Institution: University of Cambridge

Unit of Assessment: UoA 7

Title of case study: Increasing resilience to earthquake risk in developing countries

Period when the underpinning research was undertaken: 2000-present

Details of staff conducting the underpinning research from the submitting unit:

Name(s):	Role(s) (e.g. job title):	Period(s) employed by submitting HEI:
James Jackson	Professor	1980-present
Alex Copley	Lecturer	2012-present
Keith Priestley	Professor	1990-2018

Period when the claimed impact occurred:
1 August 2013 – 31 July 2020

Is this case study continued from a case study submitted in 2014? N

1. Summary of the impact (indicative maximum 100 words)

University of Cambridge research has focussed on earthquake hazard, risk and resilience, particularly in developing nations along the earthquake belt from the Mediterranean to China. The impact of this research has been:
1. To increase the resilience of developing countries to earthquake risk through the foundation (by Jackson) of the international partnership Earthquakes without Frontiers (EwF) which has:

- Led to the retrofitting of buildings and development of new building codes, resulting in safer and more resilient buildings;
- Improved hazard assessment and city development planning, thereby reducing earthquake risk;
- Empowered in-country scientists, leading to improved public safety policy and a shift in the political understanding of managing earthquake risk.

The population exposed to earthquake hazard in the 11 different countries in which EwF is active is 1 billion.
2. To allow safer and more cost-effective hydrocarbon exploration as a result of improved assessment of seismic hazard and risk in the Caspian region, an area which has attracted >USD 50 billion of investment but which is at extreme risk of earthquakes.

2. Underpinning research (indicative maximum 500 words)

Jackson's, Copley's and Priestley's research, based on a wide range of geological and geophysical techniques, has underpinned our understanding of how continents deform [R1, 2, 3]. Their studies of fault rupture have led to a quantitative understanding of the hazard that earthquakes pose in continental regions away from tectonic plate boundaries: why they occur, what controls their size and recurrence rate, why people tend to live in areas prone to large earthquakes and what factors control the vulnerability of populations to these hazards.

Cambridge research has shown that seismic risk is higher in continental interiors, where the network of faults is much less well defined, than at plate boundaries [R4]. Since 1900, there have been approximately 130 earthquakes in which >1,000 people died. 100 of these took place in continental interiors causing at least 1,400,000 deaths, compared to 800,000 at plate boundaries. Devastating earthquakes such as those in Bam, Iran (2003; 30,000 deaths), Muzzafarabad, Pakistan (2005; 75,000 deaths) and Wenchuan, China (2008; 70,000 deaths), invariably take place on faults that were either previously unknown, or whose threat had not been recognised [R4], making hazard assessment and development planning impossible.

Cambridge research identified a disparity in the impacts of earthquakes of similar magnitudes between vulnerable developing countries and richer nations; and the complex reasons behind

it [R5]. A 7.8 magnitude earthquake could kill up to 30 per million people in California, but up to 10,000 in parts of Asia (U.S. Geological Survey). Historically, population centres in Central Asia sprung up in geologically-rich areas close to water sources and mountain ridges used as trade routes; all features intimately linked to the presence of active faults. For centuries, in countries like Iran, settlements have been destroyed by earthquakes, rebuilt and resettled. Such settlements are now experiencing rapid population growth and urban development. Buildings are of a low quality and have not been managed through building codes [R4, 5]. Earthquakes in these areas will now kill tens or hundreds of thousands as people migrate into megacities in vulnerable locations and it is expected that 2 billion people will be added to the cities of developing nations over the next twenty years. The situation is similar throughout much of the Mediterranean-Middle East-Central Asia earthquake belt. In contrast, in California and Japan, with good building design codes, earthquakes are now principally stories of economic loss [R5].

These multiple findings have been applied by leveraging a long-term relationship built up by Jackson and Copley (and Philip England from the University of Oxford) with local collaborators across the Mediterranean-Himalayan-Asian earthquake belt, many of whom advise their respective governments on earthquake hazard and risk. This created the opportunity to establish the Earthquakes without Frontiers (EwF) project, 2012-2018. Jackson (with England) is the co-founder and co-lead PI on EwF, a joint NERC-ESRC consortium supporting physical and social scientists working to increase resilience to earthquakes in Asian countries. EwF aimed to increase resilience to earthquakes in vulnerable countries through (a) collaborative research to improve knowledge of the hazard; (b) translation of that knowledge into improved public safety; (c) increasing in-country capability through training in modern earthquake science. Countries involved in EwF include Italy, Albania, Greece, Turkey, Iran, Turkmenistan, Kyrgyzstan, Kazakhstan, India, Nepal and China. The population exposed to earthquake in the 11 different countries in which EwF is active is 1 billion. Jackson received a CBE in 2015 for his work in this area.

Cambridge research has also yielded insight into how earthquakes in the south Caspian Sea, and in Iran, Azerbaijan and Turkmenistan, relate to geology and tectonics [R6]. The area is one of prodigious hydrocarbon reserves, with huge investment by oil companies but extreme risk from earthquakes and over-pressured sub-surface fluids, which threaten and frequently damage industry infrastructure through blow-outs and liquefaction. Cambridge research has identified that the simple patterns of earthquake mechanisms which hold the key to the tectonics of the South Caspian region are not clear in the routinely reported earthquake bulletin data, mainly because of errors in focal depths. Those patterns are, however, clear when the focal mechanisms and depths have been improved by long-period waveform modelling [R6]. Cambridge research in the Caspian Sea therefore addresses and corrects these inadequacies, leading to requests for advice from the engineering and oil industries.

3. References to the research (indicative maximum of six references)

The following papers are peer-reviewed and published in high quality Earth Science journals. The papers are recognised internationally in terms of originality, significance and rigour, as evidenced by their citations and grant funding.

R1 2002 **Jackson J**. Faulting, flow, and the strength of the continental lithosphere. International Geology Review. 2002 Jan 1;44(1):39-61. doi.org/10.2747/0020-6814.44.1.39

R2 2012 Craig, T.J, **Copley, A. & Jackson, J.** Thermal and tectonic consequences of India under-thrusting Tibet. *Earth & Planet. Sci. Lett.*, **353-354**, 231-239. doi.org/10.1016/j.epsl.2012.07.010

R3 2006 Copley, A. **& Jackson, J.** Active tectonics of the Turkish-Iranian plateau, *Tectonics*, **25**, TC6006. doi.org/10.1029/2005TC001906

R4 2016 Talebian, M., **A. Copley**, M. Fattahi, M. Ghorashi, **J. Jackson**, H. Nazari, R.A. Sloan, R.T. Walker, Active faulting within a megacity: the geometry and slip rate of the Pardisan

thrust in central Tehran, Iran, *Geophysical Journal International*, **207**, 3, 1688-1699, doi.org/10.1093/gji/ggw347

R5 2006 **Jackson, J.** Fatal attraction: living with earthquakes, the growth of villages into megacities, and earthquake vulnerability in the modern world. *Phil. Trans. Roy. Soc. London, Ser. A*, **364**, 1911-1925. doi.org/10.1098/rsta.2006.1805

R6 2002 **Jackson, J.A**., **Priestley, K**., Allen, M. & Berberian, M. Active tectonics of the South Caspian Basin. *Geophys. J. Int.,* **148**, 214-245. doi.org/10.1046/j.1365-246X.2002.01005.x

Grants (Jackson as PI)
NERC

- International Partnership for Collaboration and Training in Earthquake Hazard Assessment and Mitigation in the Alpine-Himalayan Belt and Central Asia. International Opportunities Fund (incl. enhancement) 1.7.2012-28.2.2017 GBP233,407
- Earthquakes Without Frontiers: Increasing resilience to Natural Hazards programme (incl. Newton Fund enhancement and supplement for hire of seismic equipment to monitor aftershocks of 2015 Nepal earthquake). 1.7.2012-31.7.2018 GBP737,348
- Active tectonics and seismic hazard assessment in Shaanxi, Gansu, and Ningxia Provinces, China. Increasing Resilience to Natural Hazards in China programme. 25.1.2016-24.1.2019 GBP34,022

Shell

- Earthquakes and tsunamis in the Eastern Mediterranean. 1.10.2013-30.9.2017 GBP101,909

DFID

- Rapid release of resources for seismic monitoring in Nepal. 201884. Science for Humanitarian Aid and Resilience programme 2.5.2015-30.9.2017 GBP275,000

Royal Society

- Increasing resilience to earthquakes in North India. ICA\R1\180234 International Collaboration Agreement/GCRF programme. 1.12.2018-30.1.2022 GBP159,250

Grants (Jackson as Co-I)
Leverhulme Trust

- Earthquake Ruptures Of Iran and Central Asia 1.3.2019-28.2.2021 GBP359,347

4. Details of the impact (indicative maximum 750 words)

It is estimated that by 2050, 2 billion people in developing nations will be exposed to serious earthquake risk [E1]. University of Cambridge research, and the co-founding by Jackson of Earthquakes without Frontiers (EwF), has increased the resilience of developing nations to earthquake risk through the retrofitting of buildings and the development of improved building codes; improved hazard assessment and city development planning; and a shift in the political understanding of managing earthquake risk which is the result of the empowerment of local scientists and has led to improved public safety policy. Cambridge research in the South Caspian sea region has also led to safer and more cost effective hydrocarbon exploration.

Retrofitting of buildings and development of new building code has led to safer and more resilient buildings

In the 2015 earthquake in Nepal, 98% of the nearly 9,000 deaths were caused by collapsing buildings. In Kathmandu, 300 buildings retrofitted to increase earthquake resilience by the National Society of Earthquake Technology (NSET) all survived [E2]. NSET attributed their success in securing and delivering construction contracts in Nepal, both before and after the earthquake, to their collaboration with EwF: *'EwF definitely did help raise the trust of many bi-lateral agencies and other partners on NSET and our approaches, which we could refine and polish due to our association in EwF'* [E2].

Following the earthquake in Nepal, key findings relating to impact and resilience from Jackson and colleagues were presented to DFID, UNESCO and the Nepalese government. These reports were, as the UK government Chief Scientist explained, *'highly valued by the [FCO and DFID] for use in their operational planning'* [E3]. The Nepalese government used these reports

to guide a new building code to improve earthquake resilience. Amongst the organisations awarded contracts for re-building work following the 2015 earthquake in Nepal were the EwF-affiliated NSET, who have been awarded a USD 10 million contract by USAID for the rebuilding of more than 50,000 residential properties and thousands of schools [E2]. The new building code is being used to guide the construction of new schools that are earthquake-resistant, thereby greatly reducing the risk of building collapse and death, and allowing children to attend school without fear.

Improved hazard assessment and planning reduces risks from earthquakes

Cambridge research showed that devastating earthquakes almost invariably take place on faults that were either previously unknown, or whose threat had not been recognised. In Asia there are thousands of active faults which could slip to cause an earthquake at any time, not all of which have been identified. In Tehran – a city of over 10 million people – EwF has addressed this problem by identifying the Pardisan fault, thereby improving hazard assessment and subsequently changing planning policy. The Geological Survey of Iran states that: *'Collaborations through EwF have provided the possibility of identifying major hidden … faults ... [for example] … identifying and studying the active hidden Pardisan fault within the capital city of Tehran which was a major step in evaluating the earthquake hazard to Tehran'* [E4]. On the back of the University of Cambridge EwF assessment, the Iranian government *'decided to revise the city development plan considering the new findings'* [E4].

Empowerment of in-country scientists leads to improved public safety policy

Prior to EwF, the predominant view in developing nations was that earthquakes are predictable, so governments needed only to demand short-term predictions from scientists. A system had evolved in which (a) no action was taken on mitigation; (b) maps of seismic hazard were decades old and largely incorrect; and (c) research in modern or innovative directions was rarely encouraged [E1, E4, E5, E6]. As the US Geological Survey (USGS) makes clear, 'Neither the USGS nor any other scientists have ever predicted a major earthquake. We do not know how, and we do not expect to know how any time in the foreseeable future' [E7]. In any case, what is needed is to lower the vulnerability of infrastructure and improve the accuracy of hazard assessment and the monitoring of faults, solutions proven in the USA, Japan and elsewhere. Faith in short-term forecasting endured partly because of a lack of local scientific expertise within developing nations. EwF has helped to address this within the framework of a supportive international partnership, through the empowerment of local scientists attached to 26 international partners across 11 different countries. The UNESCO Abdus Salam International Centre for Theoretical Physics describes how *'EwF contributed effectively in fighting against the brain drain and isolation of scientists in developing countries'* [E5]. EwF is *'clearly unique…it builds a tradition and legacy not like other initiatives which have hampered the development of in country science and discourage any growth of sustainable local research in the developing world'* [E5].

EwF also contributed to increasing '*the credibility and reputation of the EwF partnership members in their own countries'* [E5]. This has influenced the political mind-set, as described by the National Society of Earthquake Technology (NSET): *'The presence of people from Italy, Nepal, China and Iran all saying the same things to politicians had more impact than in isolation'* [E2]. This has had an impact on public policy in terms of the development of building codes, the retrofitting of buildings, and the revision of city development planning, but it has also shifted the political focus of public safety policy away from short term prediction and towards increasing resilience. In Pakistan, for example, the National Disaster Management Agency has *'started investing in preparedness and prevention rather than being just a post-disaster agency'* [E5].

Safer and more cost-effective hydrocarbon exploration

Hydrocarbon exploration in the Caspian Sea is high risk as a result of earthquakes and over-pressured sub-surface fluids, but attracts huge investments. These include more than USD 50 billion in the Kashagan field [E8], and a USD 6 billion BP project with Azerbaijan [E9]. The Arup Geohazard and Risk Management Team delivers natural hazard and risk assessment

projects for clients worldwide including The World Bank, BP, Shell, HSBC, and others. Jackson and colleagues have advised Arup on assessment of seismic hazard and risk to:

- BP, for their offshore facilities in the Central Caspian region. As Arup have testified, the *'alignments of mapped geological faults and their characteristics were essential for the seismic hazard assessment'* [E10].
- BP's gas processing and export facility at Sangachal in Azerbaijan, one of the world's largest oil and gas terminals. Jackson was able to share recent research on the depth at which earthquakes occur in the region. This insight had a '*significant impact on the calculated earthquake ground shaking that would potentially occur at the surface and resulted in a safer and more cost-effective design for the oil and gas facilities'* [E10].

5. Sources to corroborate the impact (indicative maximum of 10 references)

E1 **Earthquakes without Frontiers: Final Report**. https://www.esc.cam.ac.uk/ewf/final-workshop-report-pdf See pg. 1 for population exposed to earthquake risk; pg. 2 for belief in prediction

E2 **Testimonial from National Society for Earthquake Technology (NSET) Nepal**

E3 **Testimonial from Chief Scientific Advisor to HM Government**

E4 **Testimonial from the Geological Survey of Iran.** A ministry of the government of Iran and an EwF partner.

E5 **Testimonial from the International Center for Theoretical Physics (UNESCO).** This UNESCO-run organisation is a partner in EwF and is committed to scientific education in developing countries.

E6 **Testimonial from The Yessenov Foundation, Kazakhstan.** A Kazakh charity committed to scientific education, and the principal sponsor of our major international conference in Almaty in 2016 in which they secured the participation of the mayor: http://yessenovfoundation.org/en/konferentsiya-po-zemletryaseniyam/.

E7 **USGS 'Can you predict earthquakes?'** https://www.usgs.gov/faqs/can-you-predict-earthquakes?qt-news_science_products=0#qt-news_science_products

E8 **Media article '**In a Prize for Big Oil Firms, Caspian Deal Eases Access' New York Times, 8 October 2018. https://www.nytimes.com/2018/10/08/business/energy-environment/caspian-sea-deal-eases-access.html.

E9 **Media article, '**BP seals new $6bn pact to drill for oil under the Caspian Sea' The Telegraph, 19 April 2019. https://www.telegraph.co.uk/business/2019/04/19/bp-seals-new-6bn-pact-drill-oil-caspian-sea/.

E10 **Testimonial Ove Arup & partners.**