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LIQUEFACT

Assessment and mitigation of liquefaction potential across Europe: a holistic approach to protect structures/ infrastructure for improved resilience to earthquake-induced liquefaction disasters.

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The Challenge to Improve Community Resilience to EILD Events: A Review of Theory

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List of Partners

Participant	Name	Country
ARU (Coordinator)	Anglia Ruskin University Higher Education Corporation	United Kingdom
UNIPV	Universita degli Studi di Pavia	Italy
UPORTO	Universidade do Porto	Portugal
UNINA	Universita degli Studi di Napoli Federico II.	Italy
TREVI	Trevi Societa per Azioni	Italy
NORSAR	Stiftelsen Norsar	Norway
ULJ	Univerza v Ljubljani	Slovenia
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Glossary

Acronym	Description
EILD	Earthquake Induced Liquefaction Disaster

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Executive Summary

Recent events have demonstrated that Earthquake Induced Liquefaction Disasters (EILDs) are responsible for tremendous structural damages and fatalities causing in some cases half of the economic loss caused by earthquakes. With the causes of liquefaction being substantially acknowledged, it is important to recognize the factors that contribute to its occurrence, to estimate hazards, then to practically implement the most appropriate mitigation strategy considering the susceptibility of the site to liquefaction, the type and size of the structure. The LIQUEFACT project addresses the mitigation of risks to EILD events in European communities with a holistic approach. The project deals not only with the resistance of structures to EILD events, but also with the resilience of the collective urban community in relation to their quick recovery from an occurrence. The LIQUEFACT project sets out to achieve a more comprehensive understanding of EILDs, the applications of the mitigation techniques, and the development of more appropriate techniques tailored to each specific scenario, for both European and worldwide situations.

Introduction, Goal and Purpose of this document

The aim of this report is to provide an overview of the theory of community resilience and identify those items of theory that will inform the future development of the assessment tools to evaluate the impact of the mitigation actions developed through the Liquefact project on improving community resilience to future earthquake induced liquefaction events across Europe. To this end the report will:

- Present the background and context to the Liquefact project;
- Provide definitions of vulnerability, resilience and adaptive capacity;
- Outline the general theory of community resilience to natural and manmade disaster events;
- Identify the factors that affect community resilience to natural and manmade disaster events;
- Review community resilience frameworks and toolkits;
- Review the lessons for community resilience from recent earthquake disaster events;

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- Summarise the key issues that will need to be considered by the Liquefact project partners as they develop and evaluate the potential impacts of mitigation actions to improve community resilience to earthquake induced liquefaction disaster events.

The review presented in the report should be considered a work in progress which will be amended and modified throughout the duration of the Liquefact project to reflect emerging issues identified by project partners and any location specific characteristics of the 4 case study sites identified by the external stakeholder and expert advisory groups.

Goal: **This document aims to provide the project partners and researchers with an introduction to the theory of community resilience to disaster events.**

Scope of this document

This is a working document that will be amended and modified to reflect changing needs of the Liquefact project and the views of the external stakeholder group and external advisory panel.

Target Audience

This is primarily an internal document intended for the Liquefact partners and researchers.

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Challenges to Improve Community Resilience to EILD Events:

A Review of Theory

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1. Introduction

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- Review the lessons for community resilience from recent earthquake disaster events;
- Summarise the key issues that will need to be considered by the Liquefact project partners as they develop and evaluate the potential impacts of mitigation actions to improve community resilience to earthquake induced liquefaction disaster events.

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2. Background and Context to the Liquefact Project

2.1 The Liquefact project aims to develop a more comprehensive and holistic understanding (primarily from an EU point of view) of the earthquake soil liquefaction phenomenon and the effectiveness of mitigation techniques (available now and in current development) that can be used to protect structural and non-structural systems and components from its effects. The Liquefact research and innovation project will address the following specific research areas and their associated assumptions and challenges:

- Before an effective liquefaction mitigation strategy can be implemented there first needs to be a good understanding and knowledge of where the risk of an EILD hazard is present. Even where there is some data available, this hasn't been brought together in a uniform approach.

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- Once an area/region at risk of an EILD hazard has been identified, an assessment is needed of the risk / resilience with regards to the vulnerability of the different building and infrastructure types within the area/region and the impact that a potential EILD event will have on them.
- A good understanding and knowledge of the possible options for mitigating the effect of the EILD is needed in order to be able to implement the most appropriate mitigation strategies based on the characteristic of the area / region and on the type of building / infrastructure.
- In order to implement effective liquefaction mitigation strategies, especially within an urban area, considerations need to be given to the broader urban community context and development strategies as well as the associated economic, political, social and business drivers that influence them.

This report introduces the concept of community resilience to disaster events, identifying the factors that will need to be considered by the Liquefact project as it addresses the above aims and objectives.

2.2 Earthquakes are one of the most destructive natural phenomena. During the 20th century they caused the deaths of 1.5 million people worldwide; and incurred an estimated economic loss of €75 billion in the last quarter alone. Over the past decade, earthquakes proved to be the deadliest of all European disasters, with almost 19,000 fatalities and direct economic losses of approximately €29 billion[1]. A large part of Europe is at risk from earthquake disaster events, with the most seismically active areas being located in Italy, Greece, Turkey, Cyprus and Portugal. Other European countries, such as Croatia, Bulgaria, Slovenia, Austria, the Czech Republic, and Malta are also at risk. While structural remediation/rehabilitation of the built environment against earthquakes is a widely studied subject, the knowledge on foundation improvement to mitigate the effects of earthquakes on buildings and critical infrastructure is limited, with existing remediation techniques being very invasive and costly. This is particularly true when the earthquake results in the liquefaction of the soil.

2.3 Excessive deformations of the ground surface caused by earthquakes are of great concern for civil engineering works, human lives and the environment. Such ground deformations are often associated with soil liquefaction. Earthquake-induced liquefaction is a phenomenon where the soil decreases in strength and stiffness as a result of increased pore water pressure in saturated cohesionless materials during seismic ground motion (as a result of the applied stress); hence the soil behaves like a liquid and not a solid.

2.4 Liquefaction is one of the most significant causes of damage to structures (public buildings, including schools and hospitals; together with elevated highway and port installations, water

[1] ePACT. https://media.epactnetwork.com/geographical-breakdown-natural-disasters-europe/

treatment facilities, crude oil storage tanks etc.) during an earthquake event; often resulting in the dramatic collapse of structures and infrastructures. With most deaths during an earthquake caused by collapsing structures, earthquake induced liquefaction disasters (EILDs) is an area that requires specific attention. Recent experiences with EILDs; e.g. 2012 Emilia, northern Italy; 2011 Tohoku Oki, Japan; and particularly 2010/11 Canterbury-Christchurch, New Zealand; has highlighted this phenomenon and raised its public profile. In the Emilia case; despite the relatively moderate magnitude of the earthquake (around 5.9), the macro-seismic survey showed heavy damage to infrastructures (roads, pipelines) essentially due to liquefaction or soil failure; in old masonry and recent constructions (12,000 buildings were severely damaged) (Fioravante et al., 2013, Lombardi & Bhattacharya, 2014). In the case of Canterbury-Christchurch, liquefaction affected nearly 60,000 residential buildings and the horizontal infrastructure over one third of the city area (Cubrinovski et al 2014, van Ballegooy et al, 2014). During the Great East Japan earthquake, approximately 27,000 houses, more than 2,000 levees and several ports suffered damage from the resulting ground liquefaction (Yasuda et al, 2013).

2.5 These recent experiences have made the risks that EILD events pose to urban communities very clear and highlighted the need to raise community resilience to the risks through improved public policies and standards on disaster risk reduction and mitigation. Whilst there is considerable research on the causes of liquefaction and the soil conditions which make an area susceptible in the event of earthquake ground shaking; and on the technical mitigation (resistance) interventions to reduce its impact on buildings and infrastructure; there is less understanding on how liquefaction mitigation techniques, applied to increase the resistance of a particular structure or infrastructure, affect the overall impact of the EILD event on the urban community as a whole. In particular how does improving the resistance of a building or infrastructure asset contribute to the wider community's resilience to withstand and recover from the event and its adaptive capacity to learn from the event?

2.6 Whilst resistance is about improving the strength of a structure or the ground around it to withstand an EILD event and reduce the immediate impact of the event on the built asset; resilience is about increasing the ability of the overall urban community system to cope with the impact and quickly recover after the event. Thus, whilst resistance is primarily considered from a technical perspective; resilience requires a holistic assessment of the impact that the EILD event will have on individual (people, businesses, organisations etc.) stakeholders and the wider urban community collectively. Hence, resilience is very much linked to the risk assessment and prioritisation of building and infrastructure interventions over their life cycle. Whilst the Liquefact project will explore the effect that a range of liquefaction mitigation techniques (ground improvement, physical resistance, risk appraisal etc.) has on the vulnerability, resilience and adaptive capacity of communities across Europe its context will be on how such interventions improve community resilience to EILD events. In essence the Liquefact project integrates the development of technical mitigation measures with the wider

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business case for investing in such mitigation measures within the context of the wider community resilience agenda. The remainder of this report presents the theory behind community resilience and identifies the factors that will need to be considered by all the Liquefact partners when developing and evaluating the potential impact of liquefaction mitigation interventions on the vulnerability, resilience and adaptive capacity of communities across Europe.

3. Vulnerability, Resilience and Adaptive Capacity

3.1 Vulnerability, resilience, and adaptive capacity are concepts from the biophysical and social realms that are increasingly being applied to the understanding of the complex relationships between communities, the built environment, and the drivers that may affect change. Whilst there is considerable debate over the precise definitions of the terminology (Gallopin, 2006, Foresight Final Project Report, 2012), in the context of the Liquefact project: vulnerability will be considered as the likelihood of exposure to a hazard and the adverse consequences resulting from them; resilience, as the ability of the system (physical and community) to prevent, withstand, recover and learn from the impacts of the hazard; and adaptive capacity, as the ability for a system to change (adapt) to meet the new conditions brought about by perturbations that fundamentally change the system.

3.2 Assessing the impact of a hazard on the vulnerability, resilience and adaptive capacity at the national, regional and sectoral level requires an understanding of not only the impact of the hazard on individual stakeholders but also on the interactions between stakeholders (CREW, 2012). Stakeholders who are not immediately affected by the hazard may still be vulnerable to the impacts of the hazard through the social, business or community networks that they rely on for their continued operation (*ibid*). Indeed, whilst a community's resilience to a disaster event is known to be largely determined by the strategic decisions taken before, during and after an event, many of the policies, guidance, codes and regulations currently in place across Europe tend to be complex and difficult to apply consistently and as such many individuals and businesses are unsure of how to prepare for and respond to a disaster event (*ibid*). As such vulnerabilities are heightened whilst resilience is weakened in the face of a disaster event occurring.

3.3 Whilst there is a broad understanding of the factors that affect community resilience to disaster events at the national and regional level there is much less understanding of the factors that affect local community resilience (CREW, 2012). Whilst it is generally accepted that a community's resilience and adaptive capacity is a complex association of behavioural characteristics between: households; businesses (particularly small and medium sized enterprises - SMEs); and local decision makers (politicians), the precise nature of these relationships is less well understood (Smit & Wandel, 2006, CREW, 2012). What is

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generally agreed is the need for each community to identify its own determinants of vulnerability and adaptive capacity rather than rely on generic assessments and 'preferred solutions' and to understand the sensitivities of these determinants to the wider political, social, economic and technological forces (Smit & Wandel, 2006, Ali & Jones, 2013). Thus, whilst measuring community resilience to disaster events relies on generic factors the precise relationship between the factors will vary depending on the local circumstances.

4. Factors Affecting Community Resilience

4.1 Attempts to develop practical measures of community resilience have resulted in a number of explanatory models that seek to qualify the relationships between the various determinants of community resilience for different disaster event scenarios. In developing these models the concept of resilience has replaced resistance as the key consideration in reducing loss (in its broadest terms) as a consequence of a disaster (either natural or manmade). Whereas resistance has traditionally emphasised the importance of pre-disaster mitigation measures that enhance the performance of both physical elements (built environment) and social institutions in reducing loses; resilience is more broadly concerned with improving the capacity of physical and human systems to prevent, respond to and recover from extreme events (Tierney & Bruneau, 2007). In exploring the twin attributes of inherent strength and flexibility, Tierney & Bruneau (*ibid*) developed a working definition of disaster resilience "… the ability of social units (e.g. organisations, communities) to mitigate hazards, contain the effects of disasters when they occur, and carry out recovery activities in ways that minimise social disruption and mitigate the effects of future disasters..". Tierney & Bruneau (*ibid*) also identified four attributes/determinants of a resilient system framework:

- **Robustness** - the ability of systems to withstand disaster forces without significant degradation or loss of performance;
- **Redundancy** - the extent to which systems are substitutable (by other systems);
- **Resourcefulness** - the ability to diagnose and prioritise problems and initiate solutions (by identifying and mobilising material, monetary, informational, technological and human resources);
- **Rapidity** - the capacity to restore functionality in a timely way.

4.2 In addition to these attributes, Tierney & Bruneau (*ibid*) also identified 4 dimensions/domains of resilience:

- **Technical Domain** - the physical properties of systems;
- **Organisational Domain** - the organisations that manage the physical components of the system (including emergency responders);
- **Social Domain** - population and community characteristics that render social groups either more vulnerable or more adaptable to hazards;

- **Local and Regional Economies** - ability to identify and access a range of options for coping with a disaster – the more limited the options, the lower the community resilience.

4.3 In considering these attributes/dimensions Tierney & Bruneau (*ibid*) highlighted the complex nature of resilience and emphasised the need to adopt a holistic approach to assessing community resilience that considers organisational and community capacity alongside household's and business's ability to cope with disaster events.

4.4 Paton (2007), who examined resilience to disaster events from a societal perspective, also identified 4 general components that he believed made a community resilient to disaster events:

- Communities, their members, businesses and societal organisations must possess the **resources** (e.g. household emergency plans, business continuity plans etc.) to ensure their safety and continued core function during an event.
- Communities must possess the **competences** (e.g. action coping, community competence, trained staff, disaster management procedures) required to mobilise, organise and use the resources to confront problems encountered and adapt to the reality created by the event.
- The planning and development strategies used to facilitate resilience must include **mechanisms** designed to integrate the resources available at each level to ensure the existence of a coherent societal capacity, and one capable of realising the potential to capitalise on opportunities for change, growth and the enhancement of Quality of Life.
- These resources need to be **available over an extended time period** and be sympathetic to the changing (adapting/emerging) community.

4.5 Based on these components Paton (*ibid*) used structural equation modelling to produce a model of Auckland's resilience to a volcanic eruption scenario. In developing his model Paton (*ibid*) assumed that resilience to a disaster event was a combination of personal, community and institutional factors:

- **Personal factors included**: critical awareness; self-efficacy; sense of community; outcome expectancy; action coping; and resource availability.
- **Community factors included**: collective efficacy; participation; commitment; information exchange; social support; decision making; and resources availability.
- **Institutional factors included**: empowerment; trust; resources; mechanisms for community problem solving.

4.6 By expressing these factors as a range of variables and undertaking a questionnaire survey of the Auckland community, Paton (*ibid*) identified 3 personal indicators (action coping, positive outcome expectancy and negative outcome expectancy), 2 community level indicators (community participation and ability to communicate community problems) and 2 institution level indicators (empowerment and trust) as having direct influence on community resilience. Further, in an attempt to provide local decision makers with a mechanism to evaluate potential interventions, Paton used the base-line data collected through the questionnaire survey to develop a resilience indicator that represented a composite measure of resilience (on a 1-10 scale). For the scenario examined, Auckland scored 5.53, which, whilst of academic interest, has no absolute meaning since it cannot be calibrated until a disaster event occurs. This is a recurrent problem with the use of generic models to predict community resilience.

4.7 Paton et al (2013) reviewed his theory of community resilience in the light of the 2011 Christchurch earthquakes and re-examined the factors that affected community resilience, reinterpreting his original model to reflect the lessons learnt from these events.

4.8 From reviewing community level responses to the Christchurch earthquake Paton et al (*ibid*) identified the key role that adaptive capacity played in supporting community recovery over time. Immediately following a disaster event, people needed the **capacity** to respond to the impact of the event. In the case of the Christchurch earthquake event this involved the capacity to safeguard the structural integrity of their house, fixtures and fittings and having plans and resources in place that increased their self-reliance and capacity to confront/adapt to the unfolding impacts of the earthquake. Once the immediate disaster event had passed, people's adaptive capacity was more focused around addressing local needs and community **integration** to support community recovery. During rebuilding, adaptive capacity required **effective leadership and engagement** with civic agencies. Based on this review Paton reconfigured his model of community resilience to that shown in Figure 1.

4.9 A third view of community resilience to natural disasters was proposed by Cutter et al (2008). Cutter drew attention to the fact that, whilst there is a growing body of research focussing on defining the dimensions of community resilience, little attention has hitherto been paid to the development of consistent factors or standard metrics that can be used to quantify community resilience. Cutter addressed this shortcoming by outlining a conceptual model of natural disaster resilience supported by a set of candidate variables for measuring community resilience.

4.10 The basis for Cutter's (*ibid*) conceptual model is the relationship between vulnerability and resilience. From a hazard perspective resilience is the ability of a system to survive and cope with a disaster event whilst from a global environmental change perspective resilience focuses on the ability of a system to absorb the disturbance and re-organise itself into a functioning system that may be the same as existed before the disturbance or may have

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evolved to a new state through learning and adaptation. Whilst such differences may seem esoteric to built environment researchers, they are important because of the implications that the relationships between vulnerability, resilience and adaptive capacity (see Cutter, 2008 for further details) have on the perspective, and hence the body of literature, that underpin the models. Cutter's model is based on a hazards perspective which views vulnerability and resilience as separate but linked components.

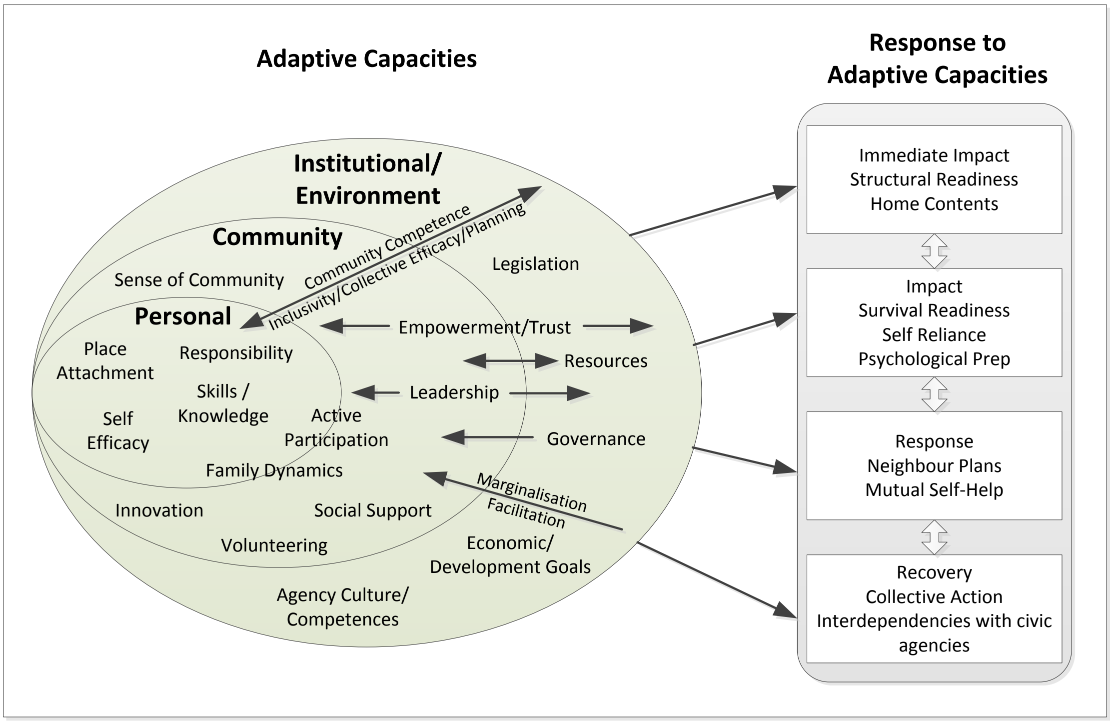

Figure 1: Summary of a) Responses to Adaptive Demands (over time), and b) the adaptive capacities and interdependencies at personal, community, cultural and Institutional / environmental level identified.
(Source: Paton et al, 2013)

4.11 Cutter's (*ibid*) DROP (Disaster Resilience of Place) model (Figure 2) considers the inherent (antecedent conditions) vulnerability and resilience of existing communities (combination of natural systems, social system and the built environment) to a disaster event. The antecedent conditions interact with the hazard event characteristics to produce immediate effects. The event characteristics include frequency, duration, intensity, magnitude and rate of onset of the event. These vary depending on the type of hazard and geographical location.

4.12 The immediate effects of a disaster event are either reduced or amplified by the presence (or lack of) mitigation actions and coping responses. After any coping strategies are implemented the hazard impact is realised. The impact of the event is moderated by the

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absorptive capacity of the local community. If the absorptive capacity of the local community is not exceeded then recovery is relatively quick. If the absorptive capacity is exceeded (either because the scale of the event is overwhelming or the coping responses are insufficient) then the community either adapts (through improvisation or social learning) and recovers relatively quickly, or does not adapt and recovery is much slower (or in extreme cases doesn't happen). If social learning occurs then there is a greater likelihood that mitigation and preparedness will be improved.

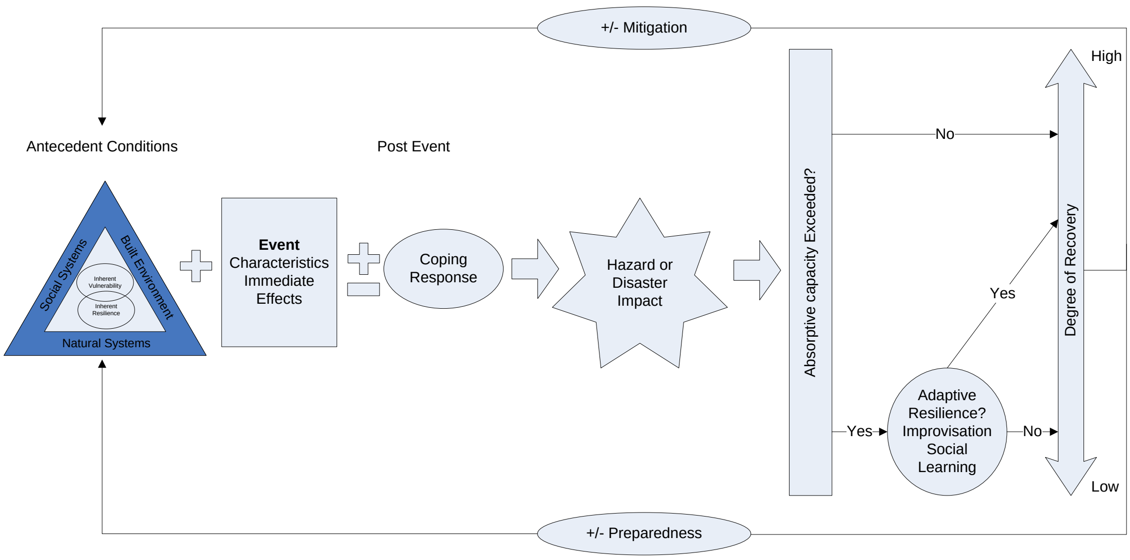

Figure 2. Schematic representation of the disaster resilience of place (DROP) model (Source: Cutter et al, 2008)

4.13 In an attempt to operationalise the model Cutter (*ibid*) suggested (from a review of other research) a range of resilience indicators that could be tested against a real world application. These include:

- **Social** - demographics; social networks; community values-cohesion; faith based organisations.
- **Economic** - employment; property values; wealth generation; municipal finance/revenues.
- **Institutional** - participation in hazard reduction programmes; hazard mitigation plans; emergency services; zoning and building standards; emergency response plans; interoperable communications; continuity of operations plans.
- **Infrastructure** - lifelines and critical infrastructure; transportation networks; residential housing stock and age; commercial and manufacturing establishments.

- **Community Competence** - local understanding of risk; counselling services; absence of psychopathologies (alcohol, drug, spousal abuse); health and wellness; quality of life.

4.14 Again however, until the model is tested against a real-world event it is not possible to quantify the impact that any of the above have on the resilience of any given location to a disaster event.

4.15 One potential problem with Cutter's model is the implied linear relationship between event characteristics, coping response and hazard impact. It could be reasonably argued that, due to varying timescales for different responses and impacts, and social differentiation in how an event unfolds, that a hazard impact for one actor can affect long-term coping response of others (e.g. via economic links). If such a relationship exists then it will demonstrate characteristics more normally associated with a complex system than a linear deterministic system.

4.16 The idea that community resilience to disasters is a complex system was proposed by Cavallo (2014). Cavallo (ibid) argued that to fully understand the issues that affect community resilience you need to move away from a command-control approach (the current norm) to a system of systems approach in which community resilience is seen as a dynamic system which changes over time as system conditions change. As such Cavallo (*ibid*) argued for a re-definition of resilience as the distance between current system conditions and the system's critical thresholds. In such an approach predicting the timing or precise nature of a disaster event becomes less important than accepting that a series of critical thresholds exit (through awareness raising) and preparing for them. This action alone Cavallo (*ibid*) argues will increase community resilience by increasing the distance to the thresholds.

4.17 Boon et al (2012) also viewed resilience as a complex system and applied Bronfenbrenner's bioecological theory to modelling community resilience to natural disasters. Boon et al (*ibid*) argued that Bronfenbrenner's theory provides a useful framework for organising the factors that enhance an individual's resilience in relation to their ecosystem which in turn allows personal factors (e.g. self-efficacy, optimism etc.) to be assessed alongside external factors (e.g. neighbourhood networks, health provision etc.) to promote individual resilience. Bronfenbrenner's approach effectively creates an inter-related hierarchy of systems with the individual citizen at the centre of the model surrounded by micro, meso, exo and macro systems (Figure 3). Boon et al (*ibid*) applied Bronfenbrenner's approach to a generic assessment of community resilience using empirically derived indicators/themes from literature to assess baseline levels of community resilience and then assessing levels of preparedness, risk perceptions, knowledge, self-efficacy, coping mechanisms and resilience of randomly selected individuals across the micro, meso, exo and macro systems to assess the overall resilience of the community.

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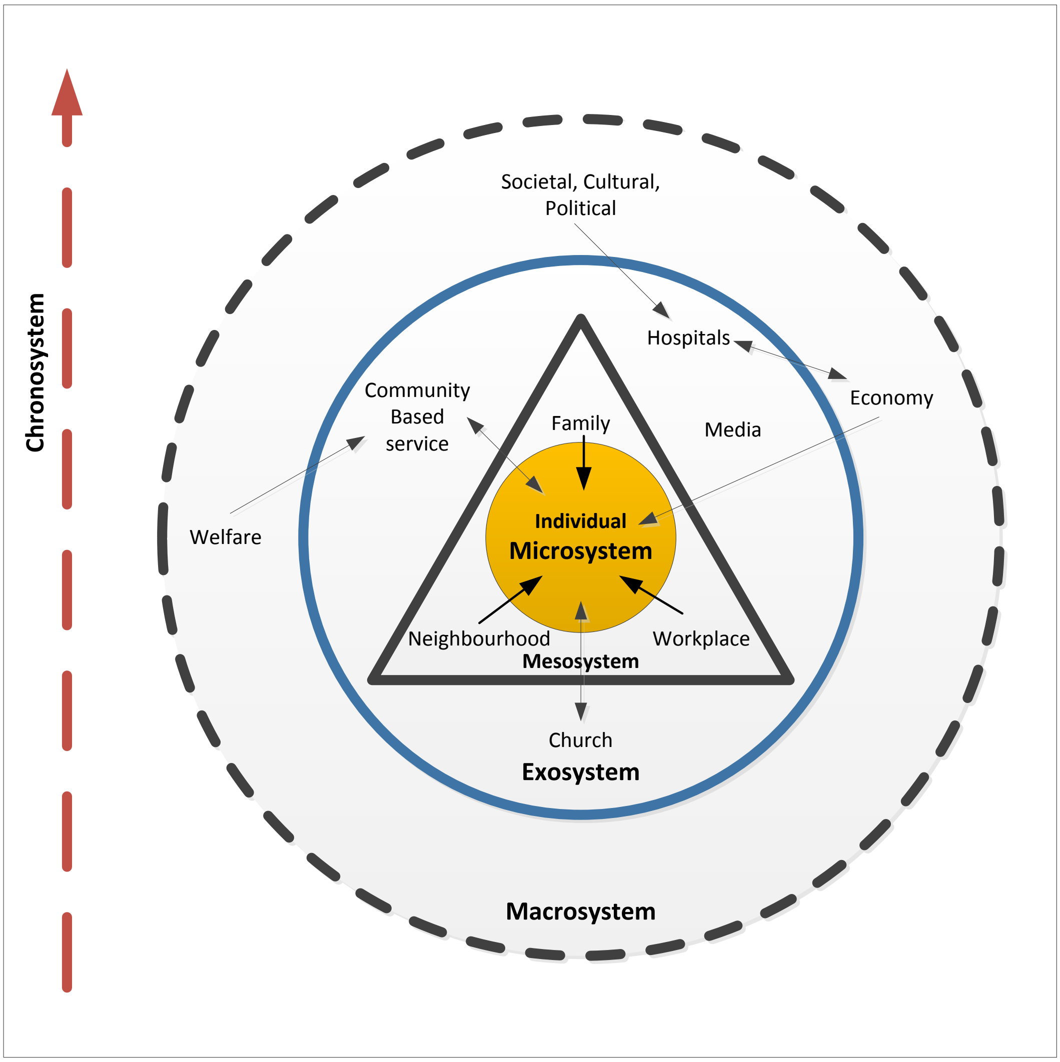

Figure 3: Conceptual scheme of Bronfenbrenner's systems and their interactions (Source: Boon et al, 2012)

4.18 Another view of community resilience as a complex inter-related system was used by the CREW (Community Resilience to Extreme Weather) project which examined the factors that affected community resilience to extreme weather events (CREW, 2012). The CREW project built on the theory outlined above for general resilience and developed a working model of community resilience to extreme weather events (Figure 4) to identify how community resilience could be integrated into adaptation planning to reduce the vulnerability and improve the adaptive capacity of a community to a potential future disaster event.

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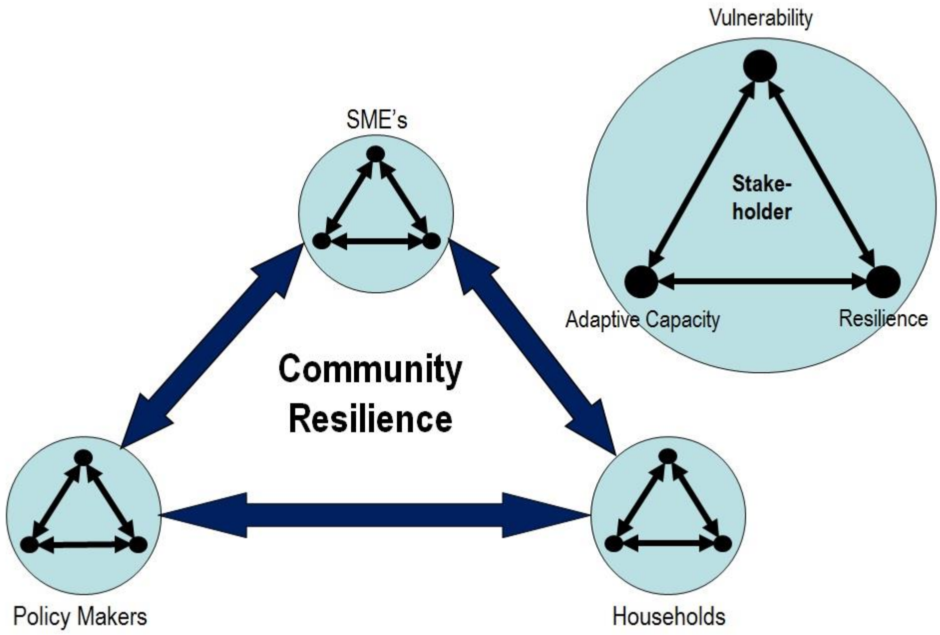

Figure 4: Model of community resilience to extreme weather events
(Source: CREW, 2012)

4.19 In the CREW model each individual stake-holder's resilience to a disaster event is perceived to be a combination of the specific characteristics of the event, of the coping measures (both technical and behavioural) that the stake-holder has in place to deal with the event, and the stakeholder's level of adaptive capacity to absorb the consequence of the event and move forward (either in the same form as prior to the event or in an adapted (changed) state). The overall community's resilience to a disaster event is perceived to be a combination of individual stake-holder resilience whose 'contributions' are either enhanced (a driver) or reduced (a barrier) by the inter-relationships that exist between stake-holder groups (Policy Makers, Households and Businesses). Each stakeholder group was viewed to have a dynamic internal structure and characteristic vulnerability, resilience and adaptive capacity, and group interrelations were seen to condition the community resilience. The aim of the CREW project was to explore these inter-relationships and identify which acted a drivers or inhibitors to adaptation planning.

4.20 The CREW project used an action research approach to explore the application of the above theoretical model to community resilience to extreme weather events in SE London. Through a series engagement with all stakeholder groups the research team explored a range of future extreme weather event scenarios and identified a number of issues that affected the perceived community resilience to each scenario event. The CREW project concluded that there was a lack of clarity regarding the responsibility of different agencies to respond to an event and in particular misunderstandings between what the agencies responsibilities were and what the

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local communities thought they were. In many cases this lead to false sense of security, confusion, and a lack of trust between stakeholders. There was also a clear lack of preparation amongst the household and business stakeholders and expectations that government agencies would be available to deal with both the immediate aftermath of an event (through emergency responders) and with the medium to long term recovery of the community. Again the mismatch between what support the householder and business stakeholders believed would be available, and what will be available, led to confusion and a lack of trust between stakeholders. These barriers ultimately manifested themselves in poor adaptation planning where a responsive 'wait and see' approach prevailed which is detrimental to the concept of a better prepared community being a more resilient community (Jones et al, 2013)

5. Measuring Community Resilience

5.1 From the review so far it is clear that community resilience to disaster events is perceived to be a result of the complex interaction of a range of factors that affect all parts of the community. What is less clear is exactly how these factors interact to enhance or reduce resilience, and the degree to which they can be converted into measureable indicators/metrics that can be used to inform resilience planning.

5.2 Normandin et al (2009) examined a range of strategic resilience indicators for cities in times of turbulence. Normandin drew on the work of the Resilience Alliance to identify 4 distinct but interdependent vectors (urban metabolism, social dynamics, the built environment, and network governance) and compared these to sustainable development indices to identify underlying resilience factors. An initial set of 273 indicators (of which only 31 were common to 2 or more studies) were derived from literature and mapped onto the Resilience Alliance vectors. Where the 4 vectors overlapped was deemed to be the point at which urban resilience is created. However, when only the 31 most common indicators were mapped back to the vectors the *network governance* vector was under represented and whilst the interdependency between indicators was apparent from this sub-set, the imbalance between vectors must be considered when deriving resilience indicators. As such care must be taken to ensure that all vectors are equally represented in any assessment methodology.

5.3 Becker et al (2013) also investigated the factors that affected adaptive capacity and resilience in the context of Hawke's Bay (1931 earthquake). Becker et al reviewed previous studies on Hawke's Bay and complemented these with a review of the current (2013) communication and education approaches being used to build resilience. A gap analysis was then performed to identify any aspects of resilience not being addressed. The resilience research concluded that current resilience levels in Hawke's Bay were low-medium with many of the factors that are known to influence resilience not being addressed by current communication and

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educational strategies. The gap analysis identified a number of recommendations to improve community resilience including: establishing a community resilience forum; developing a coordinated communication and educational strategy; and developing a detailed work programme at the individual (to improve action coping, promote positive outcome expectancy, reduce negative outcome expectancy, promote self-efficacy and raise critical awareness); community (encourage community participation and resolve collective issues); and institutional level (enhance empowerment and trust).

5.4 In addition to research projects that have examined the factors that affect community resilience; a number of generic toolkits and frameworks have been developed to assist planners and policy makers assess the inherent resilience of their communities to a range of disaster events and to evaluate the potential improvements in community resilience that could be achieved following the introduction of mitigation actions. A selection of these toolkits are reviewed in Table 1.

Table 1: List of toolkits for measuring community resilience to disaster events.

Toolkit	Description
GOAL	This toolkit measures community level resilience through the assessment of a broad range of resilience components in 5 thematic areas. • Governance (6 components) • Risk Assessment (3 components) • Knowledge and Education (3 components) • Risk Management / Vulnerability Reduction (12 components) • Preparedness and Response (6 components) Each component is scored on a 1-5 scale and then aggregated to provide an assessment of the resilience of each key component and the overall level of resilience of the community. The output is in the form of a dashboard radar plot that can compare different communities or the same community before and after interventions https://www.goalglobal.org/images/5101_HN_OP_006_11_Resilience_Toolkit_English_B02.pdf
DPRAP CoBRA	This toolkit was developed to measure the socio-economic and environmental impacts of community based disaster risk reduction to drought across the Horn of Africa. The specific aim of the toolkit is to "design a quantitative impact assessment of interventions at the community or household level". The CoBRA model establishes a baseline assessment of an individual household's resilience to an event and then measures how this might change following a range of interventions. Resilience is measured at a set point in time through a composite of 5 components (human, physical, natural, social and financial) that provide individual and overall resilience score. Measurements are then repeated after a disaster event/interventions and improvements (or reduction) in resilience can be calculated. Although the metrics developed in the toolkit are not directly applicable to earthquake disasters the principles underpinning the approach are. https://issuu.com/edwintoo/docs/cobra_conceptual_framework_and_meth

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Menoni et al	The EU ENSURE (Enhancing resilience of communities and territories facing natural and na-tech hazards) project examined the relationship between flooding vulnerability and resilience in Sondrio (Italy). As part of the project a matrix approach was developed to assess the resilience of the built environment, infrastructure and social systems. The matrix approach provided a framework for assessing the existence (or not) of a range of factors that would affect resilience to a flooding event. http://link.springer.com/article/10.1007%2Fs11069-012-0134-4
Bruneau et al	This framework was developed specifically to measure the seismic resilience of communities. The framework is based around a series of matrices that define at a global level (through performance criteria) the Robustness, Redundancy, Resourcefulness and Rapidity requirements of a community's Technical, Organisational, Social and Economic systems. Further matrices repeat the process (Robustness, Redundancy, Resourcefulness and Rapidity requirements) for critical systems (Power, Water, Health, Emergency Response) from a Technical, Organisational, Social and Economic perspective. This multiple performance metric approach allows community resilience to be broken down into three complimentary measures: reduced failure probabilities; reduced consequences from failures; and reduced time for recovery. http://earthquakespectra.org/doi/abs/10.1193/1.1623497
Kellett et al	The Future Framework for Disaster Risk Reduction: A guide for Decision Makers is a set of guidance for government decision makers on what should be included in a disaster risk reduction framework. Whilst the guidance doesn't provide specific tools it does highlight 11 areas (making the case, the architecture, monitoring and accountability, financing, vulnerability and inclusion, disaster risk, environmental and ecosystems, science and technology, conflict and fragility, stakeholders and leadership, sustainable development) that need to be addressed in any disaster risk reduction framework. https://www.odi.org/sites/odi.org.uk/files/odi-assets/publications-opinion-files/8996.pdf
Resilience Alliance	Provides a framework for assessing resilience in social-ecological systems. Their workbook for practitioners provides guidance on developing and implementing management solutions to improve system resilience. The framework provides tools for describing the system under threat; applying the adaptation cycle; identifying system interactions; understanding governance systems and social networks; and for developing conceptual models and setting threshold criteria. The resilience assessment resulting from enacting the framework can be implemented and integrated into strategic plans and management processes to improve the resilience of the system. http://www.resalliance.org/files/ResilienceAssessmentV2_2.pdf
IFRC	Earthquakes: Guidelines on Preparing, Responding and Recovering. The International Federation of Red Cross and Red Crescent produce guidelines for national societies in preparing, planning and implementing field operations in response to an earthquake event. The guidelines are built on the Hyogo Framework and although this has now been superseded by The Sendai Framework (see next section) the advice in the guidelines is valid. http://www.preventionweb.net/files/26164_earthquakeguidelinesenweb.pdf

Ainuddin & Routray	Developed a multiple indices approach to measuring community resilience to earthquake hazards in Baluchistan. Their approach was based on 4 components of (social, economic, physical and institutional) each representing its own domain and measured through 17 individual indicators. Each indicator was expressed in percentage terms and weighted to represent the relative importance of each indicator to each other. Due to lack of data the authors used a subjective assessment of the relative weights and whilst this doesn't negate the principles behind the approach it does call into question the robustness of the specific comparisons presented in the paper. The overall community resilience was then calculated by combining the individual component scores. http://link.springer.com/article/10.1007/s11069-012-0201-x

5.5 These toolkits and frameworks will be reviewed in more detail as part of the development of the Liquefact Community Resilience Toolkit to be developed in Work Package 5.

5.6 Table 2 provides an overview of the range of factors and indicators used by the various toolkits/frameworks and other researchers to measure community resilience to disaster events. The factors have been derived from the sources cited in this report to provide an indication of the range of performance criteria that will need to be developed as part of the Liquefact toolkit in Work Package 5.

Table 2: Characteristics/factors known to affect community resilience and how these are observed/expressed within a community.

Resilience Factor / Characteristic	**Indicator / Expectations**
Robustness	Damage avoidance in lifelines and critical infrastructure (transportation networks, residential housing stock, healthcare facilities, communication networks, commercial and manufacturing establishments etc.); Continuity of service provision; Continuity of functional systems performance; Avoidance of casualties; Avoidance / minimisation of economic losses,
Redundancy	Backup and/or duplicate systems; Backup or access to alternate resources to sustain operations (insurance, alternative sites, robust supply chains etc.); Alternative community logistics (food, water, power etc.); Untapped resources/contingency budgets.
Resourcefulness	Access to money; Information; Technology; Human resources; Household emergency plans; Business continuity plans; Diagnostic and damage detection systems; Contingency plans across stakeholder groups.
Rapidity	Disaster preparedness (Organisational capacities, Early warning systems, Contingency planning, Emergency response planning, etc.); Reduced time of recovery to return systems as close as possible to business as normal.
Personal Factors	Critical awareness; Self-efficacy; Sense of community; Outcome expectancy (positive or negative); Action coping and resource availability; Education and training; Psychological preparedness; Empowerment; Social norms; Trust; Personal responsibility; Social responsibility; Experience; Resources; Adaptive capacity; Cultural attitudes and motivations; Social networks; Property values; Livelihoods; Participation in recovery; Volunteering.
Community	Collective efficacy; Participation; Commitment; Information exchange; Social

Factors	support; Decision making; Resource availability; Engagement; Leadership; Demographics; Sense of community; Community values-cohesion; Collective efficacy; Place attachment; Adaptive capacity; Local understanding of risk (Hazard assessment, Vulnerability assessment, Impact assessment, Resource management, Mitigation); Counselling services; Health and well-being services; Community organisations (e.g. faith based etc.); Employment;
Institutional Factors	Empowerment; Trust; Resources; Mechanisms for community problem solving, Adaptive capacity, Participation in hazard reduction programmes; Hazard mitigation plans; Zoning and building standards; Emergency response plans; Interoperable communications; Continuity planning; Municipal finance/revenues.
Governance Factors	Policy & Planning; Legal and regulatory systems; Integration across time and scale; Leadership; Partnerships; Accountability.

Derived from: Ainuddin & Routray (2012); Becker et al (2013); Boon et al (2012); Bruneau et al (2003); Cutter et al (2008); DPRAP (2013); GOAL (2012); Normandin et al (2009); and Paton (2007).

The factors and indicators presented in Table 2 should be considered exemplars of the kind of issues that will need to be addressed when assessing the resilience to EILD events in the 4 case study regions in Work Package 7.

6 Disaster Risk Reduction

6.1 Although the subject of a risk and risk reduction is the focus of Deliverable 1.3 an introduction in this report is considered desirable as it provides the continuity between community resilience theory and the measurement toolkits used to assess community resilience to disaster events. In this section risk is defined as the "probability of an event occurring and its negative consequences" (UNISDR, 2009). Closely aligned to improving community resilience to disaster events are strategies and frameworks aimed at reducing the risks associated with disaster events.

6.2 The UK Foresight project on Reducing Risks of Future Disasters (2012) examined priorities for decision makers involved in disaster management and risk reduction. Through a review of the science and evidence around disaster risk reduction the Foresight project identified the major impacts that a wide range of disasters had on communities and identified issues that needed to be addressed to reduce such impacts in the future. In particular the Foresight project identified the need for better forecasting of potential hazard events; improved cooperation and pooling of resources including the removal of technical, organisational and commercial barriers; better assessments of vulnerability and exposure of people and assets to the impacts of disaster events; and better modelling of disaster risk. In addition, the Foresight project also identified the need for new decision making frameworks that better articulate the risks and in particular better integrate risk in new business and governance models that allow decision makers to act on the risks (transfer, avoid, reduce or accept the risk) and to evaluate the cost/benefit of risk reduction strategies. Finally, in addition to the scientific and governance

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challenges the Foresight report also drew attention to the role that stakeholders play in incorporating disaster risk into policies both in the public and private sectors. All of these issues form part of the work of the Liquefact project.

6.3 In 2015 the Sendai Framework for Disaster Risk Reduction 2015-2030 (UNISDR, 2015) was adopted at the Third United Nations World Conference on Disaster Risk Reduction held in Sendai, Japan. The Sendai Framework replaces the Hyogo Framework for Action: Building the Resilience of Nations and Communities to Disasters. Whilst the Hyogo Framework was credited with raising awareness and generating political commitment; a new vehicle was needed that provided a people-centric preventative approach to disaster risk which adopted a multi-hazard, multi-sectoral approach to disaster risk reduction. The Sendai Framework has been specifically developed to apply to a wide spectrum of small-large scale, frequent and infrequent, sudden and slow onset disasters caused by natural and man-made hazards. As such the Sendai Framework should provide a suitable vehicle for assessing the community level risk to earthquake disasters.

6.4 The Sendai Framework is based on (but not limited to) the following guiding principles:

- Disaster risk reduction is a shared responsibility between government, authorities, sectors and stakeholders. It requires all-of-society engagement;
- When managing disaster risk consideration should be given to protecting people, their health, property and livelihoods, as well as productive, cultural and environmental assets;
- Disaster risk reduction depends on coordination mechanisms within and across sectors and with relevant stakeholders; and requires empowerment of local communities;
- Disaster risk reduction requires a multi-hazard and risk–informed decision making based on scientific information complemented with local knowledge that contextualises the information to local circumstances;
- Disaster risk reduction is more cost-effective than post disaster response and recovery and a "build-back-better" philosophy reinforces future risk reduction.

6.5 These principles are consistent with the basic theory of community resilience to disasters presented earlier and with the objectives of many of the toolkits developed to measure community resilience.

6.6 The Sendai Framework suggest that national states should focus on 4 priority areas for action when applying the Framework.

1. **Understand the disaster risk**: A holistic understanding disaster risk in all its dimensions is essential to support effective risk management. Using relevant and reliable data (nationally and locally) will provide base-line information on vulnerability, adaptive capacity, exposure and hazard characterisation which

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will allow primary and secondary impact scenarios to be modelled and the effectiveness of coping strategies to be evaluated. The scenarios can also provide a mechanism to communicate the disaster risks to central planners and the wider community.

2. **Strengthen disaster governance to manage risk:** Develop clear vision, plans, guidance, command, control, and coordination activities within and across sectors that engage all the stakeholders in disaster risk management. In developing the systems consideration should be given to publicly and privately owned critical infrastructure as well as to households, communities and businesses. Whilst systems can be designed centrally they should be enabled locally with local authorities empowered to act at the local level.
3. **Invest in disaster risk reduction to improve resilience**: Public and private investment in disaster risk reduction is essential to enhance economic, social, health and cultural resilience of people, communities, countries and their assets. Effective mechanisms should exist to promote disaster risk transfer (e.g. insurance, risk sharing and retention, financial protection etc.) for both public and private assets and in particular critical infrastructure assets including appropriate design standards; building materials; and maintenance and refurbishment strategies. With regards to business resilience, effective understanding of the integration of disaster risk management into business models, including the supply chain, is critical if livelihoods are to be protected.
4. **Enhance disaster preparedness and build-back-better**: Pre-planning is essential for an effective recovery, rehabilitation and reconstruction following a disaster event. This phase also offers an ideal opportunity to build-back-better by integrating disaster risk reduction into development and reconstruction projects. To prepare for disaster events requires contingency plans and programmes to be developed and tested routinely across the community. These plans need to consider forecasting and early warning systems as well as communication systems and channels. Policies to improve the resilience of existing critical infrastructure should be developed and implemented as part of routine refurbishment. Logistics required immediately after a disaster event should be stockpiled and a distribution system established for their release immediately following a disaster event.

6.7 The framework also emphasises the role of stakeholders in disaster risk reduction; identifying in particular civil society; volunteers, organised voluntary work organisations, and community based organisations; businesses; professional associations; financial institutions; and media organisations as critical components to community resilience.

6.8 However, whilst the Sendai Framework is well founded in disaster resilience theory it doesn't provide detailed tools or metrics to allow community resilience to be measured in response to

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any given hazard threat. Indeed, the Sendai Framework poses many challenges to those seeking to implement it. The challenges to science posed by adoption of the Sendai Framework were explored in a meeting of international disaster risk experts held at the Royal Society in London on the 24-35 June 2015 (Royal Society, 2015). Whilst the meeting acknowledged the readiness of the scientific and technology communities to address disaster risk reduction it also highlighted and number of areas where further work was needed if the Framework was to be fully effective. Amongst the issues that the meeting highlighted were the need to mainstream disaster risk reduction amongst the scientific community; and a clear understanding of disaster risk reduction potential offered by scientific and technological advances. In addition a number of specific gaps in scientific knowledge were identified including:

- The need to study disaster risk reduction as multiple hazards from interdisciplinary, inter-sectoral, transboundary and transnational perspectives;
- A better understanding of how risks escalate over time and in particular the social, economic and institutional factors that contribute to risk and the transfer of risk between stakeholders;
- Development of early warning systems; and
- Improved data on risk-related phenomena and in particular people's changing vulnerabilities and expose to hazards over time.

6.9 At a subsequent meeting of the United Nations Office for Disaster Risk Reduction held in January 2016 in Geneva (UNISDR, 2016) a scientific and technology road map was developed to support the implementation of the Sendai Framework. This road map identified the expected science and technology outcomes needed to support the four Sendai Priority Action areas and provided detailed actions required to achieve each expected outcome. The Sendai Framework and UNISDR science and Technology Road map form the practical basis for the development of toolkit to assess the potential to improve community resilience to EILD event and they will be explored in more detail in Work Package 5.

7 Improving Community Resilience to Earthquake Disaster Events

7.1 Although specific toolkits to address community resilience to earthquake events will be developed in Work Package 5 the lessons that have been learnt from recent events are summarised here as they can inform the whole of the Liquefact project.

7.2 Earthquake disaster events are some of the most severe natural disaster events because their rapid onset provides minimal or in most cases no early warning of the event and as such provides no time for communities to prepare for the onset of the event. The Canterbury (2010) and Christchurch (2011) earthquakes in New Zealand provided a good opportunity to test the applicability of the general theory of community resilience to such events.

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7.3 Whitman et al (2013) examined the impact of the Canterbury aftershocks on the rural communities of the Canterbury planes. Whitman et al (*ibid*) studied the short term impacts of the disaster event on 78 organisations in the 4 months following the earthquake and identified different factors that effected speed of recovery and community resilience. Non-farming organisations were most affected by non-structural damage to buildings and the impact that this had on business continuity; with banks and insurers being the primary recovery channels. Farming organisations were most affected by disruption to critical infrastructure, which produced significant psychosocial stress with informal social networks being the primary channel of recovery. Both types of organisation were affected by disruption to the power supply and one of the key lessons from the study was the need for quick access to back-up alternatives to the power (and other critical infrastructure) supply system to ensure that organisations could continue to function as close to normally as possible once the earthquake event had passed.

7.4 Thornley et al (2015) also examined the lessons that could be learnt following the Canterbury earthquakes. Through a series of semi-structured interviews and focus groups Thornley et al (*ibid*) examined community responses to the earthquake events and explored individual perceptions of the factors that had affected community resilience to the events. The factors that affected resilience were presented at the individual, community and societal levels. At the individual level chronic stress as a result of the repeated aftershocks, poor housing conditions, uncertainty, difficulty accessing support etc. caused depression, anxiety and fatigue which in turn inhibited an individual's ability to contribute to the recovery process. Conversely, where people were able to contribute to the recovery process this had a positive effect on their well-being. At the community level, social connectedness and a sense of community clearly supported community resilience with pre-existing networks (e.g. family, friends etc.) supported through social media being particularly important. Community infrastructure was also important in aiding recovery with local community leaders and community organisations playing an important communication role following the earthquake events. Finally direct community involvement in disaster response and recovery was critical to its success with many communities seeking a positive dialogue with official decision makers over recovery and future city-wide planning. Loss of housing and community facilities had a negative impact of the sense of community. At the Societal level support from external agencies was critical. In particular flexibility from central government agencies and local councils in re-directing resources to support recovery was seen as a positive support mechanism that helped the local community as they recovered from the events. Based on their analysis of the earthquake events Thornley et al (*ibid*) concluded that "… connected communities, with strong pre-existing community infrastructure, found it easier to initiate local responses, foster community involvement and access timely external support. Conversely, communities with fewer community based groups, local leaders or existing networks found it more difficult to respond and adapt. ". These conclusions are consistent with the general theory of community resilience reported earlier and derived from a wider range of natural and manmade disaster events.

7.5 A further review of the lessons that can be learnt from the Canterbury earthquakes was carried out by Britt et al (2012). Britt et al reviewed the theory of disaster resilience, citing in particular Paton's model of community resilience (see Figure 1) and Bronfenbrenner's system interaction model (see Figure 3) in the development of a 'Resilience Tree' model (Figure 5) as a metaphor of community resilience. The tree represents resilient households and individuals. The branches represent the community, organisations and institutional environment, all of which have the potential support household resilience. The foliage identifies a number of factors that may increase or decrease levels of resilience. The trunk represents fairness and equity whilst the roots provide hope, unity of purpose and communication. Using the different elements of the 'Resilience Tree' Britt et al (*ibid*) identified a number of post-disaster practices that would enhance and promote individual and household resilience. In relation to Canterbury these included actions to: support health and well-being; support empowerment to participate in policy formulation and review; support for community level groups and networks; enhancing social capital; training and mentoring of community leaders; and public health and awareness campaigns. Again these are consistent with the findings from Thornley et al (2015) and support the application of the general theories of community resilience to earthquake disaster events.

7.6 The earthquake specific issues will be reviewed again in Work Package 5 where community resilience to EILD events toolkits will be developed.

8 Discussion

8.1 From the review of theory presented in the previous sections it is clear that the community resilience of the 4 Liquefact case study sites to EILD events will result from a complex interaction of a number of inter-related component sub-systems that describe how individual factors within each community respond to the disaster event and how each community sub-system affects, and is affected by, other community sub-systems. As such understanding each community's resilience requires a multi-dimensional systems analysis approach that allows for inter-action and feedback within and between sub-systems to support post-disaster recovery. Each component sub-system's vulnerability resilience and adaptive capacity needs to be understood in the context of the potential disaster event and of the antecedent conditions that are present in each sub-system prior to the event. These antecedent conditions include the ability of the physical, social and environmental sub-systems present within (or supporting) the community to withstand the impacts of a disaster event and to recover from the event in as short a time as possible after the disaster event. The physical, social and environmental sub-systems affect, and are affected by, the robustness, redundancy, resourcefulness and rapidity

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of the system as a whole which in turn are influenced by personal (individual), community, institutional and governance factors. Finally, the speed of recovery has to be considered against the multiple stressors that follow a disaster event and not merely against the single stressor associated with the event. In many cases it is the secondary stresses that have the longest (and most devastating) impact on a community. The Liquefact project will develop a multi-dimensional model of community resilience to EILD events (in Work Package 5) that reflects the various theoretical approaches outlined in this report.

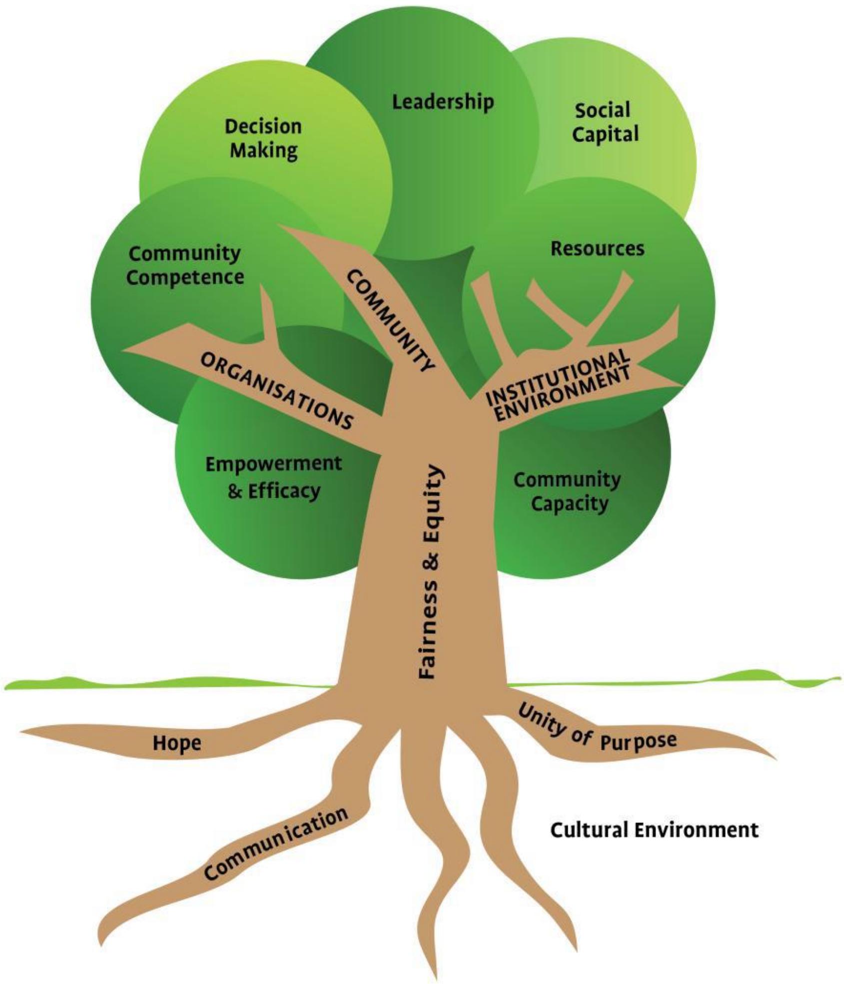

Figure 5: The individual and household resilience tree
(Source: Britt et al, 2012)

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8.2 A number of toolkits have been reviewed that attempt to translate the theory of community resilience into measurement instruments to assess a specific community's resilience to disaster events. These toolkits generally fall into two categories; those that attempt to measure the characteristics of a system (resilience scoring) or those that attempt to capture /describe the system's resilience (frameworks).

8.3 Resilience scoring systems seek to identify which resilience components exist within a community and then score each in turn against quantitative criteria. The quantitative criteria seek to divide the component into a number of operational factors. The individual scores for each operational factor are then combined to produce an overall score for the component's resilience. The aggregated scores for the components are then combined to produce an overall score for the community's resilience. However, when aggregating the individual component scores together the toolkits do not generally consider any inter-dependence between the components but in most case mealy sum or average individual component scores to provide an indicative assessment of a community's resilience. This approach limits the usefulness of many of the resilience scoring systems to comparative assessments between communities rather than an objective and quantifiable assessment of the resilience of a specific community.

8.4 Disaster Resilience Frameworks take a different approach to assessing community resilience. Frameworks seek to improve community resilience by providing a check list of actions or contingencies that should be in place to enhance community resilience to a disaster event. Whilst frameworks tend to be generic they can be customised to reflect different disaster scenarios and many use probability based risk assessments to identify and reduce disaster risk. Whilst these toolkits are good at identifying centrally organised responses to disaster events they are less able to stimulate local responses, especially where responsibility for preparing for a possible event lies with the private sector or at the individual citizen level. In essence, whilst frameworks can complement resilience scoring systems in providing an assessment of the level of engagement/awareness of a community to a potential disaster event they do not provide details metrics against which the effectiveness of mitigation strategies to improve community resilience to a potential disaster event can be measured. The Liquefact project will develop a multi-dimensional toolkit/framework to assesses community resilience to EILD events (in Work Package 5) that draws on those outlined in this report.

9. Summary and Next Steps

9.1 The Liquefact project aims to develop a more comprehensive and holistic understanding of the earthquake soil liquefaction phenomenon and the effectiveness of mitigation techniques to protect structural and non-structural systems and components from its effects. The Liquefact project will evaluate the mitigation techniques against the potential improvements that could

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accrue to community resilience in regions prone to EILD events. This report provides an introduction to the theory of community resilience and identifies some issues that the Liquefact project partners will need to consider when undertaking their research and innovation programme. The Liquefact project will use develop a theoretical model of community resilience to EILD events and develop a community resilience toolkit and disaster risk reduction framework in Work Package 5 to evaluate the potential impact that the mitigation techniques developed in the project (Work Packages 2, 3 and 4) could have on each of the case study sites (Work Package 7). The toolkit and risk reduction framework will be based on the Sendai Framework for disaster risk reduction and the principles underpinning its development will be reported in Deliverable 1.3.

9.2 Finally, this report should be considered a work in progress that will be amended and added to as the Liquefact project progresses. The primary audience for the report are the Liqueafct partners and researchers.

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