Temporal and building use implications on earthquake risk evaluation

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ABSTRACT: In addition to ongoing direct loss evaluation due to earthquake and other natural hazard perils, GNS Science has refined its loss modelling capability to take account of a comprehensive building use classification system and introduced the ability of the models to accommodate both seasonal and temporal variations when locating people. This paper describes the details of the hierarchy used to classify and group buildings according to use, importance and type, with direct implications as to replacement cost for structure, architectural components, fitout, stock and contents. The baseline census distribution of people used for night-time occupancy of residential buildings requires to be distributed between buildings and open spaces depending on the day-time, transit time or leisure time activities. The risk of injury to people in close proximity to damaged or collapsed buildings is recognised as a function of the number of people present within such spaces and the potential loss of hazardous material or cladding from the adjacent building. People in transit by road, rail or walking are considered and correction multipliers applied. The need for better base-line survey data is discussed along with the limitations implicit in the level of detail available as to building vulnerability both the structure and the people and property contained therein.

1 INTRODUCTION

The art of modelling the risk to communities from earthquake has evolved markedly over the past 25 years to the point where models relating to direct losses are routinely used and compared for setting insurance premiums by insurers and reinsurers. The modelling of other natural perils such as flood and tropical cyclone have developed strongly over this period to the point where they too have vendor models that are used by the insurance industry to enable them to understand their risk profiles and exposure within their respective regions. Tsunami and volcanic perils remain somewhat behind in their modelling refinement, but are now the focus of considerable effort and good progress is being made for them also.

Models typically require three input components, namely a) a suite of peril layers that portray the geographic distribution of intensity for each event (with its associated source location, magnitude and recurrence and attenuation model), b) the exposure portfolio for which the losses are to be derived (ideally with the location and the attributes of each entry sufficient to assign assets to their respective typology); c) a suite of vulnerability functions that establish the damage (or loss) distribution expected from each asset typology when subjected to specific peril intensity actions. For insurance models, it is the direct replacement cost that is of primary interest (although the damage state and associated outage time for business interruption evaluation is also recognised). However, as loss modelling has become more accessible, a range of other agencies have also developed both the interest and the skills necessary to use modelling techniques for both response planning and evaluation of mitigation efforts.

While each of the above components is equally important, understanding and quantifying the assets exposed within our communities is, perhaps surprisingly, the least well prescribed and is the primary topic of this paper.

2 RISKSCAPE

2.1 The Model

Within New Zealand, GNS Science and NIWA have been developing the RiskScape (1) model under contract from the research arm of the Ministry for Business Innovation and Economy MBIE (formerly the Foundation for Research Science and Technology). From its inception it was recognised that RiskScape would provide the connection between the peril models developed within the two CRI's (and others) and an array of various end-user groups such as the Territorial Authorities (for response planning and land-use risk evaluation); various central government departments (including Treasury (intrinsic liability), MfE (land use planning and risk reduction), MBIE (Building Controls and Risk Mitigation strategy development - especially Earthquake Prone Building evaluation); MCDEM (for emergency response planning and disaster response implementation); Ministry of Health (post disaster response planning); ACC (Post Disaster Risk transfer and planning); Insurance Industry (acceptance of risk levels, setting of premiums) to name but a few.

This diversity of end-users brings with it a wide range of user skills and knowledge and a similar wide range of expectations as to the results and their associated reporting expectations. Thus while some users retain the direct loss focus, others are interested in projections about people (casualties and injury characteristics), and post-event response strategies, while an increasingly large sector have a risk reduction focus and are interested in the effectiveness of alternative risk reduction strategies. The RiskScape model attempts to meet each of these end-user needs with the user interface being developed around 'simple selection' both for input options and results delivery.

2.2 Asset Exposure Data Repository

Perhaps one of the greatest surprises the RiskScape development team faced as they embarked on the development of the platform was the lack of knowledge across New Zealand of our assets and the built environment we have created. Where things are, what they are, and even a few of their key attributes are not generally known and are proving difficult to acquire. In some cases the knowledge is retained within the agencies with responsibility for particular assets (water supply and waste water facilities being two such items). In other cases there is a sensitivity that the knowledge is 'confidential' (either for commercial or security reasons), while in others the knowledge is simply unavailable (being either in hard-copy archives or simply 'lost'). Even when it is available it is seldom complete and often missing key attributes that are needed to guide the assignment of fragility or vulnerability functions. While this is the case for fixed assets, the situation is even further clouded with mobile 'assets' such as people, vehicles, and commercial stock, the locations of which vary with the time of the day, the season and normal behavioural characteristics (i.e. work-day or leisure day).

So, being faced with this deficiency the RiskScape team set about creating its own purpose-built asset repository that could provide the specific data for the particular risk evaluation. This was done with the knowledge that other countries (US, Australia, Taiwan, Japan and Europe – each of whom have larger and more complex communities than we in NZ) have overcome these issues and have well defined natural hazard risk models with which to model probable loss and impacts of natural hazards and are using these to inform their respective decision makers as we were seeking to do in NZ.

The specification for the repository required that it be capable of the following:

1. GIS display and editing capability.
2. Accepting both point locations (e.g. buildings, bridges) and line elements (e.g. pipes, roads, cables).
3. Accept and retrieve asset data captured in differing formats (e.g. .pdf, .jpg, csv, .shp).
4. Be secure when necessary (in the control of the data supplier).
5. Be expandable both as to number of entries and attributes stored.
6. Be capable of both upload and download of data to approved field observational tools.

7. Accepting crowd-sourced data (with appropriate administrative controls).
8. Interface with a variety of end-user specific applications (risk evaluation, asset safety evaluation, asset condition evaluation, etc.).

This resulted in a repository that accepts the following general classes of assets:

- Buildings: Fixed location; 240 typologies, primarily sourced from Quotable Value subsidiary PropertyIQ but with TA supplement (2.5M entries); Variable (moderate) reliability; Occupancy Use Classification;
- Infrastructure: linear networks (pipes, cables, roads, etc.) with fixed point nodes (pump stations, junction points; switch yards, etc.); At/above/below ground; Direct replacement and community resilience components; sourced utility operator (sensitive)
- Land-use plots: polygon based land-use derivatives of agricultural and forestry use, open space use, public and private
- People: Mobile locations; varying adaptive capability (demographic characteristics); Sourced Statistics Department (census and workplace), Ministry of Education;
- Vehicles: Mobile locations – passenger and freight;

2.3 Risk Applications

The same broad categories of risk application identified by the RiskScape developers was damage that resulted in a) direct costs associated either with replacement or reinstatement, b) service disruption (often affecting the broader community) c) casualty, death and/or displacement of people, d) indirect costs associated with business and community disruption the scale of which is strongly influenced by the intrinsic resilience of the community generally established prior to an event.

Loss modelling relies strongly on segmenting the assets exposed in a community into similar typologies and considering the overall behaviour of each grouping when deriving their damage and losses. While this eliminates the option of evaluating specific asset behaviour (unless considerable detail and analysis have been employed on that particular asset), it enables statistics to be employed both to understand the behaviour of the asset group and also the distribution of the response of different asset types.

3 GROUPING ASSETS

3.1 Defining Use Categories

For deriving direct losses, the replacement cost remains the most appropriate metric. To allow for different building styles and performance demands, the Occupancy Use Category provides an appropriate costing basis. The Use Categories used in RiskScape have recently been revised and can now be aggregated first to a sector level and then to a group level as indicated in Table 1. Filters are available within RiskScape that permit the loss and damage projects of one or more sectors and one or more groups to be evaluated should this need arise. Thus, for example, only the emergency response sector could be evaluated for damage state or to enable testing of various mitigation strengthening or isolation methods (through the use of enhanced modified vulnerability functions).

Table 1. Occupancy Use Categories (used for Risk Evaluation).

Group	Sector	Use Categories
Essential Services	Emergency	Police; Fire; Ambulance; Civil Defence; Military;
	Utility	Communications (phone; radio, TV; data); Electricity; Gas; Water; Fuel; Finance
	Healthcare	Hospital; Clinic; Pharmacy; Resthome; Vet
	Transport	Airport; Rail; Road; Sea/River (Major facilities only)
	Governance	National, Local; Institutional
Community	Accommodation	Housing; Village unit; Apartment; Hotel; Motel; Hostel; Outbuildings
	Education	Pre-school; Primary; Secondary; Tertiary
	Civic	Cultural; Civic hall; Community halls; Library; Marae; Museum; Monument; Religious
Business	Commercial	Office; Retail (shops); Mall (general); Mall (food); Parking; Finance; Wholesale; Vehicle sales
	Industrial	Manufacturing; Warehouse/storage; Servicing; Mining; Energy; Repair/maintenance; Packaging
	Agricultural	Livestock (dairy/sheep/beef/pig/horse/others); Crops (in Ground); Crops (above ground) Fruit; Forestry; Vegetable; Horticulture
Lifestyle	Entertainment	Bars; Fast food; Gaming; Restaurant; Theatre; Cinema
	Recreation	Sport facility; Stadium; Pools; Camping
	Open Spaces	Playground; Carpark; Reserve; Building site; Beach; Street (CBD; industrial; residential; rural); Forest
	Other	Other

3.2 Application of Use Categories

The subdivision of use categories outlined in Table 1 assists in the application of risk and loss assessments in each of the following:

a) Identification of Essential Services: The location and evaluated damage expectations for each of the essential services listed enables the potential weak links in critical facility providers to be identified, and the prioritisation of appropriate mitigation measures to be evaluated. For such facilities the lack of post-event functionality is often of greater concern than repair costs since the community response is usually highly dependent on access and application of these services in times of crisis.

b) Community Facilities: The three sectors covered within this group (accommodation, education and civic) are diverse and intended to cover those facilities necessary to enable the community to continue to function (at a base level) along with the essential services.

c) Occupancy Rates: The variation in occupancy with time and season are based on census distributions (for night accommodation) and day/transit for both workday and leisure being described below. Links have been developed between each use category specified in Table 1 and their associated industrial sector that permits daytime occupancy rates to be derived from employment, educational and institutional occupancy statistics. Pedestrian and tourism counts will be used to redistribute a portion of those to open spaces when appropriate.

d) Replacement costs: The direct material damage costs resulting from natural hazard events are a combination of the replacement/reinstatement of the structural (load-bearing) components (25~30%), the architectural (claddings, windows, doors, partitions, ceilings and fit-out) components (30~50%), the services (H&V, lifts, electrical, communication and data networks

15~25%), the plant and equipment, the contents and stock value. The risk model uses unit rates based on floor area to arrive at replacement costs for buildings and, where no better valuations are available, attempts to evaluate plant, equipment, stock and contents as a proportion of building cost depending on occupancy type (these latter sometimes being between 100 and 200% of the building value). The range of unit costs of reconstruction for each of the different occupancy classes shown in Table 1 are read into the RiskScape model for both standard and superior quality construction and used to determine replacement costs. Users can edit the rates if they wish and they will be adjusted periodically to reflect market trends.

4 LOCATING PEOPLE

4.1 Assigning people to buildings and open spaces

Different loss computations require different input data. So for losses involving people (casualty/injury) and response (displacement and community disruption) the location of people across the community at the time of an event is required. Since the source of people data is primarily through the 5-yearly census data it establishes the total number of people within each region and is applicable for their night location (at home or in accommodation).

To establish the daytime population distribution for a ‘typical working day’ some people are moved from their night location to either a) their daytime workplace (office, school, retail, industrial); b) their leisure pursuits location (often involving shopping or recreation) or c) places them ‘in transit’ (mostly road transport but also airport, rail terminals).

For evening distributions, shops, cinema, restaurant, bar and event centres attract people from their places of residence and from their workplace in different proportions.

The model developed extracts the following input parameters from the following sources:

1. Establish the total population present within an area (typically a regional authority boundary zone) from census data.
2. Establish the building areas for each of the use categories of interest by interrogation of the building asset repository (a matrix of number of buildings and m^2 for use categories)
3. Establish the open-space area assignments from map or GIS interrogation (m^2 by open-space type categories). Examples of the open-space categories are given in Table 2.

The above input provides data which is ingested into the model in order to assign people to their appropriate building location by:

1. Establishing the night-time occupancy density from population present within an area (from Statistics Department census) and sum of accommodation space available -> people / m^2 accommodation class buildings.
2. Establishing daytime occupancy density from workers per industrial sector statistics and footprint area per sector within each area; with user-prescribed open-space proportion (for both residential and non-residential occupancies; with the balance remaining in their residential buildings. Non-workers like school pupils and hospital patients are included.
3. Establishing the evening occupancy density by using the hospitality workplace classification and a host to patron proportion to establish the total number of people within this sector and a proportion of night-workers.
4. Establishing the leisure-time distribution by considering beach and recreational open-space survey data or judgement with user-adjustments based on region specific experience.

5. Establishing the anticipated population distribution during events for which warnings are possible (floods; tsunami; severe wind) in which cases ‘normal’ use population distributions will be severely distorted. (Note this aspect is still work in progress but is allowed within the model when better data as to warning effectiveness becomes available.)

Table 2. Open space classes (with maximum occupancy rates)
(refer Cousins 2015 for further details and sources)

Class	Maximum Occupancy Rate (persons/km^2)	Area per Person (m^2)	Description (with examples)
Wilderness Low	0.01	100,000,000	Wilderness (Fiordland, Southern Alps)
Wilderness High	0.1	10,000,000	Wilderness (Rimutaka, Tararua Range)
Park Low	1	1,000,000	Forest park (Orongorongo)
Park Medium	10	100,000	Park (regional park with a few high-use trails)
Park High	33	30,303	Park (special character) (bike park, Regional Park)
Mixed Low	100	10,000	Park/playground/sport, large (> 5 Ha)
Mixed High	1000	1,000	Park/playground/sport, small (0.5 to 5 Ha)
Playground	10,000	100	Playground (< 0.5 Ha)
Cemetery	33	30,303	Cemetery
Golf	330	3,030	Golf course
Garden	3300	303	Botanical/zoological gardens
Sport Low	1000	1,000	Field sports (schools or adult) (rugby, league, soccer)
Sport Medium	5000	200	Field sports (schools or adult) (bowls, croquet)
Sport High	25,000	40	Netball arena (Kilbirnie)
Farm Low	0.2	5,000,000	Sheep Farm (QV classes PF, PG, PR, PS) (1 person per 500 Ha)
Farm Medium	2	500,000	Dairy Farm (QV classes DF, AI, AN)
Farm High	20	50,000	Specialist Farm (QV classes SD, SH, SP, SS)
Forestry	0.2	5,000,000	Forestry (all QV classes) (1 person per 500 Ha)
Lifestyle	20	50,000	Lifestyle (all QV classes) (1 person per 5 Ha)
Horticulture	100	10,000	Horticulture (all QV classes) (1 person per Ha)
Mining	100	10,000	Mining (all QV classes) (1 person per Ha)
Aquaculture	200	5,000	Specialist (QV class SA) (2 person per Ha)

Each open-space category has been assigned a maximum occupancy rate, as per Table 2. For use in RiskScape, a user decides on a temporal scenario of interest, and develops a set of relative occupancy multipliers to suit the scenario. The RiskScape software used the product of maximum rate and relative multiplier to assign people to the open spaces. Some default sets of relative multipliers are listed in Table 3.

Table 3. Relative occupancy multipliers for some temporal scenarios
(refer Cousins 2015 for further details and sources)

Open Space Class	Winter Night	Summer Night	Winter Workday	Summer Workday	Winter Weekend Day	Summer Weekend Day	Com mute
Wilderness Low	0.0001	0.001	0.01	0.1	0.5	1	0.03
Wilderness High	0.0001	0.001	0.01	0.1	0.5	1	0.03
Park Low	0.0001	0.001	0.01	0.1	0.5	1	0.03
Park Medium	0.0001	0.001	0.01	0.1	0.5	1	0.03
Park High	0.0001	0.001	0.01	0.1	0.5	1	0.03
Playground	0.0001	0.001	0.1	0.5	0.5	1	0.1
Cemetery	0.0001	0.001	0.2	0.5	0.5	1	0.1
Golf	0.0001	0.001	0.2	0.5	0.5	1	0.1
Garden	0.0001	0.001	0.2	0.5	0.5	1	0.1
Sport Low	0.0001	0.001	0.3	0.5	0.5	1	0.1
Sport Medium	0.0001	0.001	0.3	0.5	0.5	1	0.1
Sport High	0.0001	0.001	0.3	0.5	0.5	1	0.1
Farm Low	0.0001	0.001	1	1	0.1	0.1	0.01
Farm Medium	0.0001	0.001	1	1	0.1	0.1	0.01
Farm High	0.0001	0.001	1	1	0.1	0.1	0.01
Forestry	0.0001	0.001	1	1	0.1	0.1	0.01
Lifestyle	0.0001	0.001	1	1	1	1	0.01
Feeder Road	0.01	0.01	0.1	0.1	0.1	0.1	0.6
Beach Low	0.001	0.01	0.01	0.1	0.5	1	0.03
Beach Medium	0.001	0.01	0.01	0.1	0.5	1	0.03
Beach High	0.001	0.01	0.01	0.1	0.5	1	0.03

With people located for a particular temporal period, RiskScape engages the casualty derivative function to generate the casualty assessments for people within buildings. For those outside buildings, a Open-Space casualty vulnerability functions have been developed for people within built-up areas during earthquakes. They are driven from the characteristics of the nearest building and they cover the fall of brittle chimneys, the fall of larger brittle objects like weak brick walls, parapets, gables and other architectural ornaments, and the fall of glass from tall buildings. Casualty functions are also developed for the impact on people in buildings of violently moving contents, again due to earthquake shaking. All of the new functions are calibrated to a degree by application to historical earthquakes, such as Wairarapa 1942, Darfield 2010, and Christchurch 22nd February 2011.

5 DISCUSSION

The combination of building occupancy use categories (Table 1) and open space occupancy rating (Table 2 and Table 3) provides a statistically justifiable basis upon which replacement costs and the variation in the location of people and thus casualty rates can be included within the RiskScape regional risk model. While the uncertainty bounds implicit in each of these tables remains high, attempts have been made within the model that their basis is transparent and open for the user to modify the default values to meet their specific situations when they wish to do so. Indeed it provides a basis to encourage better understanding of both the temporal location of people across the community and also the regional implication as to replacement costs, which can now include post-event inflation.

The need to have the ability to separate the structural cost from other replacement costs (architecture, buildings services, plant and equipment, building content and stock) has been recognised and a rather course means of evaluating the replacement value of each included. The method adopted of relating these to building typology and use categories is considered the best available alternative for the complete portfolio. Any such derivative will be recognised as being of low reliability and will be overwritten with better quality data when/if this becomes available on a building by building basis.

6 CONCLUSIONS

Earthquake Risk modelling remains an Art as much as it is a Science. Uncertainty remains high and the results therefore uncertain. It does however provide a systematic approach through which the impact of natural hazard events and be consistently processed and probable damage of loss projections evaluated and compared. This paper has described the measures being undertaken to introduce some rational subdivision into both the allocation of cost and of people between buildings of differing use and, in the case of people, their likely movements with time and space. The subdivision into these respective sub-classes is considered necessary to bring an adequate level of precision that is expected to result in plausible results, even when the uncertainty bands remain high. More importantly the means are provided to refine the assumptions based on site specific data where and when that becomes available, thereby shrinking those uncertainty bands and provided loss projections more consistent with both expectation and real losses experienced.

7 REFERENCES

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