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ABSTRACTS
BİLDİRİ ÖZETLERİ

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EARTHQUAKE RISK IN ISTANBUL

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In recent decades, earthquake risks in Istanbul have increased mainly due to a very high rate of urbanization and problems in land-use planning and construction. The other important source of the increased risk in Istanbul is the unprecedented increase of the probability of occurrence of a large earthquake. The inevitability of the occurrence of such a large earthquake in Istanbul makes it imperative that certain preparedness and emergency procedures be contrived in the event of and prior to an earthquake disaster, which in turn requires quantification of the effects of the earthquake on the physical and social environment. Rational earthquake risk and loss assessments to a portfolio, or in urban or regional scale constitutes an important element in the mitigation of economic and social losses due to earthquakes will pave the way for contingency planning, retrofit prioritization of physical elements at risk as well as for the optimization of earthquake insurance schemes.

Earthquake risk can be defined as the probable economic, social and environmental consequences of earthquakes that may occur in a specified period of time and is determined by using earthquake loss modeling procedures. In this context, the loss is the reduction in the value of an asset due to earthquake damage and risk is the quantification of this loss in terms of its probability of occurrence. Earthquake risk assessment methodologies consider and combine three main elements: earthquake hazard, fragility/vulnerability and inventory of assets exposed to hazard. The uncertainties involved in these elements and especially the correlation in these uncertainties, are important to obtain the bounds of the expected risks.

Almost all earthquake risk assessment schemes rely on the quantification of the earthquake shaking as intensity measure parameters using probabilistic or deterministic earthquake hazard models. For a given ground motion (intensity measure) the direct physical damage is determined by the fragility/vulnerability relationships that provide the probability of damage/loss, conditional on the level of intensity measure. Each step of the process incorporates stochastic or random variation associated with all aspects of the modeled phenomenon. Consequently, the earthquake risk estimations should consider the uncertainties in these steps. Challenges exist in the characterization of the earthquake hazard as well as in the determination of the fragilities/vulnerabilities of the physical and social elements exposed to the hazard. The simulation of the spatially correlated fields of ground motion using empirical models of correlation between intensity measures is an important tool for hazard as well as risk characterization.

The main sources of uncertainties in earthquake risk assessment are: Hazard uncertainty (seismic source characterization and ground motion modeling); Vulnerability uncertainty; Uncertainty in the assumptions and specifications of the risk model and; Portfolio uncertainty (location and other attributes of the building classes). Aleatory variability, that generally affects the loss distributions and exceedance curves is directly included in the probabilistic analysis calculations through the inclusion of the standard deviation of a GMPM considered in the analysis. Epistemic uncertainties, which can increase the spread of the loss distributions, are generally considered by means of a logic tree formulation with appropriate branches and weights associated with different hypotheses. Similarly, Monte-Carlo techniques can also be used to examine the effect of the epistemic uncertainties in loss estimates.

Probabilistic earthquake hazard assessment (PSHA) provides spatial distribution of the probabilities of exceedance in a given time period for given values of an intensity measure or measures. PSHA is traditionally conducted by the computation of the total probability theorem. Monte-Carlo method can also be utilized to estimate the probabilistic seismic hazard, instead of the computation through the total probability integral. The same also holds for probabilistic seismic risk applications through the total probability integral.
The essential ingredients of the PSHA are the earthquake source and ground motion characterization. As it is well studied, towards the Marmara Sea region the North Anatolian Fault Zone (NAFZ) begins to lose its single fault line character and splays into a complex fault system. Based on low-resolution bathymetric data and earthquake occurrences, several researchers have developed different tectonic models for the Marmara Sea. A number of comprehensive studies exist on the characterization of faults in the Marmara Sea, rates of slip, timing and sequence of ruptures. In Istanbul, earthquake records spanning two millennia indicate that, on average, at least one medium intensity (epicentral intensity, Io=VII-VIII) earthquake has affected the city every 50 years. The average return period for high intensity (Io=VIII-IX) events has been 300 years. Today, the Marmara region encompass one of densest seismic instrumentation in the world.

It has been shown that, for a given earthquake, spatial correlation of ground motion intensity measures exists and it is essentially attributable to the event-wide correlation of intensity measures through the intra-event and the tendency of local intensity measures being different than the GMPMs predicted median, through the intra-event variability. For the estimation of the spatial correlation of ground motion intensity measures, the semi-variograms developed on the basis of the intra-event correlation of the earthquake ground motion using the data from the strong motion instrumentation system in Istanbul.

Following risk/loss assessment studies will be encompassed in this paper.

Deterministic Earthquake Risk/Loss Assessment in Central Istanbul.
In recent studies the Princess Islands Segment of the Main Marmara Fault has been identified as the “most imminent danger” to Istanbul. This fault segment has been considered with a regional GMPM and a local spatial correlation model to compute 1000 simulations of earthquake ground motion distribution and the loss in one of the most densely populated regions of Istanbul. For loss assessment the intensity-based fragility relationships are considered. The instrumental intensities were computed from PGA and PGA-conditioned PGV distributions. Results are provided to illustrate the loss ratios and exceedance probability curves for different spatial correlation alternatives.

• Deterministic Earthquake Risk/Loss Assessment in Zeytinburnu District of Istanbul.
Earthquake risk and losses in the Zeytinburnu district of Istanbul that would result from an Mw7.2 scenario earthquake on the Marmara Fault were computed. PGA, SA(0.3s) and SA(1s) distributions based on regional GMPMs were calculated considering various spatial

correlation models as well as their cross-correlations. The effects of the different correlation models on the spatial distribution of PGA are illustrated. The loss histograms are provided with the distribution parameters consisting of mean, median, standard deviation, and skewness. It has been shown that, while the mean loss remains essentially unaltered, the coefficient of variation increases with increasing correlation.

• Deterministic Earthquake Risk Assessment in Istanbul.
The earthquake risk in Istanbul due to a worst case scenario (a Mw=7.5 magnitude strike-slip earthquake associated with the rupturing of all fault segments associated with the seismic gap) was computed using a classical approach, with no consideration of different rupture schemes and spatial variation of ground motion intensity. Geo-cell based distribution of the rates of different states of damage are provided.

• Probabilistic Earthquake Risk/Loss Assessment in Central Istanbul.
Earthquake losses in central Istanbul were computed using the probabilistic loss calculation process. Intensity-based fragility relationships were considered. Probability exceedances of different damage states for different building types were provided.

• Probabilistic Earthquake Risk/Loss Assessment in Istanbul and Marmara Region.
Classical PSHA-based earthquake risk calculation procedure was used to assess the geo-cell based building damage distributions in the Marmara Region, loss ratios and average annual loss ratios corresponding to 72, 475, and 2475 year average return periods.

The following basis conclusions are in order.

Earthquake risk and loss assessment is needed to prioritize risk mitigation actions, emergency planning, and management of related financial commitments. Insurance sector have to conduct the earthquake risk analysis of their portfolio to assess their solvency in the next major disaster, to price insurance and to buy re-insurance cover.

The reduction of the uncertainties in earthquake risk/loss assessment is an important issue to increase the reliability and to reduce the variability between the assessments resulting from different of earthquake risk/loss models. In this connection, earthquake risk/loss assessment models should explicitly account for the epistemic uncertainties in the components of analysis, especially in the inventory of assets and vulnerability relationships.

DAMAGE ASSESSMENT IN ITALY, AND EXPERIENCES AFTER RECENT EARTHQUAKES ON REPAIRABILITY AND REPAIR COSTS

Marco Di Ludovico[1]

Existing structures often exhibit poor seismic performance as demonstrated by the diffuse damage and numerous collapse, either partial or total, surveyed in the aftermaths of moderate-to-high magnitude strong motions worldwide; damage provided by earthquakes is a concern for a society as a whole in terms of loss of life and direct and indirect costs.

Italy has experienced more than 60 destructive earthquakes over the past two centuries and starting from the devastating earthquake of Belice in 1968, the death toll has been about 5,000, corresponding to approximately 100 deaths/year. In addition, direct costs and indirect costs have dramatically affected the country's economy. The direct costs only related to the emergency management and reconstruction process in Italy between 1968 and 1998 were estimated to exceed €100 billion (by the 2005 euro equivalent), mainly related to the earthquakes in Belice (1968), Friuli (1976), Irpinia (1980) and Umbria-Marche (1997), Severino and Di Pasquale 2002. These costs are considerably increased if due allowances are made for the seismic events of the last 15 years, including events in Molise (2002), L'Aquila (2009), Emilia Romagna (2012) and Central Italy (2016-2017). Indeed, the L'Aquila earthquake left nearly 70,000 homeless, the Emilia earthquake strongly impacted on productivity of primary importance for the local and national economy, and the central Italy earthquake highlighted the cumulative effects of a seismic sequence on the damage to buildings and relevant losses.

A proper quantification of lives and monetary losses as well as of time to recover the buildings' functionality is of paramount importance to give indications to decision makers for establishing seismic risk mitigation policies, and to insurance companies to value sound insurance premium for existing building in the seismic prone areas.

To this aim, it is fundamental to collect post-earthquake data regarding the usability of buildings, the type and extent of damage on structural and non-structural members, the ordinances issued to regulate the reconstruction phases and the relevant costs and time to be completed.

The data on post-earthquake surveys carried out after last 50 years devastating earthquakes in Italy have been recently collected in a wide database reported in a web-based platform named Da.D.O. (Database of Observed Damage), Dolce et al., 2019; it reports data on about 320,000 buildings inspected after earthquakes that stroke several Italian regions from 1976-2012. Since the Umbria-Marche 1997 seismic event, the damage and usability assessment of buildings is made by the first level AeDES survey form, Baggio et al. 2007. The form represents a rapid tool to assess the damage and usability based on the visual in situ inspection of the building. The form refers to the minimum structural unit with a significant impact on the people safety and reports data on damage level and extent on structural and non-structural members evaluated by teams of experts in seismic engineering. Similarly to other forms used all around the world (e.g. Japan: Goretti and Inukai 2002; U.S. (ATC, 2005); New Zealand: NZSEE, 2009) the main goal is to assess usability categories. For example according to ATC, 2005, a building is tagged "Green" for unrestricted access, "Yellow", for restricted access, and "Red" for no access, while the AeDES form leads to six usability categories: A. Usable buildings; B. Building usable only after short term countermeasures; C. Partially usable building; D. Building to be re-inspected; E. Unusable building; F. Unusable building for external risk.

The reconstruction process after the L'Aquila earthquake (2009) have offered a unique opportunity to collect and monitor data on a large scale. In particular, data focused on building damage and relevant reconstruction costs as well as indirect costs in terms of population assistance. Note that the models of post-earthquake emergency management and reconstruction used in Italy since the 1968 Belice earthquake have all been based on ensuring fair public coverage of the costs required to repair the earthquake damage while different economic thresholds were defined for local or global strengthening works.

Efforts to analyze these data have resulted in a unique database of 5,775 records related to residential buildings outside the historical centres [Di Ludovico et al. 2017a,b], and to 53,968 displaced people assisted in the emergency and reconstruction phases, Mannella et al. 2017. The distinction of two reconstruction phases, ''light damage'' related to B or C rating residential buildings and ''heavy damage'' reconstruction related to E rating residential buildings, was adopted in the L'Aquila 2009 post-earthquake reconstruction process.

The total amount of public funds allocated for B or C and E rating residential buildings outside the historical centers can be estimated of the order of 2.6 billion euros: 0.5 billion euros for B or C rating residential buildings, and 2.1 billion euros for E rating residential buildings. Out of 2.6 billion euros, 1,3 billion euros, involved repair interventions while 0,7 and 0,6 billion euros involved seismic strengthening and demolition/reconstruction interventions, respectively. In the application for funding process, E-rated buildings were further classified in sub-classes: class E-B, including buildings with a high non-structural risk that sustained slight structural damage (where a local strengthening strategy may solve most of the structural weakness); and class Edem, including buildings that needed to be demolished because of dangerous structural weaknesses, a high residual drift, local or global collapse, or a lack of economic value of required repair/retrofit interventions compared to the costs of demolition and reconstruction (Di Ludovico et al. 2017b).

The usability classes adopted in the reconstruction process and relevant number of reinforced concrete (r.c.) and masonry buildings as well as median 16th and 84th percentile of repair costs (expressed as a percentage of building reconstruction cost, %Cr = 1,350.00 €/m2) are reported in Table 1. The cost data reported in such a table refers to a subset of 3,992 buildings.

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Table 1. Repair costs on r.c. and masonry residential buildings damaged by L'Aquila earthquake.

Usability class	Building Type	N. of buildings	% Building reconstruction costs, %Cr 16th percentile	Median	84th percentile
B-C	r.c.	1,598	6%	12%	22%
	masonry	899	7%	14%	25%
E-B	r.c.	200	14%	26%	36%
	masonry	44	9%	19%	29%
E	r.c.	447	25%	39%	53%
	masonry	313	21%	33%	47%
E_{dem}	r.c.	267	78%	88%	103%
	masonry	224	71%	84%	102%

By associating these costs data with information related to the empirical damage experienced on structural and non structural members of such buildings, it was possible to define minimum and maximum values of %Cr, %Cr,min and %Cr, max, associated to each global damage grade, defined according to the metric introduced in EMS98, Grunthal 1998 (i.e. five global damage levels from DS1 to DS5), see Table 2. Global damage levels have been obtained by means of suitable conversion matrices of empirical damage data reported in the AeDES forms. These costs have been reported in the document assessing the Italian national seismic risk recently edited by the National Civil Protection Department (ICPD, 2018)

Table 2. Repair costs as a function of global damage level defined according to EMS 98 scale.

	% Building reconstruction costs, %Cr	
Global damage grade DS	%Cr,min	%Cr,max
DS1	2%	5%
DS2	10%	20%
DS3	30%	45%
DS4	60%	80%
DS5	100%	100%

The reconstruction policy based on promoting "light damage" reconstruction prior to "heavy damage" reconstruction allowed 21,960 returning home after one year and eight months from the earthquake and 43,134 (i.e. about 80% of people needing assistance in December 2009) after about eight years from the earthquake. About 72% of occupants which returned home in this period lived in buildings outside the historical centers. The costs for people assistance, 43,134 persons in about eight years, can be estimated of the order of 0.9 billion euros; this strongly highlights the impact of indirect costs in a proper evaluation of post-earthquake losses.

References

[1] Severino M, Di Pasquale G (2002) Procedures for the post-earthquake reconstruction: analysis and proposals. Alinea. Procedure per la ricostruzione post-sisma: analisi e proposte (in Italian)
[2] Dolce M., Speranza E., Giordano F., Borzi B., Bocchi F., Conte C., Di Meo A., Faravelli M., Pascale V. (2019). Observed damage database of past Italian earthquakes: the Da. DO WebGIS. Bollettino di Geofisica Teorica ed Applicata, 60(2).
[3] Baggio C., Bernardini A., Colozza R., Coppari S., Corazza L., Della Bella M., Di Pasquale G., Dolce M., Goretti A., Martinelli A., Orsini G., Papa F., Zuccaro G. (2007). Field manual for post-earthquake damage and safety assessment and short term countermeasures (Pinto A, Taucer F eds), Translation from Italian: Goretti A, Rota M, JRC Scientific and Technical Reports, EUR 22868 EN-2007.
[4] Goretti A. and Inukai M.; 2002: Post-earthquake usability and damage evaluation of reinforced concrete buildings designed not according to modern seismic codes. JSPS Short Term Fellowship, Final report, Servizio Sismico Nazionale, Dipartimento di Protezione Civile, Roma, Italy.
[5] ATC (Applied Technology Council); 2005: ATC-20-1. Field manual: postearthquake safety evaluation of buildings, second edition. Applied Technology Council, Redwood City, CA, USA.
[6] NZSEE (New Zealand Society for Earthquake Engineering); 2009: Building safety evaluation during a state of emergency guidelines for Territorial Authorities. <http://www.dbh.govt.nz/UserFiles/File/Building/information%20for/Building-Safety-Evaluation-during-State-of-Emergency.pdf.>
[7] Di Ludovico M., Prota A., Moroni C., Manfredi G., Dolce M., Reconstruction process of damaged residential buildings outside the historical centres after L'Aquila earthquake – part I: "light damage" reconstruction, Bull. Earthq. Eng. 15 (2017) 667–692, doi:10.1007/s10518- 016-9877-8.
[8] Di Ludovico M., Prota A., Moroni C., Manfredi G., Dolce M., Reconstruction process of damaged residential buildings outside the historical centres after L'Aquila earthquake – part II: "heavy damage" reconstruction, Bull. Earthq. Eng. 15 (2017) 693–729. doi:10.1007/s10518-016-9979-3.
[9] Mannella A., Di Ludovico M., Sabino A., Prota A., Dolce M., Manfredi G. (2017), "Analysis of the Population Assistance and Returning Home in the Reconstruction Process of the 2009 L'Aquila Earthquake", Sustainability 2017, 9(8), 1395; doi:10.3390/su9081395.
[10] Grunthal, G.,1998. European Macroseismic Scale, Chaiers du Centre Européen de Géody-namique et de Séismologie, 15 Luxembourg.
[11] Italian Civil Protection Department, National risk assessment. Overview of the potential major disasters in Italy: seismic, updated December 2018.

POST-EARTHQUAKE DEMOLITION DECISIONS IN CHRISTCHURCH AND THE ROLE OF INSURANCE

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Abstract

The 2010-2011 Canterbury Earthquakes in New Zealand, involved widespread damage during the February 2011 event and resulted in more than $NZD 40 billion in losses (~20% GDP), demolition of over 60% of multi-storey concrete buildings (3 storeys and up), and closure of large portions of the Central Business District (CBD) for over 2 years. The aftermath of the earthquake sequence has revealed unique issues and complexities for the owners of commercial and multi-storey residential buildings in relation to unexpected technical, legal, and financial challenges when making decisions regarding the future of their buildings impacted by the earthquakes. Using data collected from 223 RC buildings in Christchurch CBD, the presentation will discuss key factors influencing post-earthquake decisions (repair or demolish). The study, conducted in 2014, includes in-depth investigations on 15 case-study buildings using 27 semi-structured interviews with various property owners, property managers, insurers, engineers, and government authorities in New Zealand. The interviews revealed insights regarding the multitude of factors influencing post-earthquake decisions and losses. As expected, the level of damage and perceived repairability (cost to repair) generally dictated the course of action. There is strong evidence, however, that other variables, such as insurance policy details, have significantly influenced the decision on a number of buildings. The decision-making process for each building is complex and unique, not solely driven by structural damage. Furthermore, the findings have put the spotlight on insurance policy wordings and the paradoxical effect of insurance on the recovery of Christchurch, leading to other challenges and issues going forward.

DAMAGE ASSESSMENT IN JAPAN AND POTENTIAL USE OF NEW TECHNOLOGIES IN DAMAGE ASSESSMENT

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Japan is one of the earthquake-prone countries. We apply a seismic code that requires a very high seismic performance of which base-shear coefficient demand for the short-period building is 1.0. Since the demand is too high to keep the buildings elastic, non-linear behavior such as flexural yielding is accepted to dissipate the input energy safely and to reduce the demand. The base-shear coefficient demand for the most ductile reinforced concrete building is 0.30. It can be said that the buildings may suffer damage during a severe earthquake.

Rapid inspection of existing structures soon after a big earthquake is crucial in order to prevent tragedies due to aftershocks. Civil infrastructures such as public buildings that are supposed to be shelters need to be evaluated to find out the seismic performance during aftershocks. On the other hand, it is also very important to screen out the buildings that still have enough seismic capacity soon after a mainshock, since a lot of people may refuge from their houses due to fear of collapse even if they have enough capacity. It can help reduce the number of refugees.

The rapid inspection method is applied in Japan to “rapidly” figure out risky buildings against consequent aftershocks. The inspection is based on the visual observation from outside of the buildings. The risks of both structure and foundation are assessed according. The damage levels of the structural members are classified into 5 damage classes according to their crack patterns and their residual crack width. With regard to the foundation damage, uneven settlement and inclination angle are measured. Then the risk is categorized into three groups, “Unsafe”, “Limited Entry”, and “Inspected. The licenced inspector conduct the rapid inspection.

Once the building is categorized as “Limited entry” or “Unsafe”, more detailed assessment is needed to evaluate if the building should be repaired or demolished according to not only the damage level but also the seismic intensity at the site. “The standard to classify the damage due to an earthquake” is applied for the assessment. The lateral strength reduction factor according to the damage class is defined in the standard. The residual seismic capacity index, R, is the ratio of the reduced seismic index with the reduction factors and the seismic index at the original condition (w/o damage). According to the value of R, the damage level of the building is classified as “no damage” (R=1.0), “Slightly damaged” (R>0.95), “Minor damage ” (0.95>R>0.80), “Moderate damage” (0.80>R>0.60), “Severe damage” (0.60>R), and “Collapse”. The decision whether to demolish or repair the damaged building is made according to the matrix of both damage level and seismic intensity. For example, even if the damage level is “slight damage”, the repairment is not recommended if the seismic intensity at the site is small (less than 5+ according to the standard).

Currently, buildings have to be inspected one by one by engineers or researchers. For example, 5,068 engineers and 19 days were needed to inspect 46,000 buildings on a damaged area at the Kobe earthquake. Nineteen days were too long and yet the number of inspected buildings was not enough. Moreover, many buildings were judged as “Limited entry”, which needs detailed assessment by engineers. “Limited entry” judgment is a gray zone and it could not take away anxieties from inhabitants. Furthermore, the current rapid inspection system presents a dilemma since buildings should be inspected by visual observation of engineers. Thus, judgment varies according to engineers’ experience.

In order to solve the problems mentioned above, authors have been developing the real-time residual seismic capacity evaluation system, which needs only few relatively inexpensive accelerometers. The system calculates the performance and demand curves from a measured acceleration of the basement and of each point of a structure with inexpensive accelerometers, and further estimate the residual seismic capacity of a structure by comparing these curves. To draw the performance curve, the absolute response accelerations and relative response displacement at each point are needed. A certain fixture is generally required to measure the drift or the relative response displacement to the basement. This fixture can be obstructive for usage or impossible for a long-span bridge. On the contrary, it is easy to measure accelerations with accelerometers. Therefore, displacements are derived from the accelerations by the double integral in the system. The system has been installed in a few buildings and suffered several earthquakes. The system worked well with a building during the 2011 Tohoku Earthquake and it was assessed as “slightly damaged.

SIMPLIFIED ANALYTICAL (MECHANICAL-BASED) PROCEDURE FOR POST-EARTHQUAKE SAFETY AND LOSS ASSESSMENT OF BUILDINGS

S. Pampanin[1,2]

Abstract

The crucial need to develop and implement simple and cost-effective repair and retrofit strategies and solutions for existing structures has been once again emphasized, if at all needed, by the recent catastrophic earthquake events. More specifically, the urgency of a medium-long-term plan for seismic retrofit and risk reduction strategy at a national scale is becoming increasingly evident in most of the seismic-prone countries worldwide.

With no doubt the assessment of the seismic vulnerability of existing buildings and the definition of appropriate solutions – i.e. structurally effective, easy to apply, cost-effective, possibly reversible and respectful of the architectural, heritage and cultural conservation requirements – hide a level of significantly higher complexity than designing new structures.
Moreover, as if the technical complexity was not a sufficient deterrent, the constraint of economic resources for a national scale implementation and the lack of a prioritization plan based on risk considerations, loss assessment and cost-benefit analyses are often referred to, or blamed as, primary obstacles to the practical implementation of such a board and ambitious project. Yet, studies and comparative evaluations of the social-economic effectiveness of a seismic prevention strategy when opposite to a post-event reaction/repair/reconstruction approach clearly show its long-term and national benefits.

To tackle this delicate issue, it is necessary to improve and standardize the tools and procedures (‘protocols’) for the ‘diagnosis’ and ‘prognosis’ of the seismic vulnerability and of the expected performance of existing buildings, in order to estimate, prior to the event and assess in the aftermath of the earthquake, the post-earthquake safety as well as socio-ecnomic impact/consequences/losses.

Such procedures should be based on state-of-the-art but simplified methodologies (analytical rather than numerical approaches) that could highlight the structural weaknesses of the building system, while ensuring consistency of results and proper level of independently from the operators. Similarly, suitable “therapeutic pathways” or appropriate repair/retrofit strategies can be defined by comparing alternative options through a cost-benefit approach.

This presentation intends to provide provide an overview of the motivations, challenges and (possible) solutions of such a complex and delicate task with the intent to stimulate awareness, discussion and synergetic actions within the wider international community. The significant socio-economic impacts of the Canterbury earthquakes sequence in the 2010-2011 as well as of the “series” of independent events within few years in Italy (L’Aquila, 2009; Emilia, 2012; Central Italy, 2016) have triggered a step-change in the high-level approach towards the implementation of seismic risk reduction, introducing either a mandatory enforcement or significant financial incentives for a national-wide rpogram to assess the seismic vulnerability/capacity of the whole (non-dwelling) building stock including safety and expected repairing costs (economic losses).

Particular focus will be given to the development and continuos refinement of a simplified analytical and mechanically based methodology – referred to as SLaMA (Simple Lateral Mechanism Analysis) method – for post-earthquake safety and loss assessment evaluation, in order to support the engineering community as well as the various stakeholder through the various steps of the complex decisión making process of risk (assessment and) reduction.

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DAMAGE ASSESSMENT METHODOLOGY DEVELOPED FOR TCIP

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Abstract

Post-earthquake seismic damage evaluation of buildings after a severe earthquake, is a major challenge for relevant authorities. The classification of damages in buildings is a key issue that also determines the pace of the recovery stage of the earthquake-stricken community. Thus, an accurate and rapidly applicable damage assessment method is required considering the huge number of buildings and the insufficient number of qualified inspectors. For this purpose, after the destructive 1999 Marmara Earthquakes, a quantitative assessment system serving this purpose was developed (Boduroglu et al., 2013) for the Turkish Catastrophe Insurance Pool (TCIP, known as DASK in Turkey) that was also established after these events. The developed TCIP methodology aims to evaluate the damages in reinforced concrete (RC) and masonry structures. In scope of the method, the experts of TCIP (who may not be civil engineers if the number of buildings to be investigated is high), visit the building and make observations and measurements from the exterior and interior of the building. If no heavy damage state can be identified from exterior of the building, the experts continue with the interior where they assign a damage state (related with a damage reduction factor to account for the capacity lost) to each structural member. The damage state of the member is determined based on the observed residual damages, such as crack width, concrete crushing, cover spalling, crushing of the core concrete and buckling of reinforcement. Typical damage development stages for flexural damage and corresponding damage classes ranging from Type A to Type D are shown in Fig. 1. After that, the weighted damage ratio (WDR) of the structure is calculated by taking into account the damage state and the cross-sectional area of each vertical member. Since its development, this assessment method has been used by TCIP to decide the future of structures to be either 'repaired' or 'demolished' after some earthquakes that took place in Turkey.

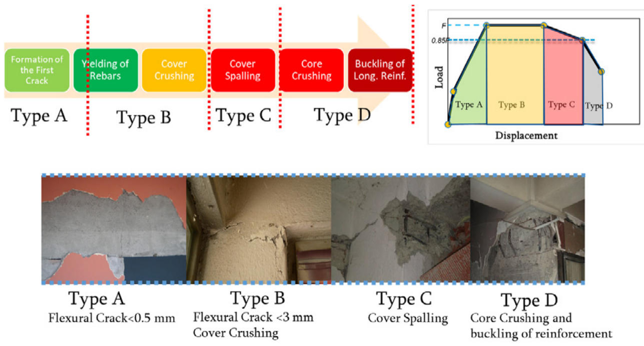

Figure 1. Typical damages and corresponding damage types

The concept of reparability, introduced for determining the threshold for decisions on damaged buildings, has become an emerging research topic for the structural engineering and insurance communities, particularly after the recent Italy and New Zealand earthquakes. Consequently, TCIP initiated a research project to develop the current damage assessment methodology with the data from state-of-the-art scientific research. This paper presents the followed methodology and brief results of different phases of the project.

In the scope of this study, firstly, an experimental database was established focusing on the performance of damaged structural members in order to further validate/revise the member damage reduction factor parameters. The generated database includes 101 tests covering a variety of test parameters including column dimensions, concrete strength, axial load ratio, use of smooth/deformed bars, longitudinal reinforcement ratio, and flexural/shear failure mode. As shown in Equation 1, the damage reduction factor (η) for each test was calculated by dividing the residual energy dissipation capacity of the damaged column (E_r) to the total energy dissipation capacity ($E_d + E_r$) of the undamaged column and compared with the current factors used in the TCIP method. This approach is also adopted in the Japanese JBDPA (2015) method.

$$\eta = \frac{E_r}{E_r + E_d}$$

Secondly, in order to define a reparability limit in terms of the building WDR value, a literature survey investigating the behavior of damaged-and-repaired RC structural elements was carried out. The main focus was on the determination of changes in the fundamental mechanical characteristics (such as stiffness, load capacity, and ductility) after the repairing procedure. To the best of the authors' knowledge, there is limited experimental data inspecting the effect of repair techniques on RC structural members. The most current tests on RC beams are performed by Marder et al. (2018) and Cuevas and Pampanin (2017). The behavior of damaged-and-repaired columns still needs further research. The compiled experimental tests indicated that after repairing RC members, the strength and the ductility features remain almost same; however, the stiffness, in most cases, cannot be restored. Bearing these observations in mind, a series of nonlinear analyses were executed on RC buildings representing the common typologies of buildings in Turkey. The analyses covered the undamaged and damaged-and-repaired conditions in order to determine the damage state/level where the seismic performance of structure deviates from that of its undamaged condition. PGA capacity of structures was selected as the metric for seismic performance assessment where the modal capacity curves of the structures are plotted on a selected spectral acceleration and spectral displacement diagram. Fig. 2 shows the PGA capacity of a typical structure for different stiffness modifiers. The PGA capacity evaluations indicated that the modifications in the stiffness properties, which represent the damaged-and-repaired condition of structures, does not alter the PGA capacity significantly.

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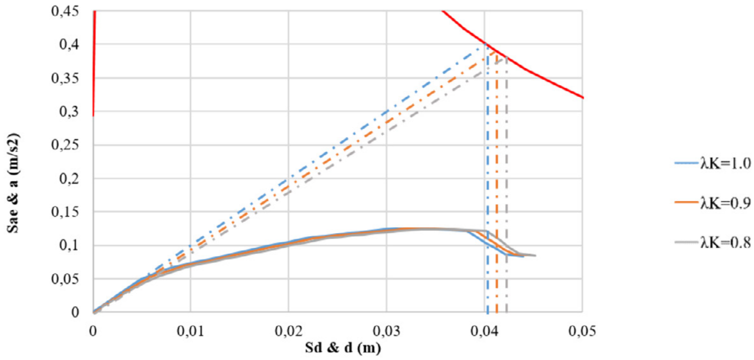

Figure 2. PGA capacity comparison on a typical building

Hence, the threshold for reparability decisions can be correlated with the repair cost rather than the structural performance for repaired condition. Therefore, a link needs to be defined between WDR and the repair cost in order to define a clear reparability limit for damaged structures taking also into account the repair cost of nonstructural elements as well. In the next stage of the project, as a further study, the relationship between the damage state and repair cost is to be investigated through the structural analyses and statistical data obtained from past earthquakes.

References

Boduroglu, H., Ozdemir, P., Binbir, E. and Ilki, A., 2013. Seismic Damage Assessment Methodology Developed for Turkish Compulsory Insurance System. 9th Annual International Conference of the International Institute of Infrastructure Renewal and Reconstruction, Brisbane, Australia.

Cuevas, A. and Pampanin, S., 2017. Post-Seismic Capacity of Damaged and Repaired Reinforced Concrete Plastic Hinges Extracted from a Real Building. in 2017 New Zealand Society for Earthquake Engineering Conference. Wellington, New Zealand.

FEMA 306, 1998. Evaluation of earthquake damaged concrete and masonry wall buildings: Basic procedures manual. ATC, Redwood City, CA, USA.

Marder, K., Sarrafzadeh, M., and Elwood, K., 2018. Effectiveness of Repair Via Epoxy Injection of Earthquake Damaged Reinforced Concrete Beam Elements. 17th U.S.-Japan-New Zealand Workshop on the Improvement of Structural Engineering and Resilience. Queenstown, New Zealand.

JBDPA (Japan Building Disaster Prevention Association), 2015. Standard for seismic evaluation of existing reinforced concrete buildings, guidelines for seismic retrofit of existing reinforced concrete buildings, and technical manual for seismic evaluation and seismic retrofit of existing reinforced concrete buildings. Tokyo: JBDPA (Japan Building Disaster Prevention Association)

RISK ORIENTED EARTHQUAKE HAZARD ASSESSMENT

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Although all components of seismic hazard analysis continue to evolve, the most signifi- cant changes in recent times have related to the application of non-ergodic approaches within ground-motion modelling. The presentation therefore focusses upon the implications of these advancements for modelling ground-motion fields within portfolio loss estimation. As a par- ticular example within this area, the presentation highlights some features of earthquake se- quences that have received little attention to date, but can have a significant impact upon post- mainshock risk assessments.

Within portfolio or regional seismic risk analyses, ground-motion fields have traditionally been constructed through the use of empirical ground-motion models along with models for spatial and inter-intensity measure correlations. These components are normally based upon the application of the ergodic assumption in which empirical data from analogous tectonic regions are compiled. These ergodic datasets are are assumed to represent a sample of ground- motions that would be observed for the target region if a longer period of observation were available. The use of the ergodic assumption can lead to biased estimates of median levels of ground-motion, and an inflation in the apparent aleatory variability for a given rupture scenario. These issues have been recognised at a conceptual level for at least two decades, but empirical databases of ground motions have only recently grown to the point where such biases can be confidently constrained.

The removal of the ergodic assumption within seismic hazard analysis has led to so-called non-ergodic, or partially non-ergodic hazard analyses, but there is very limited application of such models within risk analyses. Within non-ergodic applications it has become common to treat models for the median motion independently of the apparent aleatory variability. Site, or region-specific adjustments are made to median predictions, and it is assumed that the ergodic aleatory variability can be reduced by a certain amount as a result. The overall uncertainty in ground-motion levels is not necessarily reduced, however, as the epistemic uncertainty as- sociated with the corrections that are applied to the median model can be non-trivial. While quite a significant amount of attention has been applied to investigating the appropriate reduc- tion in the aleatory variability, the same degree of attention has not been applied to models for ground-motion correlation that are utilised within regional risk analyses. Aspects of these cor- relations are discussed within the presentation, particularly focussing upon spatial correlations and correlations among response spectral ordinates.

In particular, the presentation discusses the following issues, with varying levels of detail:

• The ergodic assumption leads to the overall variance components within ground-motion models being inflated - both between and within event components. To what extent can we make reductions to published estimates of aleatory variability?

• When partially non-ergodic hazard analyses are performed in which site-specific ampli- fication functions are employed, site-to-site variability is necessarily reduced. Further- more, estimates of this site-to-site variability should be updated progressively as more events take place. However, no ground-motion models currently take into account the known effect of scenario-dependence in site amplification, so we need to ensure that es- timates of systematic site effects are not biased by this omission.

• Partially non-ergodic corrections for systematic path effects should not be included within the models of spatial correlation. Currently, estimates of spatial correlation also include systematic effects of biases in path scaling. How does this effect manifest, and how can one look to remove its influence?

• Similarly to the case for path effects, systematic site effects should not be included within the models for inter-period correlation. Almost all correlation models developed to date include these systematic site effects (and biased estimates of such effects), so how should this bias be addressed?

• Moving to systematic source effects, estimates of stress drop and other source effects should have systematic bias within sequences when re-rupturing existing faults (differ- ent classes of aftershocks), and are also correlated spatially (regardless of whether we are dealing with aftershocks or triggered events). How should this effect be accounted for within risk analyses?

• For post-mainshock seismic risk analyses, how can we make conditional predictions of source, path and site effects as the aftershock sequence develops? What are the implica- tions of such updates for post-mainshock risk assessments?

Ways forward are suggested for addressing some of these open questions, while others are raised as areas for further investigation. It is clear that physics-based ground-motion simu- lations will gain increasing traction in the future and will compliment or supplant empirical methods at some point. However, at this point, further work is required to develop these methods in order to ensure that the correlation features implied by these methods are robust. A challenge in this regard relates to how we should benchmark the implied correlations ob- tained from physics-based simulations. In light of the issues highlighted above it is clear that a simple comparison with existing correlation models based upon the ergodic assumption will not suffice.

EMPIRICAL FRAGILITY AND VULNERABILITY OF REGIONAL BUILDING STOCK IN EUROPE

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Keywords: fragility curve; seismic assessment; macroseismic vulnerability model; masonry structures

Abstract

In the framework of seismic risk analyses at large scale, among the available methods for the vulnerability assessment the empirical and expert elicitation based ones still represent one of most widely used options. In fact, despite some drawbacks, they benefit of a direct correlation to the actual seismic behaviour of buildings and they are easy to handle also on huge stocks of buildings.

Within this context, the macroseismic vulnerability model is presented, which is based on the original proposal of [1] and has been further developed in recent years. The method may be classified as heuristic, in the sense that: a) it is based on the expertise that is implicit in the European Macroseismic Scale (EMS98), with fuzzy assumptions on the binomial damage distribution; b) it is calibrated on the observed damage in Italy, available in Da.D.O. [2]. This approach guarantees a fairly well fitting with actual damage but, at the same time, ensures physically consistent results for both low and high values of the seismic intensity (for which observed data are incomplete or lacking). Moreover, the method provides a coherent distribution between the different damage levels. The valuable data in Da.D.O. allowed significant improvements of the method than its original version.

The model has been recently applied in the context of ReLUIS project, funded by the Italian Department of Civil Protection to support the development of Italian Risk Maps [3]. To this aim, the vulnerability model has been applied for deriving fragility curves. This step requires to introduce a correlation law between the Macroseismic Intensity (adopted for the calibration of the model from a wide set of real damage data) and the Peak Ground Acceleration (at present, one of most used instrumental intensity measures). This conversion further increases the potential of the macroseismic method.

The first application of the model has produced plausible and consistent results at national scale, both in terms of damage scenarios and total risk (economic loss, consequences to people).

[1] Lagomarsino S., Giovinazzi S. (2006) Macroseismic and mechanical models for the vulnerability and damage assessment of current buildings. Bull Earthquake Eng, 4(4): 415-443

[2] Dolce M., Speranza E., Giordano F., Borzi B., Bocchi F., Conte C., Di Meo A., Faravelli M., Pascale V. (2017) Da.D.O. – A web-based tool for analyzing and comparing post-earthquake damage database relevant to national seismic events since 1976. Proceedings of the 17th Italian Conf on Earthq Eng, Pistoia (Italy).

[3] National Risk Assessment (2018) Overview of the potential major disasters in Italy: seismic, volcanic, tsunami, hydro-geological/hydraulic and extreme weather, droughts and forest fire risks, Presidency of the Council of Ministers Italian Civil Protection Department.

ELEMENTS AT RISK, FRAGILITIES, CONSEQUENCE FUNCTIONS AND VULNERABILITIES

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Within the European Horizon 2020 Project SERA (www.sera-eu.org), a European Seismic Risk Model is being developed using openly/publicly available data on all components of seismic risk from catalogues, to active faults, building data and vulnerability models. This contribution to the workshop will look at the current state of the practice when developing the exposure and vulnerability components of risk using open/public data, address where the challenges presently lie, and look towards the future directions that are being explored to address these shortcomings and lead to improved seismic risk and loss modelling.

Elements at risk

A European exposure model describing the spatial distribution of residential, commercial and light industrial building count, population, and replacement cost - characterized in terms of building classes –is being developed for 46 countries in the SERA project (Crowley et al., 2019). These residential and non-residential exposure models have been derived based on the latest national housing censuses, socio-economic indicators (e.g. labour force, population and floor area per worker per economic sector), mapping schemes (to map the available data to building classes) developed together with local experts, as well as engineering judgment. In addition to releasing the models with open data Creative Commons licenses, all sources and assumptions will also be provided to allow for increased transparency and reproducibility. Such exposure models can be used in the insurance/reinsurance industry for the assessment of ground up losses, or possibly to identify the most likely building classes within a given portfolio of assets (when such information is lacking).

There are, however, a number of shortcomings of such an approach to model the buildings at risk over large regions. Many assumptions are required to compensate for the lack of open/public data on buildings (e.g. the assumptions needed to convert dwellings to buildings, or the use of labour force statistics to spatially distribute commercial buildings), and often the model uncertainty in not explicitly estimated or documented, nor propagated through the risk/loss model. Given the significant manual work used to develop these models (which needs to be repeated when the new round of census data is collected and made publicly available), the resulting models are static and do not get regularly updated.

To address some of these limitations, the future of exposure modelling is likely to focus on producing dynamic exposure models with the necessary tools and web services that will allow them to be automatically updated. The sources of data for such models might be crowdsourced data (such as OpenStreetMap, which also includes other elements at risk such as road networks, schools, critical infrastructure) or satellite imagery (and associated algorithms for extracting building footprints and other attributes that can be updated through deep learning).

Fragility models

Fragility models for the elements at risk within an exposure model provide the probability of reaching or exceeding a set of damage states, conditional on the level of ground shaking. Whilst these models can be developed using observed damage data, the large uncertainties in the ground shaking to which the buildings have been subjected often mean that the resulting functions are flatter and highly uncertain (e.g. Ioannou et al., 2014). Analytical modelling is thus preferred as hazard consistent ground shaking at the site can be considered, the relative difference between building classes (some of which may not yet have experienced earthquake damage in past events) can be explicitly modelled, and data on the characteristics of specific buildings (when available) can be used to update the models.

Within the European seismic risk model, the evolution of design codes across Europe has been studied and the basic principles of seismic design according to three main categories of design (low, moderate and high) are being used to design prototype buildings, which are then modelled to obtain their lateral strength and deformation capacity. The MDOF designed buildings are transformed into SDOF systems and subjected to a range of ground motion recordings (through dynamic nonlinear analysis) to model the relationship between ground shaking intensity and displacement response. Uncertainties in the characteristics of the buildings (geometrical and material), the design parameters, the quality of construction (and thus adherence to code), the displacement thresholds to damage, and the variability in ground shaking can all be accounted for in the procedure.

Whilst the latest approaches do account for a wide range of uncertainties, model uncertainty (defined herein as the uncertainty associated with the selected modelling approach, rather than parameter uncertainty) is typically not considered (Silva et al., 2019). As more experimental tests of components and full-scale buildings become available, there is scope to quantify the bias or lack of precision of the structural modelling methodology used in the development of analytical fragility functions (Bradley, 2013). The modelling of epistemic uncertainty should thus become standard practice in future analytical fragility modelling, and might be based on a backbone approach with the aleatory model uncertainty represented through a logic tree (Crowley et al., 2017).

Another future direction that could reduce the uncertainties in analytical fragility modelling would be to include more sensors in (insured) buildings and use the data from ambient noise and strong motion recordings to better constrain their dynamic properties (e.g. period elongation, structural response). The measurement of the actual level of ground shaking and response of the building can also be used for a multitude of insurance related activities such as the rapid assessment of loss, the prioritisation of post-event damage inspections, and even for parametric insurance triggers.

Vulnerability models

Whilst vulnerability models could be developed directly from empirical loss data, often the resolution and quality of loss data in public databases is not sufficient for this purpose, and the benefits of analytical fragility modelling described previously cannot be exploited. Vulnerability models are thus commonly being developed by combining analytical fragility functions with consequence models, which define the probability of loss, conditional on the level of damage. This area of research has not received as much attention as analytical fragility modelling, and often the risk analyst will resort to the use of empirical consequence models. Regardless of the methodology employed, ‘sanity checks’ which verify the resulting vulnerability models using past earthquake damage and loss data should be undertaken.

Some difficulties related to the development of reliable consequence models include the lack of data in the public domain (in particular for injuries and fatalities for specific building classes), and the difficulty in forecasting additional factors that might influence economic loss, such as demand surge or country-specific legal frameworks the determine when there is a need to demolish rather than repair.

Future efforts to standardise the collection of open and publicly available consequent data is fundamental for a better understanding of the impacts of earthquakes and for better calibration and verification of loss models.

References

Bradley B. (2013). A critical examination of seismic response uncertainty analysis in earthquake engineering. Earthquake Engineering and Structural Dynamics. 42 (11): 1717–1729

Crowley H, Polidoro B, Pinho R, Elk J (2017). Framework for Developing Fragility and Consequence Models for Local Personal Risk, Earthquake Spectra, 33(4):1325-1345.

Crowley H., Despotaki V., Rodrigues D., Silva V., Toma-Danila D., Riga E., Karatzetzou A., Fotopoulou S., Zugic Z., Sousa L., Ozcebe S., and Gamba P. (2019). Exposure Model for European Seismic Risk Assessment, Submitted to Earthquake Spectra

Ioannou I., Douglas J., Rossetto T. (2014). Assessing the impact of ground-motion variability and uncertainty on empirical fragility curves. Soil Dynamics and Earthquake Engineering, DOI: 10.1016/j.soildyn.2014.10.024

Silva V., Akkar S., Baker J., Bazzurro P., Castro J.M., Crowley H., Dolsek M., Galasso C., Lagomarsino S., Monteiro R., Perrone D., Pitilakis K., Vamvatsikos D. (2019). Current Challenges and Future Trends in Analytical Fragility and Vulnerability Modelling. Earthquake Spectra, in press.

EARTHQUAKE PHYSICAL RISK / LOSS ASSESSMENT MODELS AND EXAMPLE APPLICATIONS

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A probabilistic earthquake risk model is developed that provides information about the effect of modeling uncertainty in fragility and consequence functions on loss. The risk model employs Monte Carlo simulation technique to propagate the fragility and consequence modeling uncertainty on the estimated vulnerability function. This way the risk modeler not only observes the full range of modeling uncertainty effect on the loss curve but also can understand how the uncertainty can result in a band in median loss. In essence, the band in median loss curves resembles the backbone approach that is now frequently used in advanced probabilistic seismic hazard assessment. The implementation of the risk model is described by showing the content loss in residential buildings in Turkey that uses building sensitive content fragility functions by Total Probability Theorem. The conclusions in this study highlight the importance of building inventory, fragility and consequence model compilation that can systematically address the modeling uncertainties in each component.

CAT MODELING, APPLICATION TO INSURANCE INDUSTRY: UNKNOWNS AND POSSIBLE SOURCES OF BIAS IN PRICING

Paolo Bazzurro

Catastrophe Risk models have been the backbone of many activities carried out by insurance/reinsurance companies and brokers for at least for 25 years. These models have provided more defensible risk estimates for rare events and made clear that traditional empirical approaches based on scarce historical data alone were not tenable. Insurance pricing is one such activity. The pure premium is derived by outputs of cat models but is routinely inflated to account for several items, including running costs, profit, unmodeled hazard, and unknowns. As far as the unknowns go, the inflation, however, is currently not supported by an adequate scientific basis. This presentation will discuss some of the ubiquitous modeling decisions utilized in earthquake cat models that may generate uncertainty and, in certain instances, significant biases in the risk estimates. Among the different sources of uncertainty and bias that may be present in the traditional modeling approach, this presentation will touch upon only three: the analytical derivation of vulnerability functions for classes of buildings, the use of traditional site-generic ground motion prediction equations for seismic hazard estimation, and the disregard for of any earthquake but the mainshock in a seismic sequence.

ROLE OF EARTHQUAKE INSURANCE IN EARTHQUAKE RISK AND RESILIENCE BUILDING

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ABSTRACT

Understanding Resilience

Resilience is defined as "The ability to **prepare** and **plan** for, **absorb**, recover from and more successfully **adapt** to adverse events[1]" (US National Academies). Resilience finds its theoretical basis in system theory. This is illustrated in **Figure 1**. An urban system (for example, the city of Istanbul) is a dynamic system subject to the five elements indicated in the figure. A system is resilient when environmental perturbations (i.e., shocks and stresses) cause the least impact to its outputs and will require minimum or no external resources to maintain its productive steady state. An important point is that the resilience of a system is only as good as its weakest element.

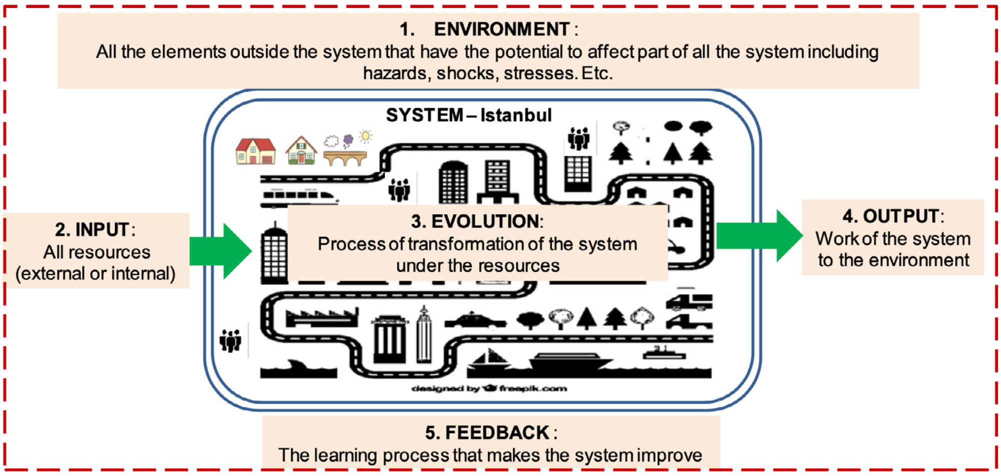

Figure 1. Resiliance finds its theoretical basis in system theory

When a system has the necessary and sufficient resilience, it should be able to sustain a "perturbation" and still maintain functionality, albeit at a somewhat diminished mode of resilient operation, thus avoiding a state of emergency (or disaster).

Within this context, how does insurance intervene in building resilience?

The core function of insurance[2] is to restore property and livelihood in case of an adverse effect. It does that by providing a cash infusion into a system immediately after the event. The cash is used to restore property and avoid interruption of commercial and industrial activity. In reference to Figure 1, Insurance is part of the Input to the system. It is essentially a resource to the system. The big advantage of insurance as a resource is that it is an immediate cash infusion. In fact, the faster the insurance funds are put back into the system, the more resilience the system has. This corollary indicates that parametric approaches to Cat Insurance are favored over indemnity approaches since the distribution of funds is much faster in the former than the latter.

Insurance is the main instrument for managing **residual risk**. At the minimum, it provides financial protection by covering losses from shocks. This is critical to the economy whether at a large scale (e.g., a country) or a smaller scale (e.g., a household or a small business). This is an important factor of resilience offering government, communities, businesses, and households the possibility to rebuild from their losses and restore livelihoods and economic conditions.

Insurance also intervenes in terms of reducing impact of stresses (which are the more extensive types of hazards) since it enables a process of maintaining functionality of a system by providing funds for recovery under minor but more frequent events.

Finally, insurance could be a contributor in awareness raising about hazards and risks, and in building confidence in the viability of the system itself. There is higher confidence to provide investment in properties, businesses and industries that are insured.

This of course, describes an ideal insurance governance system built on trust, transparency, and effectiveness. However, as explained below, there have been barriers to this "perfect" system in the past.

The contribution of Cat Models?

The introduction of cat models in the early nineties revolutionized the Cat insurance business by providing physical approaches to modeling losses with greater resolution and accuracy than conventional actuarial approaches. Cat models provided a means to

1 Several other definitions of resilience exist. They all convey the same concept.
2 The focus of the discussion in on Cat Insurance, which deals with insurance protection from catastrophic events such as earthquakes or floods or tropical cyclones.

anticipate future losses and to understand volatility thus resulting in more accurate pricing of risk and greater transaction efficiency and transparency between all parties (policy holder, insurer, reinsurer and investor). Cat models enabled new financial products directed towards the capital market. These latest advances have made insurance a greater factor in resilience building. The models have enabled Cat insurance to approach the "perfect" state, particularly in indexed and parametric transactions.

Why is society concern about the insurance matter in building resilience?

For most countries, governments have been the insurer of last resort when it comes to cat risk. The reason is that level of cat insurance penetration in many countries is very low. The ultimate government intervention coupled with the lack of effectiveness of the financial transaction negated any incentive for individuals to acquire a cat insurance policy. Other elements were also at play in affecting the business case for earthquake insurance:

- The fact that the events were rare reduced the public awareness (i.e., it will not happen in my lifetime);
- The perception that I am fine because my property/business was not affected in the last event. It only happened to others;
- The perception that construction codes provided "disaster-proof" structures;
- A general 'chronic" understanding of cat insurance and cat risk among the general public; and
- Cost – for several individuals the cost of cat insurance was not affordable.

The new dynamic in cat risk financing

Successive catastrophic events (starting with1992 Hurricane Andrew) causing devastating losses to society have raised the need for new approaches to provide financial protection from cat events. New phenomena are also taking place that caused the increase awareness:

- Urbanization causing accumulation of assets in cities and urban agglomeration;
- Wealth accumulation and society's sophistication, which increased the value of assets;
- Climate change which affects severity (and arguably frequency) of events; and
- Domino-effects caused by the complexity of the urban environment that can multiply the losses.

Governments are finding it more and more costly to come after a disaster and pick up the bill. Governments are also realizing that "physical protection" through infrastructure is not necessary full protection. Countries are looking for new strategies to cover losses and to shift losses to individuals, insurers and to the capital market.

TCIP as an early experiment

TCIP is an early experiment aimed at increasing penetration by making cat insurance mandatory. This is of course, the very first "line of defense" for government to shift losses towards property owners and reduce its contingent liability. The basic concept of insurance of spreading risk widely among as many property owners as possible is applied, thereby reducing premium cost and making insurance affordable. While in its early stages, TCIP struggled to accomplish its goals, it has progressively built strength mostly through sound insurance practices, awareness raising, keeping affordability, and relying on scientific modeling. In 2016, TCIP has 136 billion Euro coverage capacity for earthquake losses in Turkey. A true evidence of resilience contribution to Istanbul, other major cities in Turkey and the country as a whole.

More innovation in the market

With the support of the World Bank, ADB and other IFIs, more innovation is coming to the market by looking at sophisticated strategies and solutions for risk financing. The overarching mission is to protect state finances, the population, and the economy through sustainable and efficient risk financing mechanisms that cover projected disaster-related expenditures and at the same time reduce volatility and increase predictability. The stated goal is to increase transparency and efficiency by making optimum use of scientific models and an understanding of the nature and values of the exposed assets.

FIRE FOLLOWING EARTHQUAKE MODELS AND INSURANCE

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ABSTRACT

Fire following earthquake refers to a series of events or stochastic process initiated by a large earthquake. Fires occur following all earthquakes that significantly shake a human settlement but are generally only a very significant problem in a large metropolitan area predominantly comprised of densely spaced wood buildings. In such circumstances, the multiple simultaneous ignitions can lead to catastrophic conflagrations that may be the dominant agent of damage for that event. Large metropolitan areas with high seismicity and predominantly comprised of densely spaced wood buildings are the regions at highest risk of post-earthquake fire, and include Japan, New Zealand and parts of Europe, Asia and North and South America. However, any area with a large inventory of densely spaced wood buildings struck by an earthquake has the potential for large post-earthquake conflagrations. Such a situation prevails in portions of Istanbul.

Estimation of post-earthquake ignitions and fire spread is detailed in an American Society of Civil Engineers monograph (Scawthorn et al., 2005) and includes the following steps:

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• Occurrence of the earthquake –causing damage to buildings and contents, even if the damage is as simple as knockings things (such as candles or lamps) over.
• Ignition – whether a structure has been damaged or not, ignitions will occur due to earthquakes.
• Discovery – at some point, the fire resulting from the ignition will be discovered, if it has not self-extinguished although the discovery may take longer than under non-earthquake conditions.
• Report – Communications system dysfunction and saturation will delay many reports.
• Response – the fire department may be impeded by other emergencies (e.g., building collapse)
• Suppression – the fire department then has to suppress the fire – if successful, they move on to the next incident – if not, the fire grows and becomes a conflagration. Success or failure hinges on numerous factors including water supply functionality, building construction and density, wind and humidity conditions, etc.

The post-earthquake fire risk of many urban regions including Los Angeles, San Francisco, Vancouver (B.C.), Montreal, Christchurch, Tokyo and Istanbul have been assessed using this approach. For example, the recent "Haywired" project assessed losses arising from fires following a hypothetical moment magnitude (Mw) 7.05 earthquake on the Hayward Fault in the east bay part of the San Francisco Bay area (Scawthorn and et al 2018), finding approximately 668 ignitions will occur requiring the response of a fire engine. The first responding engine will not be able to adequately contain approximately 450 of these fires, such that dozens to hundreds of large fires are likely to merge into numerous conflagrations destroying tens of city blocks, with several of these potentially merging into one or several super conflagrations destroying hundreds of city blocks with an economic loss approaching $30 billion. This loss is virtually fully insured and would be one of the largest historic single loss events in the history of the insurance industry.

Mitigation of fire following earthquake at its most basic revolves about reducing ignitions and rapid response to limit fire spread. Ignitions can be reduced by use of seismic shut-off devices on gas and electric lines and industrial processes, while rapid response involves early location of fires, and effective response by trained personnel adequately equipped and supplied with water. In Japan and California the fire service has also been relatively diligent in preparing for a large earthquake—the Citizens Emergency Response Team (CERT) program is a model in that regard. However, the following opportunities for improvement exist: (a) Improvements are needed in the ability to more quickly assess the incident, and facilitate incident reporting. Reconnaissance using unmanned aerial vehicles, and cellular text messaging incident reports directly to a 911 portal, should be developed and operationalized; (b) Alternative water sources need to be better identified, and access and water movement capabilities enhanced. The water service in California has worked to prepare for a major earthquake, but more can still be done (Scawthorn 2011). One overriding issue with regard to fire following earthquake is that water agencies typically aren't focused on post-earthquake fire protection. Water system upgrades are more typically oriented to maintenance of customer service, and minimizing direct damage to the system, than to maximizing water-supply reliability. An effective approach would be for water agencies to configure and upgrade their system so as to provide a "backbone" system of water mains of high seismic reliability, that provide water to major sections of the community and from which the fire service could draw water to suppress a conflagration using an LDH system. This approach is being taken in San Francisco and Los Angeles, where the SFPUC and LADWP are implementing resilience programs including quantifying post-earthquake firefighting water demands.

Advances have occurred in recent years that improve the ability to model fire following earthquake, including:
• Accounting for spatial variation in ground motions. Previous lack of consideration of this resulted in underestimation of the number of ignitions and damage to water system.
• Better estimation of ignitions, including more data – for example, 345 fires occurred in the 2011 Japan Tohoku earthquake (Anderson et al. 2016) and mechanistic models.
• Improved exposure data, including actual building footprints and inventories of urban trees, which permits better estimation of fire spread
• Physics based modeling of fire spread (Himoto and Tanaka 2008) rather than empirical modeling.
• Improved modeling of water and other lifelines and their interdependencies (Scawthorn et al. 2018)

References
Anderson, D., R.A. Davidson, K. Himoto, and C. Scawthorn. 2016. "Statistical Modeling Of Fire Occurrence Using Data From The Tōhoku, Japan Earthquake And Tsunami." Risk Analysis 36(2):378-95.
Himoto, Keisuke, and Takeyoshi Tanaka. 2008. "Development And Validation Of A Physics-Based Urban Fire Spread Model." Fire Safety Journal 43:477-94pp.
Scawthorn, C., D. Myerson, D. York, and E. Ling. 2018. "Determining Water Distribution System Pipe Replacement Given Random Defects – Case Study of San Francisco's Auxiliary Water Supply System." Pp. 12 in Eleventh U.S. National Conference on Earthquake Engineering. Los Angeles, California: Earthquake Engineering Research Institute.
Scawthorn, Charles. 2011. "Water Supply In Regards To Fire Following Earthquakes." Pp. 173. Berkeley: Pacific Earthquake Engineering Research Center, College of Engineering, University of California, sponsored by the California Seismic Safety Commission, available at www.seismic.ca.gov/pub/CSSC_2011-02_WaterSupply_PEER.pdf with four page summary at http://peer.berkeley.edu/publications/peer_reports/reports_2011/Fire%20Following%20Earthquake-online-view-layout-sm.pdf.
Scawthorn, Charles, and et al. 2018. "Fire Following The Mw 7.05 Haywired Earthquake Scenario." in 11th National Conference on Earthquake Engineering. Los Angeles: Earthquake Engineering Research Institute.