BUILDING DAMAGE ASSESSMENT
SUVA, FIJI ISLANDS

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CONTENTS

1 ABSTRACT

An investigation of the degree of damage sustained by buildings in Suva, Fiji, following riots and civil unrest on 19 May 2000 provides an opportunity for response-planning and formulation of mitigation activities. The data collected from a rapid-building-damage-assessment survey undertaken by SOPAC's Hazard Assessment Unit are stored in a Geographic Information System (GIS) database. The data include information regarding the degree of damage or a damage flag (represented by flags coloured green, orange and red for increasing levels of damage); a digital photograph; and comments on damage specific to each building where necessary. The damage flag assigned represents the degree of structural and surficial damage that is detected visually, and does not include damage to contents and losses or damage to businesses. The study looks at the use of this damage-assessment data in a GIS platform, especially when integrated with the Suva building-assets database. The latter is extracted from the Pacific Cities GIS database, which was developed in previous years. A damage-assessment methodology adapted from other studies is used to analyse the damage data collected. The adapted methodology quantifies total damage in terms of house equivalents [HE], or number of houses totally destroyed. Damage quantification requires that replacement ratios (RRs) for representative building types are calculated and central damage values (CDVs), that are transferred from the damage flags, are assigned to each damaged building. A CDV quantitatively represents the degree of damage sustained by a building on a scale of 0.01 to 1.0, where 0.01 represents negligible damage and 1.0 represents condemnation or complete collapse. Total damage is then expressed in terms of a universal damage index (DI).

The study found that collecting data through a rapid building-damage assessment survey is quick, easy and simple and can be done in less than a day in an area the size of Suva central business district. Data entry into the pre-existing Suva building-assets database was also quick and simple, although it did require some previous knowledge regarding the GIS software, the database structure and digital-photograph spatial-referencing techniques. The study found that the quantified total sustained damage was almost 11 HEs, which is equivalent to two million Fijian dollars. The study acknowledged that the calculated value is a lot less than a total reported value of greater than thirty million Fijian dollars but that the value determined by the study is justifiable as it looks at visual structural damage and surficial damage alone. Evidence suggests that with input from other agencies, such as the insurance industry and the police, the new damage data and the Suva building-assets GIS database can be further refined and made useful for multi-agency response efforts in future disasters.

The importance of the damage index (DI) is that it allows a comparison of the relative total damage between this event and either historic or future disasters from other natural or human induced causes, in any location. The damage index calculated for the Suva riots was 3.4, which in essence implies that the total damage sustained was relatively low. As further research and calculations are required to calculate DIs for events in Suva (for example the Suva 1953 earthquake), the damage index for the Suva riot event is here only compared with damage indices from Australian events. The study found that universal representation of damage in past events could provide unprecedented advantages in determining damage that may be sustained in future hazard events through event scenario analysis and utilisation of a GIS database. This in turn would aid decision-making, and provide a baseline for hazard mitigation activities and disaster response planning. The former has been recommended as an urgent task to be undertaken by SOPAC or any other regional agency capable, together with other agencies, to achieve the latter.

1.1 Key words

Damage, assessment, GIS, building, asset, database, risk, replacement ratio, central damage value, damage index, analytical techniques, response, planning, mitigation.

2 GOAL

To save lives and livelihoods and reduce community vulnerability through coordinated and timely multi-agency disaster response efforts.

3 PURPOSE

Agencies are provided with a rapid damage assessment methodology and analysis technique to assist decision making and response coordination immediately after the impact of a hazard or disaster and for planning hazard mitigation and management activities.

4 ACRONYMS

AGSO	Australian Geological Survey Organisation
ATC	Applied Technology Council
CBD	Central Business District
CDV	Central Damage Value
DI	Damage Index
GIS	Geographic Information System
HAU	Hazard Assessment Unit
HE	House Equivalent
SIDS	Small Island Developing States
SOPAC	South Pacific Applied Geoscience Commission

5 INTRODUCTION

On 19 May 2000, at 11am, parts of the central business district of Suva were impacted by a human-induced hazard. The hazard, civil unrest, took the form of a riot. Many buildings were damaged; some were partially burnt, while others were razed to the ground. A number of business establishments were looted. Although many people sustained minor injuries, there were no fatalities. This event represented a unique opportunity to test the uses of the Pacific Cities Geographic Information System (GIS) database (see Background below) and provide SOPAC member countries[1] with a damage assessment methodology that could be used for future natural and human-induced disasters. Thus the main aims of this paper are to

1. document the process of undertaking a rapid-building-damage-assessment survey following a disaster;
2. demonstrate how to analyse rapid-building-damage-assessment data using the Pacific Cities GIS database;
3. illustrate that timely analysis of rapid-building-damage-assessment data can be used in multi-agency response efforts and damage estimation, and in future planning, mitigation and management initiatives.

5.1 BACKGROUND

Small Island Developing States (SIDS) are considered to be high-risk entities, partly due to their small size and partly due to their vulnerability to the impacts of natural hazards (cyclones, earthquakes, volcanic eruptions, etc) and human-induced hazards (pollution, civil unrest, etc) (United nations, 1994). In 1996 SOPAC established the Pacific Cities initiative, which was closely linked to the Australian Geological Survey Organisation (AGSO) Cities Project. The initiative aimed to assess hazards from high-risk urban areas of the Pacific and ultimately carry out all-hazards risk and community vulnerability assessments for each Pacific City. To do this, a database was designed to incorporate the most essential aspects (i.e., GIS data layers) required to carry out such assessments, and is now referred to as the Pacific Cities GIS database.

A starting point to assessing community vulnerability was to assess the impact of hazards on buildings. To do this, the most vulnerable attributes of buildings (or building-assets) in cities in the Pacific, had to be identified. Hence, surveys of building-assets were conducted by SOPAC and in-country personnel in Suva (Fiji Islands), Port Vila (Vanuatu), Nuku'alofa (Tonga), Honiara (Solomon Islands), and Apia (Samoa). As a result, a building-assets GIS database (a subset of the Pacific Cities GIS database) is now available for each of these cities, and is in sight for others. Specific information for each building is stored in the GIS with each building having a unique spatial reference. Having this unique spatial reference enables the users to assess the impact of a disaster (e.g., risk to life and economic damage) on a building, a community and even a whole city. This assessment normally includes the production of a map that includes the physical and social conditions in that community or city.

More recently, the Pacific Cities initiative has expanded to look at broader issues such as strengthening regional mechanisms and systems for rapid response to disasters. The current study, *Building Damage Assessment in Suva,* is the first study to test and use the Pacific Cities GIS database as a tool for rapid disaster-response action and assessment. In the following section, hazards, disasters, loss and damage assessment are defined. In subsequent chapters, specific surveying and analytical techniques and methodologies used to assess building damage in Suva are included.

[1] SOPAC member countries include:
Australia | Cook Islands | Federated States of Micronesia | Fiji Islands | French Polynesia (Associate) | Guam | Kiribati | Marshall Islands | New Caledonia (Associate) | Nauru | New Zealand | Niue | Papua New Guinea | Samoa | Solomon Islands | Tonga | Tuvalu | Vanuatu

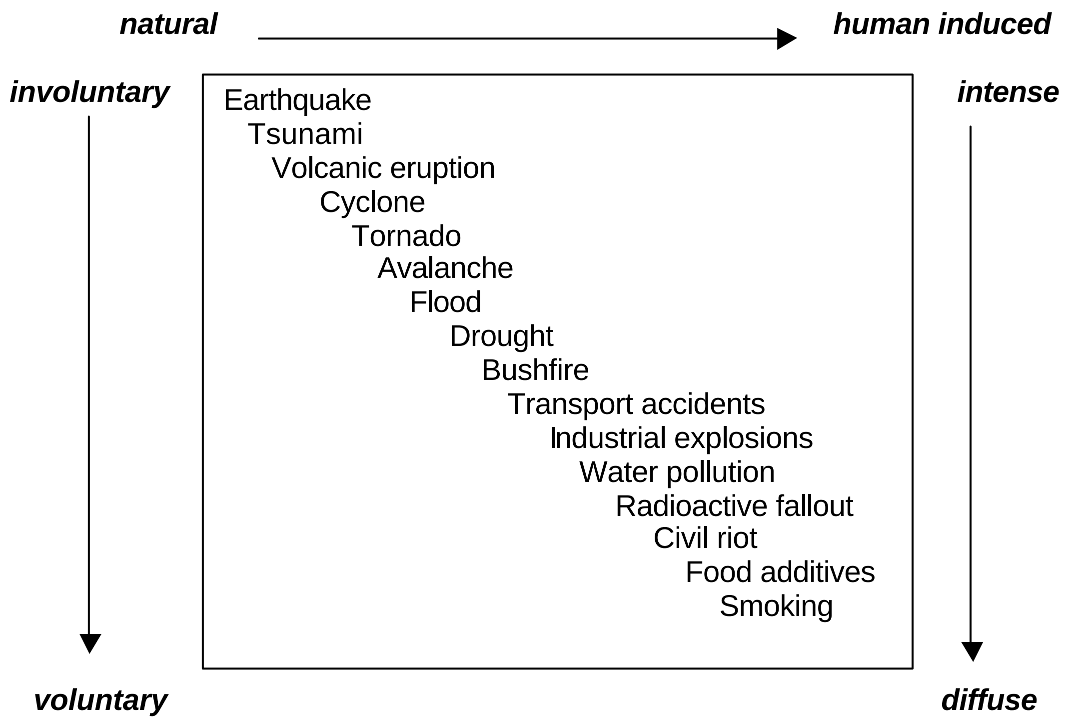
5.2 DEFINING HAZARDS, DISASTERS, LOSS AND DAMAGE ASSESSMENT

A hazard is defined as “a source of potential harm or a situation with a potential to cause loss” (Standards Australia 1999, p60). The impact of a hazard becomes a disaster when it causes a major disruption to the normal function of a society, resulting in losses, and exceeds the affected community's capability to respond (NDMC 1995).

A loss is “any negative consequence, financial or otherwise” (Standards Australia 1999, p60) and can include, but is not limited to, the loss of lives and livelihoods and damage to properties (including buildings), essential services and infrastructure (NDMC 1995).

A hazard event is either human-induced, such as water pollution or a civil riot, or natural, such as a cyclone or an earthquake. An anthropocentric view of hazards is depicted in Figure 1 where natural hazards are referred to as involuntary (people have no control over them) and intense (normally impact a specific area or location). Conversely, human induced hazards are referred to as voluntary (they result from human activity) and diffuse (the area of impact is generally scattered or dispersed).

Figure 1. A spectrum of hazards
(Source: adapted from Smith, 1996)



The Suva event (civil riot) was scattered in nature and resulted from human activity. It is thus referred to as a human induced hazard. Irrespective of whether a hazard event is human induced or natural, when it impacts ***it causes damage***. The degree of damage needs to be assessed and analysed so that damage mitigation measures can be imposed for any future hazard event.

In brief, *damage assessment* can be defined as

> "*The preparation of specific, quantified estimates of physical damage resulting from a disaster, recommendations concerning the repair, reconstruction or replacement of structures, equipment, and the restoration of economic activities"* (NDMC 1995, p x).

The first step in the rapid-damage-assessment survey of the buildings required a field survey of the area approximately coinciding with the CBD (central business district) of Suva. The assessment was performed through a visual examination of each of the damaged buildings according to a pre-determined scheme. The damage was recorded in the field by a degree-of-damage flagging or scoring method, combined with digital photography. The adopted methodology and results are described in the next two sections.

6 METHODOLOGY

Two methodologies were adapted and integrated to formulate a methodology for undertaking the rapid-damage-assessment survey of Suva and applicable analysis techniques. The California based Applied Technology Council's (ATC) sidewalk-survey methodology for rapid visual screening of buildings (for potential seismic hazards, ATC 1988) was adapted to carry out the survey; and the Australia-based damage-index methodology (Blong 1999) was adapted to undertake the analysis. Logically, data analysis commences immediately after the survey is completed. However, the method of data input into the GIS database must be decided before starting the survey so that an appropriate field survey form can be designed (the survey recording sheet is printed in Appendix 1).

6.1 EQUIPMENT AND SOFTWARE

6.1.1 Rapid-Damage-Assessment Survey Equipment

- Rapid-damage-assessment survey recording sheet (see Appendix 1), clipboard, and pen
- Aerial photograph
- Digital camera or ordinary film camera

The following were not required for the Suva damage-assessment survey, but may be required for surveys in other localities:

- Digital video camera
- GPS (Global Positioning System) device (if building locations are not already determined) that also incorporates a data dictionary with the survey recording sheet loaded (if available and if time permits)

6.1.2 Damage Analysis Equipment, Software, and Database

- Digital-camera PC memory card
- Computer running Windows 95/NT or later
- Software
  - MapInfo Professional 5.5 GIS package (version currently used at SOPAC)
  - Discover 3.0, a MapInfo Professional add-on developed by Encom Technology for geoscientists (version currently used at SOPAC)
- MapInfo Databases (available at SOPAC)
  - Pacific Cities GIS database (Suva)
    - ➢ Building-assets (Suva)
    - ➢ City cadastre (Suva)
    - ➢ City orthophotograph (Suva)

6.1.3 GIS Usage

The use of GIS is twofold:

1. Integrating damage-assessment field survey data with the existing building-asset GIS database and displaying the results on a map against available geographically referenced physical data. The latter include cadastral and orthophotograph data.

2. Analysing the assessment data for the purpose of immediate transfer and use in multi-agency response efforts; damage estimation; and future planning, mitigation and management initiatives described further in the analytical techniques below.

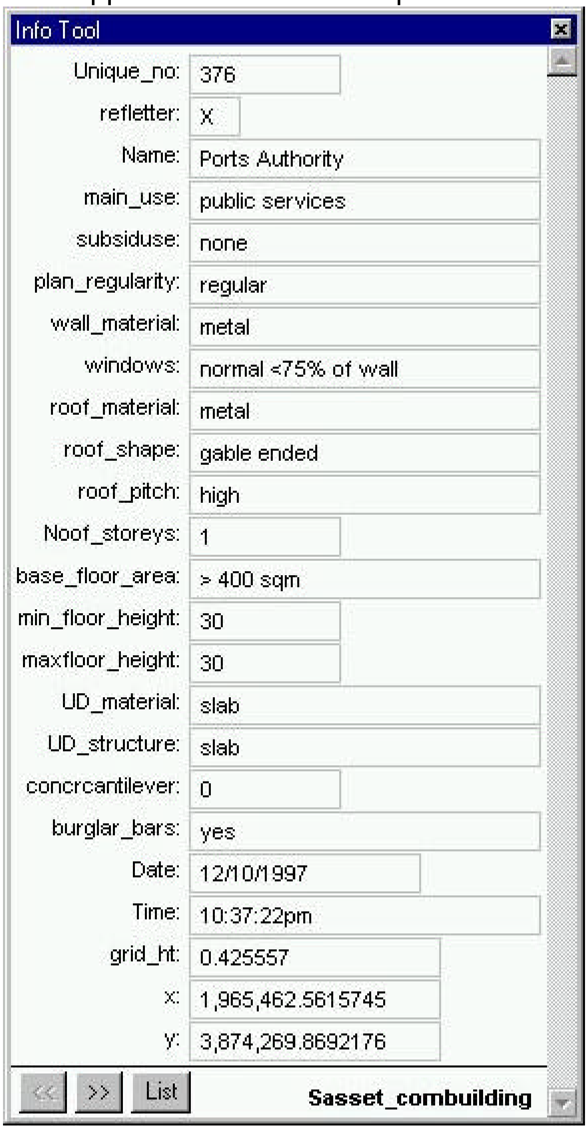
The Suva building assets database (Appendix 2) contains information on each building assessed in a series of Suva building-asset surveys from December 1997 to June 1999. Each building is mapped as an object that is linked to the MapInfo database containing the recorded attributes. For the purposes of this survey the attributes required were:

- building names;
- building use;
- number of storeys;
- wall and roofing material; and
- base floor area.

These attributes and others are listed by using the MapInfo Info Tool, which is depicted in Figure 2. More detailed information on the GIS database can be obtained from the SOPAC Secretariat, Suva, Fiji Islands.

Figure 2. MapInfo Info Tool

The Info Tool displays the tabular attributes of a selected map object. In this case the map object is a building. The attributes listed were collected in the field with the exception of grid height and x and y coordinates, which had been added after the buildings were mapped and located in MapInfo.



6.2 PROCEDURES

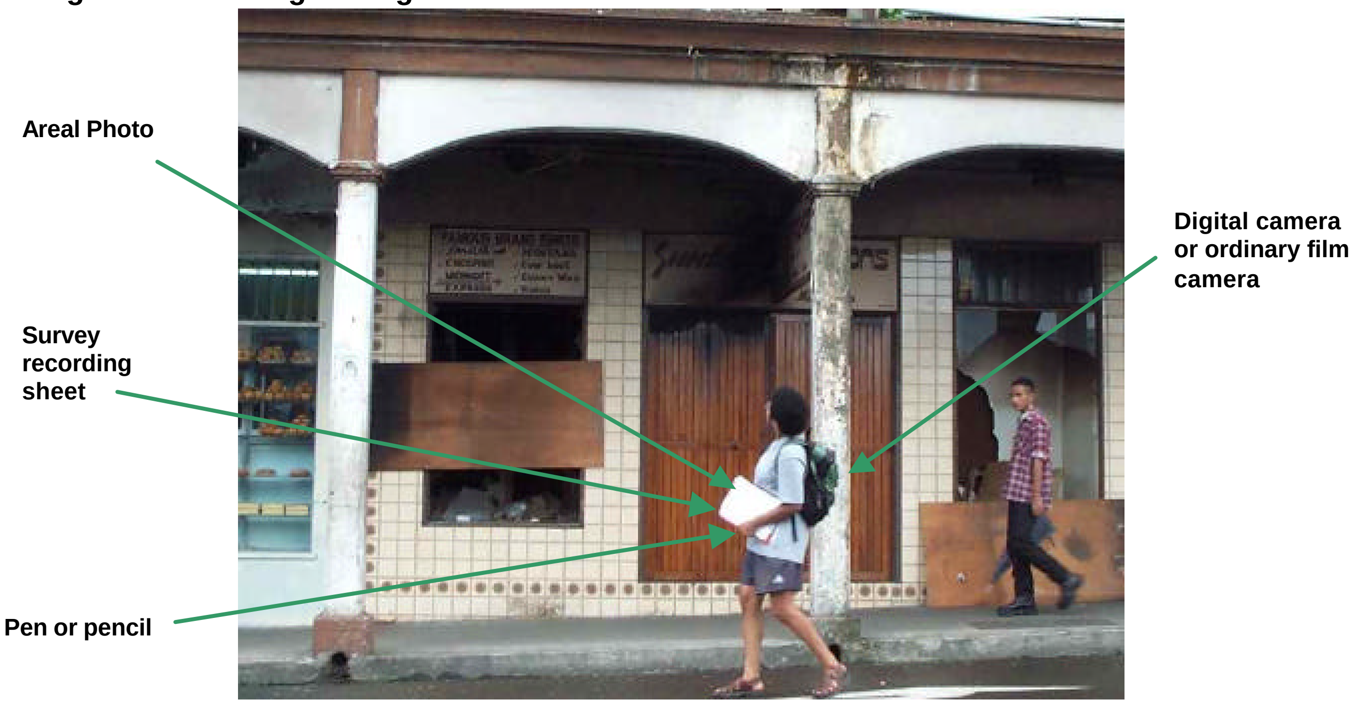
6.2.1 Rapid-Damage-Assessment Survey

It is advantageous to undertake damage assessment survey as soon as it is physically, socially, economically and politically feasible to do so after an event. Note that, even in the lowest-impact events, such as isolated flooding in a city, the damage assessment methodology must be simple, straightforward and easy to perform. If it is too complicated, it will not be used, it may take too long, and even if it is used, it may not provide the timely information to the emergency response agencies and others as it is required.

There are many methodologies for identifying and classifying differing levels and types of damage after an event. One example is the Saffir-Simpson damage-potential scale (Saffir 1974) that classifies hurricane damage on a scale of 1 to 5 in terms of wind speeds, surge heights, and central pressure. Another is the Modified Mercalli Intensity Scale (Wood and Neumann 1931), a descriptive scale which indicates the degree of shaking at a specific location as a result of an earthquake (Sheriff 1991) and can be qualitatively correlated with the degree of damage in an area. A third scale was developed by Leicester and Reardon (1976), that represents an index from 1 to 10 for the repair of non-industrial buildings, where damage results from the impact of a cyclone.

The Applied Technology Council (ATC) devised a method whereby the hazard potential of buildings or building safety can be assessed through systematic rapid visual screening after the impact of a seismic hazard (ATC 1988). Likewise, the damage-assessment survey conducted in Suva involved a swift visual assessment of buildings, particularly useful for downtown and urban areas. What is more, it can be implemented in the event of any hazard event or disaster to identify buildings that might pose a serious risk of loss of life and injury. Visual assessment is usually done at a safe distance from the building being assessed, for example, from the footpath; see Figure 3. With the aid of digital cameras or video cameras, building damage can be recorded and the assessment can be rechecked, cross-correlated and analysed later or back in the office.

Figure 3. Building Damage – Visual Assessment



The same-sidewalk survey approach is used in identifying building materials and assigning a basic structural-hazards flag based on the observed building characteristics. Application of the methodology to seismic hazards identifies buildings that are potentially hazardous and should be analysed by a professional engineer after the initial shock.

Note that one of the main reasons for undertaking the Suva damage-assessment survey and analysis exercise was to demonstrate the relative ease with which local experts could carry out a rapid damage-assessment survey in the event of a disaster.

Damage flags were determined by gauging the extent of damage using several building attributes. The overall damage to the building had to be considered even though most of the shops impacted were located on the ground floor. The building attributes examined included mainly

- windows and size of impacted area;
- wall and roofing material; and
- the integrity of the walls and roofing (that is, degree or extent of damage).

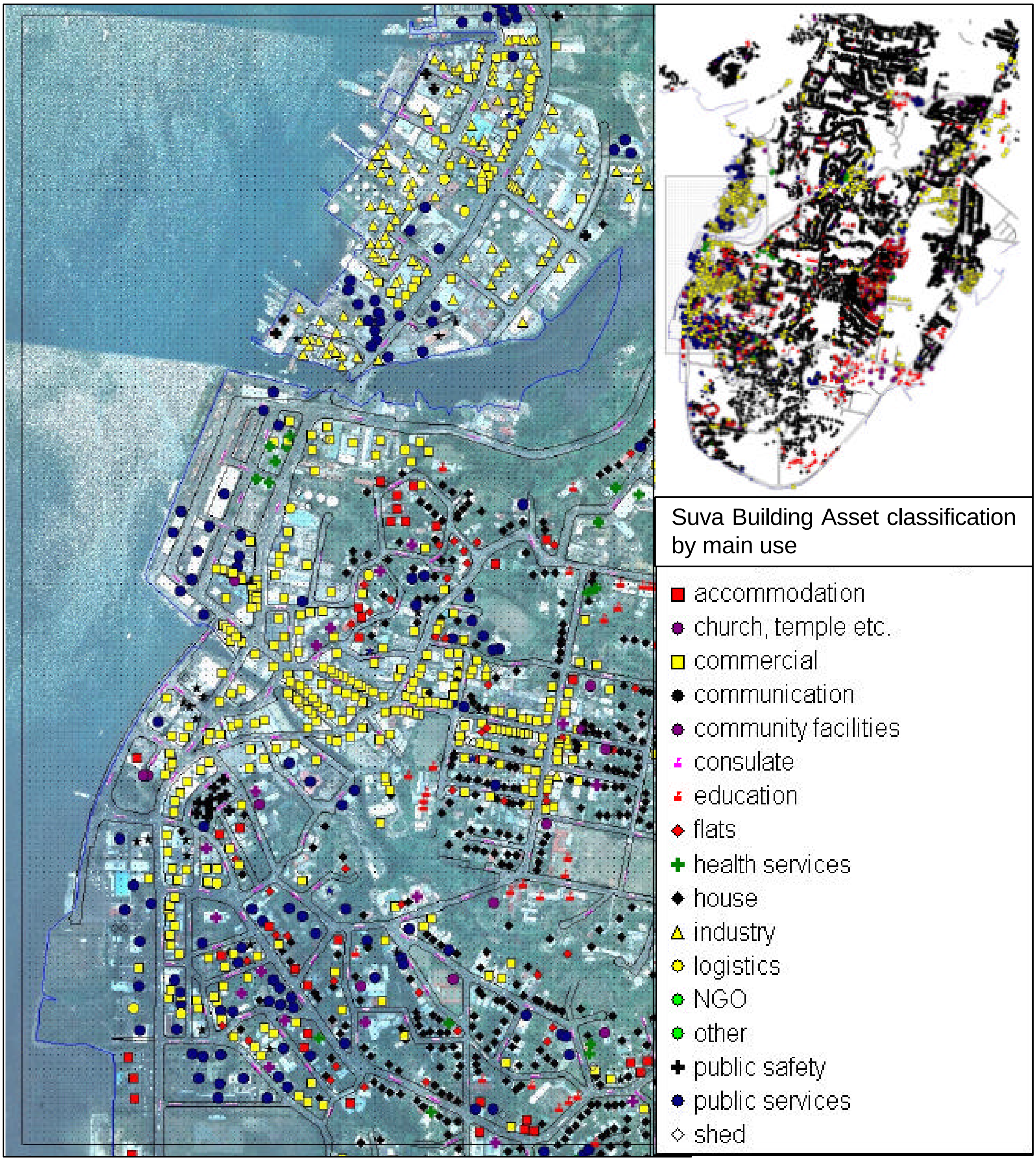
Each damaged building was flagged red, orange or green depending on the extent of damage (see Table 1). Where possible, the damaged buildings were photographed for incorporation into the Suva event database. More than 50% of the damaged buildings, including those most seriously damaged, were photographed.

Table 1. Rapid Damage Assessment flagging criteria.

Damage Flag	Degree of Damage
Green	Damaged glass windows, fittings, or contents loss
Orange	Superficial structural damage
Red	Complete structural damage or fire/smoke damage

The area selected for the survey included most of the CBD and several other selected areas where damage was reported; see Figure 4. Other buildings impacted at a later date have also been incorporated into the Suva event database.

Figure 4. Suva Damage-Assessment Survey Area
Inset is the entire Suva building-assets survey area, showing all buildings assessed, and building usage classification.



6.2.2 Damage-Assessment Analytical Techniques

The adopted damage scale is an adaptation of Blong's (1999) damage index (DI) 1999. The DI was developed for all types of hazards although Blong described only four hazards, that is tropical cyclone, landslide, bushfire and flood. To cater for the event that impacted Suva, rioting and civil unrest were added as an extra field in the damage description table (see Table 2), where it can be cross-correlated with the other hazards listed. The DI scale was constructed in a way such that damage to buildings at various locations and from various events can be compared or summed (Blong 1999). The DI therefore represents a powerful tool that enables comparison of damage to one building with that to another across the city, and also sum the total damage (in terms of a dollar value and an indexed scale). The DI is based on buildings damaged or destroyed and does not include building contents or fixtures, or business and service losses. This is especially relevant in the current study, where quantifying losses of contents or business is not possible by visual inspection alone. Complete quantification may be possible at a later date when loss estimates can be obtained from the insurance industry or private and public assessors. However, as a start, assessing the physical damage to a building is sufficient for the purpose of aiding response agencies, and gaining a quick appreciation of the extent and degree of damage resulting from the event.

The damage flag, which was used to assess damage during the survey, is easily transferable to the DI methodology by converting the flagging criteria to a central damage value (defined below). ATC's flagging criteria are uncomplicated and enable rapid data acquisition for the assessor in the field. To undertake analysis of building damage, each damage flag must be designated a numeric value so that quantitative comparison, summing and other analytical techniques can be applied. Consistent and careful judgement should be used when assigning CDVs (Blong 1999) from the damage flags, and where applicable, field notes and digital photographs should be consulted to aid the process.

Blong's DI methodology is quite simple. It requires that the average construction cost per square metre of an average house in the specified county (in this case Fiji) be determined. It then requires that the cost ratio for each building type be determined. The building types are set by Rawlinsons Classification (Rawlinsons 1999) in broad categories listed in column 1 of Table 2. Rawlinsons' Australian Construction Handbook (1999) lists 1998 building construction costs from selected countries across the globe. Fortunately, Fiji has been included. The Suva asset database was correlated with Rawlinsons Classification by taking the Main Use attributes of the database and classifying them according to the building types outlined by Rawlinsons (see Table 3).

The cost of a building is also defined by Rawlinsons (1999) and is specific to country and building-type. The cost ratio is then calculated by dividing the cost of a specific building by the cost (per square metre) of an average house. The Replacement Ratio (RR) is then calculated; see Equation 1 (adapted from Blong 1999).

Table 2. Central Damage Values (CDV) and descriptions of damage for selected events or disasters
(Adapted from Blong 1999)

CDV	**0.02**	**0.10**	**0.40**	**0.75**	**1.00**
Range	**0.01 - 0.05**	**0.05 - 0.20**	**0.20 - 0.60**	**0.60 – 0.90**	**0.90 – 1.00**
Description	**Light**	**Moderate**	**Heavy**	**Severe**	**Collapse**
Tropical Cyclone	Negligible - missile damage to cladding or windows	Loss of half roof sheeting	Loss of roof structure and some damage to walls	Loss of all walls	Collapse; loss of walls, floor and some floor-support piers on elevated houses
Landslide	Hairline cracks (< 0.1 mm) in walls or structural members	Minor settlement of foundations	Walls out of perpendicular by several degrees; floors inclined or heaved; open cracks in walls	Structure grossly distorted; partition walls and brick in-fill at least partly collapsed; footings lose bearing; service pipes disrupted	Partial/total collapse
Bushfire	Damage in yard around building; garden shed, fences etc; debris in pool	Burning of woodwork at window sills etc; complete interior repaint; new floor coverings required			> 80% of building burnt. Structural collapse
Flood	Under floor-level damage only	Water-depth over floor < 0.3 m or so		Walls holed by floating debris; partial collapse; interior inundated to 1+ m	Building demolished or floats off foundations
Civil Unrest (Riot)	Negligible - missile damage to cladding or windows	Burning of woodwork at window sills; smoke- and fire-related damage through parts of the interior	Loss of roof structure and some damage to walls; > 40% burnt; dangerous to enter	Structure grossly distorted; walls and supports damaged; > 60% burnt; likely to be condemned	Partial and total collapse of building; > 80% burnt; building condemned

Table 3. Building Type correlated with Main Use

Building Type (Rawlinsons Classification 1999)	**Comments**	**Main Use** (Suva Building Assets Database, Appendix 1).	**Comments**
Residential Individual	Includes average of medium and high standard and is defined as 1 HE (House Equivalent)	**House** **Consulate**	Includes all houses 1-3 storey, and all consulates.
Residential multi-units	Includes average of medium and high standard units	**Flats**	Includes all flats 1-5 storey.
Hotel Single storey	Includes all single storey accommodation	**Accommodation**	Includes all single storey accommodation
Hotel Med/High rise 3star	Includes remaining accommodation of 2-9 Stories, and also all grades of hotels	**Accommodation**	Includes remaining accommodation of 2-9 Stories, and also all grades of hotels
Industrial Factory	Has been considered as low cost and the only equivalent listing for Suva "Shed" Main Use attribute	**Shed**	Includes Sheds only
Industrial Factory	Includes all industry buildings Rawlinsons classifies this as type- owner occupier	**Industry**	Includes all industry 1 - 4 storey
Offices 1-2 Storey	(A/C to let)	**Commercial** **Community-Facilities** **Education** **Health Services** **Logistics** **NGO** **Public Safety** **Public Services** **Church temple**	Includes 1- 2 storey commercial, community facilities, education, health services, logistics, NGO, public safety, public services, church temples.
Offices 3 Storey	(A/C & lift)	**Commercial** **Communication** **Education** **Health services** **Logistics** **Public services** **Church temple**	Includes 3 storey commercial, communication, education, health services, logistics, public services, church temple.
Offices 4-10 Storey	(AC & Lift)	**Commercial** **Communication** **Public services**	Includes 4 -10 storey commercial, communication, public services
Offices 10-20 Storey		**Commercial**	Includes 10 - 20 storey commercial

6.2.3 Replacement Ratio Calculation

RR = (Cost Ratio x Total Average Floor Area) ¸ Average Floor Area Per House **[Equation 1]**

The RR is the ratio of an estimate of the cost of replacing a building with the cost of replacing an average-sized house. For example, the RR of an averaged-sized house is 1.0, and a house is worth 1 HE. Therefore, if the RR of a building is 2.0, then the estimated cost of replacing that building is twice the cost of an average house, that is, 2 HEs. Replacement ratios, average floor areas and house equivalents for Fiji are described in the Results section of this report.

6.2.4 Central Damage Values

Once the RR for each building type has been calculated, the damage sustained by the buildings during an event must be quantified. This is done by assigning CDVs to each building that was damaged and has a damage flag (ie, has been assigned a flag colour) through visual inspection. This enables the assessment teams to immediately determine the likelihood of collapse and hazard potential. It is important to understand that the main aim of the rapid building-damage-assessment is to rapidly determine the degree to which the buildings were damaged. This is the most urgent task so that disaster and hazard-response agencies can prioritise and manage their response efforts. (Note that these efforts are likely to succeed the immediate emergency phase of a disaster or event – often up to 24 hours following an event). Once the degree of damage has been assessed, the CDV values are entered into the database and the total Damage [HE] (defined below) to the impacted area is calculated.

The CDV is a quantitative scale that ranges from 0.01 to 1.0, where 0.01 represents light or negligible building damage, and 1.0 represents partial or total collapse of a building. The designated CDV has been adapted from the damage index 1999 (Blong 1999) for damage arising from selected events or disasters; CDVs are listed in Table 2.

6.2.5 Damage [HE] Calculation

Once CDVs have been assigned the Damage [HE] (House Equivalents) can be calculated for a single building of specific type. Any damage to buildings can be expressed as an equivalent to the number of houses totally destroyed, namely, a House Equivalent (Blong 1999). Damage [HE] is calculated as

Damage [HE] = RR x CDV **[Equation 2]**

or for several buildings of the same type, damage can be calculated as

Damage [HE] = No. of Buildings x RR x CDV = Sum of Damage [HE] **[Equation 3]**

In calculating damage with Equation 3, the damage to a building or series of buildings, which has resulted from the impact of a hazard, can be quantified. It can be quantified in terms of HEs or in terms of dollar values. This is useful for assessing and analysing losses resulting from an event and to facilitate the immediate post-event decision-making process, especially for those response agencies requiring logistics information, and response and recovery action plans.

6.2.6 Damage Index (DI) Calculation

For the purposes of comparison of one disaster or hazard event with another, calculations of Damage [HE], that is, the damage to all buildings expressed as damage equivalent to the number of houses totally destroyed, can be expressed in terms of a damage index (DI) (Blong 1999).

The Damage Index represents the HE damage in terms of a logarithm to the base 2 value. For example, 32 HEs (houses totally destroyed) will give a damage index of $\mathbf{Log_2}$ 32 = 5. Thus DI = 5. Note that the total damage would have to be greater than 1 HE so that DI will be greater than 0.0. Since more than 1.04 million HE values would be required to exceed DI = 20, the DI is normally a number ranging from 1 to 20. Representation of DI in terms of a logarithm base 2 was chosen for this reason, that is, to retain a small index value that would represent most events. In the cities of the South Pacific the DI would rarely exceed 10.

Blong states that DI values can be calculated for a location or an event. DI values can also be summed through time to provide an estimate of the total DI (eg, for all tropical cyclones at a place in a specified period). In addition, DI values can be used to estimate the sum of all damage from one or more perils at a place or in an area in a given period. In other words, the damage resulting from the impact of one event can be compared with the damage resulting from another. It also means that damage resulting from multiple hazard events in a specific region (such as Suva City) can be compared (eg, across time) to assess the cumulative damage effects. For the purpose of hazard management and mitigation planning this ability to quantify different degrees of impact is extremely valuable.

The problem with calculating DI values, like that calculated for the Suva event, is that it is assumed that considerable information is available concerning the damage to a building resulting from an event. However, this is not always the case, particularly for natural-hazard events. This is especially so in countries of the South Pacific where sometimes accurate information is either limited or unavailable, or does not exist. A generic damage index has been developed for such cases by using a combination of census data and CDVs (Blong 1999).

Calculating a generic damage index is beyond the scope of this study, but for further development in the area of damage assessment and hazard mitigation it is recommended that this be undertaken. The task should include any event that is documented, but that lacks sufficient building-damage data (eg. historic events such as the Suva 1953 earthquake event). Building damage from one event can then be compared with that of another, and used in future planning and mitigation exercises.

7 RESULTS AND DISCUSSION

7.1 RAPID-BUILDING-DAMAGE-ASSESSMENT SURVEY RESULTS

7.1.1 GIS Database Restructure

To accommodate the new field data, the Suva building-assets database had to be restructured. Data in a GIS exist in a tabulated format. The table structure of the Suva asset database was altered by adding several new fields (columns) for the new data collected. Descriptions of some of these fields are listed below.

7.1.2 New fields

1. ***The assessment survey flagging criteria***
   The results of the survey can be displayed by MapInfo “thematic-map” option, Figure 5a, to show buildings that were severely damaged (red) as opposed to those that were not visibly damaged (black circle). Of the 64 buildings flagged 54 were flagged green, 7 orange and 1 red; see the orthophotograph[2] and flagged buildings in Figure 5b.

2. ***Image directory***
   For viewing images associated with the map objects, the directory in which the image is stored needs to be defined for each map object. The column into which the directory location is entered links the map object to the corresponding defined image. Discover 3.0, a MapInfo add-on, is used to link the survey map objects to the corresponding images. By executing Discover it is possible to locate an image, open it and display it in a new window by reading the directory location. The tool provides a prompt mechanism especially for cross-checking field data in the office. By selecting each map object the user is able to view the damage sustained by that particular building provided directory location has been entered. Furthermore, the visual aid facilitates the transferral of the damage flag (flag colour) to a numerical central damage value directly.

3. ***CDV***
   The column chart depicted in Figure 6a represents a summary of the CDVs assigned to each building assessed in the survey. The CDVs were assigned to the buildings after the damage flags (red/orange/green), field comments and digital photographs were assessed and analysed. A total of 64 buildings were assessed in the survey, with CDVs ranging from 0.02 (negligible damage) to 1.0 (complete destruction). It is interesting to note that the main use of the majority of the buildings damaged in the Suva event was “commercial“; while the remaining were “accommodation” and “public services” (see Figure 6a). There is an inconsistency with the number of buildings assessed in the damage-assessment survey and those assessed by all the insurance agencies combined (well exceeding 100 buildings, pers. comm. Tower Insurance). This inconsistency is discussed further below as a component of calculating the damage. Photographic images showing the CDVs assigned to buildings that sustained different levels of damage can be seen in Figure 6b.

4. ***Damage [HE]*** (described in the analysis results below).

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[2] An orthophotograph is a geometrically corrected aerial photograph of the earth's surface (a birds-eye-view of the earth) that has had distortions due to tilt and relief removed.

Figure 5a. A pop-up display of the burnt interior of Boomerang Duty-free, Union Plaza Building.

A damage flag is assigned to a whole building. Hence, despite 3 of the businesses in the Plaza being burnt, an orange flag was assigned to represent total building damage. The Discover display images button ( ) brings up any images linked to the selected map object.

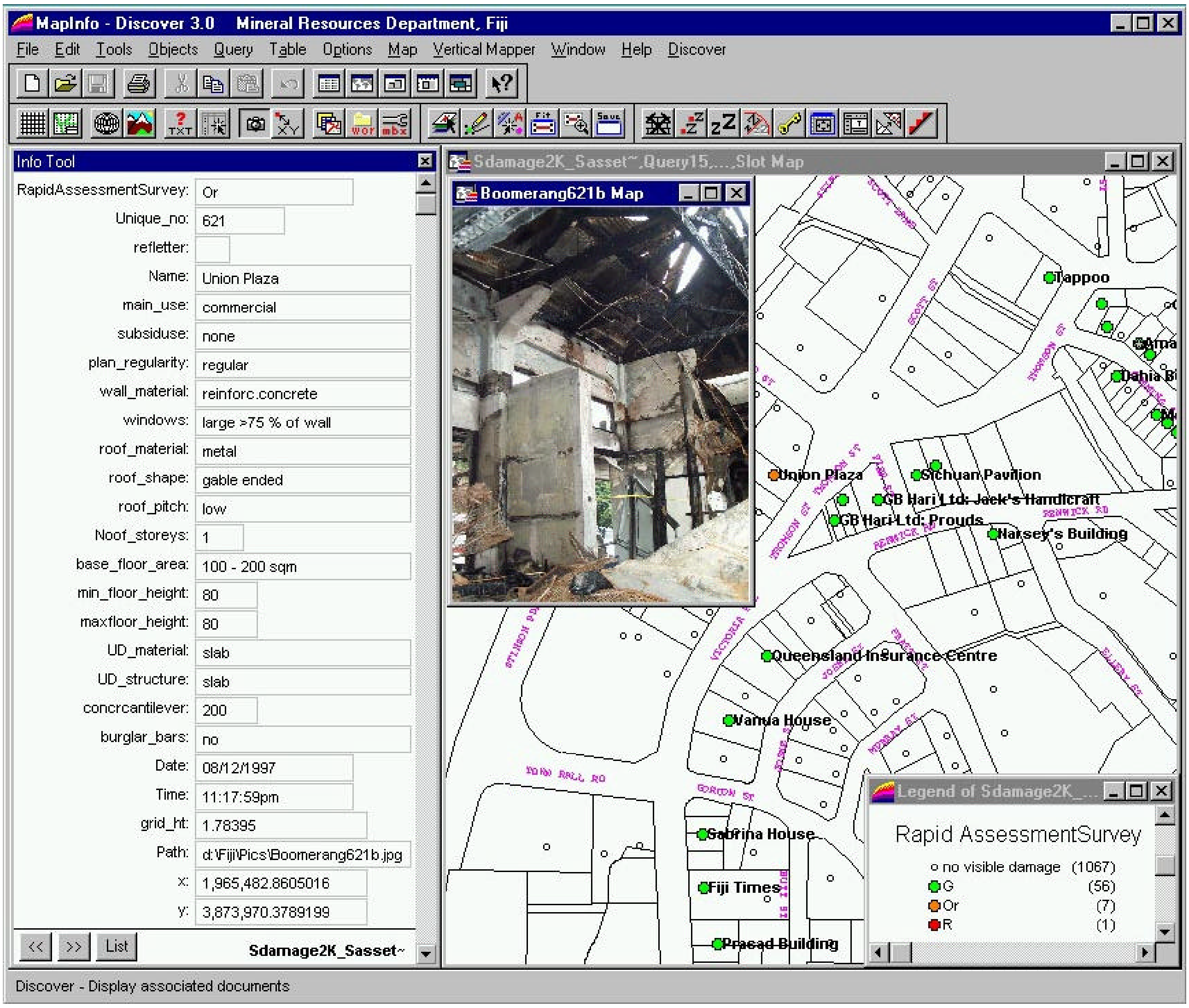


Figure 5b. Suva orthophotograph with damaged buildings assessed and flagged.

Figure 6a. Number of Buildings Assessed and Central Damage Values (CDV).

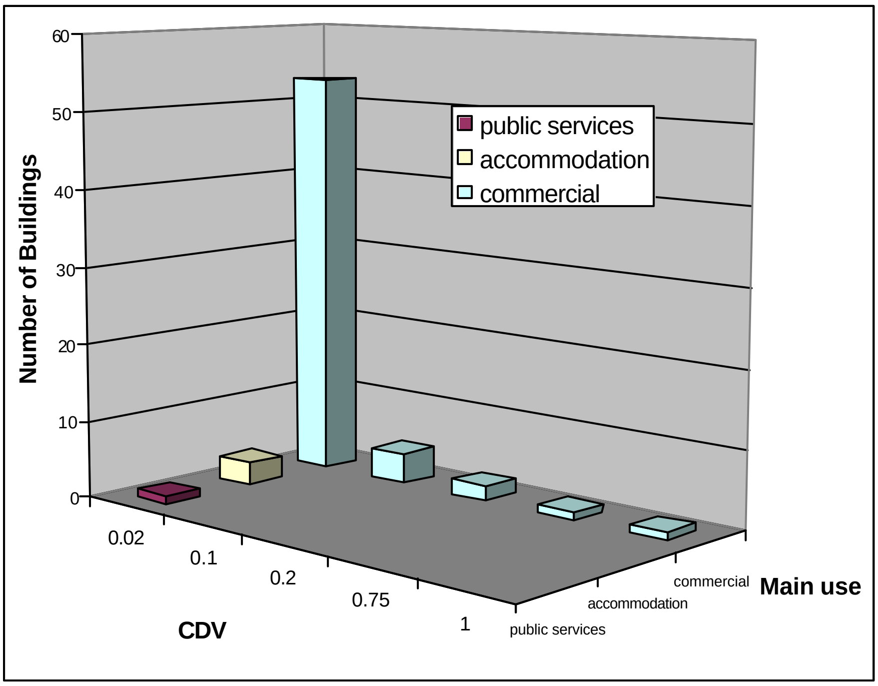


Figure 6b. Central Damage Values (CDVs) Assigned to Damaged Buildings.

CDV	Example
0.02	
0.1	
0.2	
0.75	
1.0	

7.2 DATA ANALYSIS RESULTS

The calculated replacement ratios are listed in Table 4. The values for average cost per m^2 (column 3 of Table 4) are listed in 1998 Fijian Dollars. These were obtained from the Australian Construction Handbook (Rawlinsons 1999). By using MapInfo query selections from Suva building-assets GIS database, each Main Use category (column 2 of Table 4) was grouped into a Rawlinsons Classification category (column 1 of Table 4). These groupings were retained for the remainder of the analysis; a full definition of the grouping categories can be found in Table 2 above. Note that several important factors and assumptions have been made in calculating the RR. These include:

- Not all of Rawlinsons Classification categories are equivalent to the Main Use categories from the Suva building-assets GIS database. For example, the average cost of all 2 to 9 storey "Accommodation" has been equated to the average cost listed for Rawlinsons' medium/high-rise 3 star Hotels. See Table 2 for summary of main use correlated with Rawlinsons building type.

- Rawlinsons' average cost per m^2 for each category was listed in terms of a range, but for ease of calculation, the average value was chosen instead. For example, the average cost of construction of a house was assigned to be F$1000 per m^2, whereas Rawlinsons' costs range from F$650 to F$1850 per m^2.

- The Floor Area for "Residential Individual" is the assigned value for "House Median Area" as required for the calculation of the RR from Blong's damage index (Blong 1999). In our calculations the *average* has been calculated in place of the *median*. The median is the number in the middle of a given set of numbers. Since data from the Suva Building Assets Database are defined in broad groups, the median value will be skewed towards the most dominant value, which in the selected study area is quite low. Thus, to calculate a more representative value for the total area of a house, the average base floor area of all the houses in the selected study area, including houses with 2 and 3 storeys, has been calculated. The final value used in the analysis is defined as the "Average Base Floor Area Per House".

- To simplify the calculation of the average base floor area per house, another major assumption has been made. That is, when the total base floor area per house, including 2^{nd} and 3^{rd} levels (base floor area x number of storeys) has been calculated, it is assumed that the house is symmetric across all levels. This may not be the case in reality; more often than not some levels comprise less or more floor space than the base floor area. The cost that will subsequently be calculated for damage to a house, and thus also for a building, may then be slightly underestimated or inflated. However, when more information is obtained about the shape of the 2^{nd} and 3^{rd} floors of a house, the average floor area per house and other required parameters can be further refined. See Table 5 for summary of calculations.

7.2.1 Calculating Replacement Ratio and Damage [HE]

Once the total average floor area in m^2 has been calculated for each category, the RR is easily calculated using Equation 1 through MapInfo query selections; see column 7 in Table 4 below. Note that the RR for one House, or 1 HE, is 1.0. The RR for a 10 – 20 storey office building is 80.

Once the RR has been calculated, the Damage [HE] for a specific building in the selected study area can be calculated. To demonstrate this, the Damage [HE] is calculated for Yatu Lau Arcade, a single building with a commercial main use (Rawlinsons' Classification Office 1-2 Stories). Yatu Lau Arcade was severely damaged (see Figure 7a, 7b and 7c) by fires during the Suva event. After visual inspection, it was assigned a red damage flag and subsequently a CDV of 0.75 as it most likely suffered greater than 60% damage by fire and is likely to be condemned (demolished) (see Table 3). The RR is 2.2 (from Table 4) and resultant Damage [HE] is calculated to be 2.2 x 0.75 (from Equation 2) which equals 1.65 [HE].

The Damage [HE] can be converted to an approximate monetary value, by using the unit cost of 1 HE. That is for Fiji

1 HE	=	FJD$1000 per m^2, therefore
1.65 HE	=	FJD$1650 per m^2

The floor area of Yatu Lau Arcade is approximately 400 m^2 (obtained from the Suva building-assets GIS database). Thus the total estimated cost of damage to the building only (not including contents, interior fixtures, or business values) is:

Total Est. Cost = FJD$1650 per m^2 x 400 = FJD$660,000

By using the above methodology, the total cost of damage to all buildings, based on HEs, can be calculated. After running the MapInfo GIS query selection calculations in our Suva building assets database, the following was determined:

Total Damage [HE]	=	Sum of Damage [HE]	=	**10.6 [HE]** (Equation 3)
1 HE	=	FJD$1000 x 155 m^2	=	FJD$155,000
Total Damage (FJD$)	=	FJD$155,000 x 10.6	=	**FJD$1,643,620**

According to our calculations the total damage to buildings resulting from the Suva event based on **10.6 HE** values, amounts to **FJD$1,643,620**

The Total Damage value gives a crude indication of the approximate cost of damage to buildings. If accurate data regarding the actual damage values for individual buildings are included in the database and thus in subsequent calculations, then this dollar value could be refined further.

Damage [HE] does not include damage to contents or fixtures or business interruption. If required, values for contents and fixtures damage can normally be obtained directly from the insurance agencies. Business-interruption losses can be much higher than those endured by the direct impact of the event. Blong and Associates (1994) hypothesize that in the USA, every $1 billion of direct losses generates about $1.8 billion of direct business-interruption losses which would in turn produce about $1.35 billion of indirect and induced business losses from lifeline damage alone. Estimated total losses to Yatu Lau Arcade were close to FJD$1 million dollars (pers. comm., Tower Insurance) although the damage calculated in the current study indicates a value of FJD$660,000.

The damage calculations are perhaps slightly underestimated because complete visual inspection (from all angles, inside and out) is not always possible during a rapid-damage-assessment survey. As mentioned earlier, the total number of buildings assessed in the survey was 64 (see Figure 6a) and the insurance agencies assessed more than 100 buildings. This fact may also be contributing to a low estimate for the damage calculation. However, it could also mean that the number of *buildings* damaged was just 64, but that number of businesses effected was greater than 100. In other words, our value is likely to be an appropriate estimation of actual building or structural damage, given the limited data that were collected during the survey. In short, the building-damage calculations shown in this paper are ballpark figures, and provide a good indication of the actual damage expected. After more thorough engineering and structural investigations have been completed, the damage estimation can be refined even further.

The results of the damage assessment are being presented mainly to illustrate how response efforts could be integrated and coordinated in the future for any subsequent events. Damage to buildings (and other structures) resulting from a large earthquake or cyclone could be many times greater than that experienced in the Suva May 19 events. Note, also, that if the damage database resulting from this event is refined, it is likely to prove useful for future planning, mitigation and management.

Table 4. Replacement Ratio Calculation

Building Type (Rawlinsons Classification, Rawlinsons 1999)	**Main Use** (SOPAC's Suva Building Assets Database attributes, i.e. building types)	**Average Cost F$** (per m^2) (1998 prices)	**Cost Ratio** (per m^2)	**Average Base Floor Area** (m^2)	**Total Average Floor Area** (m^2)	**Replacement Ratio** (RR)
Residential Individual	**House** **Consulate**	1000	1	155	155	1.0
Residential multi-units	**Flats** 1 – 5 storey	1213	1.2	252	541	4.2
Hotel Single storey	**Accommodation** 1 storey	1725	1.7	150	150	1.6
Hotel Med/High rise 3star	**Accommodation** 2 – 9 storey	1300	1.3	280	976	8.2
Industrial Factory	**Shed**	550	0.55	201	117	0.4
Industrial Factory	**Industry**	625	0.63	321	508	2.1
Offices 1-2 Storey	**Commercial, Community Facilities, Education, Health Services, Logistics, NGO, Public Safety, Public Services, Church or temple** (all 1 – 2 storey)	875	0.88	273	383	2.2
Offices 3 Storey	**Commercial, Communication, Education, Health services, Logistics, Public services Church temple** (all 3 storey)	1000	1	258	920	5.9
Offices 4-10 Storey	**Commercial Communication Public services** (all 4 – 10 storey)	1425	1.4	378	2055	20
Offices 10-20 Storey	**Commercial** (all 10 – 20 storey)	1550	1.6	500	7500	80

Table 5. Average Base Floor Area Calculation for Building Type Main Use = House

Number of storeys	**Main Use**	**Number of Houses in selected region**	**Av. Base Floor Area Per House (not including 2nd and 3rd level) (m^2)**	**Total Base Floor Area Per House including 2nd and 3rd level, i.e. (Base Floor Area x No. of storeys) (m^2)**	**Total base floor area all houses, ie, (Total Base Floor Area per house x No. of Houses) (m^2)**	**Av. Base Floor Area All Houses (m^2)**	**Average Floor Area Per House (m^2)**
1	House	225	107	107	24,075	47,463	155
2	House	78	136	271	21,138		
3	House	3	250	750	2250		

Figure 7a. Yatu Lau Arcade – A severely Damaged Building

Figure 7b. Burnt Debris Blocks the entrance to Yatu Lau Arcade

Figure 7c. Main Window Yatu Lau Arcade

7.2.2 Damage Index (DI) Calculation and Discussion

The damage index for the Suva event is easily calculated. The estimated total Damage [HE] equals 10.6 HE values and thus the damage index is calculated as follows:

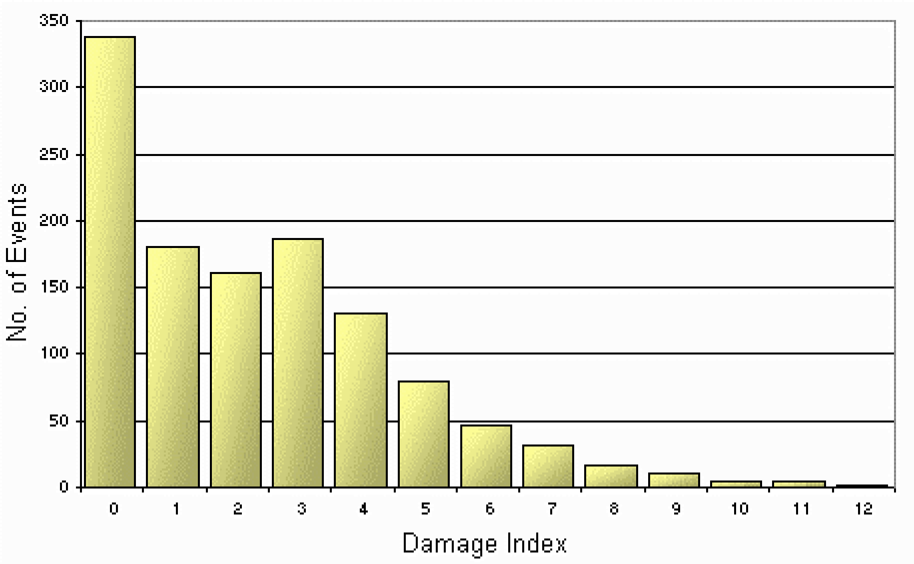
$$DI = \log_2 10.6,$$

$$\mathbf{DI = 3.4}$$

If more information from historical events was collected, then those events could be represented on the damage index or the generic damage index scales. Damage resulting from each event could also be compared geographically, locally and internationally, and analysed over time. For example it would be advantageous for planners and managers to understand further the potential present-day impact of an earthquake equivalent to the 14 September 1953 Suva earthquake and tsunami. This however, would require that a DI be calculated for the historic event.

To compare number of events and degree of damage resulting from multiple events, damage indices calculated for Australian hazard and disaster events have been plotted in Figure 8. DIs were calculated for 1191 events from all parts of Australia for the period 1900 to 1999, and include tropical cyclones, floods, severe thunderstorms, bushfires and earthquakes (Blong 1999). Note that 92% of the indices calculated have DI values less than 7 (equivalent to the complete destruction of just over 120 houses). What is more, approximately 16% of events have a damage index lying between 3 and 4, which is equivalent to the complete destruction of about 10 houses. Although speculative, if the trend in frequency of events of a certain magnitude impacting Fiji were the same as in Australia, then one could expect 16% of events each century completely destroying 10 houses in Fiji.

Figure 8. Frequency Distribution of Australian Damage Indices 1900 - 1999
(Blong 1999 Figure 1)



Looking at the historical Suva earthquake event, the economic damage documented was FJD$500,000 in 1953 dollars (MRD 1986, Houtz 1962). This approximates to FJD$1,705,000 in 2000 (this is an adjustment for inflation of the Fijian dollar at 3% per annum, and does not include an adjustment in housing and construction cost and style changes or other costs related to the earthquake impact). Due to changing trends of construction and pricing variations, the economic damage resulting from an earthquake of this magnitude today is likely to be many times that quoted in 1953. The damage to bridges, wharves, water supply installations, and buildings resulting from the 1953 earthquake was restricted to the South coast from Navua to Nausori (Houtz 1962). The loss of lives included two persons being killed outright by the earthquake, one by a landslide near Navua and another by falling masonry in Suva. A third person died later of injuries; three people were drowned in Suva as a result of the tsunami and two more on Kadavu (Houtz 1962).

The population of Suva City and peri-urban areas in 1953 was 35,000 (Houtz 1962). In the 1996 Fiji Census the population of Suva City was documented to be 90,609 (Bureau of Statistics 1998), with a further 15,873 in the urban and peri-urban areas of Nausori. If an earthquake similar in magnitude and aerial extent to the 1953 event impacted Suva today, then the population affected would be more than three times greater than the 1953 population. One could speculate that in the absence of improvement in building standards and city planning, the damage and loss of life could also be threefold. However, it is difficult to estimate potential losses without running a full event-scenario analysis.

8 CONCLUSIONS AND RECOMMENDATIONS

8.1 CONCLUSIONS

The rapid building-damage-assessment survey used a flagging method to represent the degree of damage sustained by buildings in the Suva riots. These damage flags were converted to central damage values (CDVs), numbers lying in the range 0.01 to 1.0. A total of 64 buildings were assessed in the central business district of Suva. Of the buildings assessed, 89% were assigned a CDV of 0.02, which is equivalent to negligible damage arising from missile damage to cladding and windows. Nine percent of the assessed buildings were assigned a CDV of 0.1 and 0.2, which is equivalent to moderate damage including fire damage and damage to the interior. Two percent of buildings suffered severe damage from burning. The fires grossly distorted those building structures and a few buildings collapsed completely. These buildings were assigned a CDV of 0.75 and 1.0. In disasters that have a magnitude of impact similar to the Suva event (diffuse in nature) it is expected that the majority of damaged buildings would lie at the low end of the damage scale, whilst the number of severely damaged and collapsed buildings is much less. The profile of damage (CDVs) presented is thus as expected.

Digital photographs were also taken and integrated into the Suva building-assets database. The ease of data analysis through applications in a GIS Database was illustrated through the use of pop-up pictures and descriptions. It has been emphasized that timely provision of damage assessment and analysis information provided to disaster response agencies is pertinent for enabling a swift and coordinated approach to multi-agency response after the impact of a hazard event or disaster. It is for this reason that the damage assessment information was presented in GIS map format, summary bar charts, and total damage loss estimates. Total damage was calculated in economic terms, using an adapted methodology whereby the number of house equivalents [HEs] (equal to the total number of houses completely destroyed) is converted to a value of economic loss. Through undertaking the rapid-building-damage-assessment survey and data analysis, it became clear that the ease of data acquisition and analysis is paramount to successfully incorporating the methodology into the agenda of response, mitigation, management and planning agencies.

The Damage [HE] was estimated to be 10.6 House Equivalent values with a total economic loss of FJD$1,643,620. The damage index (DI) was calculated to be 3.4 (equivalent to 10.6 houses completely destroyed). The damage index allows this event to be compared directly with any other hazard event. This information provides a timely opportunity to start categorizing past events, determining frequency and magnitude of impact and planning for future events.

It was shown that of all events impacting Australia over the past century 16% were equivalent in magnitude (DI = 3 to 4) to the Suva event (riot). The Suva event is considered to be a serious disaster in terms of total population affected, economic losses and other long-term environmental and social effects. A larger event impacting Suva, or any other city or community in the Pacific, could prove to be catastrophic.

A local event of historic significance was the Suva 1953 earthquake. An event pilot study has been attempted by some researchers such as Rynn (1997) and Prasad et al. (2000) in the Suva Earthquake Risk Management Scenario Pilot Project (SERMP). The SERMP presents many facets of hazard- and disaster-management issues, especially with respect to coordination of agencies during the emergency response period. It became apparent that lack of disaster preparedness and coordination between agencies would pose a major problem in any future event of the same scale or larger. Nevertheless, as a result of the current study it is suggested that by using GIS and quantitative analysis techniques to undertake an event scenario analysis, a damage index could be calculated for the historic Suva earthquake event. This in turn would provide a platform for comparing historical events with present or future probable events. Provision of this information to city planners, disaster managers, response agencies and others would facilitate a pro-active approach to hazard mitigation and disaster response planning. Furthermore, the results of this exercise could provide the necessary background or blueprint for hazard mitigation and disaster response planning in other Pacific countries.

Finally, if information from other agencies regarding damage estimates were to be incorporated into the GIS database, a more refined tool for future hazard mitigation and response activities would be provided. If a rapid-damage-assessment survey can be conducted immediately after an event through a multi-agency effort, then these agencies would be more accurately informed and their response efforts and decision-making ability would be enhanced. They would have more accurate mapping and planning tools, which they could use during the response and rebuilding phase after an event. Agencies would also be able to use the information and data for planning and mitigation of any future event. Recommendations have been listed below.

8.2 RECOMMENDATIONS

1. Encourage communication and cooperation between agencies and convey and assert the benefits of multi-agency response efforts through the presentation of this study in a meeting with the insurance industry, national and local governments, police and emergency services, and others.

2. Calculate a damage index for all documented disasters and hazards that have impacted Suva (such as the 14 September 1953 earthquake) and other major population centres in the Pacific, so that further development in the area of damage assessment and hazard mitigation can be accomplished. Building damage from one event can then be compared with that of another, and used in future planning and mitigation exercises.

3. Undertake a GIS damage-assessment and event scenario analysis of the 1953 earthquake so that a damage index (DI) value can be determined for that event.

4. Crosscheck central damage values (CDVs) and economic damage with other agencies (eg, insurance agencies, police departments, etc) so that the Suva buildings-assets GIS database can be refined.

5. Develop documentation of the damage assessment survey technique for use by any agency after any hazard event.

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APPENDIX 1 Rapid Damage Assessment Survey Recording Sheet

Ref Letter	Degree of Damage (R, Or, G)	Photo No.	Building Name and Business Name	Comment E.g. type of damage, number of floors impacted, windows smashed, fire, etc.

APPENDIX 2 Core Metadata elements regarding the spatial datasets used in the Suva Building Damage Assessment

MetaUID	**Sasset**	**Sroad, Slots**	**FMGSuva**
Dataset_Title	Suva Building Asset database	Suva cadastral	Suva orthophtograph
Dataset_Custodian	SOPAC	FLICC	SOPAC
Description_Abstact	Asset survey	Suva road and cadastre	Orthophotograph of West Suva Harbour
Description_Projection	FMG (WGS72)	FMG (WGS72)	FMG (WGS72)
Description_Scale	Not entered	Not entered	Not entered
Description_Northbc	3,877,904.83	3,877,774.00	3878569.10
Description_Southbc	3,871,065.62	3,871,141.02	3872782.30
Description_Eastbc	1,970,207.85	1,970,003.76	1967253.10
Description_Westbc	1,964,911.33	1,965,146.16	1964967.00
Currency_Begin_Date	November 1997	Not entered	Date/Time
Currency_End_Date	June 1999	Not entered	Date/Time
Status_Progress	complete	complete	Text
Status_Maint_Update	Not entered	Not entered	Not entered
Quality_Lineage	Not entered	Not entered	Incomplete
Quality_Pos_Accuracy	Not entered	Not entered	0.3m
Quality_Attrib_Accuracy	Not entered	Not entered	Not entered
Quality_Logical_Consistency	Not entered	Not entered	Not entered
Quality_Completeness	Not entered	Not entered	Not entered
Metadata_date	Incomplete	Incomplete	Incomplete