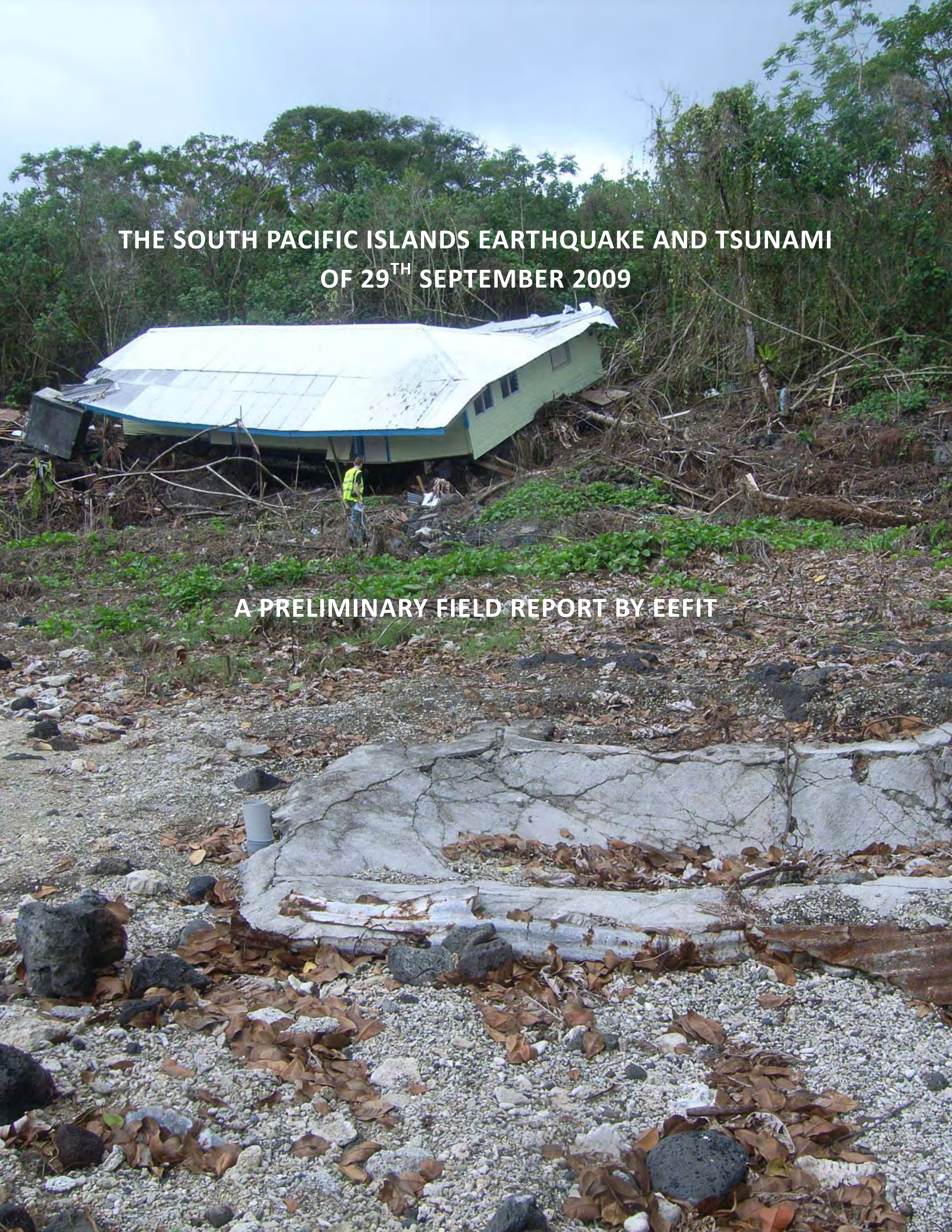

THE SOUTH PACIFIC ISLANDS EARTHQUAKE AND TSUNAMI OF 29TH SEPTEMBER 2009

A PRELIMINARY FIELD REPORT BY EEFIT

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The EEFIT Samoa Team

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INTRODUCTION

The magnitude 8.3Mw earthquake struck 175 kilometres south of the Samoan Islands on 29 September 2009 at 6:48am local time. A few minutes later, a series of earthquake triggered tsunami waves hit American Samoa, Western Samoa and the small northern island of Niuatoputapu in Tonga. The tsunami waves, some of which are said to have been as high as 6m, caused fatalities, casualties and devastated entire communities in the Pacific Island countries.

At least 143 people were killed in Samoa, 22 people in American Samoa and 7 people on Niuatoputapu, Tonga. The majority of the victims as reported by OCHA[1], were from the most vulnerable group - female, young and elderly. In Samoa, 310 people have been reported as injured, five are missing and about 3,200 people (640 families) have been left homeless in Samoa (OCHA). The hardest hit areas in Samoa were on the southeast coast of Upolu and the island of Manono. There was also minor damage reported in the northwest part of the main island and on the island of Savai'i.

Assessments by the Samoan Red Cross (SRC) indicated that 40 villages have been affected along the south-eastern coast, with 20 villages completely destroyed by tsunami waves. The Government of Samoa (GoS) estimated the cost of damage to infrastructure, public and private properties at around Samoan WS$ 380 million (over £ 90 million).

The UK Earthquake Engineering Field Investigation Team (EEFIT) decided to mount a reconnaissance mission to the Samoa Islands following this earthquake and resulting tsunami, in particular to assess the effects of the tsunami. This report presents some of the preliminary findings of the team; further images from the EEFIT Team field mission are available on the Virtual Disaster Viewer (www.virtualdisasterviewer.com). This viewer development is an ongoing project supported by EEFIT and other International earthquake reconnaissance teams. It allows the visualisation of the geo-referenced photos taken by the team, with pre- and post-earthquake satellite images for the affected areas as well as mapped faults.

This report represents the preliminary findings from the event and disseminates the factual findings from the mission, including photographs and other exhibits. Further research on the findings will be published in due course by EEFIT members in peer-reviewed journals which may also compare these findings with observations from the 2004 Boxing Day Tsunami.

[1] UN Office for the Coordination of Humanitarian Affairs

The EEFIT Mission

The mission is aimed at benefiting three separate groups:

On a local community level - advice and guidance in preparing for future events in other areas of the country and reconstruction planning can be obtained from the diverse group of experts.

On the UK engineering community - we can gain a better understanding of causes and types of damage for natural disasters. This type of work is also essential in training future leaders of the profession. Additionally, some of these findings may prove transferable to storm waves in the UK.

On the international community - this mission adds significantly to learning from earthquakes and tsunamis and enhances the UK's reputation for such field reconnaissance work.

Due to previous international tsunami surveys (UNESCO-IOC, 2009) covering the southeast coast of Upolu Island this mission concentrated on other parts of the south coast of Upolu that had not been documented, in addition to Manono Island and Savai'i Island. The EEFIT team aimed to gather key observations to enhance understanding of tsunami hazard and engineering performance. During the mission, the team concentrated on viewing the full disaster cycle, from preparedness to disaster impact assessment to the potential for long term recovery. The focus was to complement the more detailed mapping survey carried out by international colleagues and avoiding duplication of efforts.

The selected EEFIT team left for Samoa on the 3rd November 2009 and spent six days in the disaster zone. The composition of the EEFIT team was multidisciplinary, consisting of experts in earthquake and coastal engineering, tsunami risk modelling and human casualty modelling. This was therefore a well resourced team for providing a holistic insight into this earthquake and tsunami. The team members are presented in Table 1 and Figure 1.

In Samoa, the team was joined by members of the Ministry of Natural Resources & Environment, including Lagomauitumua Sunny Seuseu, Johnny Ah Kau, and Silia Faleao and Telea Kamu Kamu from the Ministry of Internal Affairs (MWCSD).

Table 1: The EEFIT Samoa Team

Name	Role	Institution	Expertise
Emily So	Team Leader, Researcher	University of Plymouth	Casualty modelling, earthquake engineering
Alison Hunt-Raby	Lecturer	University of Plymouth	Wave impacts and overtopping in the coastal zone
Tristan Robinson	Lecturer	University College London	Coastal and buoyancy driven phenomena
Stuart Fraser	Analyst	Aon Benfield	Numerical tsunami modelling, assessing mitigating impacts of mangrove vegetation
Tristan Lloyd	PhD Student	University College London	Vulnerability of coastal infrastructure to tsunami

Figure 1: The EEFIT Samoa Team (from left to right: Tristan Lloyd, Alison Hunt-Raby, Tristan Robinson, Emily So, Stuart Fraser)

Collaborations and Mission Objectives

This event brought together teams of international scientists and professionals from all around the globe. Some of these, like GNS and EERI are old alliances of EEFIT but many, including ITS and NOAA are newly formed contacts. These informal cooperation and exchange of ideas will hopefully be foundations to future international collaborations. Working with the likes of UNESCO[2], ITS, NOAA and EERI, amongst others, EEFIT had once again demonstrated its expertise in the area of earthquake reconnaissance.

Every effort was made by the mission leader to make contact with leaders of international teams deployed to Western Samoa since the 29 September earthquake. Meetings were set up on Skype with GNS to gather information and imagery prior to the mission. The draft UNESCO-IOC and ITS reports were attained and read before departure so that the team was fully aware of what areas both geographically and technically have been covered.

Whilst in Samoa, the team engaged staff and officers of relevant government ministries and worked with support from the Ministry of Natural Resources & Environment (MNRE) and UNESCO. It is the aim of the team to continue this dialogue in the post analyses phase of the field investigation. During the mission, the team focused on gathering first hand information from the survivors of the earthquake and tsunami. The help and support of locals was therefore key for this element of work.

The main objectives of EEFIT missions have usually been summarised as being:

1. To carry out a detailed technical evaluation of the performance of structures, foundations, civil engineering works and commercial units within the affected region.
2. To collect local geological and seismographic data, including strong motion records.
3. To assess the effectiveness of earthquake protection methods, including repair and retrofit, and to make comparisons of the actual performance of structures with the expectations of designers.
4. To study disaster management procedures and socio-economic effects of the earthquake, including human casualties.

[2] UNESCO- United Nations Educational, Scientific and Cultural Organization; ITS- International Tsunami Survey; NOAA- National Oceanic and Atmospheric Administration; EERI- Earthquake Engineering Research Institute; USGS- United States Geological Survey

In addition to the above, in the context of the South Pacific tsunami, the mission also had the following objectives:

1. To assess the extent of wave inundation and wave characteristics (size, type and direction), along with the influence of local topography and any coastal defence structures, using field data that has already been collected wherever possible.

2. To assess the effectiveness of the tsunami warning system and resulting human response.

3. To assess local methods of construction, including repairs and retrofits, and to make comparisons of the actual performance of structures with the expectations of building designers.

4. To assess lethality rates of different types of collapsed and damaged buildings and also the survivability in these structures.

5. Obtain an understanding of the emergency management in this earthquake and tsunami, and how this can be linked with earthquake protection especially making a comparison between Samoa and American Samoa islands.

6. To improve the "Virtual Disaster Viewer", adapt it to the Samoa earthquake and tsunami and provide a multi-source repository and dissemination system for spatially-based earthquake data.

7. To train less experienced members of EEFIT on post-earthquake survey techniques.

For the latter objective, four EEFIT members with little experience in post-earthquake surveys were included in the Team.

This report summarises the preliminary observations made in the field by the EEFIT Team and partially satisfies the objective of reporting the mission findings. This web report follows a presentation at the Institution of Structural Engineers in London on 24th November 2009. The virtual disaster viewer (www.virtualdisasterviewer.com) also contains images from the mission, satellite images from before and after the earthquake and tsunami.

BACKGROUND TO THE EVENT

The Samoan islands lie on the Pacific Plate and are situated within close proximity to the Australian Plate. This is the fastest moving convergent plate boundary in the world. The Pacific Plate is subducted under the Australian Plate at a rate of 247mm/year (Phillips, 2003) at the north end of the Tonga Trench, contributing to the high regional seismicity (see Figure 2). It was an earthquake associated with this plate boundary which led to the tsunami of 29 September 2009.

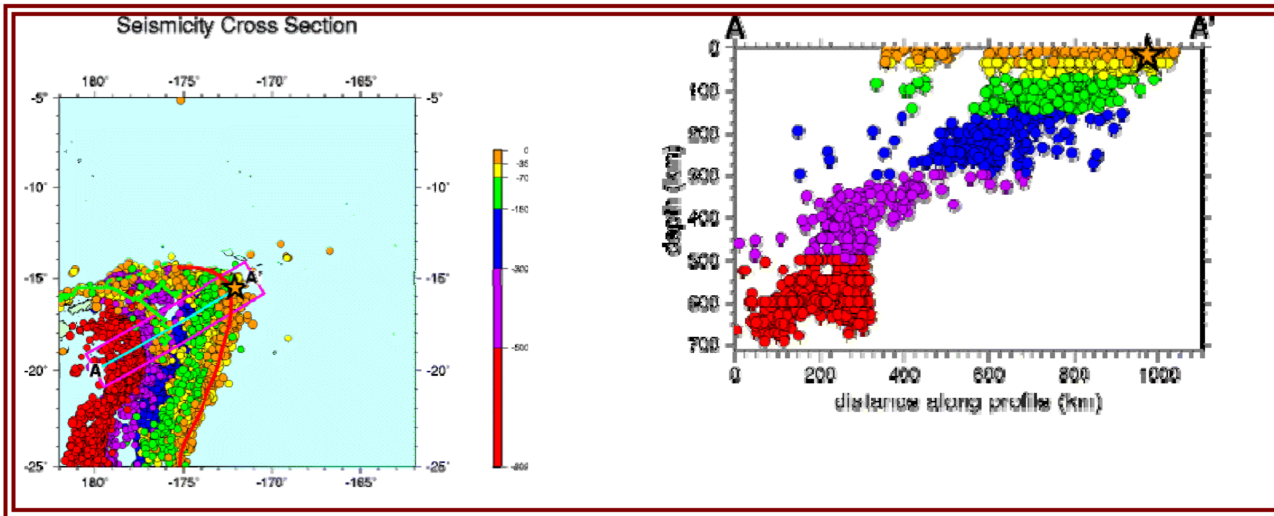

Figure 2: Regional seismicity of the Tonga Trench from USGS

United States Geological Survey (USGS) reported a submarine earthquake occurred on the 29 September 2009 at 06:48 Samoa standard time (17:48:10 UTC) close to the northern end of the Pacific-Australia plate boundary. USGS stated it was due to a normal fault rupture on or near the outer rise of the subducting Pacific plate, though data from tsunami detection DART buoys suggest the possibility of a reversed fault. The earthquake was shallow (18km) and was large, having a magnitude of Mw 8.3. The plate boundary in question stretches some 3000 km north north-east to approximately 15.6S 172W, where it curves towards the northwest and then west.

The epicentre of the earthquake was located some 175 km south of Samoa and was felt in Samoa, American Samoa, Northern Tonga and Wallis and Futuna Islands and Niuas.

Tsunamis are common in the region. Since 1837 there have been 48 separate events which caused recorded run-ups in Samoa, according to the National Geophysical Data Centre (NGDC) tsunami catalogue. These recorded run-up heights are often small because they are recorded by offshore tide gauges where the wave has not had opportunity to shoal in the near-shore region. However, it is likely that the last significant event was 1960 which is associated with the Mw 9.5 magnitude Chile earthquake. The last significant near source tsunami is likely to have been the 1917 event which was similar in characteristics to the recent 2009 tsunami.

The tsunami generated by the 29 September earthquake was regional, and impacted the islands of Upolu, Manono and Savai'i in Western Samoa; Tutuila, the main island of American Samoa; the Niuatoputapu, a northerly island of Tonga; Wallis and Futuna and numerous locations in the central south Pacific.

The Duty Standing Officer at the West Coast and Alaska Tsunami Warning Centre (WCATWC) in Alaska was alerted to a possible earthquake at 06:50 Samoa standard time (17:50 UTC) on 29 September 2009. At 06:52 he had an initial auto location of 15.3 S 171.6 W and DART buoy 51425 was auto triggered by the earthquake. At 06:58 he had an initial magnitude of Mw 7.9 when he sent an observatory message to the Pacific Tsunami Warning Centre (PTWC), NEIC, QDDS, and other NADIN and email subscribed users. He called PTWC at 07:00 according to procedure and issued a WEPA43 TIS Bulletin 1 at 07:02 for the WCATWC Pacific AOR. The PTWC issued a warning / watch for the Pacific islands at 07:04. The Samoan government received an official warning message from the PTWC and enacted its own protocols. A description of GoS protocols in the event of a local tsunami is provided in the section "LOCAL DISASTER MANAGEMENT PLANS",

The tsunami took less than 15 minutes to reach the south coast of Upolu after the earthquake. The arrival time from when the initial ground shaking was felt is on the whole fairly consistent with eye-witness accounts. These varied between less than 5 minutes and 20 minutes for the wave to arrive. Clearly this has implications for the early warning systems in place in the Pacific which are very effective for far source tsunami but require a certain period of time. The PTWC issued their first warning 16 minutes after the earthquake, which is just after or around the time the first wave reached Samoa.

LOCAL BUILDING INVENTORY AND CULTURAL INFLUENCES

In order to make a meaningful assessment of the impact of the earthquake and tsunami, it is essential to understand the local setting in which the affected houses and residents are situated, both in terms of climatic and cultural influences. Through close collaborations with the MNRE, the team was able to attain an insight to the Samoan way of living and building ethos.

Western Samoa, located about halfway between Hawaii and New Zealand in the Polynesian region of the South Pacific, consists of the two large islands of Upolu and Savai'i and seven small islets. The main island of Upolu is home to three-quarters of Samoa's 180,000 population (Census 2006) and its capital city of Apia. The two main Samoan islands of Upolu and Savai'i are volcanic in origin, mountainous, and covered in tropical forest, cultivated with taro, bananas, breadfruit, and other staples. Some of the smaller islands are coral atolls but not all of the islands are inhabited. Most of the villages in both of the main islands extend from the coast to plantations inland, situated uphill. The highest peak is Mout Silisili on the island of Savai'i which is one of the highest peaks in Polynesia at 1858 m. Coastal roads, built by European and American settlers in the 1940s changed the layout of Samoan villages as families moved from the hills to settle by these coastal roads.

Samoans are very traditional, and their culture is steeped in a complex set of social hierarchies, courtesies and customs that regulate their social, religious and political life. The culture is based on fa'amatai, a system of government that has a chief, or matai, governing an entire aiga or extended family. Wealth and food are distributed on a needs basis and honour and social standing is shared or shouldered equally by all members of the aiga. The matai represents the family on the village council, metes out justice, and makes sure that all customs are properly observed.

Traditionally houses are open sided wooden structures raised off the floor with just one large open room and a thatched roof. These *faleo'o*s, as they are called in Samoan, are ideal for the tropical heat, and these would be accompanied by a smaller *tunoa* (cookhouse) next to the main faleo'o.

As new building materials such as reinforced concrete are introduced to Samoa, the way traditional Samoans build have changed. *Fale apa*, which refers to houses with concrete floors and corrugated iron roofs are now commonly seen in Samoa. Samoa, like all tropical climatic countries has a rainy season and is also subjected to seasonal cyclones during the summer months. Hence, a desire for durable and cost efficient roofing makes corrugated iron very popular. *Fale palagi*, which are closed houses with concrete masonry walls and rooms are also increasingly found. Typically, each family home would comprise of a combination of these structures as shown in Figure 3. The traditional cookhouse, now known as *umkuka,* are built with a few timber posts with a corrugated iron roof, often also accompanied by a toilet block and shower.

Figure 3: A typical household with 3 different types of fales. The closed masonry fale palagi to the left, the main fale apa in the centre and a traditional faleo'o to the right.

The foundations to these houses are often elevated and substantial in comparison to the actual housing structure. In Samoa, there is a belief that a strong foundation is what constitutes a better house. These were often found during the mission to be the only structure left post tsunami. These foundations typically comprise a wall of volcanic boulders or concrete blocks enclosing rubble or sand, and blinded with inch-thick concrete.

The open style living is typical of Samoan social structure. Samoans share everything they have, from food to wages, with their extended families and the church. By far the most important agents of change in Samoa were the western missionaries arriving in the islands in the late 1700s, converting the people from belief in Gods for the sun, earth, heavens and sea to the one God. The church is the focal point of village life and the larger the church, the more esteem the village has over its neighbouring villages. This is the reason why there are so many elaborate churches around the island. Very few churches were structurally damaged by the tsunami as these were evidently better built.

In addition, the Samoan culture also influenced the relief operations and the recovery from this event. There were no mass tented villages evident as seen in many other disasters as the affected population would move to reside with relatives or move to another area of their village further inland. Some were still by the coast and had set up shelter on the old remaining foundations to look after the family grounds (i.e. sought after rocks and other foundation materials). The reasons for remaining by the coast are often influenced by culture as well as economic reasons. Some of the interviewed survivors were quoted to saying that they needed to stay with their ancestors who are buried in front of their dwellings.

The rate of recovery from this event and how the villagers rebuild will very much depend on the collaboration and consultation between the ministry and the village councils. For the recovery from this event, the influence of the traditional hierarchy of Samoan village communities on reconstruction and relocation cannot be underestimated.

LOCAL DISASTER MANAGEMENT PLANS

The government of Samoa has had a national disaster framework in place since 2006, which includes the Disaster and Emergency Planning Act 2007, outlining disaster management structure and planning, response agency and community planning.

The GoS submitted the following national tsunami response plans to UNESCO-IOC:

Local Tsunami:

The threshold for declaring a potential threat of local tsunami is an earthquake of Mw>=6.5 located in the Tongan/Samoan regions or Fiji Islands. The event is identified by the Meteorology Division of the MNRE based upon the single GSN station located in Samoa.

Pacific Tsunami Warning Center (PTWC) bulletins are received by SMS and fax, and unverified data is available to the Meteorology Division within seconds of the event through the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO) website. These sources are cited by GoS as unreliable due to interruptions in electricity and internet connections. The decision whether or not to undertake national tsunami watch / warning procedures is taken based on the combination of this information.

The Disaster Management Office (DMO) is responsible for coordinating all mitigation, preparedness, response and recovery programs, in collaboration with the Disaster Advisory Committee (DAC) and ministerial level National Disaster Council (NDC). The DAC comprise CEOs of emergency response agencies, government ministries and private sector companies with a role in disaster management.

The Samoan media receives SMS messages and fax copies of tsunami watch/warning once it is published. Upon receiving a “watch” message, TV and radio stations broadcast the information. If a warning is given by the DMO, local TV and radio stations activate emergency messages and evacuate to emergency locations. SMS messages are sent to village representatives by the country’s two mobile telephone operators, Digicel and Go Mobile. Upon receiving a warning in a village, church/school bells are rung or sirens activated (a tsunami watch message is passed on by word of mouth among the villagers).

Distant Tsunami:

The Meteorology Division relies solely on receiving PTWC bulletins via SMS, fax and email. In the case that this information is a tsunami watch or warning, the mobile phone service providers are immediately contacted to disseminate a local bulletin SMS to all selected village representatives. The DMO are also immediately contacted to establish appropriate actions.

Education:

In 2008, the DMO aired TV programs on earthquake and tsunami warning systems and drills and a village based Disaster Risk Management Awareness program was run, which gave education on tsunami hazards, mitigation measures and safety procedures, and also involved developing village disaster plans.

The UNESCO office in Apia also ran media workshops to improve the capacity of local media in reporting of disaster management. Tsunami related articles were published following this workshop. Further articles on tsunami hazards have been published in the weeks following the September 2009 event.

Additional fact sheets have been disseminated to the public and media, and hazard information signs were due to be implemented in mid-2009 although EEFIT observed no evidence that the latter has commenced.

Observations:

Although the MNRE states that tsunami mitigation and preparedness is still in its infancy, there are on going projects to improve this situation:

- Establishing a national seismic network in collaboration with China. Network would include additional seismic stations on Upolu, and to provide coverage of the active volcano on Savai'i island.

- Efforts to establish a South Pacific Tsunami Warning Centre in Fiji are underway.

- DMO and DAC are developing improved tsunami information for education of the wider community.

Current issues observed by the EEFIT team:

- All radio and TV stations are closed between midnight and 6am, broadcasting automatic transmissions so bulletins during this time can only be disseminated via SMS.

- In the case of this event, the warning systems in place did not provide warning to villages in time. One interviewee stated that she received the text warning at 9.32am – over 2 hours after the tsunami had caused severe damage to her business. Repeated anecdotal evidence shows that no SMS message was received in villages prior to evacuation. Additionally there was apparently no broadcast on the radio (Maninoa Beach resort)

- Not all villages have been involved in the government awareness program yet, for reasons of village politics or timescale of rolling out this program. Some interviewees cited information given by Women's Groups that gave them early warning on the occurrence of ground shaking.

- In many cases, villagers acted to warn their communities by ringing church bells on seeing the sea recede. This highlights that traditional village warning dissemination functions well, but that the dissemination of early warnings from scientific agencies and government must be improved.

- No tsunami routes have been signposted, as has occurred in regions of high tsunami hazard in other parts of the World.

Observed Relief Provisions

- Relief and reconstruction has been concentrated on the Aleipata region of Upolu.
- $18,000tala (~£ 4,700) has been promised for each collapsed house damaged by the event.
- DMO have provided many affected villages with temporary water supply or water storage tanks and food and other aid once a week to the affected families.
- Counselling has been provided through churches and womens' groups.

FIELDWORK METHODOLOGY

In consultation with Secretariat of the Pacific Regional Environment Programme (SPREP), Ministry of Natural Resources & Environment (MNRE) and UNESCO it was agreed that the EEFIT team should concentrate the field investigation on areas that have not been documented by other groups: NWS: Oct 4-8, USGS: Oct 4-18 and NSF: Oct 4-11. Due to the relatively short duration of the field study, Nov 4-9, three regions were identified: Manono Island, Savai'i Island and part of the South coast of Upolu Island that had not been studied by the other groups. However, in order to put the current field study into context with the existing surveys of the southeast coast of Upolu Island a brief tour of the coastline was carried out with a team from the Disaster Management Office (DMO).

The more detailed field work comprised of two parts:

1) Dialogue with residents of affected villages – determine severity of injuries, local education and awareness of tsunami threat, establish the initial damage caused by the earthquake, gather local knowledge on the shoreline and offshore history.

2) Mapping of damage – establish a 'before' and 'after' map of the village, document coastal infrastructure, measure a threshold of damage on buildings, photograph the structural damage and biological and physical effect on the natural environment.

Communication with the villagers was initially established by members of the DMO; once permission was granted from the village matai, the team dispersed within the village to capture the structural damage, the characteristics of the coastline and record testimonials. The composition of the team allowed for both the inland structural damage and coastal protection to be assessed in a detailed manner.

The established coastal structure and recommended mitigation strategies had been previously recorded by the Government of Samoa in two phases CIM (01-02) and SIAM-2 (06-07). These reports provide documents on the coastal infrastructures and existing guidelines. Some comparisons will be made between these documents and observations from the field study.

FIELD SURVEYS (BY VILLAGE)

As outlined in the methodology, the team concentrated on areas which have not been covered by other teams, which in some cases were found to be villages where there has been no systematic government / NGO post-tsunami clean up operations. In this section, important observations and lessons gathered from each of these locations are summarised. The local setting of the villages, often instrumental in the damage observed are described and where possible, shown by acquired satellite imagery. Figure 4 shows the locations of villages surveyed during the EEFIT reconnaissance mission.

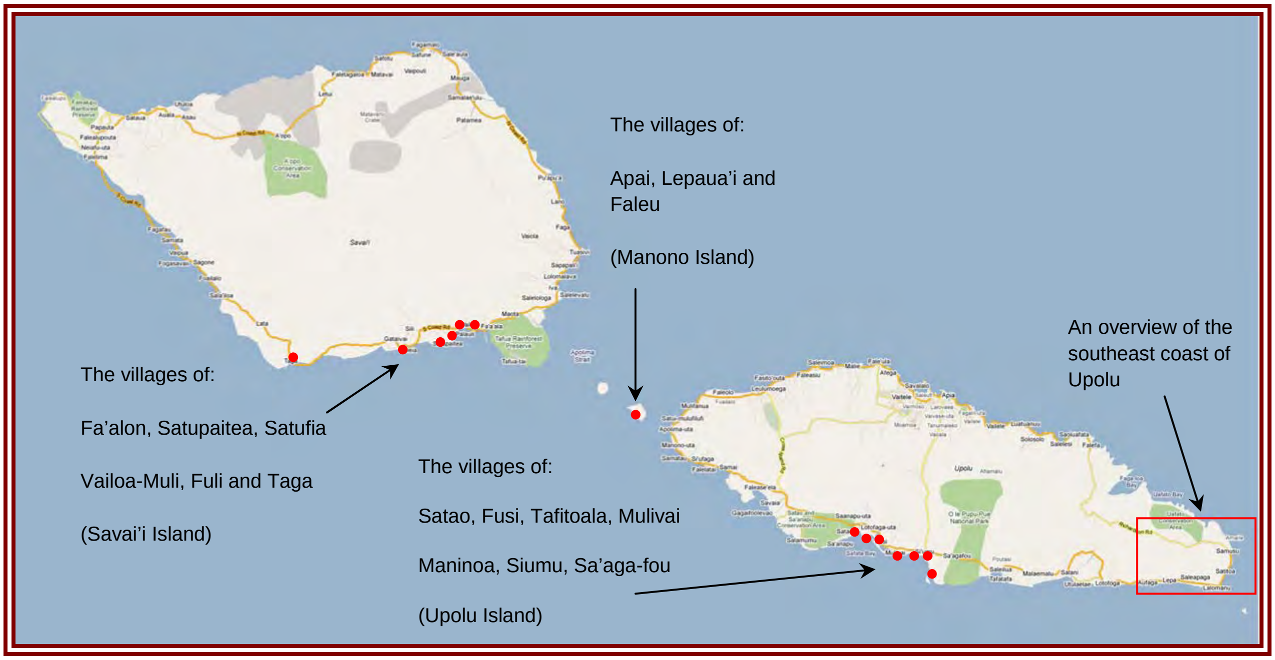

Figure 4: Map showing surveyed villages during the EEFIT reconnaissance mission

Upolu Island

Surveys and interviews

The EEFIT team carried out detailed surveys and interviews in 9 locations along the south coast of Upolu over 2 days during our mission. The damage and inundation at each of these locations were highly varied, even though the total distance between the furthest villages was only 15km. To fully explore these variations, lessons learnt from each of these locations are summarised at the end of this section.

Satoa

The local setting heavily influenced the ability of residents in this village to evacuate and reach safety. There is a row of houses with beach fales in front which were adjacent to the coast; these timber structures were completely destroyed by the incoming waves. A mangrove forest lies inland of the village, offering no elevated land to escape to. This location is detailed in a CIM plan (CIM, 2006). An original pier used to lead to old fales which had been removed prior to the tsunami. At this location there are two visible coral reefs, estimated at 200m and the other at 700-800m offshore. A seawall made up of various volcanic rocks (up to 50cm in diameter) and mortar lined the coast (see Figure 5).

Figure 5: A seawall found at Satoa made up of various volcanic rocks and mortar lined the coast

The team interviewed 2 people at this village, there were said to be two waves on bearing 120^{o} and 80^{o} respectively. The 2nd wave was described by the villagers as bigger and the surges were 17cm and 34cm at 50m inland from the coast. The back wash of the 1st wave was said to have countered the 2nd incoming wave.

There were no sirens and the villagers have had no tsunami drills. Residents saw the water recede and a wave "taller than coconut trees" coming towards them. They decided to evacuate in their car as it was recognised as faster than running along the coastal road (no alternative routes available) though the wave did hit the car.

Further west along the road, there are brick masonry beach fales, 10m from the coastline. Water height at this location was 1m high and caused damage to doors and louvres, and deposited sand in the buildings, but no structural damage resulted and the fales remained intact.

The findings from Satao can be summarised as follows:

- Energy of the waves (and therefore wave heights) was possibly reduced by the reefs, sea wall and the interaction between the waves. These features were recognised by the villagers and conveyed to the team.
- No awareness, drills, government warning or sirens occurred at this village.
- The coastal village layout made evacuation very difficult.

Fusi

This village suffered no damage to buildings as it is in a sheltered lagoon, as shown in Figure 6. A resident interviewed by the team had heard the warning on the radio that morning and left his house but later returned and observed there had been no change in sea level. He also mentioned that fishermen had observed erosion on the seaward side of the sandbank offshore after the tsunami.

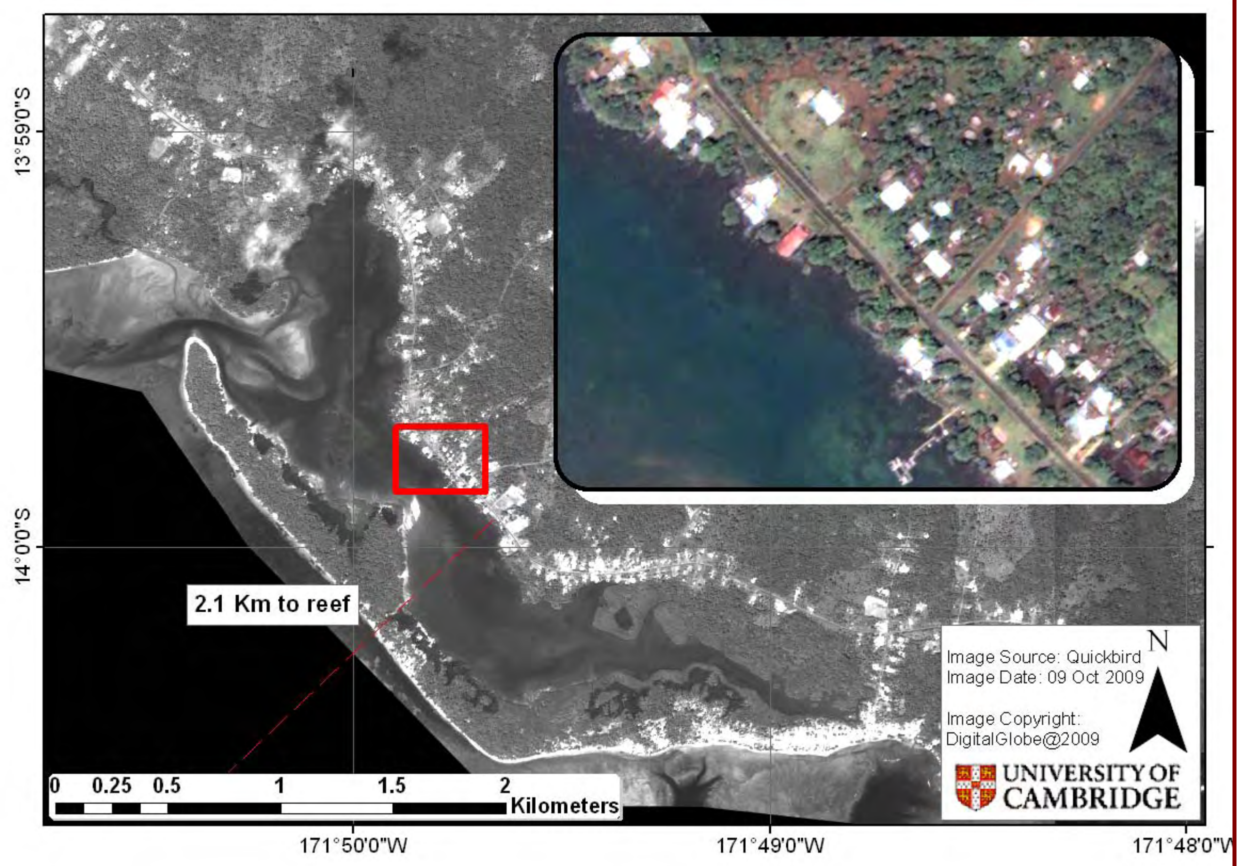

Figure 6: The village of Fusi is protected by a spit as shown in this satellite imagery. The inset post event image shows no signs of damage, as confirmed in the field.

Tafitoala

The village of Tafitoala is on a moderately sloping natural beach with two reefs offshore. There was no seawall although the coconut trees along the coast survived well. Witnesses saw the sea recede from the bay and described waterfalls forming at the reefs. Surfers at the reef reacted to the natural warning by paddling further out to open water.

This coastal village had a row of houses on the landward side of the road with a mangrove forest behind. Directly along the shoreline, all 8 beach fales were completely destroyed, including a beach bar. The waves were said to have arrived from different directions interacting with each other.

Figure 7: Tafitoala have no exit routes inland at the west end of the village as shown

Three interviews were carried out at this village and the accounts of when the first wave arrived after the earthquake varied from 5-15mins. The villagers were aware of tsunamis and evacuation routes as a workshop on the subject was convened 4 months previously by the Women in Business organisation. However, as the water came into the village, which reached 1.85m at the bar (shown in Figure 8), villagers were all caught as they ran down the roads that run parallel to the coastline. They then evacuated directly inland into the mangroves and had to cling onto trees until the water receded. The elevated and well built masonry church located at 30m inland from the coast offered refuge for one villager; as she ran inside, the water surge was around her ankles. Some injuries were sustained by floating debris though no one died in this village.

The church hall (adjacent to the church) was said to have protected the lower-lying vulnerable timber fales landward, where a woman was washed and trapped under the raised fale floor until the water receded. There was no backwash noted at this location as there is a lagoon and low lying mangroves behind the church and the wave had flowed through the vegetation and into the lagoon.

Summary of findings at Tafitoala:

- There is no artificial coastal protection and no mention of coastal erosion over time by local residents.
- There was no backwash observed by residents at this village.
- For no obvious reason, there was differential damage between closely located and similarly built fales, although one was elevated by 80cm.
- The majority of timber beach fales adjacent to the beach were destroyed, with 1 remaining built with strong concrete pillars. No other structural losses occurred, but villagers gave accounts of contents and non-structural damage to doors and louvres.
- Residents were aware and trying to evacuate in cars along the tarmac road but the wave caught up with them before they could reach the road uphill.

Figure 8: Tsunami wave height at this fale's location in Tafitoala was around 1.85m, as shown by the local resident

Mulivai

Most of this village is inland though one family and the pastor's house were by the coast. They are located there because their ancestors are buried by the coast. The water inundation was measured at 80m inland. There are signs of significant beach loss and a steep beach remains. There is also extensive coastal erosion observed with large turfs of grass undercut by the wave and lifted in one large mat (2x2mx10cm deep), and exposed coconut tree roots. There is no structural protection of the beach in front of this house although the trees lining the coast seemed unaffected in the wave.

Figure 9: Large turfs of grass undercut by the wave and lifted in one large mat (2x2mx10cm deep) were evident at Mulivai

The family did not expect a tsunami after the earthquake. They did hear sirens from the adjacent beach resort and were also alerted by two children fishing that they should look out to the sea. When warned, the wave was already half way between the shore and the reef, only 3 to 4 minutes after the earthquake. The wave had just come in behind them as they managed to run to main road leading inland. All the furniture from their closed timber fale was washed outside and there was scour at the foundations.

The pastor's concrete masonry house which was behind the old sea wall was undamaged.

Key findings from Mulivai:

- SIAM suggests earlier replenishments of sand had occurred in this village, which is to the west of Coconut Beach Resort.
- Good evidence of coastal stabilisation by vegetation was observed.
- The reason for not relocating with the rest of the village was determined by ancestral graves as shown in Figure 10.

Figure 10: A reason for not relocating with the rest of the village was determined by the location of ancestral graves

Maninoa and the Sinalei Reef Resort

There are four business establishments at Maninoa: the Coconut Beach resort which is owned by an American company, the Sinalei Reef Resort and two locally owned bar and surf clubs. Reconstruction was well underway at the Coconut Beach resort when the team arrived although a family who owned the laundromat uphill of coconut beach were not happy that they received little attention from the government. Businesses interviewed have had to find money from donors and help from volunteers to reconstruct. There are no plans of any of these businesses to relocate as they rely on the coastal location for their livelihoods.

There was a driveway along the beachfront in front of the coconut trees constructed of compacted sand but no coastal armouring was found at this location. All except the coconut trees have been removed by the tsunami.

All of the open beach timber faleo'os housing surfers and equipment were completely destroyed at the bar and at the surf club. Three closed wooden fales some 30m from the coast were also damaged. The reported wave height was about 4m, arriving from the east bearing on 120°. The water brought in natural debris as well as cars parked by the coast. One car was said to have hit a coconut tree at a height of 4m, 30m inland from the shore as shown in Figure 11. The owners did not hear any warning on the radio, only music.

Figure 11: The mark left by floating debris on a coconut tree gives an indication of the force and height of the water at Maninoa

Sinalei Reef Resort

The Sinalei Reef Resort just east of Maninoa suffered substantial damage to all its coastal assets. Along this resort, there is virtually no man-made coastal protection, only natural shoreline (shown in Figure 12).

Figure 12: The natural shoreline as witnessed at the Sinalei Reef Resort

A group of coastal houses had damage to floors which had been pushed upward to the ceiling and at the time of the team's visit these were being rebuilt following an insurance claim. There were also volunteers on site who were previous hotel guests with specialist skills from New Zealand helping to rebuild uninsured properties. A bar/restaurant on the reclaimed spit was destroyed and washed away. Due to the high premium, this was an uninsured structure and as shown in the Figure 13, was one of the main entertaining venues for the resort.

Figure 13: A picture of the beach bar restaurant at the Sinalei Reef Resort before and after the tsunami

All of the beachfront fales were completely destroyed. These were closed fales made of timber. The honeymoon suite jacuzzi (concrete structure), located right by the coast, was intact with no structural damage but the decking around the structure and the accompanying fale were completely washed away. Alongside the path behind the row of beachfront fales, the tsunami wave had eroded a steep, densely-vegetated slope, exposing pillar foundations of fales some 6m above sea level as shown in Figure 14.

Figure 14: Photo taken from the www.preferencetravel.co.uk website of the Sinaeli Reef Resort of the dense forested area before the tsunami (left) and the same location with exposed foundations after (right)

The wooden fronts of these fales were also ripped and there was evidence of boulders and rocks washed in by the wave into the gardens and the spa at this level. The resort owners intend re-opening in April 2010 after reconstruction of the beach fales and will continue to be diligent about natural disasters.

The owner of the resort had felt the earthquake and was waiting for the SMS alert which did not arrive. They waited for 2 minutes because they did not want to wake their guests but they sounded their warning siren after seeing the sea recede. Their siren also warned others, including surfers and divers who all went beyond the reef to deeper water. The owners had previously sought emergency training for resort staff as they wanted them to be prepared. They therefore had a well-practiced evacuation drill which saved the lives of all the guests. She also remarked that her dog had acted strangely during the earthquake.

Summary of findings from Maninoa:

- Text messaging is not the best way of alerting people. The owner of the Sinalei Reef Resort only received her text at 9:32am on the day of the tsunami.
- The siren installed and sounded at the Sinalei Reef Resort helped alert many people in the local area. This is a key lesson for DMO to consider, where and how to install alerting sirens in the future.

- Local businesses are not first priority for relief and reconstruction by the government and some have voiced discontent over the matter.
- This was the team's first observation of business interruption by the tsunami. The economic costs of this event are inconsequential to the insurance industry since there are negligible insured assets. There is also evidence that some businesses were reluctant to take out high premium earthquake and tsunami insurance.
- The knock-on effects of the closure and reconstruction of the resorts to local workers is significant as many must be laid off while resorts are reconstructed.

Si'umu-sisifo

The coastline of this village is a rocky beach with dark sandy fluvial deposits. Some of rocks had been moved from the beach by the waves and deposited inland. There is a river to the east of the village which created a conduit for the tsunami to propagate inland a distance of 300m. The tsunami was said to have followed two paths through the village, one along the river and the other through the houses over an elevated ridge as indicated in Figure 15. The water inundation to the west of Si'umu-sisifo was measured at 77m.

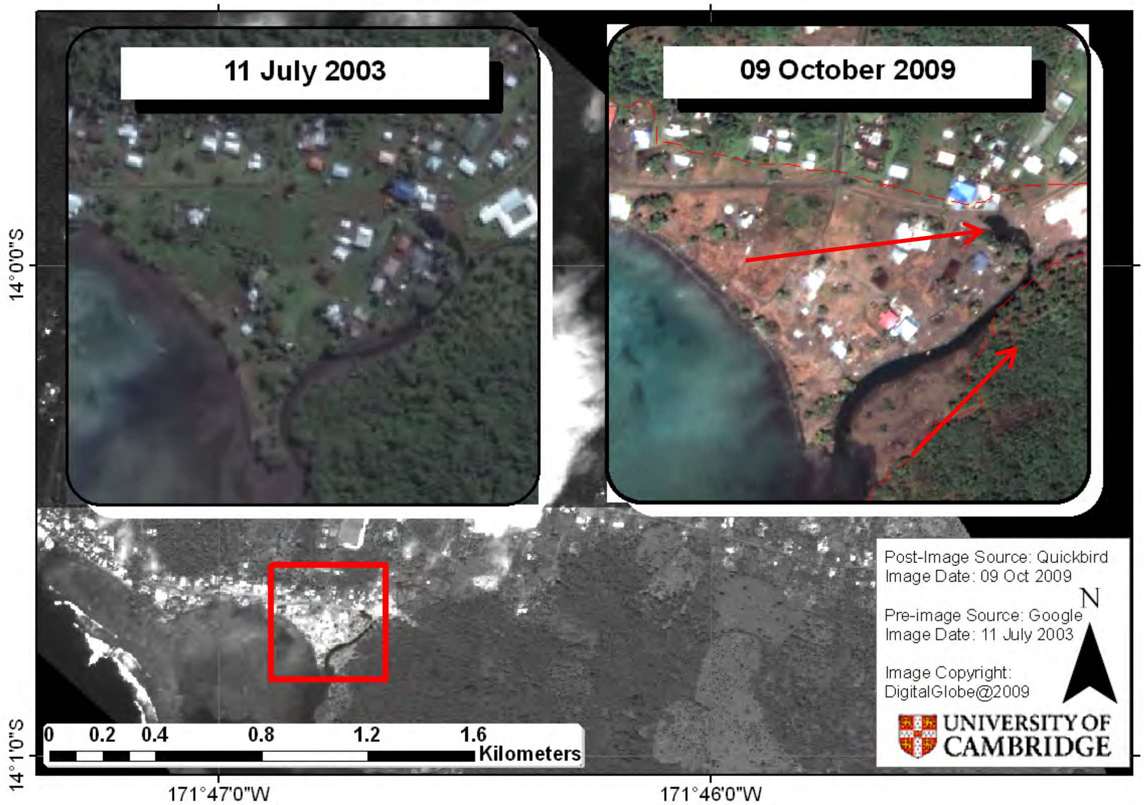

Figure 15: The tsunami was said to have followed two paths through Si'umu-sisifo, one along the river and the other through the houses over an elevated ridge shown in this imagery

Accounts by the village mayor mentioned there were 5 minutes between the earthquake and arrival of the first wave, and then 2 minutes between the two waves. The 1st wave was on bearing 220^{o} perpendicular to beach and the 2nd on bearing 250^{o} (from the west).

There had been no education or drills prior to the event and warning was given by the siren from the nearby Sinalei resort as the first wave hit. Only minor injuries caused by debris were reported in this village. The most significant structural damage was to a reinforced concrete house built in 2007, where the front and back infill walls and all partition walls inside had been damaged, although the structure remained standing (Figure 16). Other damage reported includes destruction of timber and corrugated iron out-houses and water damage to contents.

Figure 16: This reinforced concrete frame house built in 2007 had damage to the front and back infill walls. All partition walls inside was also damaged, although the structure remained standing.

The house shown in Figure 17 would suggest the wave may have impacted from above as the corrugated iron roof had been bent downwards, at some 4m from the ground, 20m inland.

Figure 17: This photograph would suggest the wave may have impacted from above as the corrugated iron roof was bent downwards

An idle metal shipping container which was closed at the time of the tsunami was also said to have ripped open by the waves and a Suzuki car was also lifted and carried 57m inland.

Figure 18: Residents at Si'umu-sisifo recounted how this metal container was "ripped open" by the wave

From this location, the key lessons were:

- Shower blocks and small outbuildings (*umkuka*) were most vulnerable.
- Evidence showing impact of the wave at this location was notably different from other accounts and observations at locations a small distance along the coast.
- There was notable interaction between the wave travelling up the river and through the village which could potentially explain the degree of damage observed here compared to the adjacent village. There were no flood defences evident on the river channel.

Siumu-sasa'e

Although adjacent to Siumui-sisifo, there was damage to only one concrete framed residential house in this village. Other damage reported was to outbuildings and contents losses. The water inundation at Siumu-sasa'e was measured at 62m from the coast. There is a natural rocky shoreline up to 2m high and the land dips away to the west. The current in the inundating wave was reported to be very strong and came from the west though the wave was not very high. The sea receded 10 minutes after the earthquake, and reportedly took less than 1 minute to recede to the horizon. There were two waves noted at this location and though one interviewee had recently watched a documentary about the Solomon Islands tsunami, his initial reaction was to stand and observe the wave.

Three interviews were carried out at this village and most notably, on the eastern end of this village, the ground surface between the houses, the road and the coast had been eroded. The pastor says there has been erosion of 5m of coastal reclaimed land seaward of his house. There was a little scouring of the road on the seaward side as there was no protection but the surface was still intact. Debris marks were observed 4m up the side walls of an infill concrete frame house (6m in total above the beach), and the adjacent natural spring is now blocked with debris carried by the tsunami as shown in Figure 19.

Figure 19: A natural spring at Siumu-sasa'e was blocked by debris brought inland by the tsunami

As the team travelled west around the cove there was very little damage to buildings, despite being built on reclaimed land 2 years prior to the tsunami and being situated right by the coast. Residents evacuated only 5-10m inland and the wave did not reach them.

Key observations from Siumu-sasa'e

- Continual blockage and obstructions to springs, a key source of fresh water supply to some villages may disrupt village life.

- There were highly variable levels of inundation and damage along neighbouring sections of coastline, possibly due to offshore protection.

Sa'aga-fou

The offshore coral reef at this location is the closest to the shore observed to date, approximately 100m away. The beach is almost entirely coral of moderate slope and there is a substantial area of decimation. Three families live here, served to the main road by a long dirt track. Most of the village was relocated inland after 1945 and one family the team interviewed had moved to the coast in 1993.

A keen fisherman and captain of the boat at the Sinalei resort recounted that the water was very warm, at about 40^{o}C. The 1st wave looked like a rolling breaker and sounded like thunder, towering 6m by the shore. The 2nd wave came from the east and his timber house was picked up, then smashed and floated passed him as he was carrying his mother-in-law trying to get to safety. She died after the 2nd wave hit them and he was pushed to the trees behind leaving him with a deep cut on his left thigh and leg. He was sent to the hospital to treat his injury and had a tetanus jab. His daughter-in-law and daughter also died. He had recently dived on the reef and saw all the flattened coral. He is currently taking a 2 month break off work.

Figure 20: A photograph showing the water inundation and devastation left at Sa'aga-fou

The timber walled house with a corrugated iron roof as shown in Figure 21 belonged to a local family who had this house and fales in front as a holiday rental business. The location had a natural rocky (lava outcrop) shoreline and the inundation distance from the shore was measured at 70m. From the remains of the concrete steps and foundation base, it can be inferred that the house had been lifted and carried 50m inland, stopped in its path only by the trees behind.

Figure 21: A photograph showing a timber house carried inland some 50m by the tsunami at Sa'aga-fou

A sign on the tree at this location as shown in Figure 22 indicates that the residents of this house no longer wish to have claim on the land.

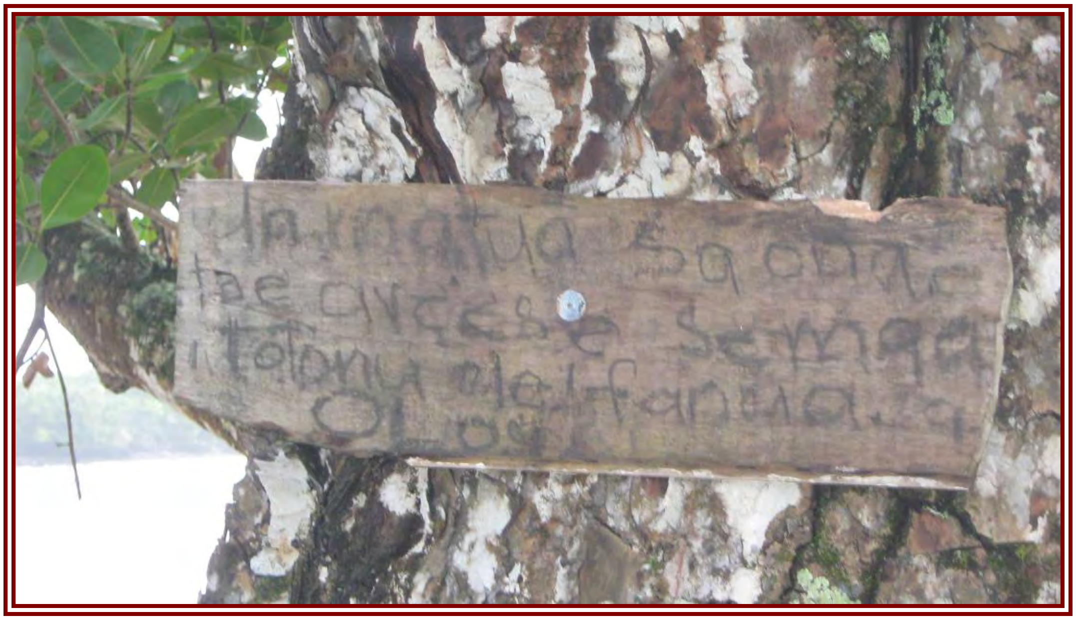

Figure 22: A sign saying that the residents at this house no longer wish to have claim on the land

To the east of Sa'aga-fou, there was a very steep beach with a slope of 1 in 5 where there was an extensive area of destruction and 200m of inundation.

Summary of findings from Sa'aga-fou

- Houses were picked up and carried for over 50m.
- There was extensive damage at this village, comparable to that observed in the most damaged villages on the southeast coast.
- The relocation of the village in 1945 saved lives as the lethality rate of these 3 families was 30%.

Overview of Aliepata

The southeast coast of Upolu (Aliepata region) was the most damaged area of Samoa Islands by the tsunami. The villages listed below have been covered in detail by the UNESCO-IOC group therefore they are not examined in detail but some images and information collected during the mission are summarised below.

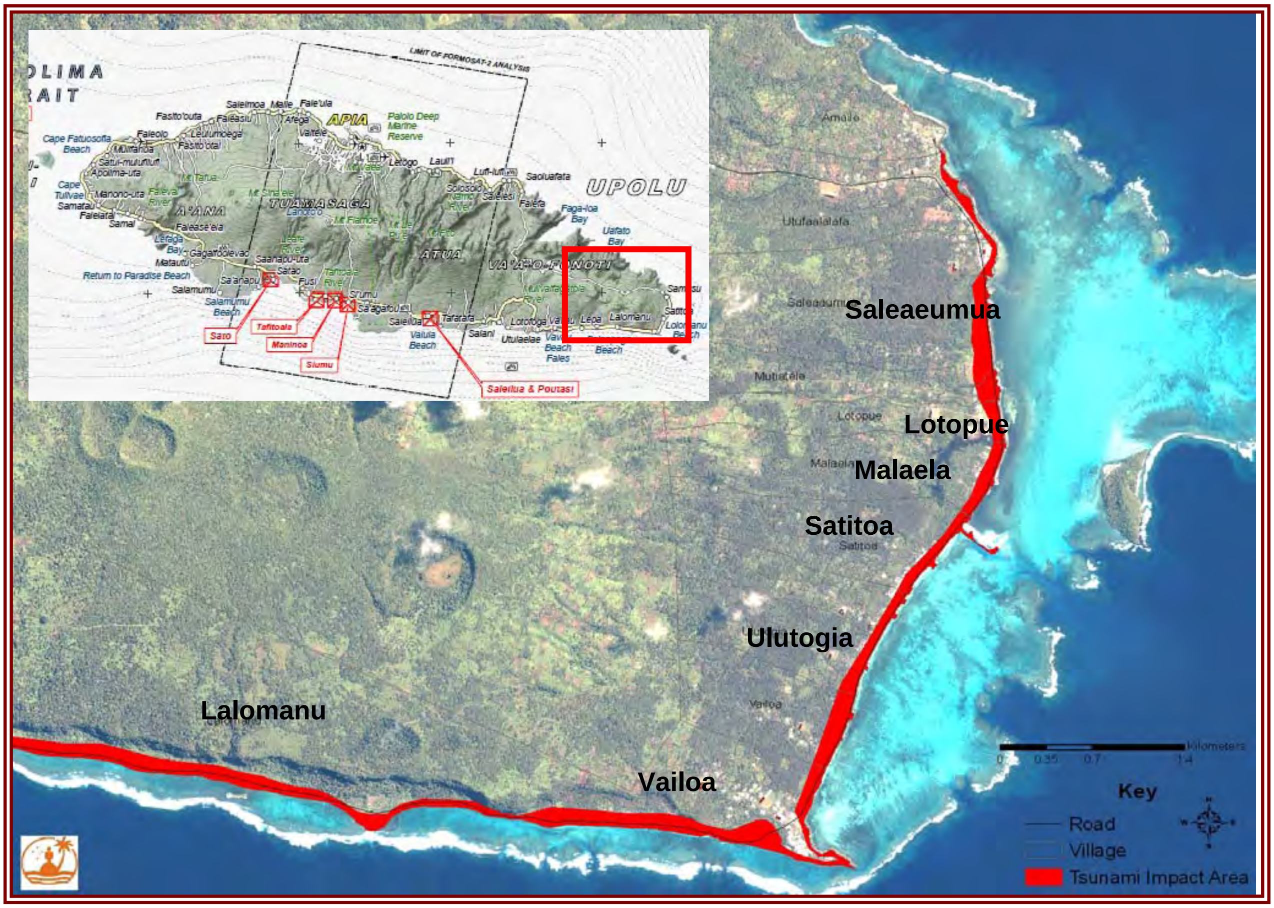

Figure 23: Map showing the tsunami impacted area at the southeast coast of Upolu island and the villages the EEFIT team visited

Satitoa - This village of around 250 people (in 20 families) suffered over 90% damage to its housing. During the visit there is evidence that some reclaimed timbers have been used to make temporary structures inland and the team were told by MNRE that the majority of affected families have temporarily or permanently moved inland. Along this beach front coast, there were remnants of concrete-frame infill masonry building visible, showing severe damage to the front and significant scour at foundation corners. The MNRE informed the team that the water took a week to drain away from the area. Further south from Satitoa, at the village ***Ulutogia***, the entire village of around 30 families has been temporarily relocated near the school grounds at higher grounds.

Lalomanu - This village, a famous tourist destination with many beach fales and tourist facilities were completely destroyed by the tsunami. During the team's visit, significant clean-up operations were underway following the devastation in the area. As shown in Figure 24, only concrete base foundations remained. This village was entirely exposed to the incoming waves, which can explain the high level of destruction, and the steep vegetated cliffs immediately inland of the beach resorts prevented effective evacuation.

Figure 24: View of the village of Lalomanu from the southern coastal road

Lepa, the Prime Minister's village was mainly located high above ground inland. By the coast, there is significant rock armouring of shore and several patches of reclaimed ground.

Lotopue, suffered very little damage. There is a lagoon at the front of the village which is 35m away from the shoreline and the tidal ranges from 1.2m at high tide to 0.5m at low tide.

Figure 25: Photographs showing the difference in damage between the village of Lotopue (left) and Malaele (right), which was not protected by the lagoon

In contrast, the villages of ***Saleaumua*** (immediately north of Lotopue) and ***Malaela*** 50m south of Lotopue (shown in the figure above) suffered severe damage. The difference in damage to these three villages could possibly be explained by the shelter offered to the village of Lotopue by the offshore island of Namua and by the presence of the lagoon.

Summary of findings from Aliepata

- Natural features such as lagoons, offshore islands and spits appear to have a significant impact on damage in coastal villages.
- There was significant spatial variability in tsunami damage within several kilometres of coastline.

Manono Island

On Manono island, located between Upolu and Savai'i, 3 out of the 4 villages were affected by the tsunami. The affected villages are all located along the southern coast of the island.

The 3 affected villages were surveyed:

A = Apai

B = Lepuia'i

C = Faleu

Figure 26: The 3 surveyed villages on the island of Manono were Apai, Lepuia'i and Faleu

Since the tsunami, there are still problems with water supply even for the unaffected village as under-sea water pipes carrying supply from Upolu were damaged and service has not resumed to normal. Plastic water tanks were being used as temporary water storage and weekly water deliveries were being made while the pipeline is down. According to DMO, the rebuilding of homes will be happening in the week following the visit as Aleipata (the southeastern coast of Upolu) was given priority. The residents here were told that government of Samoa will be giving WS$18,000 (~£4,700) to each family who lost their house in the event.

The coastline in the village of ***Apai*** is a gentle sloping beach with a few rocks of diameter 30cm protecting the short cropped grassed area. There are some coconut trees offering protection and roots binding the soils but land was seen to have fallen away from the coast. According to the village mayor, up to 4-5m of beach has been lost and where sand had been covering rocks, these are now exposed though the erosion observed is not consistent along the shore.

Figure 27: Photograph taken at Apai showing the erosion of the coast caused by the tsunami

According to the village mayor, after the earthquake, the sea receded and they were able to see the seaweed from the shore, estimated at approximately 150m from the shoreline. When the wave came in, the water was very turbulent, bringing with it coral debris of up to 1m in diameter. Two trees were uprooted by the tsunami, ending up in the lagoon as shown in Figure 28.

Figure 28: Photograph taken at Apai showing the uprooted trees in the lagoon

The team carried out 3 interviews at the village of Apai including an account by the village pastor. There are 16 families living in this village and only one closed timber house collapsed whilst other dwellings had water and sand damage and loss of contents. There was also damage to out-buildings such as shower and toilet blocks and most significantly, damage to and displacement of water tanks. As shown in Figure 29, the two water tanks moved 12m and 27m respectively and were lifted from the very thin concrete screed foundation. At this location, waves were observed at 4m above sea level.

Figure 29: Two water tanks moved were lifted from their very thin concrete screed foundations 12m and 27m respectively

There were no expectations of tsunami after the earthquake by the villagers in Apai and responses indicated that although there had been a tsunami awareness programme, they did not think that it would happen to them. There was a delay time of 5 minutes between the earthquake and the first wave and in total, there were two waves, the first coming straight on and the second from the side, being the strongest and highest. The water inundation was measured at 125mm whilst the 1st row of housing is 35m from the shoreline. There was no structural damage to the church building apart from windows and doors and 13 of the 16 families had run to the church and hid behind the mayor's house which was shielded by the community centre in front. A 75 year old lady in this village lost her life after ingesting a large amount of water, dying the next day.

Lepuia'i was the worst affected village on Manono island. Out of the 30 families in this village, 20 of them had houses severely damaged by the tsunami, this included many older timber faleo'os tied loosely to their concrete base. There is a rocky outcrop at the back of the village which prevented further inundation but most of the houses at the shoreline suffered some level of damage.

Figure 30: The remains of a timber fale at the village of Lepuia'I completely destroyed by the tsunami wave; only the concrete base foundation remains.

In total, 5 interviews were carried out in this village. The first was at the Sunset Resort where two waves were reported up to 2.5m high, their arrival being on bearings of 250° and 160°. The wharf and all 5 beach timber fales along the shore were completely destroyed. A new wharf had been built at the time of the survey with small rocks of 30cm and a mortar infill overlain by a 10cm layer of concrete. The old sea wall with rocks of 50cm was also evident at this location and the mayor plans to fill the new sea wall with masonry and cover with soil and plants. There was also yellow coral debris observed at 300m inland. The nephew of the Sunset Resort owner was injured as he was dragged by the wave inland and had to be transferred to the hospital on Upolu island. The rest of the families in this resort were able to get to safety as a path up to higher ground provided a close and easy route for evacuation.

Other interviewees reported up to 3m of water with strong backwash, which was enough to move a 1.5m square concrete water tank over 20m from its concrete base. One interview with an old lady also revealed that the waves and backwash were strong enough to displace an open thatched old timber fale, which was behind an open concrete fale. This was washed by the 1st wave to a similar wooden fale behind, with an 81 year old disabled man inside. He was still in the house when the fale was dragged by the backwash to the concrete foundation of the stronger house in front and he was stuck behind the high foundation. He survived, as he was able to break open the thatched roof in order to breathe.

Figure 31: The set of fales at Lepuia'I where the front open fale prevented the old faleoo in the middle from being washed out to sea by the backwash of the waves

A similar story where a young woman was unable to move her parents out of the house was reported in Lepuia'i. The wave had broken all the windows and the thin cardboard interior walls were punched through. As the 2nd wave came in, they were swimming in their closed masonry house with the floating contents of her house. Luckily, her father who had suffered a stroke and therefore unable to move, only had scratches from the debris.

The most significant damage to reinforced concrete house was observed in this village. A strong side wave had pushed the side of the house in, bending the columns at the base. As shown in Figure 32, there is no lateral reinforcement and the vertical bars are slight. Fortunately, the children were already at school inland and the occupants were warned by a man out by the coast yelling that a wave was coming. The husband was in a boat out at sea on his way to Apia and saw the water breaking on shore as the tsunami arrived.

Figure 32: Damage to the weakly reinforced concrete columns and infill walls of a house at Lepuia'i

The final village affected by the tsunami the team visited was ***Faleu****.* There are 60 families in this village, of which 25 had property affected by the tsunami. Since the tsunami, the seawall had been rebuilt up to a height of 1.4m using reclaimed rocks and coral. The village mayor informed the team that they are waiting for heavy machinery to provide backfill for the seawall. The rebuilding of the seawall for Lepuia'i and Faleu was sponsored for two weeks by the Work for Cash scheme under South Pacific Business Development (SPBD), which pays villagers to carry out the rebuilding work.

The villagers recount three waves of bearing 210° with the third being highest. The 1^{st} wave had broken at the reef, and the 2^{nd} wave was reported to have covered the offshore island to the height of coconut trees, at approximately 6m. The height of the wave reached 2.5m in a house, 50m from the coast. One of the beachside fales were said to have been lifted 6m high then carried inland on the wave; a half-full water tank was also lifted behind a house and carried along the plantation road to a distance of 170m from the shoreline. A pre-school in this village was destroyed which was the only reported school damage in any of the villages the team visited.

In this village, the pastor had been involved in previous tsunami drills but was unfortunately away at the time of tsunami. The church bell was rung as warning by a villager and people evacuated up the small hill behind the village.

Since the event, only three families out of the 25 affected have relocated up to the plantations though others may follow once compensation has been allocated. The plantations are located 128m along a slope uphill and the interviewed families seemed prepared to use cultivated land in their banana plantations in order to build houses.

At the elevated church shown in Figure 33, which was located 30m from the coast, there were watermarks at 1.2m though no damage to this building was recorded.

Figure 33: No damage was evident at this reinforced concrete frame church at Lepuia'i. As observed in many of the surveyed villages, churches, possibly better built fared much better than other structures.

Summary of findings on Manono Island

- The government visited on the 3rd day of the tsunami after being informed of damage by a Manono resident travelling to Upolu by boat. The local people were all much traumatised and could only give an account of the event after counselling from church groups.
- There are no cars on the island and people evacuated on foot.
- Some people would choose to remain in their houses even though there is obvious danger if there are dependents unable to move.

- In the village of Apai, there was no obvious higher ground, whereas villagers from the other villages managed to evacuate uphill to safety where there were obvious routes inland.
- There is a need to tie down water tanks to bases as water tanks were simply lifted by the incoming water and displaced as debris, causing additional damage to buildings.
- The under-sea water supply pipeline from Upolu island was vulnerable to the earthquake / tsunami and disruption to this service had significant implications in the weeks after the event.

Savai’i Island

The island of Savai’i is 20 km west of the main island of Upolu. There had been reports of damage from village mayors at Savai’i to the MNRE though one village mayor failed to report damage in his village. On the last day of the EEFIT reconnaissance mission to Samoa, the team visited 6 villages on Savai’i, accompanied by the MNRE and staff from the Ministry of Police and Prisons.

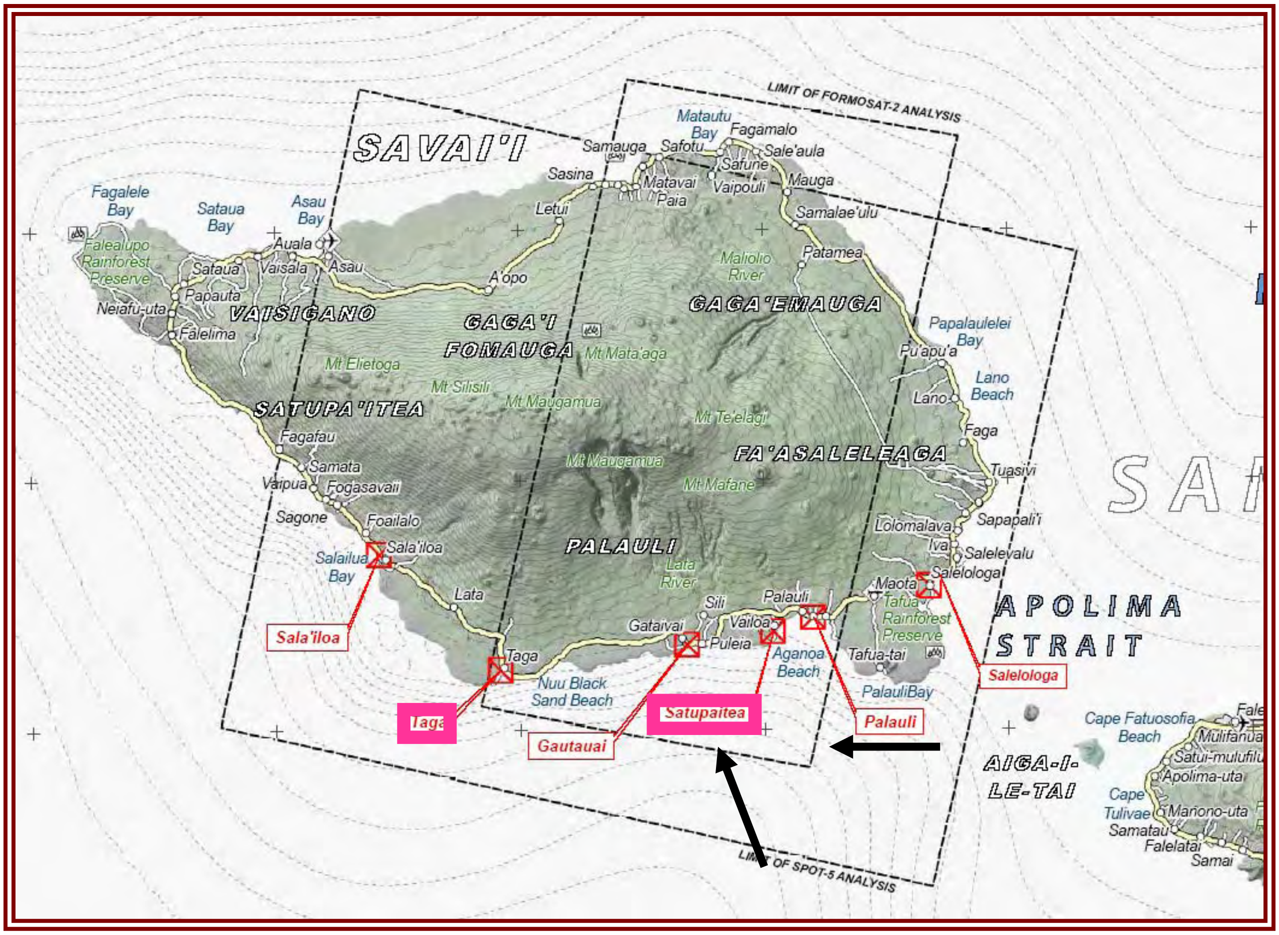

Figure 34: Map showing the villages the EEFIT team visited. The arrows show the general direction of the waves as noted by the villagers at Savai’i

At the village of ***Fa’alon,*** the wave had reached the coastal road but had not caused any damage to the road surface. There were two waves observed and the water had retreated from the bay. In total, 9 timber fales suffered some form of structural damage.

The village of ***Satupaitea*** spreads along the south coast and has a gentle-sloped dark sand beach of volcanic material. There is 6m of low-lying vegetation followed by boulders of 40cm diameter and grass leading to the coastal road. The placed rock protection along the coast at this village was 70cm high and the trees along the coast did not appear to have been affected by the tsunami. Visual assessment of satellite imagery by UNOSTAT had suggested road damage at several points along the south coast road, however, no erosion of this road was observed during our investigations. These were possible incorrect inferences made from areas of debris post-event.

The village mayors accompanying the team had mentioned that the fire and emergency services had sent their trucks from the port to warn villagers of the incoming tsunami. However, by the time they arrived in the village, the tsunami had already struck and debris from the seawall prevented the fires services passing through. No SMS warning was received in this village. The time between earthquake and tsunami was reported to be 3-5 minutes. Most damaged buildings were Samoan-style open timber faleo'os and a few closed concrete masonry houses.

Reports from residents say that the water came across road and hit a house, at 44m from the shoreline with water depth of 1.4m, and the total inundation distance from the shore varied from 62-75m. The direction of the tsunami waves also varied (160° and 80°). In most interviews, four waves were cited with the strongest occurring fourth in the sequence. This was described as a "spiraling" wave. Villagers suggested that the strength of tsunami was reduced by long distance of shallow water inside reef. There was a very fast recession of water as far as the reef about 2 minutes after the earthquake. The most reported damage was to lightweight out-buildings being washed inland by the tsunami. There were no reports of structural damage to residential buildings but the water did deposit mud and debris. In one instance, a boat was afloat and pierced the seaward wall of a residential building, causing a 0.5m square hole to the masonry infill wall and additional damage to the corrugated iron roof. Evidence of scour was found in some seaward side foundations and in one or two cases there was cracking and lifting of concrete floors as water rose through foundation and ruptured concrete blinding (usually <20mm thick).

Figure 35: Evidence of lifting of concrete floors as water rose through foundation and ruptured concrete blinding (usually <20mm thick)

At the west end of the village, there was a large black rocky outcrop approximately 20m wide but unusually there was no offshore reef protection. At this location, there were no signs of the tsunami having hit the area though the tsunami inundation was approximately 30m inland.

Along a dirt track was a small settlement of 3 to 4 families. There was no damage to the buildings (some of which had raised floors 80cm above ground level) and most people were away from the village at the time of the event. There was no warning siren and though they felt earthquake they were unaware that a tsunami would come so they did not move from the house. They could not see the sea from the house as it was hidden by trees so did not observe any change in the water level.

On the waters edge on another rocky outcrop a youth said that the tsunami moved the sand level down by about 30cm. As the team were leaving, there was a woman from neighbouring village collecting deposited stones and coral fragments to decorate her church. Inundation at this location was measured at 86m.

Further along the coast, the team conducted a group interview at an undamaged women's centre at ***Satufia*** village (this building raised on a 56cm high concrete surfaced foundation).

Some of the villagers knew a tsunami would come after earthquake because it was stronger and longer than most other earthquakes they had experienced. They had been involved in tsunami drills so were aware of what action to take, despite there being no warning siren. The interior of some houses suffered damage. One interviewee stated his awareness of tsunami threat, and in the event he took the receding water as a warning and ran inland, aiming for high ground, which in this area was some way inland. The residents had been educated as to available evacuation routes, but were apparently unaware of how far inland they needed to evacuate.

Three waves were observed at this location with respective bearings of 160°, 80° and 80°, occurring after the sea receded. The third wave was said to be the strongest. The arrival of the first wave was reported to be 5 minutes after the earthquake with subsequent waves occurring about 1.5 minutes apart. It was low tide when the tsunami hit and the wave heights were about 1.5m and took the turbulent form of “white water”.

It was believed by one interviewee that the natural curve of the shoreline protected his property. There was one death associated with evacuation at this village where an elderly woman managed to walk up some distance but collapsed due to high blood pressure.

The village of ***Vailoa-Muli*** is lined by a steep 1:3 rocky beach with boulders of up to 1m in diameter. The coral reef at this location is situated far away approximately 2km offshore. There were two waves observed; the 1^{st} was a wave from 120° (perpendicular to the beach) and the 2^{nd} wave (the stronger of the two) came from 180°. The waves were described as a flood rising up, with water spinning beneath the surface. The water height reached 1.2m inside the coastal dwellings at Vailoa-Muli.

Again the cooking houses, timber frame outbuildings similar to the one in Figure 36 were destroyed. A concrete masonry wall of one residential house showed cracks on the seaward side but apart from this slight damage, only contents were washed from houses and there was no other structural damage reported at this village. Some of the residents in this village had minor scratches from being struck by moving debris.

Figure 36: The cooking houses shown here were mostly destroyed by the incoming waves

At the village of ***Fuli,*** there was one wave observed and the backwash had pushed the natural spring wall out. The wave had picked up a truck and moved from behind to the front of the house, some 15m.

Two waves were witnessed here, and again the second was the biggest wave. The incoming water had lifted the floor of one concrete foundation building with an 80cm high foundation as shown in Figure 37. The occupant ran to higher ground, just behind his house.

Figure 37: The incoming water had lifted the floor of the concrete foundation to this residential building, although the foundation was 80cm high

Taga

This village is a popular tourist destination with only a few families living at the shore. There is a black and fairly steep beach strewn with rocks in a bay enclosed by rocky coast. According to the local village mayor, approximately 7m of coastal land had eroded due to the tsunami. There was also a 1.4m level drop from the row of coconut trees (new edge of land) to the top of the beach and the roots of the palm tree are exposed, as shown in Figure 38.

Figure 38: At Taga, the erosion due to the tsunami is said to be approximately 7m

There is a rocky shoreline all around the bay and 4 beach open faleo'os along this coast of a resort were completely destroyed. Water had flowed around a disused church building and contaminated a freshwater spring which is situated behind a women's group building. This building had been severely damaged from the impact of a displaced water tank, said to be almost full of water at the time of the event as shown in Figure 39. The large water tank had been lifted and displaced 11m at a bearing of 350° before hitting the open reinforced concrete column building.

Figure 39: A photograph showing the impact of a displaced concrete water tank on an open reinforced concrete column building at Taga

Upon inspection, two lengths of vertical rebar were noted in the broken columns, however, these were not tied together at the point they were exposed and were not regularly spaced in the column as shown in Figure 40. Luckily, the building was not occupied at the time of the event.

Figure 40: Two lengths of vertical rebar were exposed in a broken column showing its poor spacing and insufficient lateral reinforcement

The village used to be located along the coast but in 1974, there was a tsunami that hit the village and in 2000 all but three families moved to higher grounds. The village mayor informed the team that after the recent tsunami, all three remaining families are planning to relocate to higher ground.

This was the most western village the team visited. West of Taga, most of the villages are on higher grounds so were unaffected by the tsunami.

Summary of findings on Savai'i Island

- The coast has rocky outcrops but had no obvious correlation with tsunami inundation.
- There were varying levels of tsunami awareness within one village.

- There was evidence of insufficient reinforcement in reinforced concrete columns, supporting earlier findings on Upolu island.
- There is further evidence of damage from large displaced water tanks and confirmation that even tanks that were full at the time of the event could become buoyant and be displaced from their weak foundation.

RECOMMENDATIONS

The team were encouraged by the Ministry of Natural Resources and Environment to produce a set of recommendations based on the reconnaissance survey of the islands. These recommendations have been compiled based on the team's preliminary findings and in talking to local villagers. It is hoped that these will be reviewed by the MNRE and consultations with the team and other international groups will continue beyond this report.

1. Corrugated steel roofs are a significant hazard during tsunami and cyclone as they become lethal objects once detached from the roof structure. Reports of serious injuries and beheading caused by roof debris were noted during the mission. It is appreciated that this type of roof is a cost-effective and convenient method of roof construction but:

    a. Guidance on best practice on fitting corrugated roof to beam is recommended. As a minimum, the nails used to fix the roof to the structure should not be left protruding as they currently are, as shown in Figure 41.

Figure 41: Nails protruding through a corrugated iron roof to underlying timber beams

Cyclone washers should be fitted on the upper side of the corrugate sheet to nail fixings to reinforce the contact of the corrugate sheets to timber frame. This, and other steps (i.e. introduce a maximum allowed overhanging distance) would reduce the potential for sheeting to become detached in both tsunami and cyclone events. Alternative fixing solutions such as using nuts and bolts should also be considered. In either fixing method, **roofing sheets should be allowed to partially detach to allow pressure equalisation (in the case of cyclones) and outflow of water, while the sheet remains attached to the building. This can be achieved by fixing only one edge of the sheeting strongly, allowing the other three edges to detach more easily.**

b. Following damage by wind or wave the detached corrugated **sheets must be made safe by storing in an appropriate manner** as soon as possible in the cleanup operation so that they do not become lethal objects in subsequent events.

c. Ideally the **steel roofs would be phased** out as they need replacing, either going back to more traditional thatching or a new material that does not present the same hazard. Introduction of new materials, such as bituminous cardboard used in India could be investigated as an alternative roofing material. This is an affordable material which can be produced locally as well.

2. Siting villages and coastal resorts within close proximity of the shoreline puts people and property at an inherent risk. It is recognised that there are justifiable reasons for wanting to remain in those locations: some villagers have a strong affinity to the sea (fishing and other recreational activities), historical infrastructures (churches, family graveyards and communal gathering buildings) and coastal resorts are attractive to tourists by the very nature of their location close to the sea. Whilst the best option would be for settlements to be positioned at safe distances from the shoreline, those who stay within the hazardous region need:

    a. Improved warning systems

    b. Improved escape routes

Regarding (a), some villagers and resorts who had been waiting for text messages never received them, and some villages had not be involved with tsunami drills due to their village matais not prioritising this training. Introduction of posters in public locations such as bus stops, shops, schools and communal buildings in the village will ensure everyone is aware of the drill. There was also some comment that text messages may not be the best method of warning as people turn off their mobiles at night. The current church bells are not sufficient to warn neighbouring village, as oppose to a siren system, at Sinalei was very effective at warning those out at sea and neighbouring villages along the coast. **Siting of sirens at regular intervals across the island**, perhaps on telephone masts should be considered. These could be dual-function, being used in the warning of cyclone too. **Automatic cut-in to mobile phones, radio, siren & television** is also recommended. Consideration must be given to who can authorise activation of the warnings in order to minimize the delays whilst ensuring the validity of the threat.

Regarding (b), it was suggested that the work roads would be a good escape route. However in at least one village that the team visited, the tsunami followed the direction of the escape route. **New work roads could be designed to follow an initial kinked route** to inhibit fast flow of water along a straight section. Also, at least one village had mangrove plantations inland of the village which inhibited escape from the coast inland and some evacuation routes follow the coast road which led to people and cars being caught by the approaching wave. **Where evacuation routes cannot be followed within say 5 minutes by any means of escape, locations of dwellings should be assessed. Tsunami evacuation route signs should be placed on primary routes.**

3. The shape of foundation to houses. **High, rounded foundations** built of volcanic boulders bound together with mortar as exterior foundation wall appeared to perform better than concrete block foundation, infilled with loose sand, gravel and boulders. The latter were seen to a) suffer percolation of water within the foundation itself, leading to the concrete floor being pushed upward and ruptured; and b) be easily compromised where the concrete block wall was destroyed and loose infill was washed out.

4. **Evacuation distances.** It is not possible to predict runup height and inundation from site to site because offshore conditions (wave heights and direction)/bathymetry/defences are different at each location and from event to event. Therefore, in evacuation, people should be encouraged to evacuate inland as far as possible to ensure safety. They should be encouraged to use their local knowledge where possible to guide how far to evacuate to areas recognised as safe from previous significant events.

5. **Critical infrastructure** (including schools and hospitals) should continue to be **built inland and on higher ground** where possible.

6. **Community education should continue to be implemented around the islands**. Anecdotal evidence collected on this mission showed that whole families survived the tsunami because a family member or neighbour knew the natural warning signs (earthquake occurrence, sea receding) due to previous community education. The prevalence and level of community education was however variable between villages.

EEFIT

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