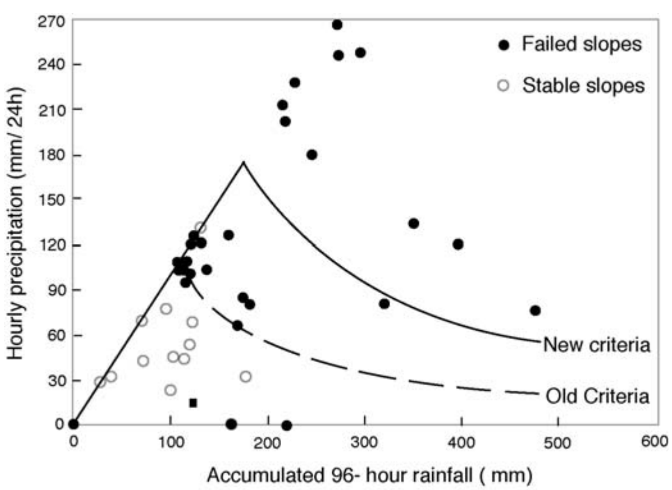

Figure 4. Landslip alarm level based on the daily rainfall rate against accumulated rainfall in 96 hours.

Alarm

The 25 January 2000 weather conditions led to an alarm issued by GeoRio. It is certainly not among the severe cases faced by Rio de Janeiro, but the radar image shows interesting features (Figure 5) like its development, path and duration. The storm originated in the NW and propagated towards SE. The image sequence shows all phases of the storm: formation, propagation and maturing.

Once the Rio-Watch meteorologists detect an alarm condition, GeoRio contacts the Civil Defence Division of the Rio Government in order to assess the situation before the final decision to issue an alarm. When a warning is issued, faxes are sent to the media informing about the high risk of landslips and the Government takes a series of preventive measures. These measures include: public warnings about the current situation, areas or roads that should avoided, notice to hospitals, fire, rescue brigades, etc.

The alarm on 25 January 2000 was issued by GeoRio at 17:30 *Z* time. Within four hours severe rainfall struck West Rio, as predicted.

No casualty or landslip was recorded on this night. The alarm was cancelled at 23:00 *Z* time.

Conclusions

Rio-Watch system has been an important tool in the risk management programme in Rio de Janeiro. It is based on data from the following sources:

- Large scale studies by other parties;
- Regional-scale numerical modelling;
- Doppler radar;
- Automatic raingauge network.
- The cost of Rio-Watch is small as compared to the benefits.

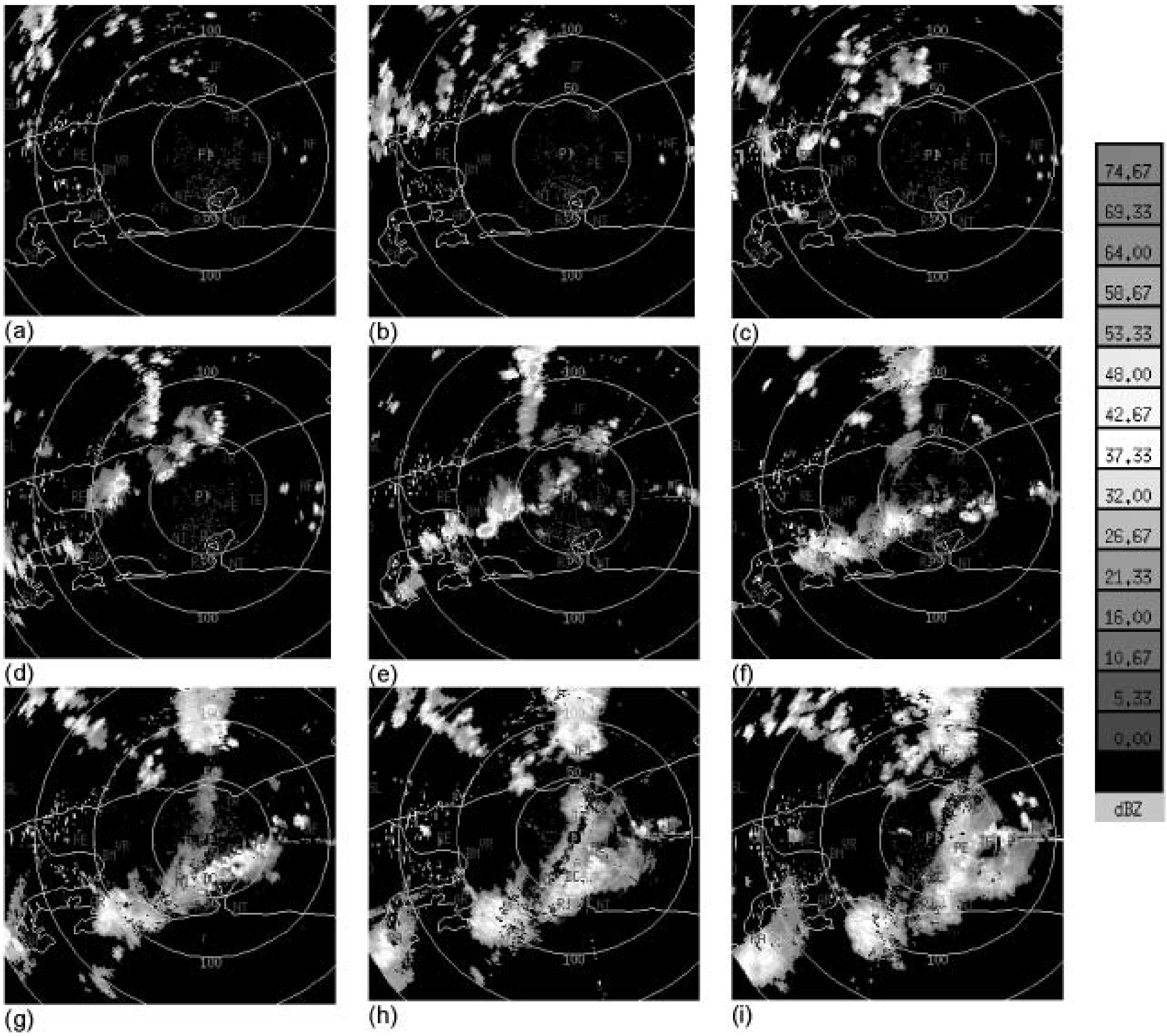

Figure 5. Radar imagery on 25 January 2000.

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