The magnitude 8.3 Arequipa, Peru earthquake & tsunami: closing a gap in our understanding of earthquake hazard

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ABSTRACT: We present a precis of our reconnaissance trip to the area of the Magnitude 8.3 June 23 2001 Arequipa, Peru earthquake and tsunami. It is the only earthquake to occur in nearly 40 years that is a realistic analogue for the maximum-size earthquake expected on our Hikurangi subduction zone. We found that the earthquake produced only "moderately strong" levels of earthquake shaking (e.g. peak ground accelerations of 0.3g on alluvium), relatively minor ground damage (liquefaction and landsliding), and a large and devastating tsunami. If we apply our observations to New Zealand they imply that a Hikurangi subduction zone earthquake may be less damaging to built-up areas (e.g. Wellington) than earthquakes on major active faults. However, the extent of the area of strongest shaking in a subduction earthquake (300km length for the Arequipa event) and the associated tsunami generation will make the earthquake very significant in the regional context.

1 INTRODUCTION

1.1 *General*

In this paper we give a precis of the observations made during a two week reconnaissance trip to the area of the M8.3 June 23 Arequipa, Peru earthquake and associated tsunami. The reconnaissance trip took place some five weeks after the earthquake and was funded by the Earthquake Commission Research Foundation (EQC) and the Institute of Geological and Nuclear Sciences (GNS). Unlike previous reconnaissance trips this trip was run by GNS rather than by the NZ Society of Earthquake Engineering's (NZSEE) "Understanding Earthquakes" programme. This is because the trip was exclusively for the purpose of understanding the physical features and natural hazards of the earthquake and the associated tsunami, rather than the more multidisciplinary scope of NZSEE trips.

This paper is a brief summary of our reconnaissance report to EQC (Stirling et al. *in preparation*), the report based on the public seminar "Tsunami" held at the Te Papa Museum of New Zealand in September 2001.

1.2 *The Earthquake*

On the June 23, 2001 a large area of southern Peru and northern Chile was shaken for over a minute by a strong earthquake. The earthquake was centred approximately 175km west of Arequipa (the second largest city in Peru) and was given a Moment Magnitude (M_w) of 8.3 by the US Geological Survey. The earthquake was produced by slip on the subduction interface between the Nazca and South American plates, in which the Nazca plate thrusts beneath the South American plate at a long-term rate of about 70 mm/yr. Great earthquakes such as these are typical events for so-called "Chilean-type" subduction zones (Uyeda, 1982), in which the subduction interface is strongly coupled (locked) due to the shallow angle and high friction between the two plates, and also because of the rapid convergence rate between the plates. The Arequipa earthquake produced damaging shaking, ground deformation, liquefaction and tsunami inundation in a 300km long zone in the Arequipa area.

At M_w 8.3, the Arequipa earthquake is the largest earthquake to occur in the world in the last 25 years. The maximum strength of shaking during the earthquake was Modified Mercalli Intensity 8 (L. Ocola pers comm.), which was a moderately strong level of shaking. The duration of shaking was over a minute and the strongest (damaging) shaking lasted about 30 seconds. The earthquake also produced a 12-15 m high tsunami at the coast in the Camana area of southern Peru about 15 minutes after the earthquake. The 130 fatalities from the event were mainly due to the tsunami. Another 21,000 people were displaced or otherwise effected significantly by the earthquake. Nearly 15,000 dwellings were destroyed and the Peruvian Government have allocated the equivalent of US $300M to earthquake-related relief.

1.3 *Motivation and Relevance to New Zealand*

The motivation of reconnaissance trips of this nature are to make first-hand observations of hazardous natural events that could happen in New Zealand. In this respect, we saw the great Arequipa earthquake as highly relevant to seismic and tsunami hazard assessment in New Zealand. It is the only earthquake to occur in the world since the Good Friday, Alaska earthquake of 1964 that is a realistic analogue for the maximum-size earthquake expected on our Hikurangi subduction zone. The Hikurangi subduction zone in contrast has not produced any such earthquakes in our 160 year historical record. The South American and Hikurangi subduction zones both appear to be strongly coupled (locked), and involve the rapid subduction of oceanic crust beneath continental crust. As such they are both of the "Chilean Type" of subduction zone (Uyeda, 1982). The occurrence of the great Arequipa earthquake and previous earthquakes in the long historical record of Peru (Robinson et al. 2001) shows that these subduction zones accommodate slip by the occurrence of large-to-great earthquakes. It therefore is the case that our 160 year historical record in New Zealand has been too short to capture any of these large-to-great earthquakes and associated tsunamis from the Hikurangi subduction zone. The Arequipa event therefore presented us with a rare opportunity to see the onland effects of the maximum-size event that we might expect on the Hikurangi subduction zone, where the Pacific Plate thrusts underneath the Australian Plate at a long-term rate of 40 to 50 mm/yr.

2 OBSERVATIONS

The areas visited along the 300km long earthquake area in chronological order were Arequipa (the second largest city in Peru), Camana, Chala, Ocona, Mollendo, Punta de Bombon, and Moquegua. Our reconnaissance observations were made according to the three categories of; (1) ground shaking and associated damage, (2) ground damage (i.e. landslides and liquefaction), and (3) tsunami effects.

2.1 *Brief Summary of Earthquake Shaking and Ground Damage Effects*

We only saw evidence of moderately strong levels of shaking along the entire length of the earthquake zone. The strongest shaking appears to have occurred in Moquegua, where the alluvial ground conditions almost certainly amplified the ground shaking to give the only measured peak ground acceleration (PGA) of 0.3g (again, a moderately strong level of shaking).

Cities located on hard rock sites within the earthquake zone (Mollendo) were virtually absent of damage. Only minor liquefaction and landsliding was observed within the earthquake zone, and significant damage from mass movement was observed along the Pan American highway and other major highways. In general, no shaking intensities stronger than about Modified Mercalli 8 were observed in the entire earthquake zone.

2.2 *Brief Summary of Coastal Effects*

The most significant coastal effects of the earthquake occurred in the Camana area, where a number of coastal resort towns are located. The effects were subsidence of the near coastal zone and damage and inundation by a 12 to 15 m high black (sand laden) tsunami wave that arrived about 15 minutes after the earthquake. The run-up was about 5-7 m above sea level. The tsunami wave was devastating and erosive, smashing nearly all buildings and structures as it advanced across the near coastal area. The tsunami was the cause of nearly all of the deaths in the earthquake Sheets of sand were deposited over thousands of hectares of crop land, and salt water was left standing among the destroyed buildings and devastated crops. Salination of the inundated farmlands will impact crop production for some time into the future, and the tsunami will have generally had a large impact on the economy of southern Peru. The death toll would have been considerably greater if the tsunami had impacted the area in summer, when the coastal resort towns are full of holidaymakers.

3 CONCLUSIONS AND IMPLICATIONS FOR NEW ZEALAND

The Arequipa earthquake has provided us with the first opportunity in nearly 40 years to see the effects of the type of earthquake that might occur on our Hikurangi subduction zone. The earthquake shaking was “moderately strong” in areas of “soft ground” (0.3g on alluvium in Moquegua) and considerably less in areas of hard rock (perhaps less than 0.1g in Mollendo). We consider it possible that shaking during a great Hikurangi subduction zone earthquake will be of similar levels, and the influence of site conditions significant in this earthquake. The most serious damage would occur in areas of “soft ground” (e.g. numerous low-lying parts of greater Wellington, Napier, Wairoa and Gisborne), whereas places underlain by basement rock would experience less damage. In Wellington, it is likely that the earthquake would not be as hazardous to the city as a Wellington Fault earthquake (M_w~7.5), which would rupture the ground surface instead of rupturing some 25km beneath the city as in the case of a great Hikurangi subduction zone earthquake. The shaking from the subduction zone earthquake would therefore be more attenuated at the ground surface than the shaking from the Wellington Fault earthquake. The Wellington Fault earthquake may also produce much stronger shaking at the short spectral periods most damaging to one to two-storey buildings than the subduction zone earthquake (i.e. a PGA of about 1g for the former versus the 0.3g measured in Moquegua). Great subduction zone earthquakes tend to be much richer in long period energy than short period energy, which could explain the relatively low levels of earthquake damage from the Arequipa event. Ground deformation (liquefaction and lateral spreading) would also perhaps not be as severe as in a Wellington Fault earthquake.

The Arequipa earthquake rupture zone was 300 km long, which in the eastern North Island would stretch from southern Wairarapa to southern Hawkes Bay. A great Hikurangi subduction earthquake would therefore affect all of the southern North Island (or more), so it is possible that the impact of this earthquake would be more significant in the regional context than a Wellington Fault earthquake.

We have drawn many parallels between the Hikurangi and Chile-Peru subduction earthquakes, and should express our caution in this regard. We therefore acknowledge the fact that the two subduction zones are not identical, in that the locked area of subduction zone is mostly beneath the seabed in southern Peru, whereas it is mostly under land in New Zealand. However, given that the two subduction zones are of similar depth beneath land we think it is plausible that the strength of shaking might be equivalent to the Arequipa earthquake in Wellington city during a great earthquake on the Hikurangi subduction zone.

The Arequipa earthquake produced a major tsunami in the central part of the earthquake zone. We expect a similar tsunami to accompany a great Hikurangi subduction zone earthquake, and thus consider tsunami hazards to be very serious for centres such as Gisborne, Napier, Wairoa and greater Wellington. Loss of life, near-total destruction of nearshore buildings, subsidence, salinisation and tainted water supplies will result from a tsunami when it impacts one or more of these areas.

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