Executive Summary

The major obstacle to accurate modelling of travel times, inundation levels, and the physical impacts of lahars is the lack of knowledge of the internal properties. In particular, their typically high sediment concentration makes analogies with hydraulic governing equations difficult to justify.

To address this knowledge gap, we are developing and testing a range of instruments and geophysical monitoring techniques to measure the internal properties of moving lahars. In this EQC-funded program, geotechnical and hydrological pore-pressure and earth-pressure (load-cell) sensors are being customised in attempt to weight lahars to determine sediment concentrations in active flows. This effort is part of a wider approach within GNS Science and Massey University with support from FRST and the RSNZ Marsden fund.

Considerable challenges surround equipment suitability (and survivability) in high-energy mass-flows such as lahars. Although laboratory tests under controlled conditions have demonstrated that the concept works, field trials at Semeru volcano, Indonesia, and Ruapehu, New Zealand have met mixed success.

1. Sub-bed pore pressure transducers, both cabled and non-cabled have proved the most successful, as they suffer least from thermal disequilibrium.
2. Non-cabled load-cells are proving problematic due to leakage and loss of calibration as a result of the customisation process, and thermal disequilibrium due to temperature variations. Cabled load-cells should be immune to both issues due to factory-finish and calibration, and thermal stability as a result of deep burial. However, installation is more problematic.

However, a great deal has been learnt about the realities of measuring active lahars over the course of the program, and these data will make future quantitative studies of lahars more accurate.

2.0 Activities 2005-06

During the period 1 January to 1 June 2006, a Geokon earth pressure “load-cell” and a Druck pore-pressure transducer were purchased, assembled, and programmed. These were installed in March 2007 in a 0.4-0.5 m deep, hand-excavated trench in the
bouldery-sand bed of the Curah Lengkong river channel on the SW flank of Semeru
volcano, Indonesia. This site was selected to test tools before application to Ruapehu,
and as a back-up should there be no Ruapehu lahar within the time-frame of the
Marsden and EQC grants. Along with these instruments, acoustic flow monitors (AFMs)
and a broad-band seismograph were installed, video footage was shot and flow-dip
samples were collected. Three small rain-triggered lahars were sampled (two with the
earth-pressure and pore-pressure equipment), but the highly erosive flows scoured the
channel base, severing the cables linking the instruments to the data-logger. The sub-
bed pore pressure transducer captured the 1.2 m high rising limb of the lahar flow, but
mis-wiring of the earth-pressure cell by the supplier caused strong signal interference
and no useable data were collected.

3.0 Activities 2006-07

During the second project year, work focussed on preparation for the predicted Ruapehu
Crater Lake break-out. Due to increasing Crater Lake levels at Ruapehu, Manville
continued the process of equipment preparation for Ruapehu while Cronin led a second
visit to the Curah Lengkong, along with studies at Merapi volcano (Central Java,
Indonesia).

3.1 Non-cabled sensors

Because of the impossibility of installing cabled sensors in bedrock river channels, non-
cabled alternatives were developed. These comprised an adapted Geokon jack-out
earth-pressure cell connected to an all-in-one Hobo pressure logger (pressure sensor,
datalogger and power supply combined in a 15 cm long, 2.5 cm diameter stainless steel
assembly). The jack-out cell was modified to accept a Hobo pressure logger in place of
its normal cabled sensor. A second Hobo pressure logger was used in tandem with the
earth-pressure assembly. Tank-testing demonstrated that the concept was sound,
provided that adequate correction was made for atmospheric pressure variations and
thermal drift (Fig. 1).

![Tank load-cell tests](image1)

![Back-analysis](image2)

**Fig. 1:** Results of tank-cell tests involving progressive loading with water and/or granular
sediment. Panel to right shows correlation between measured sediment depth and that predicted
by analysis of instrumental measurements.
3.2 Curah Lengkong, Semeru

A comprehensive lahar monitoring suite of equipment was installed in a bedrock reach of the Curah Lengkong c. 100 m upstream of the site occupied during 2006 (Fig. 1), comprising:

- Two acoustic flow monitors
- A broadband seismometer
- An ultrasonic water level gauge (on a bamboo derrick over the stream centre)
- A cabled pore-pressure cell (as used in 2006)
- A jack-out earth-pressure cell assembly
- A Hobo pressure-logger
- Three Massey-designed capacitance impact/load sensors

Sockets for non-cabled sensors were cut with rock drills and masonry-cutting equipment. Although time-consuming, this approach was more robust than excavating trenches in the bouldery gravel of the river bed. Once installed, the equipment was manned for the following 10 days, during which period the rainy season in eastern Java refused to cooperate (despite a serious flood disaster in west Java at the same time). No rain-triggered lahars were recorded before the team left: a large lahar occurred 5 days later.

This installation process, however, proved an effective dummy-run for Ruapehu, making the later installation much easier. Issues identified during this exercise included:

- Broadband seismic data is the easiest to collect and proves an effective proxy for sediment concentration and perhaps also discharge.
- The earth-pressure assembly data is seriously affected by temperature changes, making calibration problematic.
- Communications with the (Hobo) pressure-logger attached to the earth-pressure assembly were unreliable.
- The non-looping memory of the Hobo pressure-loggers means that for long installations only low-frequency data can be collected (2 minutes for 1 month).

3.3 Ruapehu

A concession permit was secured from the Department of Conservation to install sensors in the hard-rock bed of the Whangaehu gorge inside the Tongariro National Park. An earth-pressure cell and pore-pressure sensor were installed in February 2007 using rock-cutting tools (Fig. 2).

The pore pressure sensor successfully captured the 18 March 2007 lahar (Fig. 3). Comparison of this data with the radar stage gauge mounted c. 80 m upstream will permit estimation of the effective density and hence sediment concentration of the lahar, once correction is made for possible hydraulic ponding effects near the former bridge crossing (currently being evaluated with differential GPS surveys of high-water marks). The pore pressure sensor proved better able to cope with the very rapid rising limb of the lahar (c. 8.2 m in < 4 minutes), which overwhelmed the response time of the radar stage gauge, and channel aggradation which raised the riverbed by 2.7 m below the radar gauge.
The load-cell assembly failed to collect any data from the flow due to communication difficulties during its pre-lahar servicing that prevented it executing a logging program, but the pore pressure transducer collected high quality data (Fig. 3).

**Fig. 2:** A) Cutting the sockets for the paired non-cabled jack-out load-cells and pore pressure transducers at the Round-the-mountain-track. B) Close up of jack-out load-cell and socket. C) Completed installation.

**Fig. 3:** Pore-pressure stage data from the 18 March 2007 Crater Lake break-out lahar.
Resource consents were lodged with Horizons Regional Council in February 2006 to permit trenching of the bed of the Whangaehu River with a heavy excavator to install conventional cabled load-cell and pore pressure sensors at the OnTrack gauge and the Tangiwai Rail bridge, 27.8 and 39.0 km from Crater Lake respectively. The consenting process proved to be very time consuming due to the need to secure the permission of the many affected parties at the two nominated sites. Resource consents were obtained in late January 2007, and four cabled Geokon load-cells plus four cabled Druck pore-pressure sensors were ordered. An earthmoving contractor with experience of working in the Whangaehu River bed was engaged to excavate the two required trenches, and a 20-tonne digger was on standby at Tangiwai.

Unfortunately, the lahar occurred before the sensors could be installed. However, they remain in storage while plans are developed for the GeoNet project to take over lahar monitoring on the Whangaehu River. Should this occur, they will be installed as originally intended. Information gathered from the 18 March event will provide invaluable information on the minimum depth of scour associated with a large lahar, and hence the depth of the trenches required. Deep burial in the riverbed should provide a thermally stable environment, solving many of the calibration issues encountered during laboratory testing and field deployment of the jack-out cells.

4.0 Activities 2007-2008

During the final project year, Massey University-led fieldwork at Semeru volcano, Indonesia, in February 2007 and 2008, continued experiments with load-cells. These used more advanced (Solinst™) integrated pressure transducers and dataloggers. However, studies were hampered by: (i) the driest rainy seasons in eastern Java in living memory, which reduced the number of observable rain-triggered lahar flows; (ii) leakage and pressure loss from some of the cells; and (iii) problems with thermal equilibration (Fig. 4). This last is probably the most serious problem with the sealed load-cells units as thermal expansion and contraction of the pressure vessels and their fluid filling is asynchronous and causes major variations in the pressure reading that exceed those produced by any flows.
Fig. 4: Data from rain-triggered lahar in Indonesia. Arrival of lahar cools sensor, resulting in thermal disequilibrium. Once the temperature of the sensor stabilises, more meaningful data is recorded showing multiple lahar pulses. Long wavelength trend is diurnal heating cycle.

Work on resolving the thermal disequilibrium effects are ongoing. The cabled sensors purchased for the Crater Lake break-out lahar remain in storage. It is hoped that a submission on lahar monitoring to the GeoNet Triennial review will make a successful case for combination of the EDS (Eruption Detection System) and ERLAWS (Eastern Ruapehu Lahar Warning System) and their integration into GeoNet, with the support of such stakeholders as the Department of Conservation, EQC, Genesis Energy, OnTrack, and Horizons Regional Council under the auspices of the Central Plateau Volcano Advisory Group (CPVAG). The equipment will then form part of a comprehensive deployment.

5.0 Future directions

A great deal of progress has been made in the development of instruments for monitoring lahars through this and related projects. Particularly through the Ruapehu event (and supported by the Indonesian records) our new data are changing our concepts of lahar flows and the ways in which they can be modelled.

It is clear that the pore-pressure record at Round the Mountain Track site is vital in interpreting the nature of the lahar wave at this point. Based on this example, Horizons Regional council is now considering operating pressure transducers in addition to conventional stage gauges at many of their hydrological monitoring sites.

Time-varying measurements of sediment concentration in lahars remain the ‘Holy Grail’ for lahar researchers. Work under this program has taken the first step in the challenge of weighing an active flow, and continued developments will address many of the issues that have arisen during prototyping. Continued work at GNS and Massey as part of Marsden and FRST-funded programmes is building on the lessons learnt at Ruapehu and Semeru. Meanwhile discussions are underway with GeoNet over the future of lahar monitoring on the Whangaehu River. It is hoped that the sites and equipment developed during the course of this study will play a role in monitoring the most common hazard at New Zealand’s most active onshore volcano in the future as well as other mass-flow phenomenon such as the Matata debris flows, and glacial lake outbursts and landslide-dammed lake failures in the South Island.
6.0 Budgeting and billing

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Total EQC grant06/518 = $30,000.00
Less invoiced for 2005-2006 year = ($9325.92)
To be invoiced for 2006-2007 year = $20,674.00
Total paid to data = $27,000

Balance of $3000 invoiced on completion of this report.