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FROM SEISMIC HAZARDS TO RESILIENT CITIES: THE CONTRIBUTION OF ENGINEERING GEOLOGY

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EXTENDED ABSTRACT

Diverse tipologie di pericoli naturali interessano la superficie terrestre esponendo molte comunità ad elevate condizioni di rischio anche in corrispondenza di intensi agglomerati urbani quali le megacity. La consapevolezza dell'esistenza del rischio e della possibilità che questo crei un impatto negativo sulle persone o sulle comunità, ha determinato la necessità di definire delle strategie efficaci di prevenzione, reazione, gestione e recupero a seguito dell'avvenimento di disastri naturali. In questo contesto si è sviluppato il concetto di resilienza

Questo inizialmente è stato considerato come un processo di reazione all'impatto negativo degli eventi calamitosi in cui la comunità veniva considerata come un elemento passivo che subisce il disturbo ed in seguito avvia il processo di recupero. Alla fine degli anni '90, a questa filosofia si è contrapposto un approccio basato su un ruolo attivo della singola comunità tale per cui essa non subisca l'impatto dovuto al disastro naturale ma si prepari e si adatti alle circostanze disastrose al fine di potenziare la propria capacità di risposta e reazione all'evento sia minimizzandone i danni sul piano economico e sociale che attutendone gli effetti nel medio/lungo termine. Una comunità resiliente rappresenta l'unica strategia che permetta di ridurre l'impatto e le perdite dovute ai disastri naturali ed al contempo di preservare la salute stessa della comunità. Una città può essere definita resiliente quando può essere preparata, rispondere e superare un disturbo tollerando il danno e trovando un nuovo assetto. Il raggiungimento della condizione di resilienza di una comunità è legato all'applicazione di strategie volte ad incrementare la resilienza strutturale e quella sociale. La resilienza sociale fa riferimento al contesto umano e della società che è definita resiliente quando riesce a sopravvivere ai disturbi esterni tramite beni essenziali, stili di vita e cultura. L'obiettivo della resilienza sociale di una comunità è migliorare questi aspetti attraverso un processo di adattamento a diverse tipologie di disturbi (i.e. disastri naturali). Costruire una città resiliente richiede investimenti sia economici che in termini di tempo, su attività che permettono di definire alternative applicabili a diversi scenari. La resilienza strutturale invece, fa riferimento agli ambiti urbani e spazia dai domini politico-economici a quelli infrastrutturali e tecnologici. Questa è composta da tre tipologie principali di resilienza:

- resilienza infrastrutturale legata all'assetto infrastrutturale della comunità in termini di reti di trasporto, strutture, etc.;
- resilienza istituzionale associata ai sistemi governativi e non – governativi cui è affidata la gestione della comunità;
- resilienza economica che fa riferimento alla diversità ed allo status economico delle comunità.

Il raggiungimento dell'obiettivo di una città resiliente richiede l'inclusione di approcci sia tecnici che sociali che determinino una connessione sostenibile tra le comunità umane ed i sistemi fisici.

Alcuni esempi tratti dalla storia moderna, ed in particolare i terremoti di Lisbona (1755), di Città del Messico (1985) e de L'Aquila (2009) attraverso diverse epoche e contesti socio-culturali consentono una comparazione tra livelli di conoscenza ed attitudine alla resilienza sociale e strutturale. Inoltre, nel corso del XX secolo si sono definite alcune linee strategiche che portano ad individuare distinte tipologie di strategie di resilienza tra cui quelle definibili come "Modello Californiano" e "Modello Giapponese" che polarizzano l'attitudine alla resilienza sociale rispettivamente sulla risposta di un sistema statale sovraordinato e sulla risposta individuale dei soggetti della comunità. A tutt'oggi, tuttavia, possono riconoscersi numerose identità sociali "Non ancora resilienti" per le quali le attitudini alla risposta resiliente a disastri naturali non sono sufficienti a contenerne l'impatto socio-economico di medio-lungo termine. La geologia applicata può essere considerata uno strumento multidisciplinare che attraverso la gestione degli effetti e la prevenzione dei rischi naturali contribuisce ad incrementare la resilienza delle comunità. Le tecniche e le tecnologie messe a punto e ampiamente utilizzate nell'ambito della geologia applicata contribuiscono ad incrementare la resilienza strutturale e sociale. La comunicazione e la formazione della comunità e delle istituzioni consentendo di aumentare la consapevolezza e la conoscenza della società permettendo così di incrementare la resilienza sociale. D'altro canto, la comprensione dei processi naturali e delle loro interazioni con l'ambiente e le strutture antropiche può migliorare la componente strutturale della resilienza.

ABSTRACT

Different types of natural hazard affect the surface of the Earth, exposing human communities to high-risk conditions. This fact makes it imperative to identify strategies for preventing, responding to, managing, and recovering from natural disasters. It is within this framework that the concept of "resilience" has arisen. Achieving a resilient condition is the only way to mitigate the impact of and the losses due to natural disasters, as well as to protect the health and well-being of communities. The paper discusses the contribution that engineering geology can provide to increasing the structural and social resilience of communities to the impact of earthquakes. Creating awareness of engineering geology applications in society and among public institutions can enhance social resilience, while promoting the understanding of natural processes and their interactions with man-made structures and the environment can improve the structural component of resilience. The paper describes the role of engineering geology as a new player in strengthening community resilience, suggesting the need for a multidisciplinary approach to achieving a resilient condition.

***Keywords**: Seismic Hazards; Resilience; Community Impact; Resilient City; Land-Use Planning*

INTRODUCTION

The term "resilience" derives from the Latin word Resiliens, -entis. i.e. the present participle of the verb resilire (re + salio), meaning "to jump back". According to its formal definition, resilience expresses the ability of individuals or society to adjust to and recover from shocks or disturbances. In the modern age, the concept of resilience has been used in ecology, physics, psychology, and psychiatry. With regard to natural and anthropogenic disaster responses (the aspect of resilience on which this paper is focused), some authors (Wildavsky, 1991; Horne, 1998) have referred to a process reaction.

Definitions based on the expressions "have to face up to; resist and absorb the negative impacts and get back to normal as soon as possible" reflect a reactive attitude. More recent definitions of resilience, like those proposed by Pelling (2003), Comfort *et alii* (1999), and the United Nations Office for Disaster Risk Reduction - UNISDR (2005), have largely used expressions such as "coping with" and "adapting to", highlighting resilience as an immediate response to natural disasters. In recent decades, community exposure to natural and anthropogenic disasters has been rising, thus leading to a wide application of the resilience concept in risk management and vulnerability reduction. A city can be defined as resilient if it is prepared for, responds to, and survives a disturbance by tolerating damage and finding a new structural setting (Drobniak, 2012). Resilient communities combine their experience and knowledge of natural and/or anthropogenic phenomena to successfully adapt to their impacts on and/or changes in the environment. From this point of view, resilience has emerged as a "boundary object" (Star & Griesemer, 1989; Star, 2010) placed between two scientific communities, i.e. natural and social sciences. Good engineering geology practices can be very effective in identifying and managing areas that are susceptible to natural disasters, causing severe damage and inducing high-risk conditions. At the same time, the contribution of engineering geology to understanding the interrelationships between the processes involving the surface of the Earth, ecological systems, and human activities is a key tool to mitigate earthquake disaster risks through a social resilience strategy.

Among natural hazards, earthquakes are events whose intensity and magnitude can severely threaten communities living in large urban areas. Furthermore, owing to its destructive potential, an earthquake is the natural phenomenon with the highest areal impact and the largest involvement of communities. In the modern age, numerous destructive seismic events have devastated large cities: San Francisco (USA) in 1906, Reggio and Messina (Italy) in 1908, Mexico City (Mexico) in 1985, and L'Aquila (Italy) in 2009. More recently, strong seismic events have occurred in large areas which were not densely urbanised, but hosted numerous resident communities, as in the case of the earthquakes in Nepal in 2015 and in the Central Apennines (Italy) in 2016-2017.

In the near past, strong earthquakes (e.g. in Belice and Irpinia, Italy, in 1968 and 1980, respectively) have contributed to the abandonment of entire urbanised areas, leaving "ghost towns" (a definition coined by the Swedish journalist Jan-Olof Bengtsson in 1977) in their wake; examples are Gibellina in Belice or Conza della Campania in Irpinia. By contrast, in some cities hit by strong earthquakes (Lisbon, Portugal, in 1755, San Francisco in 1906, Mexico City in 1985, and Kobe, Japan, in 1995), the disasters gave impetus to urban regeneration (infrastructure, social fabric, and cultural life). The resilience of urban communities to high-intensity seismic events has significantly improved over time, thanks to civil engineering and technological solutions: the former have mitigated the vulnerability of residential buildings, while the latter have resulted into early warning alert and monitoring systems. However, important contributions can also be provided by disciplines related to earth sciences, such as engineering geology applied to natural risks. In this regard, major protection and communication strategies have been put in place, on one hand to mitigate the vulnerability of the urban system and on the other hand to make urban communities aware of the seismic risks to which they will continue to be exposed in the future.

This paper discusses and exemplifies the contributions that engineering geology can provide to the different components of a resilient city within the framework of earthquake risk management.

RESILIENT COMMUNITY AND RESILIENT CITY

Urban areas cover nearly 3% of the surface of the Earth (Figs. 1, 2); 75% of them are vulnerable to strong natural risks. As highlighted by Blaikie *et alii* (1994), 13 out of 22 megacities are located in areas with high levels of seismic, volcanic, and hydrogeological risks. Cities are systems featuring a complex coexistence of social, environmental, and economic components, which are managed by decision-making institutions. A flexible relationship between these components and decision-making institutions may give rise to a resilient city.

A resilient city can reorganise itself to respond to and recover from stresses (Drobniak, 2012). It usually features resistance, redundancy, autonomy, adaptability, but also flexibility, cooperation, interdependence, and efficiency (Zimmerman, 2001; Bell, 2002; Tierney, 2002; Drobniak, 2012). In other words, it is intended to be flexible rather than fragile (Godshalk, 2003), since flexibility is key to managing disaster response (Coles & Buckle 2004; Klein *et alii*, 2003). On the other hand, a non-resilient city fails to change itself and to grow, remaining in a steady-state condition (Simme & Martin, 2009). Urban resilience consists of two components, structural and social:

- social resilience focuses on human society settings in which some dimensions can be defined: society, culture, religion, and demography.

Fig. 1 - Location of the ten largest built-up urban areas according to "Demographia World Urban Areas"(2017)

Fig. 2 - Aerial view of two megacities located in high seismicity zones: Los Angeles (left) and Mexico City (right). The urban texture completely covered the natural landforms overlying a heterogeneous geological subsoil, making the urban areas susceptible to different local seismic effects (Open source pictures)

- structural resilience involves an extended concept of a physical system, i.e. including infrastructure, buildings, land, and the environment.

As stressed by Godshalk (2003), both technical and social components are needed to achieve the goal of a resilient city and establish a sustainable connection between human communities and physical systems,

Social capital and demography are fundamental components of the social resilience of a community. Social capital indicates the sense of belonging of citizens to the community and to the area in which the community is located (Cutter *et alii*, 2010).

Social resilience is the strategy adopted by human groups or societies to overcome disasters and it results from social, political, and environmental adjustments (Adger, 2000). These adjustments are possible in settings where communities can participate in decision-making processes, be informed, and contribute to the dissemination of information about risks (Abahs *et alii*, 2013). This implies that communities can maintain their structures, provide basic services after any occurrence of disturbances, change, and reorganise themselves (Resilience Alliance, 2002). The basic investments needed to achieve social resilience are focused on poverty minimisation and reduction of vulnerability to disasters (Pasteur, 2011; Pelling, 2010; Venton, 2010).

In the event of a seismic risk, social resilience expresses the capability of minimising the negative effects on society due to the loss of key services based on human supplies (Chang & Shinozuka, 2004). Social and governmental systems are held together by the human communities (schools, associations, companies, etc.) that operate in the city (Hirokawa, 2014). A city without a resilient social system, i.e. not hosting resilient communities, will be extremely vulnerable to disasters (Godshalk, 2003) and therefore responsible for an increased natural risk, even if hazard mitigation strategies are applied.

On the other hand, structural resilience can be described by three main components:

- infrastructural resilience deals with the infrastructural setting of a community in terms of transportation networks, structures, etc. (Cimellaro, 2016); it refers to a reduction of the vulnerability of all the different urban structures, e.g. buildings, connections, roads, and strategic structures, e.g. hospitals, emergency and post-emergency routes (Abahs *et alii*, 2013);
- institutional resilience is associated with the governmental and non-governmental systems that manage a community (Abahs *et alii*, 2013);
- economic resilience refers to the diversity and number of businesses and jobs in a given area, to the economy of the local community, and to its ability to remain functional after disasters (Abhas *et alii*, 2013): it represents the ability to minimise the occurrence of losses incurred by local companies and regions (Rose & Liao, 2005).

Based on these considerations, Fig. 3 shows that the entities responsible for risk mitigation must operate by anticipating the potential natural events causing a disaster. The strategies that can be implemented by these entities involve governors, technical practitioners, and environmental managers. In general, the attention of the media is not focused on the risk mitigation stage; therefore, communication is mostly entrusted to the technical-scientific community, or to political leaders when the measures taken are the object of propaganda.

Conversely, the emergency stage attracts the attention of the media and operates "in real time" through institutional services (such as civil protection) or volunteers.

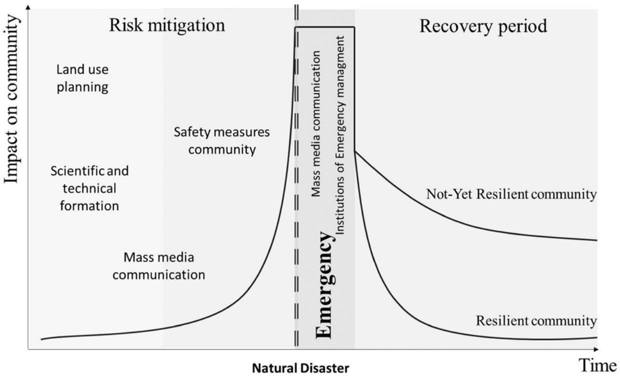

Fig. 3 - Impact of natural disasters on society: from risk mitigation towards resilience strategies

The post-emergency stage is accompanied, once again, by a reduction in media attention; it is at this stage that the community affected by the disastrous event expresses its resilient attitude.

The more readily the socio-economic system is capable of absorbing the damage suffered, the more it will be resilient. However, this resilience is commensurate with the effectiveness of preventive measures (i.e. structural and/or social strategies) adopted before the disastrous event. Among the strategies for resilience, those concerning structural resilience encompass multiple aspects of the urban framework, ranging from political/economic to infrastructural/technological ones.

HISTORICAL EXAMPLES OF CITIES RESILIENT AND NOT YET RESILIENT TO SEISMIC HAZARDS

In the last century, several strong earthquakes affected megacities all over the world, providing some lessons about seismic hazards and risks. The most significant events that marked two important achievements in the area of seismic research were the Mexico City (Mw 8.1 in 1985) and Loma Prieta (Mw 7.1 in 1989) earthquakes.

The Mw 8.1 Mexico City earthquake demonstrated the relevance of local seismic response, since it took place almost 400 km away from Mexico City (offshore in the Pacific Ocean), but had a high level of amplification and damage within the city due to the trapping of seismic waves by the paleo-lacustrine geological setting and the occurrence of a resonance phenomenon (Singh *et alii*, 1988; Fores-Estrella *et alii*, 2007). The 1985 Mexico City earthquake showed a severe double resonance effect, which caused a selective collapse of buildings (having similar vulnerability classes) sitting on the same geological subsoil, because of their different heights and related resonance periods (Fig. 4). About a century earlier, Milne (1886) had suggested the non-negligible role of soil-structure interactions: "sometimes the harder ground proved better foundation, sometimes the softer. The superiority of one over the other depends on local circumstances".

The Mw 7.1 Loma Prieta earthquake, occurred in 1989 (i.e. four years later), gave further evidence of the importance of site effects (Borcherdt & Glassmoyer, 1992). In the city of San Francisco, structures and infrastructure with the same vulnerability suffered different levels of damage due to the main seismic event. This evidence confirmed that amplification due to weak deposits filling San Francisco Bay could be much stronger than that due to other sediments close to the epicentre (Chin & Aki, 1991). In this case, some effects of the nonlinear behaviour of soils were also observed (Fig. 5). The earthquakes of Mexico City and of Loma Prieta demonstrated that local seismic effects due to ground motion can be coupled with the dynamic response of structures, causing severe damage to buildings and seriously threatening human lives. After the aforementioned earthquakes, structural resilience could no longer be neglected in planning resilient city strategies.

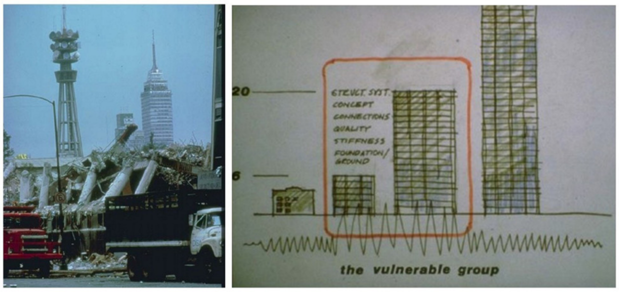

Fig. 4 - In downtown Mexico City, some types of structures failed more than others during the 1895 Mw 8.1 earthquake. Owing to the double resonance effect, buildings with 6 to 20 floors were those that suffered the highest damage (From ftp://ftp.ngdc.noaa.gov/hazards/cdroms/geohazards_v2/document/647003.htm)

The study reported in this paper inferred different "resilience strategies" from some examples of resilient cities, capable of preparing themselves for, tolerate, and reorganise themselves after natural disasters (Fig. 6). The first model is the one based on the Japanese management philosophy ("Japanese Model"). The Japanese government prepared a new prevention plan, which was incorporated into its earthquake survival manual, in order to improve social and structural resilience. The plan consists of six points: i) large-scale prevention awareness campaigns with flyers, manuals, and various documents distributed in schools and tourist attraction sites (Fig. 7); ii) creation of emergency preparedness facilities with photos, signage, maps, and instructions (shelters, maps, evacuation routes/areas, etc.); iii) detailed planning of post-event evacuation; iv) use of seismic isolators and sliding friction elements in such structures as buildings, plumbing, and power supply systems to make them earthquake-resistant; v) provision of survival kits enabling communities to survive a few days while waiting for help; these kits are also available in public and private offices, schools, and homes, and vi) regular earthquake drills in schools, offices, and public buildings, to educate communities on how to cope with earthquake emergencies and panic attacks. Points i), ii), v) and vi) of the aforementioned list are mainly focused on mass media communication and require properly

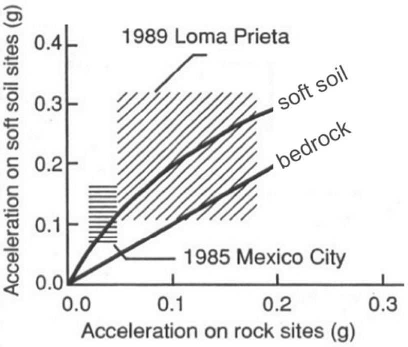

Fig. 5 - Observed seismic amplification in soft soils vs. the bedrock for the 1985 Mexico City and the 1989 Loma Prieta earthquakes (Modified from Idriss, 1990)

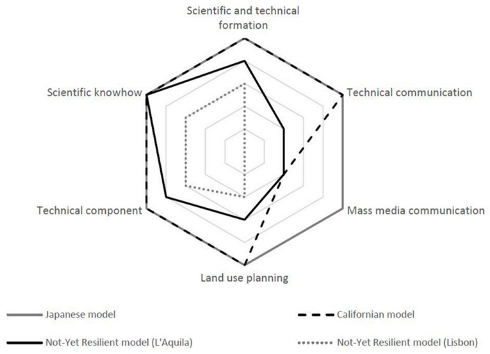

Fig. 6 - Weight of structural and social contributions to resilience to seismic hazards in different models of a resilient city

Fig. 7 - Emergency training (top) and disaster mitigation information for society (bottom) (GENSAI Project, 2015)

skilled scientific and technical personnel for dissemination efforts. Points iii) and iv) contribute to both social and structural resilience, because they are the consequence of sound choices in terms of land-use planning.

The latter choices indicate that the government is well informed about the risks affecting Japan and that technical communication is likely to work well. Additionally, the "Japanese Model" features a high level of structural resilience thanks to the knowledge of historical and traditional earthquakes acquired by the technical and scientific community.

Japan is actually showing the most applicable and sound ways to face and adapt to natural hazards and risks. Indeed, risk awareness can lead to an urban community that can cooperate with (central and local) governmental institutions in risk management practices.

Another example of a resilient city is based on the "Californian Model", in which the role of citizens is significantly different from the Japanese one (Fig. 6). In this model, the community plays a passive role, in that risk management is completely in the hands of a specific federal institution, whereas in Japan people are individually trained for, informed about, and can manage natural risks. The institution that deals with risks in California is FEMA (Federal Emergency Management Agency) and includes public and private partners working together to ensure the safety of the urban community (Fig. 8). The Californian example demonstrates that it is possible to combine scientific and technical partners in order to set up a task force in charge of managing emergencies due to natural risks. This kind of organisation issues risk mitigation plans, thus contributing to both social and structural resilience and allowing each citizen to feel protected.

In the "Californian Model", structural resilience is founded on a strong community of earthquake and earthquake-engineering scientists, who continuously improve their knowledge of environmental processes and natural risks. The comparison between these two models shows that different countries (and mindsets) express different philosophies for managing natural risks and achieving a resilient city condition. Hence, there are different ways to obtain a resilient city, based on comprehensive knowledge of natural processes and related risks, and on respect for the cultural, historical, and social features of a community.

Another approach to resilience achievement is represented by the "not-yet resilient city", which prefers moving towards a resilient condition only after a catastrophic event. This is the case in Lisbon, which was struck by an earthquake on 1 November 1755 (Fig. 9), the first modern natural disaster in a "not-yet resilient city" (Fig. 6). This event can be also considered as the first natural disaster that triggered an emergency reaction by social communities and governmental authorities, resulting into a more adequate post-event rebuilding plan.

Fig. 8 - FEMA campaign to encourage participation in earthquake drills (FEMA, 2015)

The main seismic event occurred at 9:40 am, and it was followed by a seismically induced tsunami and fires that killed 70,000 people (nearly 40% of the population). To cope with and recover from this disaster, the government took an approach based on the principles of the Enlightenment movement that was being developed at the time in opposition to the Catholic and superstitious tradition that had characterised the city until then (Mendez-Victor *et alii*, 2009).

Hence, an innovative city, based on scientific and technical knowledge, was created thanks to the knowledge of building construction engineers and experts. In response to the earthquake, Lisbon moved away from the traditional religious and superstitious approach to embrace a more rational approach, and its government played a fundamental and central role in the operational stages of emergency management and recovery. The case of Lisbon reveals that social and structural resilience can be improved when: i) government and society are willing to overcome traditional religious ideas and adopt a more scientific and technical approach, and ii) rational land-use planning can bring together social and structural resilience. A more recent example of a "not-yet resilient city" is the one proposed for L'Aquila (Italy), which was hit by a

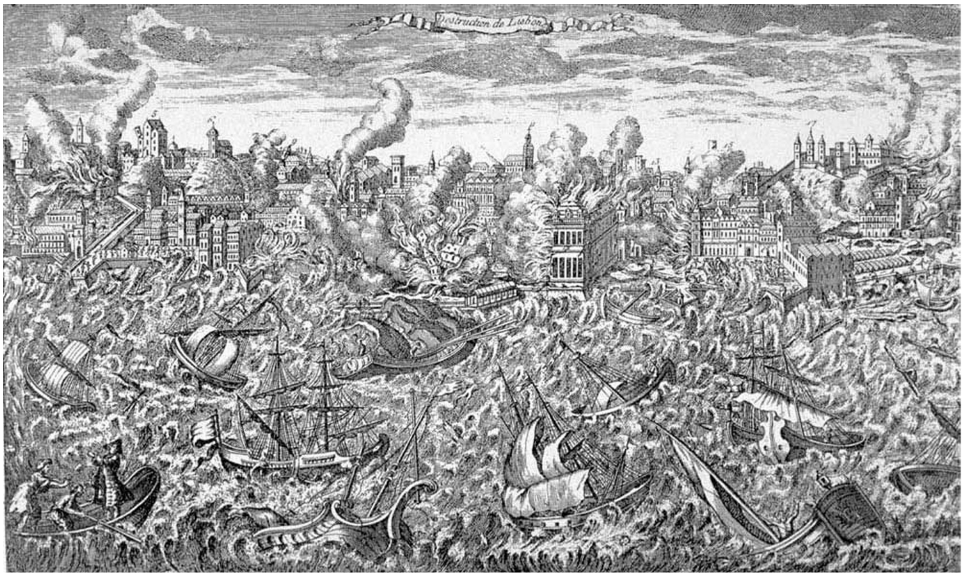

Fig. 9 - This historical painting shows the city of Lisbon, Portugal, during the great earthquake of 1 November 1755. Note the city ruins and fires (Open source image)

6.3 Mw earthquake on 6 April 2009; the earthquake completely destroyed the historical centre of the city (Fig. 10). Even though scientists and technical practitioners were adequately skilled, social resilience was very poor owing to a lack of communication between the scientific and technical community, governmental institutions, and society (Fig. 6). This lack of communication resulted into inadequate land planning choices, considering that strategic structures were located in the portion of the city with a high-risk level and seismically induced effects.

Structural resilience, too, was inadequate, even though the scientific and technical community had good knowledge of the natural phenomena threatening the city. Many Italian cities have important historical heritage, are not prepared to cope with severe natural events, and usually suffer considerable damage from earthquakes. As pointed out by Valensise *et alii* (2017), at least two urgent tasks should be accomplished in order to improve the resilience of Central Apennines cities (e.g. L'Aquila). The first should monitor and control the vulnerability of structures, and improve structural resilience. The second should enhance social resilience by creating a new and more effective awareness of risks. After the disastrous event in 2009, L'Aquila started to formulate reconstruction, urban mobility, and innovative strategic plans aiming to increase the resilience of the urban area through the application of smart tools. Moreover, in July 2013, the municipality of L'Aquila (and other nearby villages) signed a memorandum of understanding to promote and support the development of L'Aquila towards a smart city condition and therefore a more resilient city. The goals of this project are the following: i) building a transportation network connecting all the parts of the city; ii) installing an urban wireless network for the community and improving high-speed Internet access (Fibre To The Home - FTTH) in all the parts of the city, including its historical centre, and iii) creating "smart grids", i.e. power grids capable of minimising overloads and brownouts thanks to rational management of grid resources. This project is centred on the development of specific technologies to encourage new (or revitalise) social behaviours by the community; it does not cover all the resilience aspects discussed here, but it represents a first step towards a resilient city, a sign that the scientific community, governmental authorities, and the public at large have acquired more awareness of risks and of the need for a resilient city.

Fig. 10 - The building of the provincial government (Prefettura) in L'Aquila after the earthquake, showing the destruction of the city (Ministero dell'Interno - Italian Ministry of the Interior, 2009)

CONTRIBUTION OF ENGINEERING GEOLOGY TO A RESILIENT CITY

In recent decades, engineering geology has acquired a key role within the scientific community in managing natural disasters and enhancing people's awareness of natural multi-hazards (Juang *et alii*, 2016).

Engineering geology can be regarded as a technical tool to create a resilient city, capable of accommodating the effects of natural hazards, but also of anticipating and preparing for disturbances (Fig. 11). The following sections of the paper describe the contribution of engineering geology to the resilient city concept. Some experiences of resilient and non-resilient cities are presented to stress the role that engineering geology played in historical disasters in strengthening structural and social resilience.

Contribution of Engineering Geology to Social Resilience

For a resilient city, engineering geology can raise community awareness and provide knowledge and solutions to strengthen the structural component of resilience. The resilience of a community depends on dissemination of information within it and on its preparedness (Chen *et alii*, 2008). Disseminating information means disclosing the unknown and making the uncertain certain. Raising awareness of disasters based on the memory of historical ones and reflecting on their impact on communities (Valensise *et alii*, 2017) can improve social resilience. Risk awareness can be defined as the intentional transfer of scientific information about health and environmental risks to the parties concerned: businesses, governmental organisations, media, scientists, public-interest groups, and individuals. Information dissemination may pursue three main targets: i) education, training, and awareness of scientific and technical communities; ii) communication to governmental authorities, and iii) mass media communication. Engineering geology can organise education, training and awareness plans for technical and scientific communities, so that they can communicate risk strategies to institutions, local authorities, and mass media. Training of technical practitioners and scientists is the most important tool for communicating risks: it is the starting point of the subsequent communication stages. Technical and scientific communities can communicate risks to governmental authorities and society. Communication to governmental authorities can increase their knowledge of the local urban environment, of its built heritage, and of land uses. This is a fundamental step to organise plans aiming at protecting people and infrastructure, as well as addressing possible emergencies. Communication to society through mass media can make each member of a community aware of risks and of their impact on society. This objective can be achieved through direct and explicit communication campaigns that are based on both linguistic and visual forms of expression and are attractive to the public. Strategies of oral communication may also rely on social media and blogs. Digital tools may facilitate the development of a "one-to-many" communication, thus speeding up information dissemination.

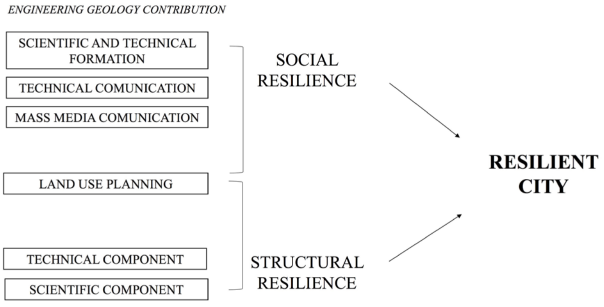

Fig. 11 - Schematic representation of the different contributions of engineering geology to a resilient city

Contribution of Engineering Geology to Structural Resilience

As stated by UNDRR in 2016, the structural resilience of a city can be achieved by an approach based on the "know more, invest wisely and build more safely" paradigm. The technical community of engineering geologists can contribute to structural resilience in the "know more" stage of the process, by gaining greater scientific and technical insight into natural phenomena and their interactions with the environment. Planning for a resilient city requires defining the physical and mechanical parameters of natural systems and understanding natural phenomena. Understanding the stratigraphic setting of soils and rocks, locating and characterising aquifers, identifying and mapping landslides or areas prone to liquefaction, and defining areas affected by seismic amplification or seismically induced effects can provide a fundamental contribution to the structural resilience of a city. This contribution is widely supported by 2D and 3D numerical models, suitable for simulating complex and multivariate systems and quantifying the following aspects: the effects of natural phenomena, resulting from different geological and/or environmental processes, including the combined effects of chemical and hydrogeological components in aquifer contamination; the mechanical effects of fluid circulation on rock cracking; the impact of road traffic on rock damage; and the mechanics of the interaction between structures and subsoil.

A scientific and technical understanding of natural phenomena can help identify and minimise inappropriate land uses, which may exacerbate future natural disasters. In this regard, awareness of land uses, and risks can lead to avoid the disruptive interaction between man-made structures and the environment. Natural hazards are the result of environmental processes, and their impact on communities is due to the interaction between these hazards and the communities themselves. By improving its awareness of environmental risks, a community can be better prepared for natural disasters. Furthermore, scientific knowledge of natural phenomena plays a fundamental role when defining local urban planning and management strategies, so as to adapt land-use rules and plans to specific local situations, i.e. not applying the same strategy upon the occurrence of a natural disaster.

SEISMIC MICROZONATION STUDIES FOR RESILIENT URBAN PLANNING

Land-use planning managed through engineering geology plays a fundamental role in integrating both the structural and social components of a resilient city (Fig. 11). It relies on tools that can be used by technical and administrative departments to define adequate and low-risk land uses. Engineering geology has a crucial role in urban planning, as it can improve both structural and social resilience, e.g. by mapping hazards, assessing vulnerability, assigning vulnerability classes to buildings, and developing scenarios of natural disasters. As stressed by Alberico & Petrosino (2015) for the case study of the island of Ischia (Italy), appropriate land uses can improve the resilience of the island, historically exposed to several types of hazards (volcanic, seismic, etc.). Nevertheless, the latest Mw 4.0 seismic event occurred on 21 August 2017 (epicentre close to Casamicciola) caused two casualties and the collapse of several buildings. This event demonstrated that the structural resilience of Ischia is not yet appropriate, although a similar event occurred in 1883 (epicentre near Casamicciola again), causing a generalised collapse of buildings and almost 2000 casualties. Knowledge of possible local effects induced by seismic events can help identify areas, emergency facilities, and strategic buildings located in stable zones, as well as critical aspects of the road and service infrastructure for which specific safety assessments are required.

The seismic sequence occurred in Italy in 2016-2017 completely destroyed numerous historical centres (including Amatrice, Accumoli, Pescara del Tronto, and Arquata del Tronto) deeply damaging the socio-economic fabric in a vast area straddling four Italian regions (Lazio, Umbria, Marche, and Abruzzo). After these earthquakes, the government decided to adopt strategies of local planning and post-earthquake reconstruction projects laying the foundations for more resilient communities.

To this end, Ordinance no. 24, issued by the Italian Council of Ministers on 12 May 2017, launched in-depth studies for the seismic microzonation of over 150 municipalities in the areas hit by the earthquakes of 2016-2017. Moreover, for the first time in Italy, Ordinance no. 55, issued by the Italian Council of Ministers on 24 May 2018, provided guidance for applying microzonation studies to the design and planning of post-seismic reconstruction projects, substantiating the fundamental role of engineering geology, geotechnical engineering, and civil engineering in increasing structural resilience (Centro per la Microzonazone Sismica e le sue Applicazioni, 2020). The same ordinance laid down provisions for compensating local communities for damages and real-estate losses, thus contributing to their social resilience. The ordinance implicitly encourages future microzonation studies as a key part of seismic risk mitigation strategies in Italy. As regards the municipalities involved in microzonation studies, detailed quantitative studies were conducted only for Accumoli and nearby villages (Pergalani *et alii*, 2019).

The seismic microzonation map obtained for Fonte del Campo/Accumoli (Fig. 12) displays the perimeter of areas with the same seismic amplification factor (AF) as a reflection of the heterogeneous nature of the subsoil of alluvial deposits present in the Tronto river plain. These deposits have a geometry of the seismic bedrock characterised by terraced levels sculpted by the Tronto river and currently suspended some tens of metres from the substratum underlying the alluvial deposits that fill the present valley. As reported by Pergalani *et alii*, 2019, six microzones were defined; the AF threshold value was taken to be a difference in AF equal to or greater than 0.2 for each selected range of periods in the response spectra. The number of microzones that were defined indicated that the complexity of the subsoil gives rise to complex amplification phenomena, which are mainly ascribable to 2D basin amplification effects (Martino *et alii*, 2019). Moreover, during the seismic microzonation studies, the technical-scientific community (including professional geologists, representatives of the academic world, technical staff from specialised research institutes, representatives of regional and municipal authorities) initiated a transparent dialogue with communities to make them aware of and involve them in the choices regarding reconstruction and/or relocation of the towns destroyed by earthquakes, thus laying the groundwork for more resilient communities and socio-economic groups. This experience exemplifies both the social and structural role of engineering geology in supporting planning strategies for more resilient communities and cities. Furthermore, the technical activities that were carried out ensured a constant communication between the members of the technical staff - through a central coordination unit organised by Centro per la Microzonazione Sismica e le sue Applicazioni (Research Centre for Seismic Microzonation and its Applications) of CNR (Italian National Research Council) - and between the technical staff and local communities - through the national civil protection team - as well as the regional and provincial technical services working at local level.

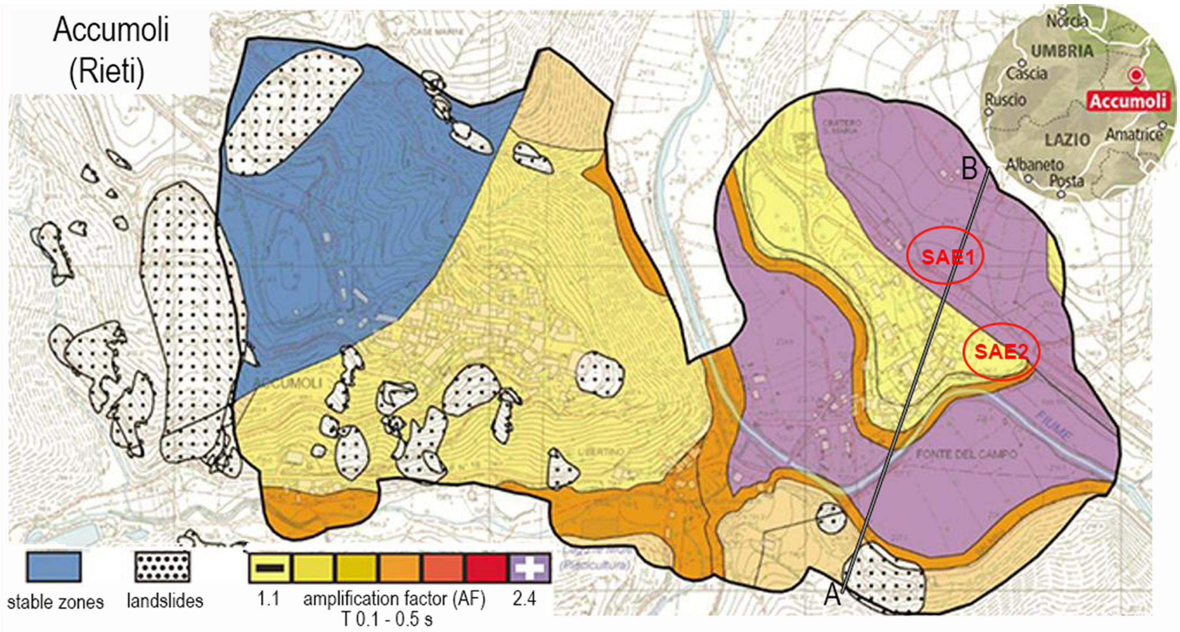

Fig. 12 - Part of the seismic microzonation map of the municipality of Accumoli (Fonte del Campo village), displaying multiple zones with different levels of amplification factor (AF), computed in the period range 0.1-0.5s. The map also shows the location of emergency buildings (SAE) and the geological cross section AB. (Modified from Pergalani *et alii, 2019)*

CONCLUSIONS

A city can be defined as "resilient" if it can tolerate disruptions before reorganising around a new set of structures, anticipating, responding to, and recovering from a disrupting damage scenario. Resilience expresses the possibility that communities can recover from shocks and disturbances after natural disasters. This concept, initially used in ecology and physics, is now widely applied also in risk management, mitigation of the impact of and recovery from natural disasters. This new field of application is related to the progressive increase of natural and anthropogenic disasters and to the need for resilient cities. In terms of seismic risks, engineering geology can contribute to the different components of a resilient city, i.e. to both structural and social resilience, providing major benefits to cities exposed to seismic risks. Engineering geology contributes to structural resilience by acquiring and providing scientific and technical insights into natural phenomena and their interactions with the environment. At same time, engineering geology can raise community awareness of natural risks by undertaking information dissemination actions targeted at the scientific and technical community, governmental institutions, and society. Moreover, adequate land-use planning, based on engineering-geological knowledge of land and of the built environment, can bring together structural and social resilience. From both historical and present case studies, the Authors have inferred three different strategies to achieve a resilient city in terms of seismic risk. The "Japanese Model" strategy implies a high level of structural resilience coupled with an active role of the members of a community in natural risk management. The "Californian Model" strategy implies that the community plays a passive role and risk management is assigned to specific institutions, consisting of government members, scientists, and technical practitioners. Both approaches aim to achieve a resilient city condition in the prevention stage. A third strategy is the one adopted by the "not-yet resilient city" that decides to move towards a resilient condition only after the occurrence of a catastrophic event. The latter strategy, in which the prevention element is missing, involves emergency and short- and long-term post-emergency response.

The management of recent natural disasters, such as the earthquakes occurred in Italy in 2016-2017, exemplifies the attempt to transform not-yet-resilient communities, rooted in a historically urbanised fabric and highly vulnerable to seismic hazard, into more resilient ones. Establishing transparent communication channels between the technical-scientific community and the local population in the early post-earthquake stages can make people more aware of and involve them in reconstruction choices.

Contributions to structural resilience can derive from advanced knowledge of the geological features of the subsoil and from a quantitative evaluation of local seismic response. Planning studies aiming to rationalise land-use options and providing useful information for land management, design of buildings and structures, emergency planning, and post-emergency recovery, while making social communities aware of and participants in the decision-making process, can represent a novel approach to achieving urban resilience.

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