

Preliminary Report

**Earthquake and Tsunami Damage Assessment in Port Vila**

January 2002

Dr G. G. Shorten

**SOPAC**

**Background**

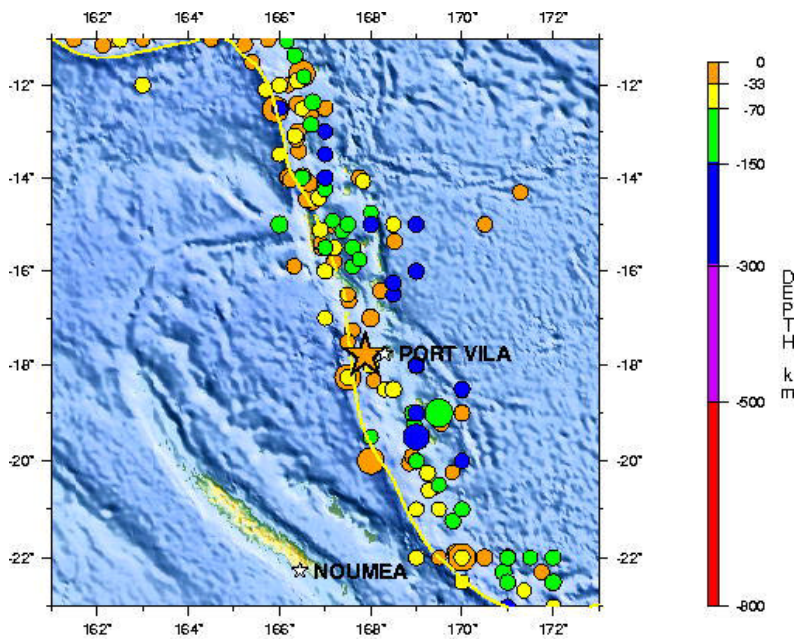
On Thursday 3<sup>rd</sup> January 2002, a magnitude Mw 7.1 earthquake, the largest recorded so far in the vicinity, struck Port Vila (Figure 1). Although a significant event, it was by no means the largest possible in this setting. Estimates of maximum possible seismicity sit around magnitude 7.8

The shock occurred at 04:22 am local time (UTC 2002/01/02 17:22:50), only 50 km to the west of Port Vila and at the shallow depth of 21 km below the sea floor. Fifteen minutes after the main shock, a tsunami (Figure 2) struck Port Vila Harbour. The event was followed that same night by another large aftershock of magnitude Mw 6.4 which also produced a tsunami, though much smaller.

The following day, the Director of SOPAC made a plea for international coordination of scientific and engineering assessments, and volunteered SOPAC as the reference point for information on the event. A SOPAC assessment team was readied and dispatched to Port Vila on Tuesday 8<sup>th</sup> January, and will remain there until 24<sup>th</sup> January, to obtain details of damage. The team has already consulted widely in Vanuatu: A list of persons and organisations with which meetings, discussions and inspections were held between 8<sup>th</sup>-13<sup>th</sup> of January is appended.

The UK Department For International Development (DFID) Suva responded rapidly and favourably to an approach and request from SOPAC, providing the much-needed funding for the assessment to take place.

**Figure 1: Historical seismicity of Vanuatu; mag. 7 and larger since 1900**

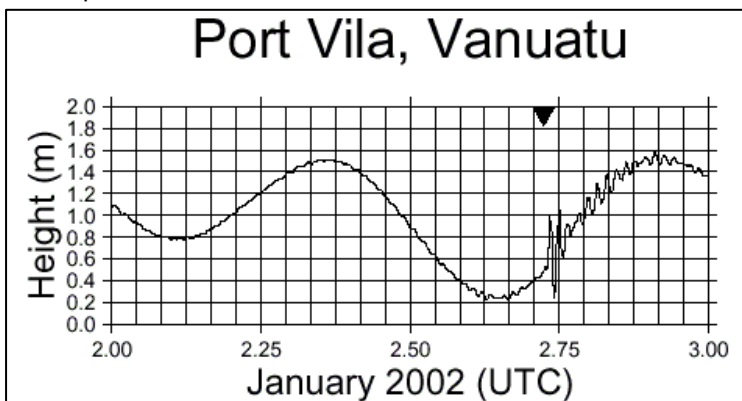


**VANUATU ISLANDS**

2002 01 02 17:22:49 UTC 17.76S 167.88E Depth: 33.0 km, Magnitude: 7.1

Earthquakes, Magnitude 7 and Greater, Since 1900

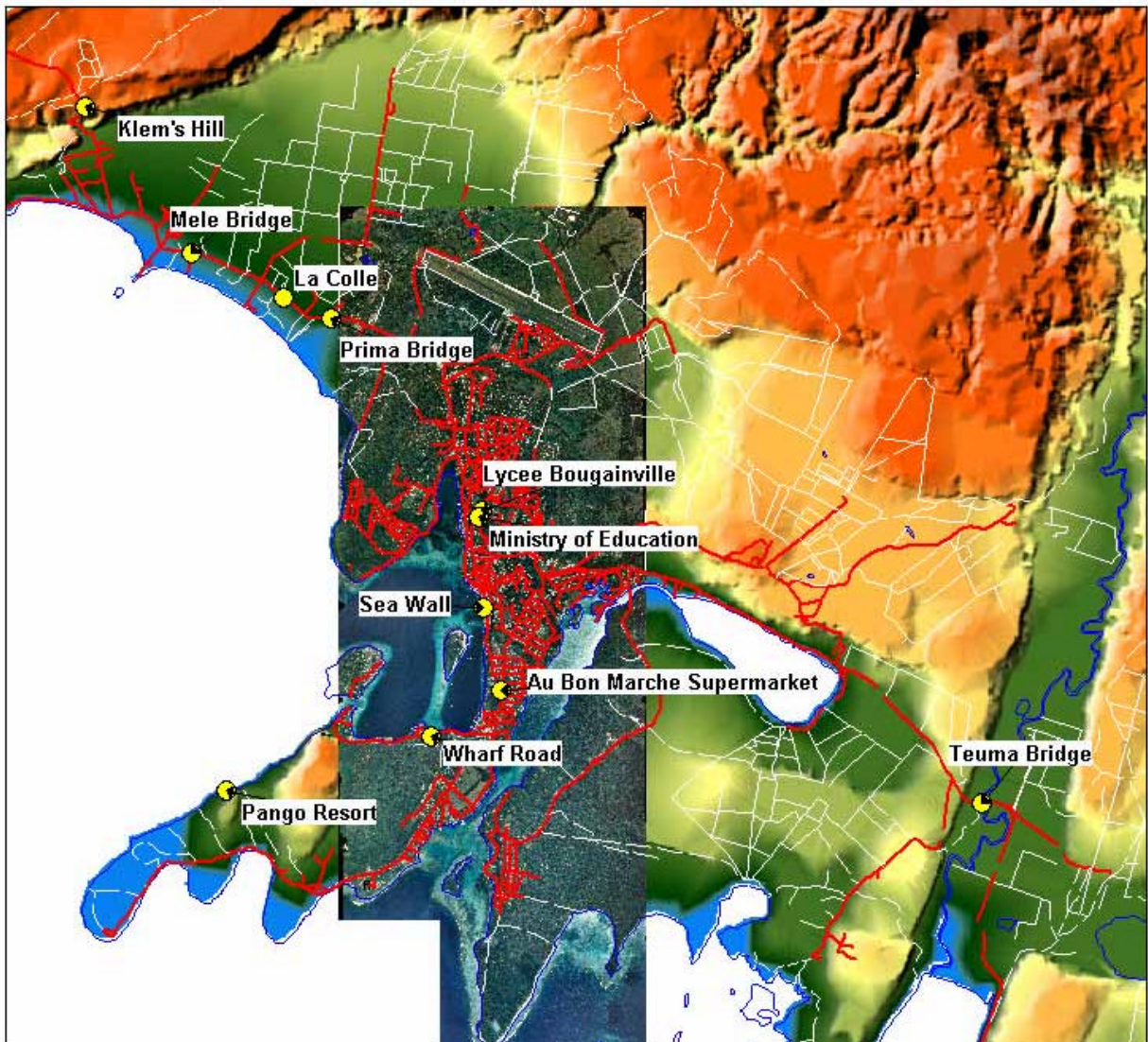
USGS National Earthquake Information Center 02/01/02 22:07:24 UTC



Damage to the city and to southeast Efate in general was surprisingly light, although several bridges were destroyed and much cracking in concrete structures and superficial damage was recorded (Figure 3). The tsunami that struck Port Vila Harbour some 15 minutes after the first shock, was fortunately small enough, given the low tide at the time, not to cause any significant flooding above Highest Astronomical Tide level.

**Figure 2: NTF tide gauge record of the tsunami in Port Vila Harbour**

Figure 3: Locality map of Port Vila area showing areas of major damage



The majority of buildings fared well in the earthquake, and the most of the damage appears to be the result of either ground failure or inadequate structural design. Although the full extent of damage is still being assessed, earthquake damage currently falls into several categories:

- Significant structural damage
- Superficial building damage
- Foundation failure
- Slope failure

### Significant Structural Damage

Significant structural damage occurred to the Lycee Bouganville where a 3-storey school classroom building was severely damaged, displaying short-column failure concentrated at the top of the infill walls throughout the entire ground floor level (Figure 4), an adjacent dormitory block suffered similar, significant structural damage, and a 2-storey classroom block reached the stage of incipient failure.



The school buildings are built on a cut and filled slope. Damage consistently increases from upper to lower floors. The pattern of failure suggests that the fixity of the ground-floor infill walls has concentrated stresses and promoted shear failure in the short, lower-floor columns. The design strength of the concrete has been exceeded, possibly due to poor concrete mix characteristics. A retrofitting program should be undertaken without delay for this particular design (where not already condemned) especially in the case where they are used as public school buildings.

**Figure 4: Short columns spalled and failed, ground floor, Lycee Bouganville**

Unreinforced concrete blocks set in a checkerboard pattern in the stairwell spaces of the Lycee buildings (Figure 5) have failed catastrophically, highlighting a dangerous and unnecessary construction practice. The blocks should be removed immediately and replaced by alternative materials.

The neighbouring 3-storey section of the Ministry of Education building was damaged in a very similar fashion to the 3-storey classroom block at the Lycee.



**Figure 5: Infill blockwork in stairwells sheared and collapsed**



**Figure 6: Damage around ground-floor columns at Au Bon Marche**

The 3-storey Au Bon Marche in No.2 district was badly damaged (Figure 6) through column failure, probably due to inadequate foundation floor beams.

The building housing the Australian and British High Commissions suffered thoroughgoing cracks in piers on the eastern side, as well as significant distress in internal infill walls. The degradation of concrete in the under surface of the lower floor due to the placement of reinforcing too close to that surface does not engender confidence in the construction practices used in that building. Eyewitnesses in this same building reported the toppling of shelves during some of the larger aftershocks; a feature not reported elsewhere.

## Superficial Building Damage

A large number of buildings suffered minor structural damage, including shearing of infill walls and window breakage. The full extent of damage is currently being compiled and will be published as a joint Department of Geology and Mines-SOPAC-IRD report, providing earthquake details, effects and damage, all geo-located on the SOPAC Pacific Cities Risk-GIS database.

## Foundation Failure



Figure 7: Fissuring in back-fill behind sea wall, north of Market

Movement of the sea wall during the main shock has led to some permanent deformation to seaward and subsidence of the foreshore in reclaimed areas around the Central Business District. The worst affected area runs for some 150 m from the open park area north of the main public Market (Figure 7), southward through the seaward end of the Market building and car park and then through the seaward end of the Sea View Restaurant/Bon Marche in a 25 m-wide zone adjacent to the sea wall.

This has led to the subsidence and tilting of the Sea View Restaurant, detaching it away and rotating it to seawards from the main Bon Marche building, and causing significant distress and cracking to structural columns and beams throughout the restaurant. Similarly, the toilet block on the seaward end of the Market (Figure 8) has detached 150 mm away from the main structure. It is likely that both structures are founded directly on fill in an inherently unstable area.



Figure 8: Detached Market toilet block

The ground distress also extends into the floor slab up to the first row of columns of the main market where the first (westernmost) slab construction joint has opened up. Between the public Market and the restaurant, the concrete slabs of the car park have also opened up some 50-100 mm on construction joints (Figure 9) due to the same cause.



Figure 9: Car park slabs opened south of Market

Subsidence and rotation of the sea wall has also occurred further south in the vicinity of the Waterfront Bar (Figure 10). Fissures that opened in filled ground behind the sea wall there reportedly issued water under high pressure.



Figure 10: Ground fissures and tilted sea wall near Waterfront Bar

A gap of around 20 mm is present between the concrete sea wall and backfill in much of the reclaimed area around the CBD (Figure 11).



Figure 11: Gap between sea wall and back-fill



The Teuma Bridge (Figure 12) to the southeast of the city has suffered significant structural damage as a result of the shearing of the eastern pier set/pile cap due to a rotational soil failure in the eastern abutment. The bridge superstructure has shifted eastward and tilted down to the east, causing some tilting of the western pier set as well. Soil failure due to liquefaction is also apparent in the western approach.



Figure 13: Embankment failure, Mele Bridge

The PWD has plans in hand to drive new piles, re-establish the level of the superstructure and repair the piers.

Figure 12: Damaged Teuma Bridge

Both the Mele (Figure 13) and Prima Bridges to the northwest of Port Vila have been affected by failure of their approach embankments and abutments due to liquefaction in the underlying alluvial soils (Figure 14), although the main bridge structure in both cases is considered by the PWD to be sound.

Figure 14: Slumping due to liquefaction, Prima Bridge



Fissures in the roadway and underlying embankment fill (Figure 15) opened up to 500 mm wide with depths in excess of a metre in places.



Figure 15: Embankment failure, Prima Bridge

### Slope Failure

A number of large landslides occurred on the access road to the main wharf at the southern end of



Port Vila Harbour (Figure 16). The geology of Port Vila is characterised by a thick series of weak volcanic tuffs capped by a cemented limestone some tens of metres thick. The slope failures in the wharf road were principally in the weaker tuffs although undercutting of the top of the cliff has brought down significant blocks of limestone as well (Figure 17). Failures in the tuff have been variously initiated on wide shear zones, areas where the layering dips out of the cliff face, and also within fossil gullies containing weak colluvial material.

Figure 16: Massive slope failure in tuff above Wharf access road

Whereas the interface between the tuff and overlying limestone lies high in the cliff face on the city side of the harbour, it dips towards the west so that it lies within several metres of sea level on the western margin of the peninsula. Accordingly, the slope failures have been concentrated in the tuff composing the cliff face above the southeastern part of the harbour with very few in the southwest where the cliff face is almost entirely composed of limestone.



**Figure 17: Toppled limestone boulder puncturing road surface**

The fill in the roadway to the wharf has fissured and failed in numerous places (Figure 18). The security of the wharf access road is a key issue requiring further geotechnical investigation and remedial work.



**Figure 18: Road embankment collapse, Wharf road**

Significantly, the one catastrophic slope failure that did occur in the west of the peninsula (Figure 19) was in the area between Pango and



**Figure 19: Toppling failure from the cliff face behind Pango Resort**

Watarua-Paradise Cove where prior erosion of the tuff had undercut the overlying limestone. Shortly after the major shock, a section of the cantilevered limestone, including one house-sized block of limestone of about  $75 \text{ m}^3$ , toppled from the 10 m high cliff line to partially demolish a modern concrete bungalow used as a reception area for the Pango Resort.

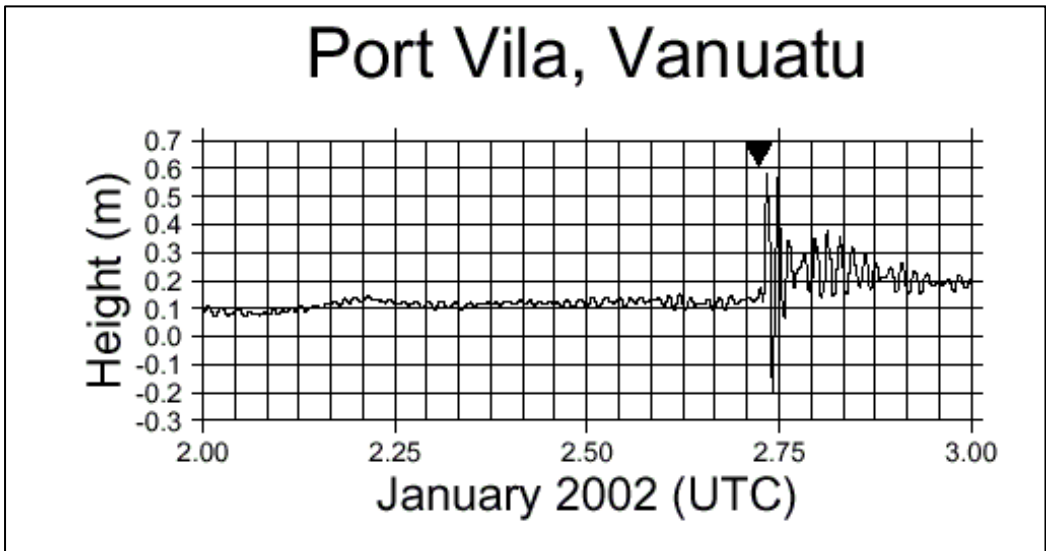


**Figure 20: Road embankment collapse, Klem's Hill**

## Tsunami

A tsunami generated with the earthquake struck Port Vila Harbour some 15 minutes later according to records of the National Tidal Facility supplied by Bill Mitchell through the Acting Director of the Vanuatu Meteorological Office.

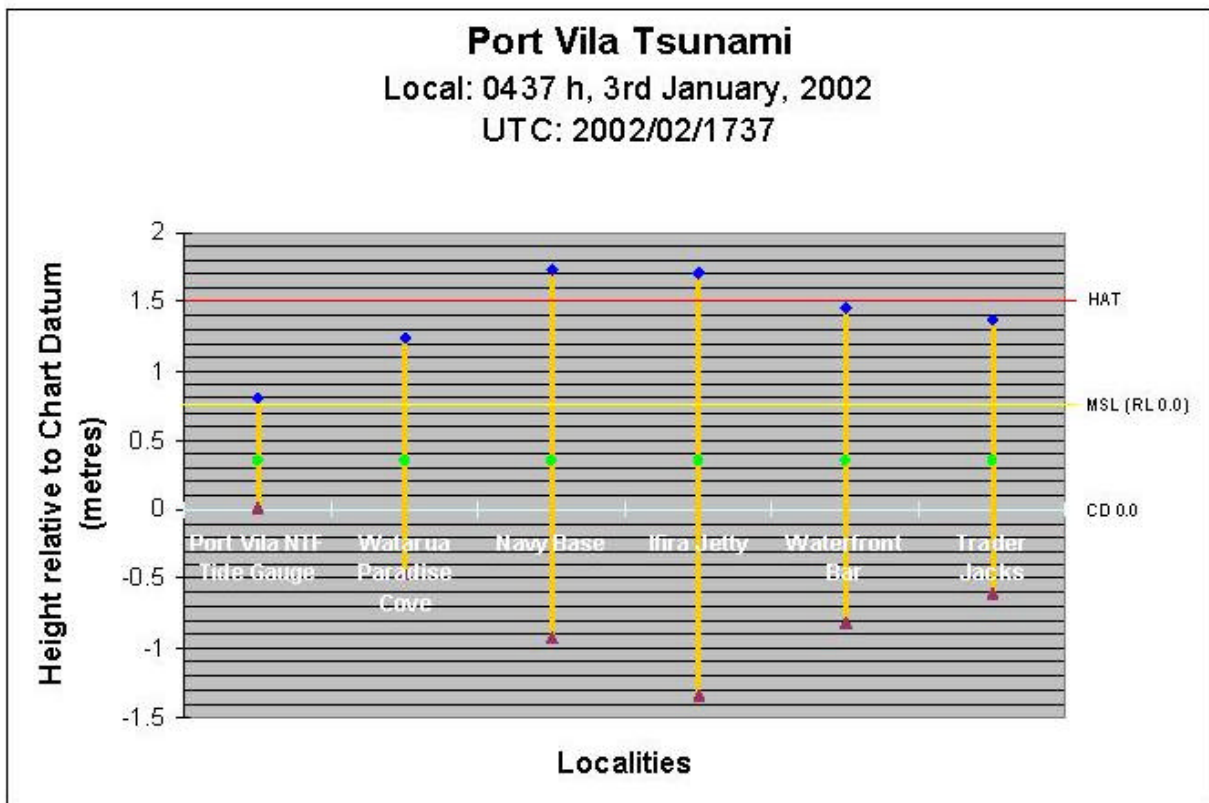
Figure 21: Tsunami record, Port Vila Wharf – differences between observed and predicted sea level



Although the tsunami only registered on the tide gauge as having a crest to trough amplitude of 0.8 m (Figure 21), eyewitness accounts in different parts of the harbour put the maximum effect at around 3.0 m (Figure 22), several times that of the recorded height, making it large

enough to cause significant damage.

Figure 22: Eyewitness account of the tsunami effects around Port Vila Harbour



Predictive tsunami modelling carried out by Vasily Titov and the Pacific Disaster Center, Hawaii as part of the Port Vila Pacific Cities project prior to the actual event, confirms that such amplifications are likely due to resonance and interference effects within the harbour (Figure 23). A video-animation of the simulated tsunami in Port Vila harbour, based on the scenario of a larger, M 8.2 earthquake occurring in a similar location, is available from SOPAC.

Fortunately the tsunami occurred at a time close to one of the very lowest tides of the year (predicted CD+0.15 m), when the tide was close to Chart Datum. If the earthquake had occurred four hours later

at high tide (CD+1.35 m), flooding would have reached up to 1 metre over the top of the sea wall in the CBD area. A much smaller tsunami occurred following the major aftershock that night, but passed unnoticed.

**Figure 23: Model of tsunami heights in Port Vila Harbour based on tide gauge record**



### Press Reports

One of the most disturbing features following the earthquake was the local Trading Post publication (albeit with strong reservations) of the views of a disturbed water-diviner cum prophet-of-doom who predicted a much larger earthquake later in January. Most residents of Port Vila quite emotionally shaken by the earthquake, and this so-called prediction fed that general sense of unease. Given that that expert advice was available, it was irresponsible for the Trading Post to even put those views into print at that time.

### Summary

Although of large magnitude, the earthquake that struck Port Vila on 3<sup>rd</sup> January, 2002, occurred far enough to the west of Efate so that attenuation of the effects through the intervening crust and sea floor was great enough to ensure that relatively little damage was caused in Port Vila and the surrounding area. The great majority of buildings escaped with little more than superficial damage. Buildings that were seriously damaged either had serious design or construction flaws or were founded on fill or reclaimed land that subsided due to liquefaction or other soil failure phenomena. The bridge

and approach embankments failures in the Port Vila area were mainly due to a combination of the high liquefaction potential of saturated, fine-grained alluvium, and the construction of embankments high enough to cope with flood conditions. Slope failure was almost entirely confined to volcanic tuff in high cliff faces, although the overlying limestone was involved in consequent landslides.

A tsunami of significant size was generated with the earthquake and, although it may have gone unnoticed by those not living by the harbour, had the potential to cause much flooding, damage and perhaps loss of life had it struck on a high, rather than an extremely low, tide as it did.

The potential for Port Vila to experience similar, or even significantly worse, earthquakes and tsunamis can be considered relatively high in the 50-100 year timeframe – this was not an isolated or unexpected event.



## Conclusions

SOPAC has been accumulating information on population demographics, infrastructure vulnerability and property values and the likely intensity of natural and human-induced hazards on the Port Vila area for the past five years in its Pacific Cities program. Currently, it is undertaking a pilot study on Port Vila to determine the most apt form of catastrophe insurance that might be applied in this developing-country situation, as well as community vulnerability assessments in the peri-urban area that involve the perceptions of local communities of their own vulnerability and resilience.

Pacific Cities aims to collate all data relevant to urban planning and risk assessment on a single GIS database, including hazard information, subsurface data, physical and survey information, building, infrastructure and life-line information, census data, insurance information, planning and development data and much more.

The immediate result of the work undertaken to date is that it is easier to identify and map building damage from the current event as every building in Port Vila is registered on the database

The information base enables modelling and prediction of the effects of tsunamis and storm surges knowing the bathymetry of harbour and the detailed heights of potential flood areas onshore, and the effects of cyclonic winds over the land areas. In this case, the effects of the current tsunami were able to be predicted with reasonable accuracy. Furthermore, the actual recorded effects of the tsunami will be incorporated back into the model to ensure better predictions of consequence and likelihood in future.

The earthquake microzoning undertaken earlier will be modified as a result of the lessons learned from this event, but significantly the predictions from that work that widespread foundation failure could be expected in the appropriately zoned areas, was borne out in practice.

The Pacific Cities project also seeks to gather together all geotechnical subsurface information and boreholes in Port Vila as it has done in other cities, which is a critical first step to assess the geotechnical performance of embankments on alluvium and reclaimed land.

The SOPAC Applied Community Vulnerability project funded through further UK DFID extends this work into peri-urban areas like Blacksands and, furthermore, takes into account the community's own assessment of their vulnerability in proposing concrete solutions.

The World Bank Catastrophe Insurance Project funded by AusAID is using the information gathered for Port Vila as a pilot project to form an economic model in order to assess how Vanuatu in particular, and the Pacific Islands in general, might fund recovery from such disasters.

All of this effort, together with a concerted program to build the capabilities of the National Disaster Managers Office has resulted in a significant increase in the awareness of the local scientific, disaster response and lay communities of the risk facing the conurbation of Port Vila.

## Recommendations

A program to identify and retrofit/modify suspect public buildings, especially schools, is considered critical. The performance of the sea wall structure and associated reclaimed area in the CBD, and buildings founded thereupon, should be assessed and improvements made. Slope hazard mapping is necessary for major and significant access roads (especially the Wharf road) to identify the risk to critical transport routes and lifelines, and to treat that risk with suitable options. A geotechnical investigation program is needed to improve performance of embankments over liquefiable soils, and road embankments and reclaimed areas on the margins of the harbour.

It is critical that support be given to the Pacific Cities concept both in terms of support for predictive modelling of earthquake, tsunami, storm surge and wind hazard, and in terms of wholehearted support for the program from Government Departments and private organisations through freely providing information for all aspects of urban planning to be incorporated on the Risk-GIS database.

### **Persons/Organisations - Meetings, Discussions and Inspections between 8<sup>th</sup>-13<sup>th</sup> of January**

SOPAC wishes to express its appreciation to the following people for agreeing at short notice to provide information and hold extensive discussions on the event:

Mr Chris Ioan, Director, Department of Geology, Mines and Water Resources

Mr Job Esau, Head, National Disaster Managers Office

Mr Michael Mangawai, Acting Director-General, Ministry of Lands Mines and Natural Resources

Dr Marc Regnier, Seismologist, IRD Noumea

Mr Goeff McConnell, First Secretary, Development Cooperation, AusAID, Port Vila

Ms Victoria Hillman, Senior Program Officer, AusAID, Port Vila

HE Mr Michael Hill, British High Commissioner, British High Commission Vila

Mr Nick Duggin, DFID, Port Vila

Mr Richie Nichols, Project Engineer, PWD Vanuatu

HE Mr Brian Smythe, New Zealand High Commissioner, Vanuatu

Ms Elizabeth Wilson, Deputy High Commissioner, New Zealand High Commission, Port Vila

Mr Sergei Terzaghi, Sinclair Knight Merz, Auckland

Mr Geoff Hales, Project Engineer, PWD Vanuatu

Mr Bae Williams, Forecaster, Department of Meteorology

Mr Kevin Lindsay, RISKMAN, Vanuatu

Mr Alastair Rodger, AON Risk Services, Port Vila

Mr Tony Kanas, Surveyor, Department of Lands & Survey

Members of Blacksands Community

Members of Blacksands and Ifira Communities

#### **Disclaimer**

SOPAC has attempted to ensure that the information in this report is as accurate as possible. However, it does not guarantee that this information is totally accurate and complete. Therefore you should not rely solely on this information when making commercial decisions.

#### **Acknowledgments**

The author wishes to acknowledge the permission of the Government of Vanuatu to publish this information, and specifically the assistance of the DG of Lands & Natural Resources and SOPAC National Representative Michael Mangawai, the staff of the Department of Geology, Mines & Water Resources including Director Chris Ioan, Morris Stephen and Eslin for their assistance, Tony Kanas of the Department of Lands & Survey, the Acting Director of the Vanuatu Meteorological Office Jotham Napat for permission to use information from the Port Vila tide gauge, the team performing damage surveys, and the cooperation of Job Esau, NDMO. The author also wishes to acknowledge the assistance of Marc Regnier and his team from IRD, Noumea in providing information on seismological aspects, and to SOPAC members Monika Swamy and Purnima Naidu for their part in the investigations, and the National Tidal Facility in Adelaide, Vasily Titov, and Stan Goosby, PDC Hawaii for tsunami information. Funding for the investigation, damage assessment and follow-up work was kindly supplied by UK DFID Suva