A Building Inventory for Seismic Policy in an Earthquake-Prone City

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ABSTRACT

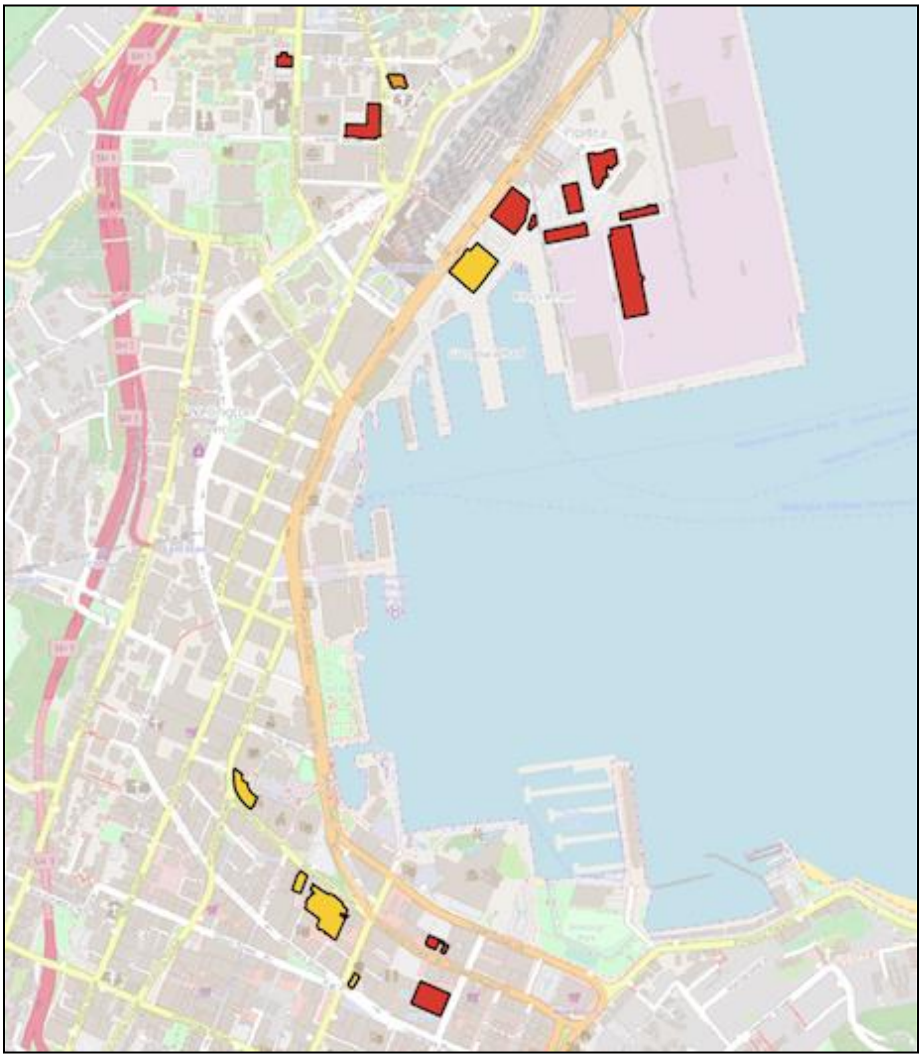
After Christchurch, and recently in Wellington after the Kaikoura earthquake, the absence of a clear source of information about the state of buildings in NZ became glaringly obvious. In the immediate aftermath of the quakes, authorities did not know what damages to expect, and long-term policy is now being formulated without any clear view of the empirical extent of the problem. Moreover, without this knowledge it is difficult to anticipate what the available legal and regulatory tools will do. In this poster, we describe the creation of a building inventory database for Wellington, an endeavor supported by QuakeCoRE (one of NZ's Centers of Research Excellence). This database aims to assist the generation of research on the risks, impacts, and viable solutions for reducing the seismic risk of existing multi-story concrete buildings in Wellington's Central Business District. The database includes structural, economic and market information on virtually every significant building in the Wellington CDB. Its primary purpose is to inform a multi-disciplinary policy-driven research project whose aims are: (1) to provide best scientific knowledge about the expected seismic performance of concrete buildings; (2) to assess the impact of multiple building failures including the downstream consequences of associated cordoning; (3) to provide a path for seismic retrofitting that includes prioritization of retrofits; and (4) to inform the design of a regulatory structure that can facilitate the reduction of risks associated with earthquake vulnerable concrete buildings as described in aims (1)-(3).

KEYWORDS

Earthquake-prone, building inventory, retrofit, building occupancy, building standards.

THE PROBLEM

Earthquakes pose a serious threat to Wellington, New Zealand's capital city. The most recent significant earthquake had a magnitude of 7.8 (M_w) and occurred on November 14th, 2016 at 12:02am local time. Although the fault movement was centred on the South Island in Kaikoura, many kilometres away, it still caused significant damage to buildings across the city. In the immediate aftermath of the earthquake about 11% (167,000m^2) of the city's office space was closed for assessment, thereby forcing relocations of thousands of workers from their offices (Harris, 2016). By November 2017, 21 buildings, mostly office or commercial buildings, had been demolished or were scheduled for demolition, 9 were initially closed but then re-opened upon further inspections, and another 10 remained closed awaiting further decisions by their owners and their insurers (Rutherford, 2017) – see figure 1 with data updated to 2018.



Source: WCC (2018).

Figure 1. Locations of damaged buildings in Wellington following the 2016 Kaikoura earthquake

Most of these damaged buildings were located in the central business district of the city. A large concentration was located around the port, on reclaimed land or land along a shoreline that was uplifted by a strong 19th century earthquake (the top right of Figure 1). Other damage hot spots were in Thorndon (the area West of the port and its reclaimed land) and Te Aro (the oldest part of the city with its stock of the oldest unreinforced masonry buildings; in the bottom part of the map). Most affected buildings were moment-resisting concrete frame buildings between 6 and 15 floor levels constructed since the 1980s (Brundson et al., 2017).

Statistics House, one of the office buildings located in the port area (top right in map), experienced structural failure when two precast floor units collapsed. Fortunately, there were no injuries as the earthquake occurred when the building was empty, as was the case with most other buildings that had structural or non-structural failures (the earthquake occurred just after midnight). The Ministry of Business, Innovation and Employment (MBIE) followed this failure with a comprehensive investigation into the structural performance of Statistics House (MBIE, 2017). The Wellington City Council (WCC) identified buildings with characteristics similar to Statistics House, buildings with precast floor systems, and ordered owners of those buildings to conduct further investigations. Sixty-four buildings were identified for intensive investigation within the Targeted Damage Evaluation (TDE) programme focusing on multi-story buildings of reinforced concrete, with precast concrete slab floors with various levels of structural damage. As can be seen in Figure 2, the locations of these buildings subject to the TDE programme are not as concentrated in the port area; these multi-story buildings are spread out throughout the inner city, including in the all major commercial and entertainment areas.

Source: Brundson et al. (2017).

Figure 2. Targeted Damage Estimates Programme in Wellington

This recent experience of the Kaikoura earthquake in 2016 highlighted some key structural vulnerabilities of mid-size reinforced concrete buildings that were not appreciated sufficiently before the event. Pre-Kaikoura, most of the attention of the research community and policymakers was directed at older un-reinforced masonry buildings which were frequently assessed as earthquake prone (this is a legal definition which implies certain obligations for retrofitting of these buildings within time periods as specified in the Law). Although pre-1976 reinforced concrete buildings were acknowledged to have a potentially high inherent seismic vulnerability, some newer buildings also appear to have structural weaknesses that pose life safety risk and require further scrutiny (May, 2001). Statistics House, Customs House, as well as Defense House and the BNZ Building were all buildings that were built since the 1990s, but all failed, to some extent, in this event.

The earthquake therefore further highlighted the need to understand the vulnerabilities in the existing building stock in the city, and consider which buildings pose substantial risk and need to be retrofitted or improved. It is important to note that the need to identify the vulnerabilities of existing buildings is well known, and was actually identified already at least as early as more than two decades ago (EQC, 1995). Besides reducing the risk of structural failure, implementing any retrofitting of buildings identified as vulnerable can have other benefits, so should be considered not only for the legally-defined earthquake-prone buildings (Mentz and Goble, 2015).

The collapse of one concrete building in the 22/02/2011 Christchurch earthquake, the CTV building constructed in 1986, accounted for about 60% of the 185 fatalities in this catastrophe. The loss of precast floors in Statistics House in Wellington during the Kaikoura earthquake, as discussed above, would have likely caused multiple deaths had the earthquake occurred during the working day.

Beyond the life-safety risk associated with mid-size concrete frame office buildings, both the Christchurch and Kaikoura earthquakes damaged numerous concrete buildings resulting in wide-ranging costs imposed on property owners (e.g. through loss of rental income or uninsured damage), building occupiers (e.g. through business interruption), and insurers. In addition to all these impacts, the Kaikoura earthquake also exposed the paucity of information that local emergency managers, city planners, and other stakeholders have about the existing stock of buildings in an earthquake-prone city like Wellington. It is the paucity of this kind of information that the database described here aims to ameliorate.

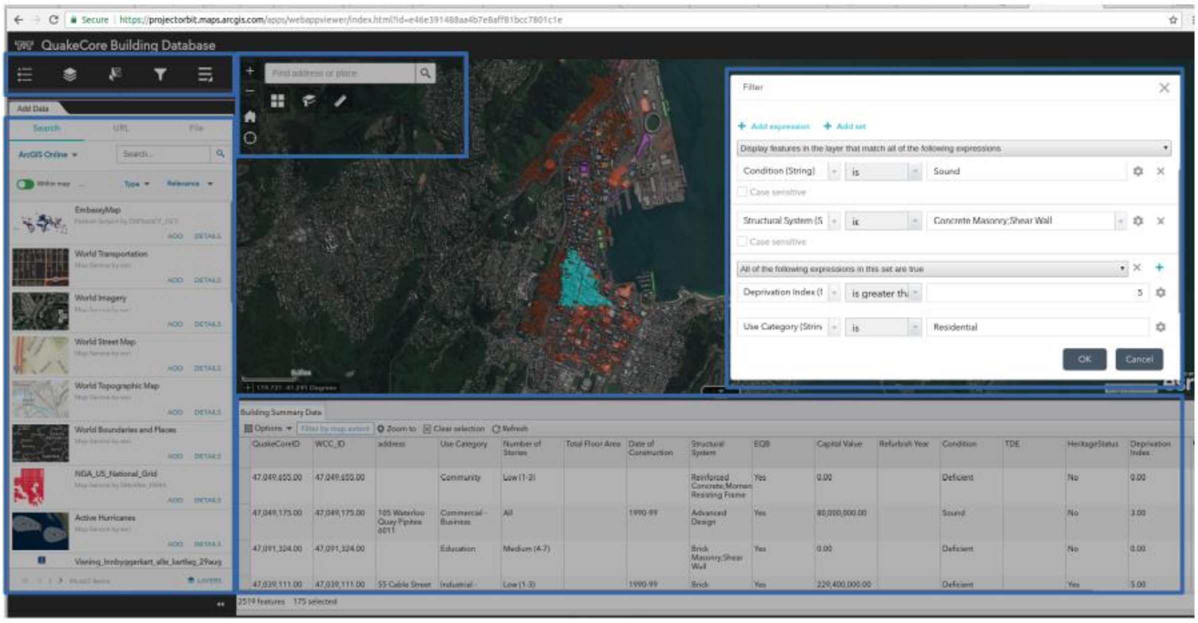
In Wellington, renters of office space (private firms, government and other public and non-profit entities) have already responded to the 2011 Christchurch earthquake by demanding spaces that are well above the 34% of the National Building Standards (NBS) threshold that is the legal threshold for ‘earthquake-prone’. After 2011, the market signaled a general consensus that 67% of NBS was an acceptable level, with many renters (including Central Government) inserting clauses in rental contracts demanding the premises always be above 67% of NBS (Filippova and Noy, 2018). Post Kaikoura, though, tenants are seeking out spaces with NBS ratings of 80% and above. Many new assessments that will incorporate insights learned in the past few years are likely to put some buildings below 67%. This will put pressure on owners to strengthen their buildings or consider redevelopment options. In addition, planned densification of the CBD with 50,000 new residents over the next 20 years will prompt conversion of many lower grade commercial buildings to apartments which will change in the risk profile for the city.

At this point, neither the Wellington City Council (WCC), nor its Wellington Regional Emergency Management Office (WREMO), nor the central government’s Ministry of Civil Defense (Wellington is the national capital) know which buildings are in the city, what is their risk profile, who resides in them, and what are the implications for city of any of these buildings failing in an earthquake event. This paper aims to close this knowledge gap.

THE DATABASE

This paper describes the creation of a building inventory database that is created for Wellington, whose ultimate aim is to assist the generation of research on the risks, impacts, and viable solutions for reducing the seismic risk of existing multi-story concrete buildings in Wellington’s Central Business District (CBD). The database’s primary purpose is to inform a multi-disciplinary project whose aims are: (1) to provide best scientific knowledge about the expected seismic performance of concrete buildings; (2) to assess the impact of multiple building failures including the downstream consequences of associated cordoning; (3) to provide a path for seismic retrofitting that includes prioritization of retrofits to describe a dynamic path that will lead to increased levels of seismic resilience in the city. Examples from other countries of such prioritization of retrofits program include Comerio (2004), Sucuoğlu et al. (2015), and Grant et al. (2007); and (4) to inform the design of a regulatory structure that can facilitate the reduction of risk associated with earthquake vulnerable concrete buildings as described in aims (1)-(3).

As is seen in Figure 3, the database being constructed is embedded within a GIS viewer that will allow approved users access to all the information directly on mapping applications or to download whatever part of the data inventoried in this project they require and are permitted to access. Currently, multiple stakeholders possess different strands of this data; with some of it typically remaining isolated to specific audiences with little means for cross-disciplinary sharing of resources and information.



Source: the authors.

Figure 3: The Database MapViewer

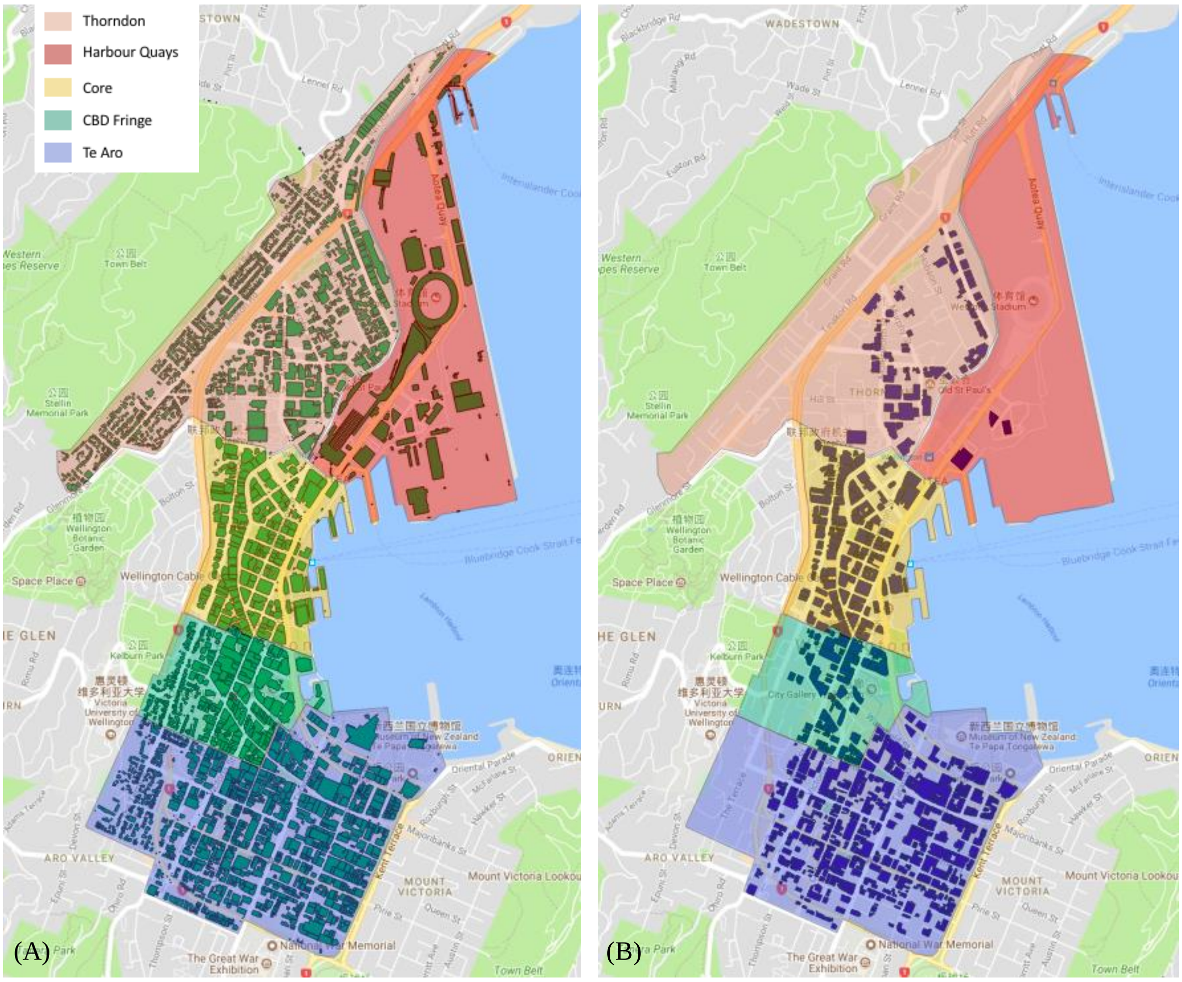
This inventory information database will contain critical spatial, structural and non-structural information about the buildings engineering characteristics, and occupancy related information that is building-specific. Together, these will therefore present a useful description of the existing building stock in the Wellington CBD and its role in the local economy. All data will be validated and readily updateable; in the long-term, we plan for this data to be managed and maintained either by one of the local universities or the city council.

The database will be stored in a server outside of Wellington, and will be accessible from anywhere, so that it will remain accessible during the emergency phase of a seismic event, should one occur. Within this paper, our aim is to present some of the information currently known about the building stock that are within the project's scope area and identify future directions for this database and its uses.

THE INFORMATION

The inventory information included in this database contains spatial, structural, non-structural, and occupancy related information for each building. Wellington City building footprints, from a dataset collected by the City Council, are used as the base layer to which other building characteristics are merged using spatial attributes. Data included in Riskscape (https://www.riskscape.org.nz), a risk assessment project software developed by GNS and NIWA (two New Zealand Government-owned research institutes) provides additional information about each building.

Colliers International, one of the largest property management companies in New Zealand, provided us their vacancy survey. This survey covers commercial buildings in the Wellington CBD - its main purpose is establishing the amount of vacant office space available and is conducted every six months. The Colliers dataset includes information on the building address, name, tenant/occupant company name, and amount of space occupied by floor level. Colliers also assess the building's quality for use as office space (not its structural integrity); this is provided using a grading system (A, B, C). The area covered by the survey is divided into five precincts, namely Core, Fringe, Thorndon, Harbour Quays and Te Aro. Figure 4 shows the division of the CBD into precincts and shows representation of buildings covered in the vacancy survey within the building footprints as available from the City Council.



Note: Panel A describes the Wellington City Council Building Footprint dataset. Panel B notes the buildings for which the Collier data are available. Source: the authors.

Figure 4: Wellington Office Buildings Data

One early problem we encountered is that most datasets do not comprehensively cover the whole building stock in the target area. For example, the Colliers dataset only includes information about 25% of the building stock identified in the Wellington City Council building footprint dataset. Colliers only aims to cover office buildings of a certain minimum size, so it will not include information, for example, on storage facilities, or buildings that have other uses (e.g. religious houses of worship).

In order to answer questions (2)-(4), we also need to know the industry composition of building tenants, and their spatial distribution within the CBD. Occupancy type is not included in the Colliers dataset but was needed to be assigned to each tenant. For that we combined Colliers dataset with the NZSIOC dataset to create the occupancy dataset. This was done by assigning each tenant an industry classification code as designated by the NZSIOC. We based these classifications on online research using company names and addresses in order to identify the services they provide. We assigned a level 4 classification to the occupants to retain the high level of resolution this dataset provides. For example, “Travel Harbour City” is a travel agency in Wellington. Thus, it was assigned “MN211” according to NZSIOC.

Multiple additional datasets are now being sourced and combined in order to fill the gaps in the building inventory data set. Datasets providing information that is not focused on the engineering structural specifications of the buildings tend to cover more buildings than the structural ones. For example, WCC’s District Valuation Roll holds information for each rating unit within the CBD area. This Valuation Roll offers each unit’s capital value, indicative period of construction and floor area. We then match these Valuation Rolls with the WCC footprint dataset to get the overall assessed market value of each building. Some buildings have multiple rating units in them, as, for example, might be for each floor in an office building as it is occupied by different tenants - so this matching is not always straightforward and because of some inconsistencies in the data cannot be fully automated.

Riskscape's asset layer covers most of the buildings in the scope area containing building height and use, age and type of structural system. However, Riskscape's coverage is for all of NZ and is often based on estimates of characteristics rather than actual on-site observations. This dataset appears to have low reliability. In contrast, datasets with structural characteristics offer the highest reliability but least coverage. As part of the meta-data we preserve for this database, we also record the source of each data point, and some assessment of its reliability.

Such datasets are also usually created for a specific purpose. For example, records within WCC's earthquake-prone buildings dataset would capture almost only pre-1976 buildings. Still, since each building would have been investigated by a registered engineer, the data included in this dataset is very reliable. Similarly, the Targeted Damage Estimate Programme dataset, created in response to the Kaikoura earthquakes, covers only a small subset of multi-story reinforced concrete buildings, but includes a lot of very reliable and verifiable information. Similarly, the New Zealand Heritage List/Rārangi Kōrero is a list of Heritage designation that is based on a careful assessment of a small number of buildings and their historical importance. It includes a small number of buildings, but provides a lot of very reliable information about them.

Ultimately, the inventory dataset aims to provide researchers with building-related information that has high level of confidence/accuracy. As mentioned above, the inventory is built from multiple dataset that have varying degree of accuracy and coverage. To assist with this effort, a street survey is being conducted which is co-funded by WCC. The purpose of the survey is to validate information contained within the inventory database. The surveyors (engineering students) will be supplied with tablets pre-loaded with the building inventory GIS viewer for field data collection. Within the viewer a number of fields are editable such as number of stories, building condition, evidence of current retrofit, cladding, and ground and upper floor use. In addition, students will be taking photos of the exterior and interior (ground floor/lobby) to be added to the inventory database.

THE USES OF THE DATABASE

As an initiative which is part of a coordinated project focused on seismic retrofitting options for mid-size reinforced concrete commercial buildings, we also collect detailed structural information, from primary and secondary sources, about the multi-story (>4) buildings within the scope area. This information will be particularly important for the second objective of the project (scenario testing and consequences of building failure). For that, a collection of detailed drawings is being extracted from property files held by the council. So far, this effort has amassed drawings for 262 buildings. Consequently, a number of variables will be created from the drawings files (for example, buildings that have concrete columns or which of several types of flooring systems). Within the GIS tool being developed for the project, researchers will be able to identify vulnerable buildings by specific characteristics (e.g., concrete columns) and access links to other resources such as drawings or photos for each building that satisfied a specified set of conditions. Using these data, we aim to be able to estimate more accurately which buildings will be at risk of failures under various scenarios, and identification that is a necessary first step for prioritization proposals.

For the prioritization part of this project, we have already identified three sets of criteria that will structure our prioritization project; though these three sets of criteria will only follow a full consideration of life-safety risk assessment (including identifying buildings which are especially important in this context – for example, schools). The three sets of criteria are: the economic role of the building, the cultural/social place and role of the building, and its functioning within the transportation network, including its potential impact on the extent of any cordoning decision. The data included in the database will allow us to provide quantifiable measures of these three sets of criteria, while weighting them will be determined by expert and stake-holders consultations (e.g., Phillips and Bana e Costa, 2007). This prioritization project will also aim to inform the design of regulatory frameworks whose goal will be to find ways to achieve the retrofitting prioritizations that we identify.

CONCLUSIONS

Addressing the earthquake risk posed by existing concrete buildings is complex even from a structural-engineering perspective, given the difficulty of identifying the truly dangerous buildings from those expected to be damaged without significant life-safety concerns. The legal framework requires the retrofits of buildings if they pose life-safety risk in a moderate earthquake (i.e., being designated earthquake-prone). Some of the buildings in question, however, may pose life risk only in earthquakes that are stronger than the 'moderate' threshold, but failure in these could mean life risk to dozens or maybe even hundreds of people. As such, a basic premise behind the construction of this dataset is that the current regulatory regime and financial incentives driving building owners behaviour are as yet insufficient to achieve the vision of a resilient city that is behind the construction of this dataset.

Ultimately, this multi-disciplinary project aims to provide a vehicle for the dissemination and use of the best scientific knowledge about the expected seismic performance of concrete buildings, the economic and social impact of building failures including the downstream consequences associated with their failure and introduce new ideas regarding the prioritization of retrofits and optimized regulatory structure to address this risk.

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