# Data Analytics Applied to Seismic Disaster Risk Reduction for Building Portfolios

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## Abstract

The positive impact of digital transformation and data analytics is evident in earthquake engineering and disaster risk reduction. Rapid response following an earthquake using real-time ground motion estimation and vulnerability data provides a situational awareness of risk that is for an effective response. In disaster response environments, using digital analytics and visualisation to better understand design basis ground motion exposure history across a portfolio can support building inspection and the recovery processes. Quantified earthquake exposure history integrated with earthquake engineering domain knowledge on building design, performance and maintenance allows for statistical analysis and machine learning concepts to derive engineering insights on design, resilience and asset performance against natural phenomena. The emergence of a number of digital technologies in earthquake engineering is enhancing seismic resilience and seismic risk management across a large portfolio of buildings.

**Keywords:** real-time earthquake alerts, ground motion exposure history, machine learning in earthquake engineering, seismic disaster risk reduction

## INTRODUCTION:

Digital transformation is the profound transformation of business and organisational activities, processes, competencies and models to through integration of a mix of digital technologies.

The impact of digital transformation is already evident in earthquake engineering and disaster risk reduction. Examples include advances in cloud computing, affordable accelerographs connection to the Internet of Things (IoT), image processing to support disaster response, and building information management systems (BIM) to enhance design.

This paper demonstrates the emergence of a number of digital technologies in earthquake engineering and the transitory steps taken, particularly in the enhancement of seismic resilience and managing seismic risk across a large portfolio of structures.

The first is rapid response following an event using real-time ground motions and vulnerability data when an event occurs. The second is how to leverage data analytical processing to understand ground motion exposure history following a major disaster to support our response. Finally, an analytical process is presented on can begin to learn by looking back in time.

## 1 REAL-TIME RISK REPSONSE

Current earthquake engineering practice is starting to look beyond code to resilience and enhancing the recovery of the greater community (Almufti 2013). Situational awareness in the immediate aftermath of a damaging earthquake is of fundamental importance for an effective response. When a potentially damaging earthquake occurs, decision makers have an urgent need for information about potential impact to ensure safety, restore system functionality, and minimize losses.

With the internet and mobile technology there are a number of existing earthquake hazard alert systems with varying degree of capabilities from providing early warning to automated publication of ground motions to large scale loss assessment modelling. The U.S. Geological Survey's (USGS) ShakeMap (Wald et al. 2008) is a widely known tool used to portray the extent and severity of ground shaking immediately following an earthquake. These systems can provide immediate hazard magnitude or intensity, but there is often a disconnect between the hazard information and an immediate understanding of the risk to the built environment. The systems provide hazard information, but not the vulnerability or consequence to the assets of concern to understand risk.

To enhance response, Arup has developed a multi-hazard risk information platform that compares natural hazard data from public domain feeds to known asset design, vulnerability and consequences in real-time. Triggers are pre-defined based on knowledge of design and compared to reported ground motions in real-time.

### Application to the 5 February 2016 M6.4 Taiwan Earthquake

To support seismic risk management of a global portfolio, seismic evaluations following ASCE 41-13 were undertaken for 400 buildings of which 40 are located in Taiwan. The results of the evaluation were primarily intended for corporate risk management practice to enforce safe work place requirements and inform decisions on property management such as lease renewal. The seismic evaluation noted that two of the 40 properties in Taiwan were altered structurally, by removal of a wall to create more open space. The results were put into practice to provide an immediate situational awareness of the potential portfolio impact following an earthquake.

At approximately 20:00 UTC 5 February 2016 (4am local Taiwan Time Saturday 6 February) a M6.4 damaging earthquake occurred in southern Taiwan. The event occurred early Saturday morning local Taiwan time during the Chinese New Year Holiday. A global network of seismographs located the event and the USGS shortly afterward disseminated an estimate of the amount of ground motion as a ShakeMap through their RSS feed.

Within minutes following the event, Hazard Owl, automatically extracted ground motions estimated in the ShakeMap feed for each of the properties and compared to the seismic design basis (Figure 1). Five of the 50 buildings felt earthquake ground motions up to 0.10g at Sa 1.0sec. The previously completed seismic evaluation, showed that these buildings were designed following the Taiwan Seismic Design Code for $S_{D1}$ of 0.3g and the ground shaking was generally <30% of their design load.

Risk alerts were sent to the portfolio seismic risk management team with the percentage of shaking versus the design basis and findings from the previous seismic evaluation. This provided the portfolio manager a contextual situational awareness of performance that could not be realised from traditional event feeds (e.g. Twitter) noting a M6.4 occurred in Taiwan, rather than information relevant to earthquake engineering. The alerts also noted the two problematic buildings, which led to recommendations cautioning re-occupancy and prioritizing inspections.

Although the ShakeMap feeds has inherent uncertainty in its ground motion estimation based on distribution of local recording stations, ground motion prediction equations, and ground conditions, it is still effective as an initial estimation tool across to support disaster risk decisions across a portfolio.


Figure 1. Ground motion contours from the 5 February 2016 M6.4 Taiwan Earthquake relative to a portfolio of 40 buildings.

## 2 DISASTER REPONSE GROUND MOTION EXPOSURE

A key component of earthquake engineering is rapid building inspections to support recovery following a damaging event. For large events that impact urban areas, the number of buildings that require evaluation before re-occupancy often will exceed thousands. In the disaster response environment resources are limited. Time is critical, qualified engineering personnel are under resourced, and typical building structural or foundation design information is limited.

To better understand risk ground motion exposure history relative to ULS and SLS design levels across a portfolio can be rapidly estimated to provide input in the inspection.

### Application to 2017 Puebla, Mexico M7.1 Earthquake

The recent Puebla, Mexico Earthquake sequence impacted densely populated Mexico City through a sequence of three significant earthquakes (M8.1, M7.1 and M6.1). Building inspections are being carried out by teams of qualified engineering on site.

To help support the assessment, ground motion values where extracted from ShakeMaps of the three events to provide a quick visual representation of ground motion history values at each of >800 buildings assigned to Arup for evaluation.

The process involved downloading the USGS ShakeMaps for the three events into a GIS, georeferencing the buildings based on the address provided, and then extracting ground motion values (PGA, Sa1.0sec, Sa3.0sec). Figure 2 shows a map of building inspections locations and select “spark” graphs reflecting estimated ground motion exposure for the three earthquake events. The map shows bar graphs representing Sa1.0 second and the table shows PGA, Sa1.0sec and Sa3.0sec for the three respective events.

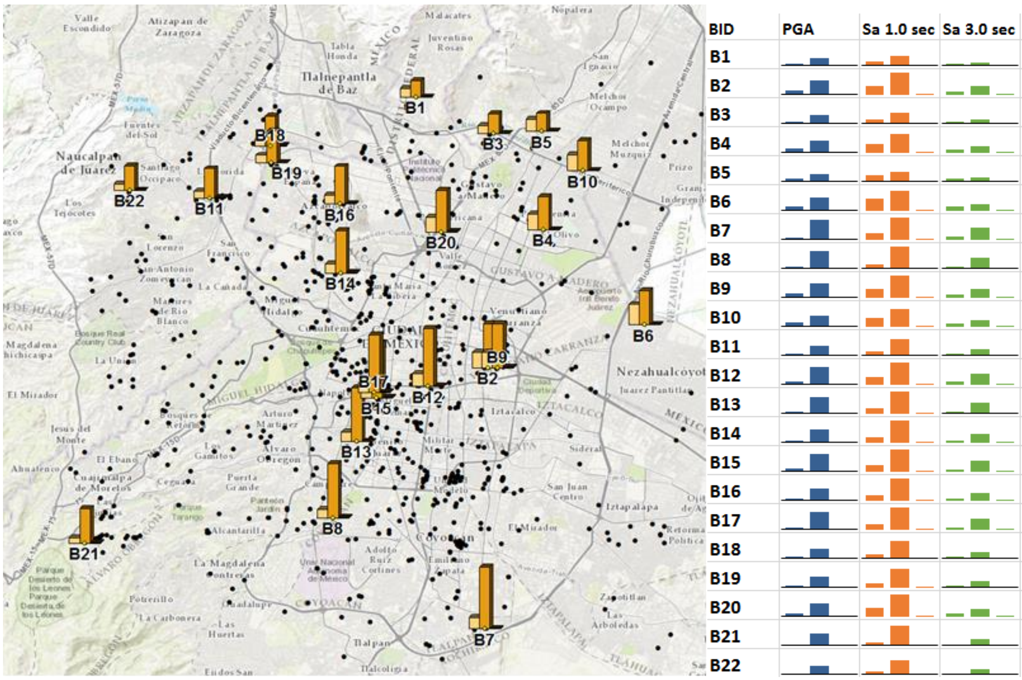


Figure 2 Estimated ground motion exposure in Mexico City for the three earthquake events

## 3 LEARNING BY LOOKING BACK

Learning from earthquakes has always been a valuable advancement of the practice. The ability to make observations rapidly and precisely following a disaster has long been recognized as critical to managing emergency response activities in the short term and improving the understanding of natural hazards in the long term (EERI 2017).

One of the emerging technologies included as a key component of digital transformation is machine learning. Machine learning is a method of data analysis uses algorithms to iteratively learn from data and find hidden insights without being explicitly programmed where to look. Conceptually this is an easy to understand in the context of earthquake engineering. By comparing domain knowledge on design, performance and maintenance of a building portfolio and to the historic records of earthquake impacts event, one can begin to extract insights.

To take a step towards this and explore the analytical methodology, a tool was developed to calculate the history of ground shaking from 600,000 recorded earthquakes at 70,000 previous projects as a percentage of their seismic design basis.

### Application to Arup's project portfolio

Different from the previous Taiwan and Mexico City examples, ShakeMap or equivalent ground motion recording maps do not exist for the entire earthquake catalogue.

The major analytical challenges included developing an efficient and on-demand analytical workflow. A brute force approach would take 24 trillion executions of the ground motion prediction equation. Geospatial analysis tools calculated the distance from earthquakes to Arup projects and extracted the ground conditions at the project location from SRTM Vs30 site class mapping.

Figure 3 shows four graphs of estimated ground shaking (PGA, PGV, Sa1.0 sec and Sa2.0 sec) at the location over the duration of the earthquake catalog at the Maison Herms Tokyo project. One can see 2011 M9.5 Fukishima earthquake and the associated response at the project location.

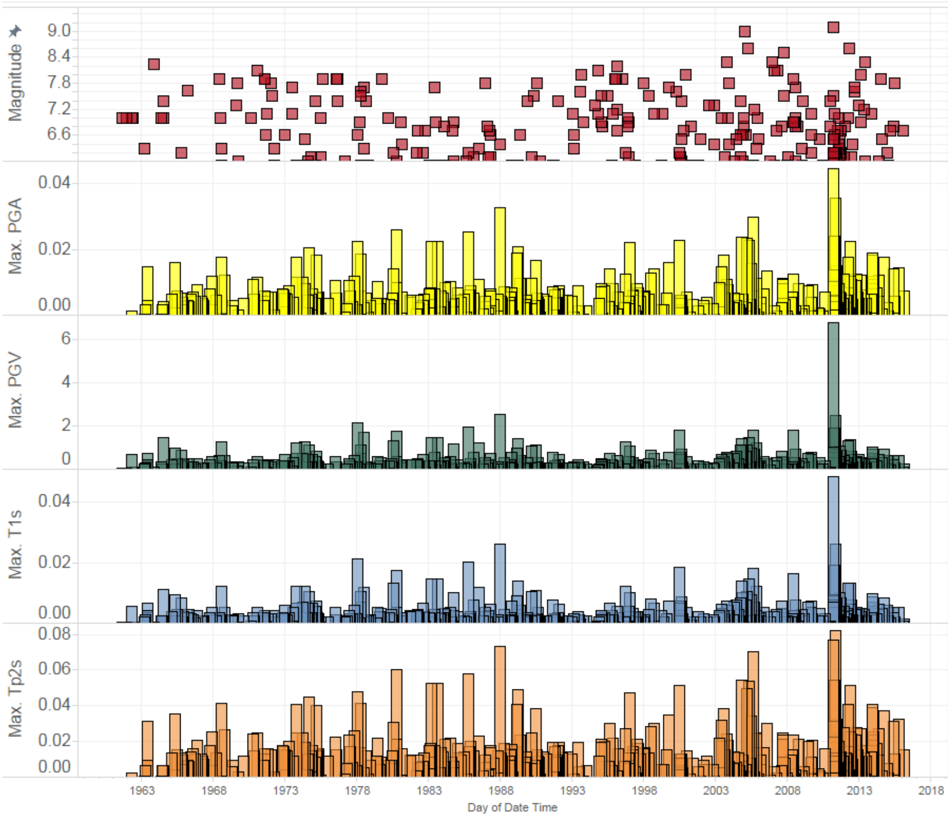


Figure 3 Maison Herms Tokyo detailed ground shaking parameters

The ground motion values can then be compared to the seismic design basis for that project based on domain knowledge of that building or local code at that time. Figure 4 shows a percentage of design basis shaking across four global projects. It shows Japan (red) has a high rate of seismic activity with >10 events approaching 20% of its design basis. Taiwan (green) has 5 events in excess of 10% seismic design basis. Christchurch (orange) is historically quiet, until 2011 when a catastrophic event impacted the city and exceeded design levels. San Francisco (brown) has not had a significant shake since 1960 and maybe overdue for a major event. Note that the damaging 1989 Loma Prieta earthquake had little impact at this location.

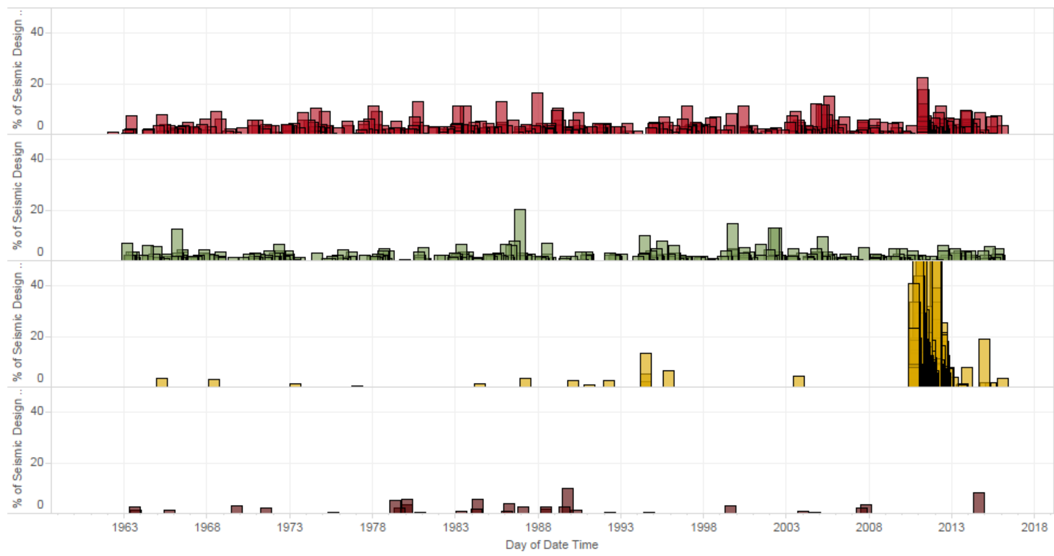


Figure 4 Historic shaking as a percentage of seismic design at four projects: Tokyo (red), Taiwan (green), Christchurch (orange), and San Francisco (brown)

When this is applied to a large number of building types, in different seismotectonic regions, at different locations, different construction practices, and built under different design codes you have the building blocks to apply machine learning to extract insights.

## 4 CONCLUSIONS

A number of digital technologies are enhancing seismic resilience and managing seismic risk across a large portfolio of buildings. This paper presented three examples of transitory steps.

Real-time earthquake ground motion estimates integrated with the results of portfolio seismic risk evaluation can provide a contextual situational awareness of performance and allow informed rapid response. Real-time monitoring doesn't reduce the vulnerability of the building, but rather provides a rapid situational awareness to allow the response and ultimate recovery to occur faster. This is a key component of a resilient system. A realised value from these alerts, from a business continuity perspective, is the knowledge that a building is not impacted following an event that is highly covered in the media. In the near-future, the IoT will make structural health monitoring common-place through ubiquitous accelerographs and other sensors.

In disaster response environments, resources are limited. Time is critical, qualified engineering personnel are under resourced, and typical building structural or foundation design information is limited. Using digital analytics and visualisation to better understand design basis ground motion exposure history across a portfolio can support recovery processes.

With BIM becoming the standard digital documentation of a structure's design, the ability to quantify and learn from the design's performance against natural phenomena will become second nature going forward, but this dataset is limited as it starts today. Quantified earthquake exposure history integrated with earthquake engineering domain knowledge on building design, performance and maintenance allows for statistical analysis and machine learning concepts to derive engineering insights on design, resilience and asset performance against natural phenomena.

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