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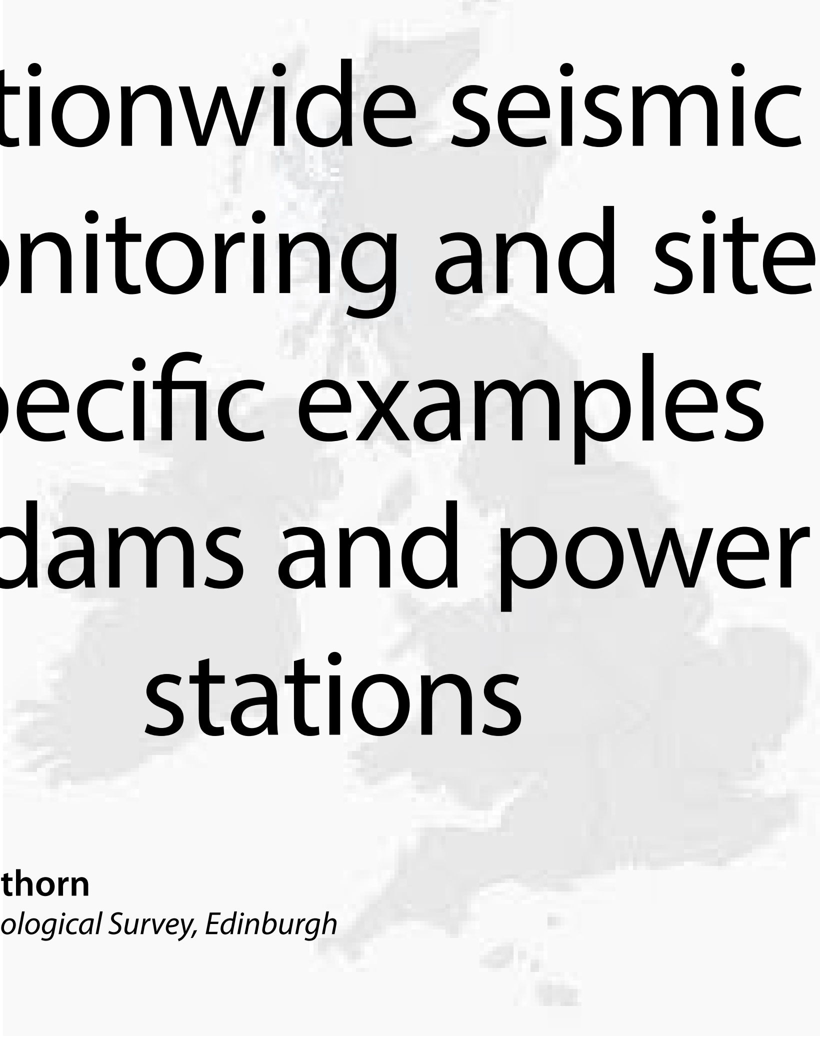
The UK's earthquake detection network: nationwide seismic monitoring and site specific examples at dams and power stations



In this issue

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Editor's note: on 30th September 2020 Dr David Hawthorn from BGS gave a talk on the UK's earthquake detection network at a SECED online evening event. David provided the following article as a summary of his presentation.

1. Introduction

Earthquake detection in the UK is dominated by around 100 seismic stations owned by the British Geological Survey (BGS) and a small number of stations the BGS operates on behalf of others.

There are also a small number of stations operated by other agencies, and data sharing agreements exist between the BGS and national monitoring agencies in neighbouring countries. These are not discussed here.

Networks of seismic stations are required because a single station cannot discriminate between earthquakes and near sources of noise. Calculating an accurate location and magnitude for an earthquake also requires multiple stations.

In the UK the BGS operates three different types of station:

- Firstly, there are long term high quality stations that should be in place for many decades.
- Secondly, there are a varying number of temporary stations deployed to supplement the permanent stations. These study specific occurrences, for instance natural earthquake swarms or induced earthquakes (fracking, dam impoundment, etc.).
- Thirdly, there are stations providing site specific monitoring of civil infrastructure like dams or power stations. These are typically optimised to provide an absolute value of ground motion, rather than working out the location and magnitude of a distant earthquake.

In this paper these three types of station are examined. The examples used here are from the UK, although similar monitoring capacity is present in many other countries.

2. Permanent stations

The UK has 42 permanent stations (Figure 1) providing the long-term backbone to its seismic monitoring. Modern broadband seismometers can accurately record frequencies of ground motion between 500 Hz and 0.001 Hz with a resolution of 1/100000 metres. For this to be useful for the detection of earthquakes the sensors must be located in areas of very low seismic "noise", that is away from ground motion caused by traffic, vegetation moving in the wind, coastal noise etc.

To achieve this, the location of permanent stations takes into account their proximity to roads, railways, fences, cattle, trees, buildings, pylons, running water and pumps, proximity to the coastline and land usage. Finding new permanent station locations can take many years trying to satisfy these criteria.

Because the main instrument at each permanent station is so sensitive, an earthquake occurring close to the station could saturate the sensor, limiting the data available for that earthquake. Because of this, the majority of permanent stations have a secondary sensor, known as a strong motion sensor. These will not even register the majority of earthquakes, but ensure that any very near or very powerful earthquakes will still be accurately recorded.

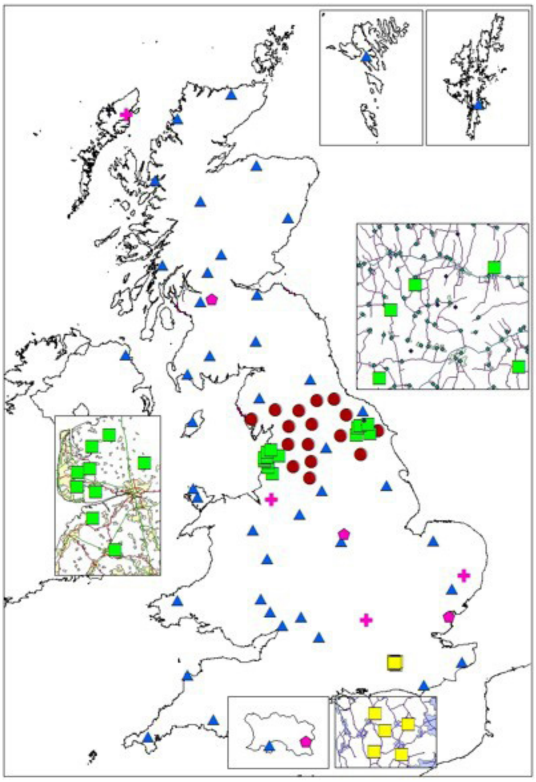

Figure 1: Location of seismic stations around the UK. Blue triangles are permanent stations. Yellow squares, green squares and red circles are temporary stations achieving different goals. The magenta hexagons are already deployed monitoring stations and the magenta crosses are monitoring stations under development.

All stations continually transmit data in real time at sample rates between 100 samples per second (sps), or 500 sps. The majority of sites are powered by mains electricity and have data transmission via ADSL lines. In many cases this requires the laying of long (100s–1000s of metres) buried cables to bring power and data from the nearest available point to the location of the station. In a small number of cases, this isn't possible and solar panels and either satellite or 3G data links are used.

The sensors are deployed on a layer of concrete about 1–2 m below ground level (Figure 2). At most sites the concrete has been lain directly onto bedrock to allow the best possible coupling between the sensor and the ground. The sensors are housed within insulated barrels (Figure 2) that provide a stable temperature regime, which improves sensor performance.

Ideally, the BGS aims to operate permanent stations indefinitely. Some of the oldest stations have been running since the 1960s, although installation of modern broadband equipment started in the 1990s, replacing older and less capable equipment.

Figure 2: Maintenance of a Permanent BGS station In Scotland, with the inspection hatches of both sensor pits open. The primary sensor has been removed from its pit and is visible to the left of the person.

3. Temporary stations

Most national seismic monitoring agencies will have a number of temporary stations for a variety of reasons. In the UK the BGS currently has three temporary networks in operation, as shown in Figure 1. Generally, temporary networks are used to enable the detection of earthquakes too small to be accurately discerned by the permanent network. This is because the energy from smaller earthquakes attenuates quickly, so only by having stations in the near vicinity can they be detected. This can be seen with deployments of sensors in Surrey, Yorkshire and Lancashire (Figure 1).

In Surrey, five stations are deployed within a 10 km^2 area. These are used to monitor an ongoing sequence of earthquakes first detected in 2018. Over 140 earthquakes have been detected here since then, ranging in magnitude from -1.4ML to 3.1ML. Nine events were of magnitude 2.0ML or higher, and could be resolved by the permanent network. The remaining smaller earthquakes required the dense array of sensors in the area. Surrey has a number of conventional oil and gas fields in development or operation, and there was public concern these could be the cause of the seismicity. The full data set, including smaller earthquakes, identified the swarm as being natural in origin, and not induced (Verdon et al., 2019).

In Lancashire and Yorkshire networks of similar density were deployed in relation to active or proposed hydraulic fracturing of shale gas reserves. Previous, and now recovered networks have examined other earthquake swarms (for instance Baptie and Ottemmoeller, 2003), examined aftershock sequences (Moretti et al., 2016) and monitored the impoundment of new dams (for instance Luckett and Baptie, 2012).

Unlike permanent stations, temporary stations need to be located and installed quickly. All the temporary stations utilise solar power and 3G data communications to facilitate this goal. Subject to landowner approval a new station can be located and installed within a day. An example of temporary station installation is shown in Figure 3.

Figure 3: An example of a temporary station. Power is provided by the solar panel in the background. The sensor is buried and is not visible here.

4. Site specific monitoring by borehole

Deployment of seismic sensors in boreholes has been a common practice for many decades. By situating a seismometer deep underground many of the sources of seismic noise, such as human activity, can be mitigated against. This can allow the detection of ground motion from earthquakes that otherwise would be obscured by noise. However, until recently such equipment was problematically expensive for many monitoring agencies, and required very specific types of borehole for successful installation. Technological advances have lowered the cost of such instrumentation and made them far easier to deploy. In many cases pre-existing boreholes can often be used, further decreasing cost. Newer technology also allows multiple sensors to be deployed within the same borehole (Figure 4).

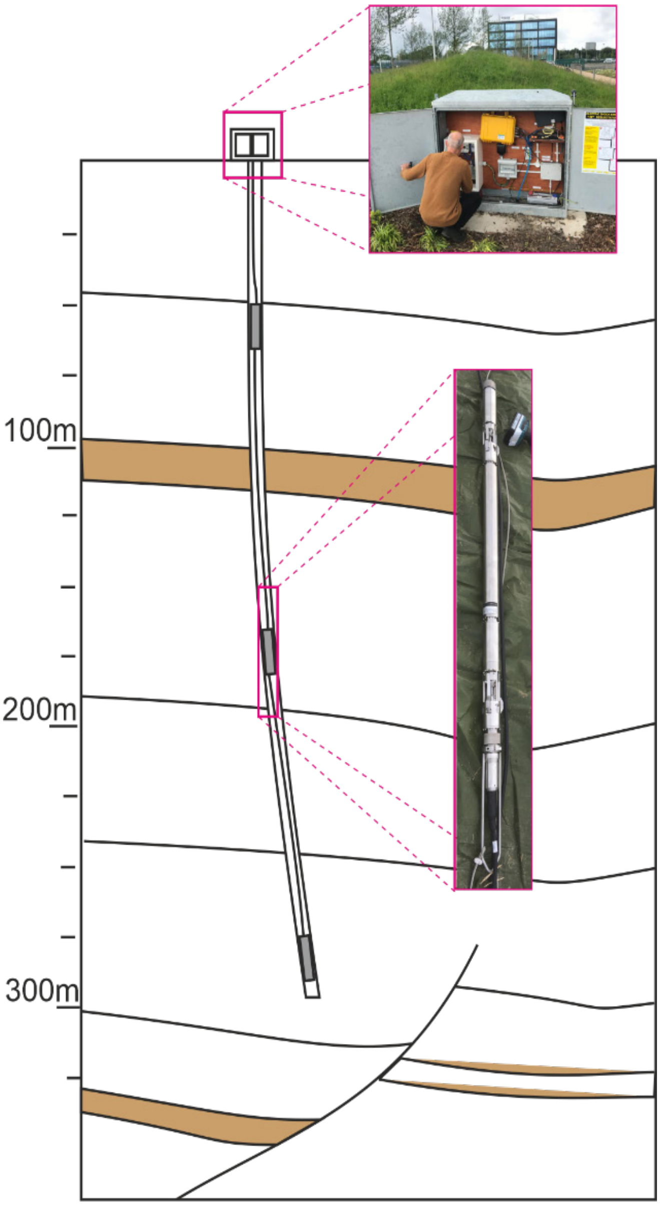

Figure 4: Schematic layout showing a borehole deployment of three seismometers in 200m borehole.

There are currently three sites in the UK utilising multi-sensor borehole monitoring.

In Glasgow, five sensors are deployed within a 200 m deep borehole as part of the BGS UKGEOS observatory. This project examines the potential of using abandoned mine workings as a geothermal heat source. This activity is not expected to be seismogenic, and borehole monitoring should verify that. The location of the borehole, in the heart of one of the UK's largest cities also illustrates an advantage of borehole deployments. The high levels of human induced seismic noise in a city would normally preclude the deployment of a "normal" surface permanent station. By integrating the data from this borehole with other permanent stations, effective seismic monitoring across the Strathclyde region is possible.

At Sutton Bonnington, in Nottinghamshire, the BGS operates a borehole station to monitor a small trial of onshore carbon capture and storage. Again, whilst this is not expected to be a seismogenic activity, the monitoring should verify that.

Finally, China General Nuclear (CGN) maintains a multi-sensor borehole as part of its Bradwell B development in Essex. This station is operated on CGN's behalf by the BGS, with data passed on to Jacobs Ltd. BGS integrate the data from this borehole with other BGS stations in the area to enhance earthquake detection across the region. Jacobs Ltd use the absolute motion recorded by the sensors within the borehole during earthquakes to calculate the Kappa value, as part of the site characterisation process for the probabilistic seismic hazard assessment of the Bradwell B site.

The problem faced by all these stations, and site specific monitoring solutions generally, is the possibility of a false positive. That is, that a local source of noise that isn't an earthquake (for instance a heavy goods vehicle going past) is mistaken for an earthquake. This is a standard problem in seismology and is solved by using the data from multiple stations. Only if the signal is seen on multiple stations it is regarded as an earthquake. This means these borehole stations are all reliant on the wider BGS network.

5. Site specific monitoring by surface station

A number of power stations and dams in the UK have surface stations installed on them. The BGS operates several of these on behalf of the operator. Because many of these sites are nuclear licensed sites confidentiality agreements prevent most of them being discussed in detail here.

The reason for deploying these stations is generally to ensure that an absolute value of Peak Ground Acceleration (PGA) is available during an earthquake that may affect the facility. This reduces the uncertainty associated with Ground Motion Prediction Equations (GMPEs) to estimate what ground movement is likely to be at site based on earthquake magnitude and location. Operators can use this information in a number of ways, from adjusting inspection routines in response to critical events, to carrying out emergency procedures (reservoir draw-downs, power station shut-down, etc.).

Site specific stations are generally based around a minimum of two sensors on site, ideally separated by several hundred meters. Having two sensors allows false positives to be filtered out; i.e. unless both sensors show a signal it is not an earthquake. Whilst such arrangements are able to identify an earthquake, they are not suitable to accurately calculate the magnitude and location of any earthquake. For that a wider network of sensors is needed, which can usually be provided by the BGS, using their permanent network of stations.

How these systems notify their operator of a problem also varies. In some cases all data is processed off site, for instance by the BGS, on behalf of the facility operator. The facility is then notified when events affect it and can request PGA values.

In other cases automated on-site processing can be set up. This can generate an immediate alarm in response to two or more sensors experiencing more than a pre-set value of PGA. Alarms like these can be connected to automated emergency response procedures for the fastest level of response to potentially harmful levels of PGA across a facility. Automated seismic alarms can operate independently of any external seismic network, and without a short term need for expert seismologists to process or oversee the data. However, they do require a long-term maintenance and verification programme to ensure they will work in the event of a problematic earthquake. This is generally difficult to do without recourse to a wider seismic network.

A practical example of a site specific monitoring solution in shown in Figure 5. This shows a station operated by

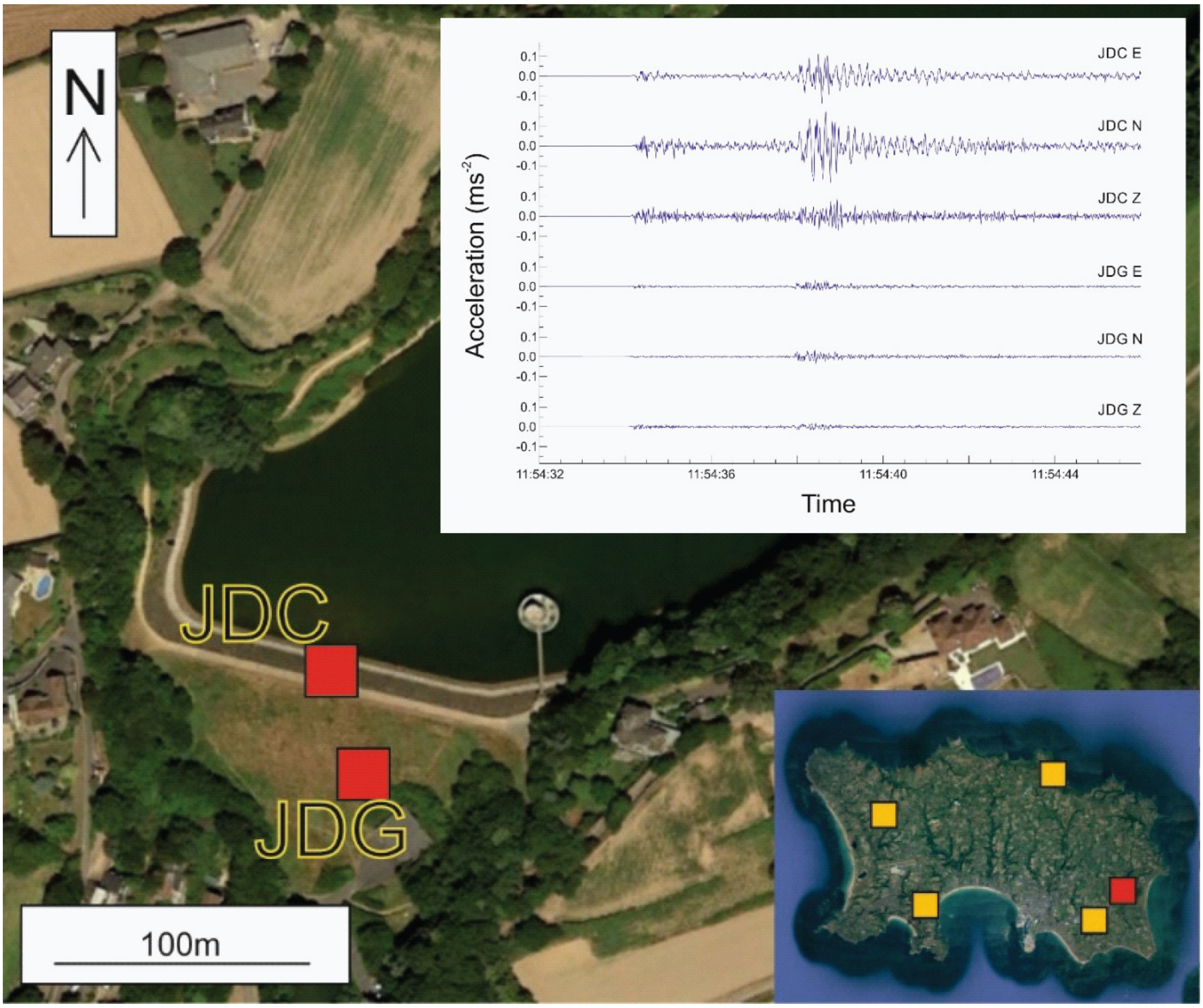

Figure 5: Site specific monitoring of a reservoir in Jersey (seismic stations JDC and JDG, respectively located at the crest and at the base of the dam). The inset seismograph shows the acceleration resulting from the ML 4.3 earthquake of 2014/07/11 that occurred 27 km from the dam.

the BGS on behalf of Jersey Water. Two seismic monitoring stations are installed around the dam. The seismometer labelled JDC is installed within the crest of the dam and JDG at the base of the dam. In normal circumstance these stations might be too close to allow discrimination of false positives, however because BGS has several other stations on the island, they can provide that function. In this case having the two sensors so close together means information on the response of the dam itself is available. JDG records ground motion, whilst JDC shows the movement at the top of the dam. As can be seen by the inset seismograph of figure 5, JDC (upper three traces) shows considerably more movement in response to an earthquake than JDG.

6. Dealing with data, accessing network performance, providing results

The BGS operates around 100 stations across the UK. Each generates between 50 MB and 1.2 GB of data per day. Continuous data from each station is transmitted in real time (within 2 seconds of generation) to the BGS data centres in England and Scotland. These data centres are identical, and provide security even in the event of a catastrophic failure of one.

Incoming data is subject to automated routines that look for possible earthquakes. If these detect an event occurring within the same time window on three or more stations the result is pushed to a human operator. They will confirm the event, and calculate location and magnitude. Seismic alerts are then issued by email and text, and detected earthquakes will also eventually be published on the website.

The continuous data from all stations is archived in perpetuity, and the digital record from seismic stations at the BGS now dates back to the 1970s. There is an ongoing program of digitisation of older analogue seismic records. Data is publically available via a number of international archives of seismic data, and direct from the BGS.

The generated seismic records are also an essential way of assessing the operational health of the stations. The seismic data (or lack of it) as well as a variety of non-seismic information generated by each station can be used to detect both faults, and the precursory indicators of faults. Station repair and maintenance can then be scheduled in an intelligent and resource efficient way.

7. Summary

In the UK earthquake detection is dominated by around 100 stations across the UK which are managed by the British Geological Survey. These are a mixture of permanent stations and temporary stations to ensure that in some areas smaller earthquakes can be detected than would normally be the case. The data from these stations is used to detect and classify earthquakes, and seismic alerts are issued as a result. The continuous waveform data from these stations is all publically available.

There are also a small number of stations providing site specific monitoring. These are a mixture of borehole and surface stations. They are used for a variety of reasons, but mainly to provide absolute values of ground motion during an earthquake.

In all cases a single station is of little or no use because it cannot discriminate between near sources of noise and actual earthquakes. Even where a single station is deployed to provide an absolute value of ground acceleration during an earthquake, it is reliant on other stations to know there has been an earthquake.

References

Baptie B. & Ottemoeller, L. (2003). The Manchester earthquake swarm of October 2002, *EGS-AGU-EUG Joint Assembly*, Nice, France, 6–11 April 2003.

Luckett, R. & Baptie, B. (2012) Seismic monitoring of inundation of the Glencoe Hydro Scheme Reservoir. *British Geological Survey*, 11pp. (OR/12/062).

Moretti, M., Baptie, B., Segou, M. et al. (2017). SISMIKO: emergency network deployment and data sharing for the 2016 central Italy seismic sequence. *Annals of Geophysics*, **59** (5). 8pp.

Verdon, J., Baptie, B. & Bommer, J. (2019). An improved framework for discriminating seismicity induced by industrial activities from natural earthquakes. *Seismological Research Letters*, **90** (4): 1592-1611

SECED Newsletter

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Please contact the Editor of the Newsletter, Damian Grant, for further details. This edition of the Newsletter was co-edited by Manuela Daví.

Editor's note: this article is a summary provided by Sebastian Kaminski on the talk he gave on 20th October 2019 at the SECED Young Members' Annual General Meeting.

The April 2016 Muisne (Ecuador) earthquake. Behaviour of low-rise RC frames with masonry infill, and recommendations for new construction

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1. Introduction

The 2016 Mw 7.8 Muisne earthquake in Ecuador caused nearly 700 fatalities, 230,000 injuries and over 35,000 damaged or collapsed homes (Reliefweb, n.d). Associated intensities were VI–VIII on the Modified Mercalli Intensity scale, and Peak Ground Accelerations (PGAs) ranged from 0.51g to 1.55g in Pedernales (Instituto Geofísico, 2016). The majority of the building stock in the area affected by the earthquake was low-rise (1–6 storeys) reinforced concrete (RC) frame with unreinforced masonry (URM) infill. This system is commonplace for housing throughout the world because it uses widely available materials, is low-cost and simple to construct. However, it also has many vulnerabilities, and because of its heavy weight its failure can often lead to injury or fatalities.

This article is a summary of the 2019 SECED Conference paper 'The April 2016 Muisne (Ecuador) Earthquake – behaviour of low-rise RC frames with masonry infill, and recommendations for new construction' (Kaminski et al., 2019), but also expands upon the idea of appropriate technologies for reconstruction in developing countries.

This article briefly reviews the most common typical construction system for low-rise construction in the affected region, and summarises the damage observed in the seismic event. A critique of the selection of appropriate technologies for reconstruction is then provided, discussing past issues and good practice, before providing a case study in Ecuador that follows modern best practice.

2. Low-rise RC frames with masonry infill walls

This system tended to have a slender RC frame, with thin columns and either a shallow beam or in some cases no beam at all, and a conventional RC slab (Figure 1). Slender clay brick masonry walls formed the façade and internal partition walls of most buildings, which were in some cases connected back to the frame with light reinforcement. Wall density was relatively high, however at ground floor there was often a shop front and/or a sheltered corridor, resulting in lower wall density.

These buildings were often built in stages, with the first floor or two constructed first and then additional floors added when money becomes available. The buildings appeared to be largely non-engineered, likely built by a local builder, possibly with some input from an architect and limited, if any, input from engineers. In reality, the lateral load-resisting system of these buildings is likely to be the RC frames braced by the masonry infill walls. By inspection, the RC frames without infill walls are too slender to attract significant load when compared to the stiff masonry wall panel, and it's likely that any hinges would form first in the columns and not in the beams.

The system is not too distant from confined masonry (CM), at least visually, however the construction sequence (first the frame then the masonry instead of the opposite) means the panels are not fully confined and generally not positively connected to the frame. Furthermore, the detailing of the columns and tie beams appeared inadequate, and the masonry wall panels are too slender for out-of-plane loads. As a result, the masonry and the frame do not

Figure 1: Typical low–rise RC frame with masonry infill in Ecuador

purposefully act together under lateral load as shear walls, but rather as a frame partially braced by an interfering infill wall. Therefore, these buildings tended to be hybrids, a cross between a moment frame and a CM building, but lacking the correct design and detailing for either.

3. Observed building damage

The seismic performance of these low-rise non-engineered RC frames with masonry infill during the Ecuador earthquake is what one would have expected (Franco et al., 2017, Franco et al., 2018). The issue for this typology is considered to be simply that these buildings are neither a moment frame nor a CM building as they lack the correct design and detailing for either systems. Reasons for damage typically were (Figure 2 and 3):

- Inadequate design and detailing of RC moment frames.
- Inadequate masonry infill design and construction.
- Inadequate shear design and detailing.
- Weak and soft storeys.
- Inadequate laps.
- Short columns.
- Insufficient cover to steel reinforcement.
- Pounding.
- Inadequate design of hinges.
- Inadequate securing of non-structural elements.
- Poor quality concrete.
- Corrosion due to use of sea sand and/or sea water for construction
- Use of smooth bars as reinforcement

Figure 2: Inadequate design and detailing for shear link spacing and detailing

Figure 3: Weak/soft storey failure

4. How do we select appropriate technologies for reconstruction?

Designers (engineers and especially architects) are generally taught that new designs need to be different to be better. After each major earthquake, there is often a feeling from some groups within the international community that the solution to that country's housing problem is to import a new alien technology or material. There are good examples of this after every humanitarian disaster. After the 2010 Haiti earthquake, for example, some NGOs (non-governmental organisations) were promoting earthbag construction, despite the designs having no proper load path and the system being completely inappropriate for the context. Other unusual "structural" materials that have been promoted as the saviour to a developing country's shelter needs include cardboard, paper, plastic bottles, straw bales and shipping containers, all of which it's fair to say were disastrous in terms of the most fundamental housing requirements. In some extreme examples, foreign interventions with alien technologies and materials have left target communities in more seismically vulnerable housing than they would have been exposed to had they completely self-reconstructed. However the foreign agents have been so successful in their salesmanship of the design that the homeowners are blissfully unaware of the extreme seismic vulnerability of their own houses.

In nearly all cases though, there is no need to reinvent the wheel or introduce alien materials or technologies. Existing designs available in-country are generally already very appropriate, understood and with existing supply lines. Their seismic resistance can often be relatively easily improved with some simple tweaks target at improving detailing or durability. There is also much to be learnt from vernacular systems which, thanks to communities adapting them through trial and error over hundreds or thousands of years, are designed for the local hazards, use local and affordable materials, and achieve the requirements of a home.

5. Reconstruction in CM

The current construction practice for low-rise non-engineered RC frames with masonry infill in Ecuador is not so distant from CM. The CM structural system consists of horizontal and vertical RC confining elements built on all four sides of an unreinforced masonry panel (Brzev, 2007). The confining elements work by:

- Enhancing the stability and integrity of masonry walls for in-plane and out-of-plane earthquake loads.
- Enhancing the strength (resistance) of masonry walls under lateral earthquake loads.
- Reducing the brittleness of masonry walls under earthquake loads and hence improving their earthquake performance.

Their overall performance is superior to non-engineered RC frames with masonry infill, and they are a properly codified structural system. They are also very durable and relatively simple to construct. Most importantly, as they do not differ significantly from the current practice of construction, it can be relatively easy to train locals to build CM themselves because it is not a completely foreign concept.

The new Ecuadorian Construction Norm NEC15, introduced in 2016, includes references to CM, however its concept and fundamental mechanics were neither explained nor understood properly by local builders, engineers and architects. While CM had been used in the past in Ecuador, over the last decades the knowledge and skills required to implement this system have been mostly lost. The 2016 earthquake provided an opportunity to re-introduce CM in Ecuador with correct design and detailing practices.

6. Case study on CM training in Ecuador by SDC

The SDC reconstruction programme in Ecuador was an excellent example of a successful upskilling project post-earthquake in a developing country. Their approach to the introduction of CM was twofold:

i. the training of workers and small-scale contractors in the CM technique (Figure 4).

ii. the promotion of this building method among the general public, construction professionals and authorities (Carlevaro et al., 2018). This involved producing various tools and using different media to disseminate information as widely as possible (Figure 5).

This strategy aimed to ensure the training of workers in a construction technique that is appealing and familiar to the public; i.e. there is no point in promoting a construction technique and training workers in a system nobody wants to use.

Figure 4: SDC's training house

Figure 5: SDC's calendar containing key messages for CM construction

7. Summary

In order for seismically-resistant building techniques to be successful in a post-earthquake reconstruction context, these systems must: (1) be based on familiar concepts, (2) use local materials, (3) be easy to construct and replicate, (4) be affordable, and (5) be functional and desirable to the community. CM was already so close to what people are constructing that it fulfilled all of the above criteria. In addition, CM is durable and resilient to earthquakes when properly constructed, and it has proved to be a successful construction technique in many other countries.

Introducing a new construction technique takes time. Changing a habit is changing a culture, and cultural changes require patience. Therefore, any future implementation of CM needs to change the culture of the broader population, influencing not just masons, but engineers, architects and homeowners. This is best accomplished by mixed teams of technical specialists, community organizers and social scientists targeting the population in various different ways. When this is done well, it can have positive and long-term benefits.

References

Brzev, S. (2007). Earthquake-resistant confined masonry construction. National Information Centre of Earthquake Engineering, Indian Institute of Technology Kanpur, Kanpur, India.

Carlevaro, N., Roux-Fouillet, G. & Schacher, T. (2018). How to build safer houses with confined masonry: A guide for masons. Practical Action Publishing, Rugby, UK.

Franco, G., Stone, H., Ahmed, B., Chian S.C., Hughes, F., Jirouskova N., Kaminski, S., Lopez, J., van Drunen, N.G. & Querembás, M. (2017). The April 16 2016 Mw7.8 Muisne Earthquake in Ecuador – Preliminary Observations from the EEFIT Reconnaissance Mission of May 24 - June 7. *16th WCEE, 2017, Santiago, Chile.*

Franco, G., Stone, H., Ahmed, B., Chang, S., Hughes, F., Jirouskova, N., Kaminski, S., Lopez, J., van Drunen, N., Molina Hutt, C. & Querembás, M. (2018). The Muisne, Ecuador Earthquake of 16 April 2016: A Field Report by EEFIT. EEFIT, London, UK.

Kaminski, S., Schacher, T., Lopez, J. et al. (2019). The April 2016 Muisne (Ecuador) Earthquake – behaviour of low-rise RC frames with masonry infill, and recommendations for new construction. *SECED 2019 Conference,* September 2019

Reliefweb. (n.d.) Ecuador: Earthquake – April 2016: Overview. Available from: https://reliefweb.int/disaster/eq-2016-000035-ecu. (Accessed May 2019).

Editor's note: On 14th May 2020, Dr Francesca Roscini gave a presentation during an online lunchtime talk organised by the SECED Young Members Group . She kindly provided this article summarising aspects of her reasearch.

Strengthening of masonry vaults with Steel Reinforced Grout

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Recent earthquakes in Italy have highlighted the need to ensure the safety of existing buildings and increase their resilience. This is particularly true for cultural heritage, which, in addition to external actions, has been subjected to environmental degradation, several changes of use and sequences of hazard events. With this in mind, different solutions for the strengthening and rehabilitation of heritage structures have been adopted throughout history, ranging from techniques using more traditional materials and systems (not always appropriate), such as chains, connectors, anchors, steel pins, concrete edge beams (concrete curbs), reinforced injections, as well as more innovative materials, such as Externally Bonded advanced composites Reinforcements (EBRs). In the past decades, the use of advanced composites in strengthening solutions, has been receiving a great deal of attention (Valluzzi et al., 2014) because of their ability to increase load-bearing capacity without altering original geometry, mass and stiffness of the buildings. The rapid uptake of advanced composites in strengthening applications has been facilitated by their versatility and adaptability, thus making them suitable for installation on any structural element of an existing building and to comply with the preservation criteria for cultural heritage. Therefore, given also the availability of codes on EBR in literature, Steel Reinforced Grout (SRG), comprising Ultra High Tensile Strength Steel cords embedded in a mortar matrix, is emerging as a particularly advantageous solution for the externally bonded strengthening of existing structures. Nevertheless, its development is still at a relatively earlier stage with respect to the already well-established Fibre Reinforced Polymers (FRP, which make use of organic matrices), as well as to other mortar-based composite materials, such as Textile Reinforced Mortars (TRM) or Fabric Reinforced Cementitious Matrix (FRCM, which comprise carbon, glass, basalt or PBO meshes). Therefore, a deep knowledge needs to be gained on mechanical properties, acceptance criteria and behaviour of reinforced structural members in order to develop suitable design relationships and assessment criteria, which would allow for a more confident use of SRG in structural rehabilitation practice.

This research provided a wide experimental evidence of SRG composites with lime-based mortars for the reinforcement of masonry vaulted structures. Firstly, direct tensile tests on bare textile specimens and SRG coupons as well as single-lap shear bond tests were performed to investigate the main mechanical properties (tensile strength and stiffness, crack pattern, cord-to-matrix and SRG-to-substrate load transfer capacity, failure modes) and derive fundamental acceptance and design parameters. Then, bond tests were performed on curved substrates to investigate the influence of convex and concave curvatures on the SRG-to-masonry bond behaviour. Both double-lap double-prism test and four point bending tests were performed to study intermediate debonding mechanisms and analyse the effect of testing setups. Simplified relationships accounting for substrate curvature were also derived, which may be useful for a preliminary estimate of SRG bond strength. Finally, full-scale tests on masonry vaults reinforced either at the extrados or at the intrados (respectively the external and internal part of a vault), with different SRG systems were carried out.

In detail, this experimental investigation was performed in the laboratory on four vault specimens with 2.9 m span, 65 cm rise and 55 mm thickness, provided with buttresses and backfill. One specimen was unreinforced and three were reinforced with SRG, comprising unidirectional steel cords applied with a lime-based mortar (De Santis et al., 2017), with the aim of enhancing the load carrying capacity. With respect to the other fabrics used in TRM reinforcements, steel fabrics are stiffer and stronger than glass and basalt, and thicker than carbon, aramid and PBO. They are more durable in an alkaline environment, and their shape provides a better interlocking within the mortar matrix (Ascione et al., 2015). To ensure durability, steel wires are coated with zinc to provide protection against salt attack and prevent rusting. SRG was applied either to the extrados or to the intrados of the vault to investigate the different strengthening layouts that could be faced in field applications. Reinforcements included connectors at the abutments along the barrel vault. A vertical load was applied over the backfill at 1/3 span and increased cyclically up to failure to investigate the increase in load carrying and deflection capacity provided by SRG (Figure 1) and the modification of the associated damage pattern, failure mode (Figure 2), and arch-fill interaction.

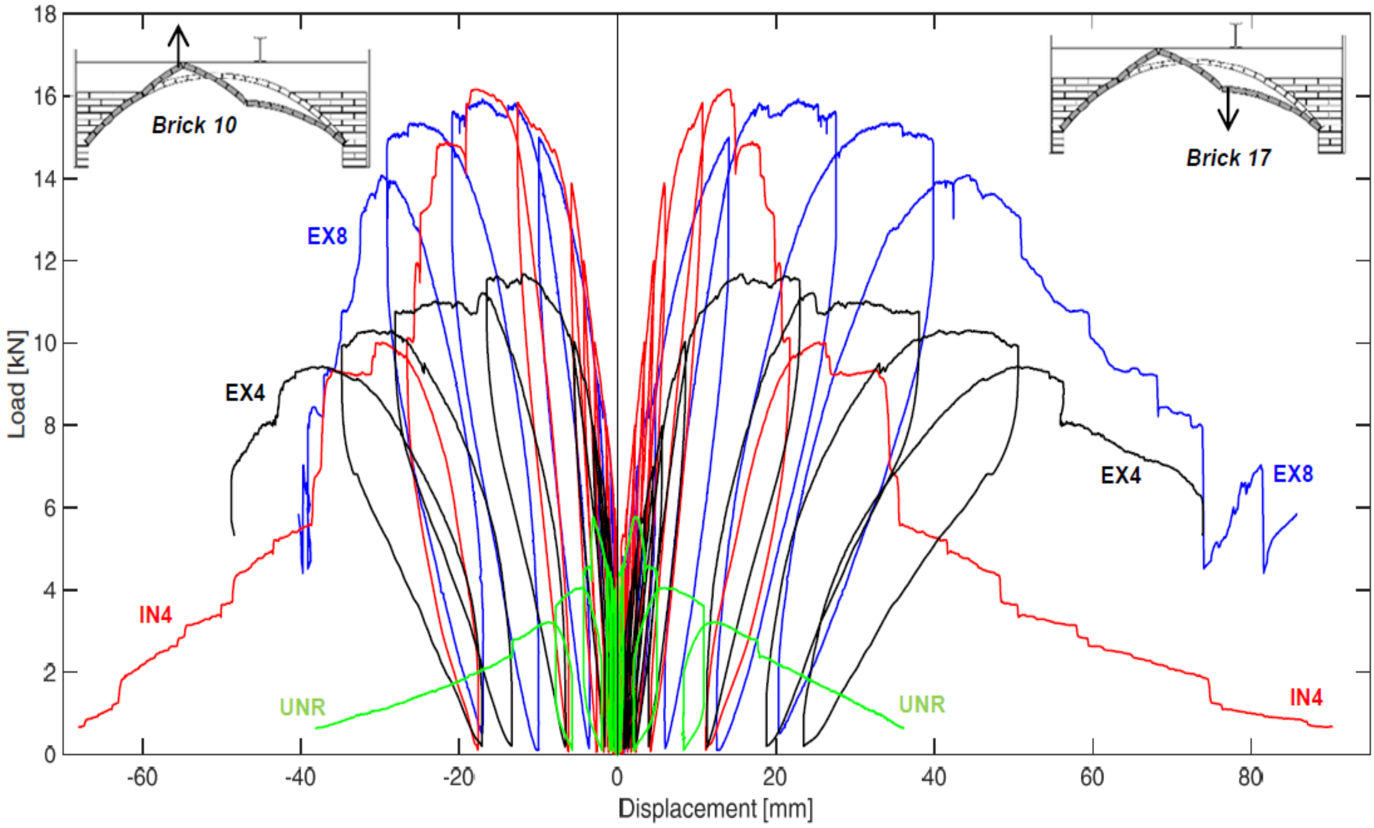

Figure 1: Load-displacement response curves. UNR = un-reinforced vault; EX8 = reinforced vault with extrados 8 cords/inch strengthening system; EX4 = reinforced vault with extrados 4 cords/inch strengthening system; IN4 = reinforced vault with intrados 4 cords/inch strengthening system.

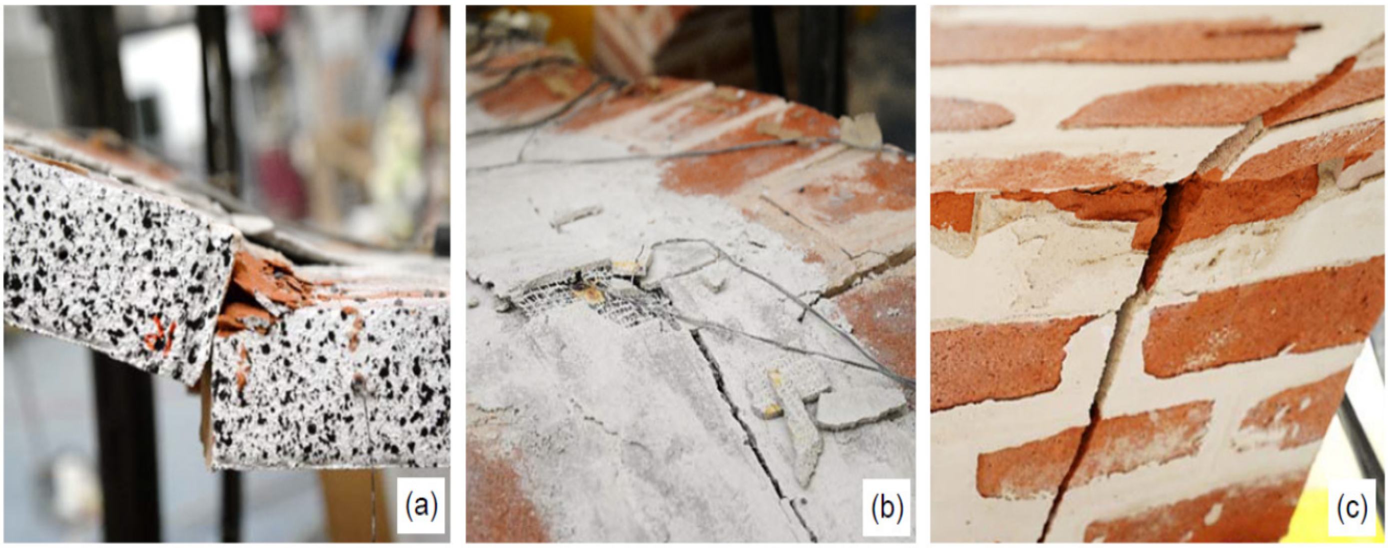

Figure 2: Failure mode details for extrados 8 cords/inch reinforcement: (a) sliding, (b) cracks between bricks; (c) longitudinal crack in the middle of the arch barrel.

Finally, the load carrying capacity of the strengthened arches was estimated by limit analysis, using both a static and a kinematic approach. The use of unconventional measurement techniques, such as the digital image correlation, provided information on crack occurrence and arch-fill interaction, analysing the development of displacements and strains fields during the tests. For instance, the displacement fields (Figure 3), mainly related to the collapse mechanism, indicate that in IN4 (Figure 3d) a larger volume of backfill was mobilized below the load with respect to the other specimens, thanks to the broader distribution of downwards displacement provided to the arch barrel by the SRG applied at the intrados. On the left side, instead, a localization of displacement was detected in IN4 (Figure 3d). Such concentration was found also in UNR (Figure 3a) but not in EX8 (Figure 3b) and EX4 (Figure 3c) in which the SRG at the extrados entailed a broader distribution the load transferred to the backfill by the arch barrel moving upwards.

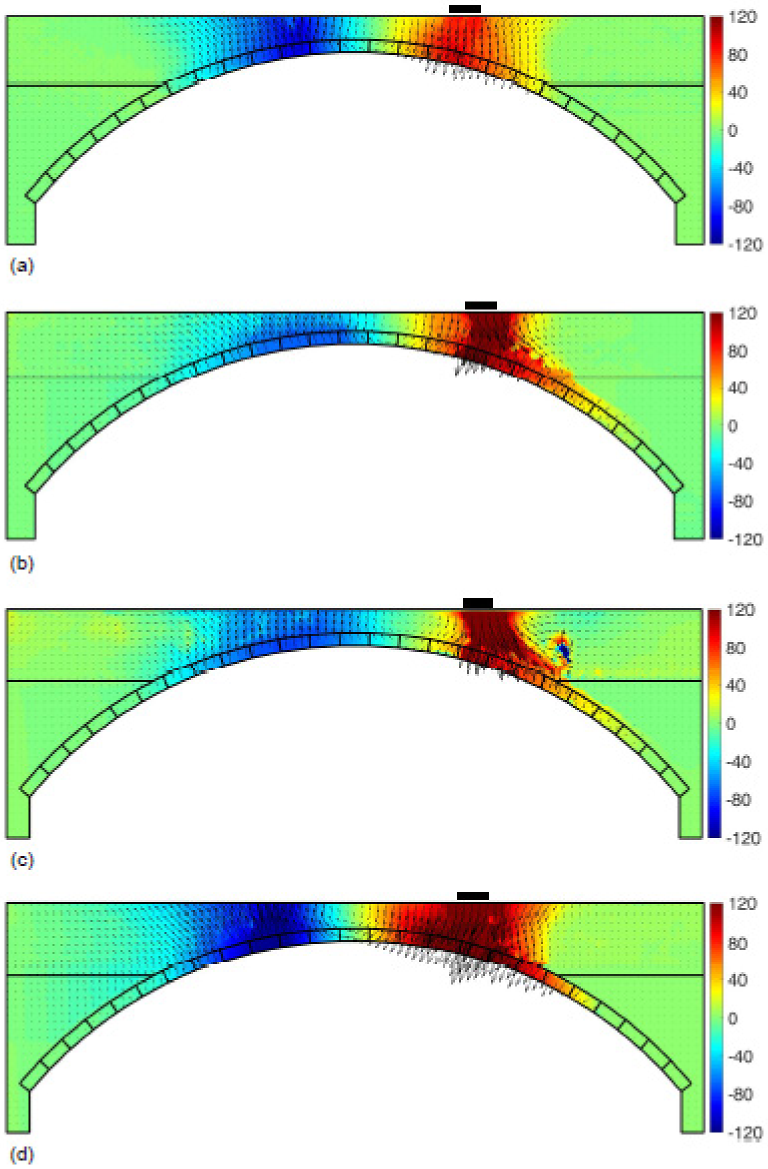

Figure 3: Field of vertical displacements and arrows of total displacements at collapse in un-reinforced vault [UNR] (a), reinforced vault with: extrados 8 cords/inch SRG strengthening system [EX8] (b), extrados 4 cords/inch SRG strengthening system [EX4] (c) and intrados 4c ords/inch SRG strengthening system [IN4] (d). Arrows scaled by 0.8.

In conclusion, test outcomes revealed the effectiveness of SRG in improving the load-carrying and the deflection capacity of masonry arched members. In particular, it should be noted that:

SRG increased the load-carrying capacity both when applied to the intrados and when applied to the extrados, with respect to the unreinforced specimen. More specifically, the intrados reinforcement, provided with intermediate connectors installed along the arch barrel at 50 cm spacing, led to an increase of 179% of the load-carrying capacity. The extrados reinforcements, provided with end connectors in the abutments, entailed an increase of 100-174%.

The displacement capacity was also increased in terms of both peak displacement (by 4–10 times) and ultimate displacement (up to two times larger than that of the unreinforced specimen).

References

Ascione, L., de Felice, G. & De Santis, S. (2015). A qualification method for externally bonded Fibre Reinforced Cementitious Matrix (FRCM) strengthening systems. *Composites Part B: Engineering*, **78**: 497-506.

De Santis, S., Ceroni, F., de Felice, G., Fagone, M., Ghiassi, B., Kwiecień, A., Lignola, G., Morganti, M., Santandrea, M., Valluzzi, MR. & Viskovic, A. (2017). Round Robin Test on tensile and bond behaviour of Steel Reinforced Grout systems. *Composites Part B-Engineering*, **127**: 100-120.

Valluzzi, MR., Modena, C. & de Felice, G. (2014). Current practice and open issues in strengthening historical buildings with composites. Materials and Structures, **47**(12): 1971-1985.

Aknowledgments

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Notable Earthquakes
January 2021 – March 2021

Reported by British Geological Survey

Issued by: Davie Galloway, British Geological Survey, March 2021.
Non British Earthquake Data supplied by: United States Geological Survey.

			Time			Dep	Magnitude			
Year	Day	Mon	UTC	Lat	Lon	km	ML	Mb	Mw	Location
2021	11	JAN	21:32	51.28N	100.44E	10			6.7	NORTHERN MONGOLIA
At least 53 people injured in Moron and several buildings damaged in the Lake Khovsgol area and as far south as Moron.										
2021	12	JAN	18:48	53.06N	1.85E	10	2.3			SOUTHERN NORTH SEA
2021	14	JAN	18:28	2.97S	118.89E	18			6.2	SULAWESI, INDONESIA
At least 105 people killed, over 3,300 others injured and some 6,000 buildings damaged or destroyed in the Mamuju-Majene area, West Sulawesi.										
2021	18	JAN	06:40	51.59N	3.43W	3	1.5			TONYREFAIL, RHONDDA CT
Felt Tonyrefail, Clydach Vale and Trealaw (3 EMS).										
2021	18	JAN	07:41	56.55N	5.82E	8	1.9			LOCHALINE, HIGHLAND
Felt Lochaline, Morvern and Drimmin (3 EMS).										
2021	19	JAN	02:46	31.84S	68.82W	16			6.4	ARGENTINA
Fourteen people injured, several buildings damaged or destroyed and roads cracked in the San Juan area.										
2021	20	JAN	08:55	53.30N	2.40W	15	1.9			KNUTSFORD, CHESHIRE
2021	21	JAN	12:23	4.99N	127.52E	80			7.0	TALAUD ISLANDS, INDONESIA
2021	23	JAN	23:36	61.82S	55.51W	10			6.9	SOUTH SHETLAND ISLANDS
One building damaged at Chilean scientific base in Antarctica. Small tsunami waves were observed on some deep-sea gauges in the region.										
2021	01	FEB	18:05	51.96N	3.04W	13	1.9			LLANVEYNOE, HEREFORDSHIRE
2021	03	FEB	05:23	36.28S	97.80E	10			6.7	SOUTH PACIFIC OCEAN
2021	08	FEB	05:42	57.62N	5.57W	2	2.1			DIABAIG, HIGHLAND
Felt Diabaig, Gairloch, Poolewe and Charlestown (3 EMS).										
2021	10	FEB	13:19	23.05S	171.60E	10			7.7	LOYALTY ISLANDS REGION
A small tsunami was generated with maximum wave heights of 78 cm, measured at Lenakel, Vanuatu.										
2021	13	FEB	14:07	37.75N	141.75E	49			7.1	OFFSHORE HONSHU, JAPAN
One person killed, some 185 people injured and many buildings were damaged in Chiba, Gunma, Ibaraki, Kanagawa, Miyagi, Saitama, Tochigi and Yamagata prefectures. Several landslides were triggered that spilled onto the Joban Expressway, a major roadway stretching along the east coast of Japan and another section of the expressway lifted around 10 metres. Some 830,000 households in the Kanto region and another 90,000 in the Tohoku region were left without power following the earthquake.										
2021	14	FEB	09:04	57.03N	1.84E	9	3.1			CENTRAL NORTH SEA
2021	03	MAR	10:16	39.76N	22.18E	10			6.3	THESSALY, GREECE
At least 100 buildings, including several churches, seriously damaged in the Thessaly region. Felt throughout Greece and also in Albania, Turkey, North Macedonia, Bulgaria, Montenegro, Kosovo, Serbia, Croatia, Bosnia & Herzegovina and Italy.										

			Time			Dep	Magnitude			
Year	Day	Mon	UTC	Lat	Lon	km	ML	Mb	Mw	Location
2021	04	MAR	13:27	37.56S	179.44E	20			7.3	OFFSHORE NEW ZEALAND
A small tsunami was generated with a maximum wave height of 28 cm, measured at East Cape, New Zealand.										
2021	04	MAR	17:41	29.68S	177.84W	43			7.4	KERMADEC ISLANDS
A small tsunami was generated with a maximum wave height of 31 cm, measured on Raoul Island, Kermadec Islands										
2021	04	MAR	19:28	29.72S	177.28W	28			8.1	KERMADEC ISLANDS
Some damage to buildings and landslides occurred on Raoul Island. A tsunami was generated with wave heights of 35-40 cm measured at Gisborne, 15-20 cm measured on Great Barrier Island and 70 cm measured on Norfolk Island, Australia.										
2021	08	MAR	17:35	56.11N	2.29W	5	1.8			CENTRAL NORTH SEA
2021	16	MAR	18:38	54.70N	163.21E	22			6.6	KAMCHATKA PENINSULA
2021	17	MAR	23:56	52.19N	2.18E	10	1.9			SOUTHERN NORTH SEA
2021	18	MAR	00:04	36.92N	5.20E	8			6.0	NORTHERN ALGERIA
Damaged occurred in 12 provinces in northern Algeria with at least 17 people injured.										
2021	20	MAR	09:09	38.48N	141.61E	54			7.0	OFFSHORE HONSHU, JAPAN
2021	29	MAR	04:23	56.28N	3.76W	7	1.1			BLACKFORD,PERTH & KINROSS
Felt Blackford (3 EMS).										
2021	30	MAR	06:57	52.87N	0.26W	7	1.8			GOSBERTON, LINCOLNSHIRE
Felt Gosberton (2 EMS).										
2021	31	MAR	00:05	56.60N	10.47W	34	2.0			NORTH ATLANTIC OCEAN
2021	31	MAR	02:47	56.61N	10.45W	34	2.3			NORTH ATLANTIC OCEAN

Forthcoming Events

Evening Lectures

Annual General Meeting 2021

28 April 2021 (5:15 pm) , online event

Agenda

All SECED members are invited to attend the Annual General Meeting (AGM) of the Society. Non-members are also welcome to attend, but will have no voting rights. A full agenda will be distributed to all SECED members (via email). The agenda is as follows.

APOLOGIES FOR ABSENCE

MINUTES OF THE AGM 2020
To confirm the Minutes of the Annual General Meeting of 29 April 2020.

MATTERS ARISING
CHAIRMAN'S ANNUAL REPORT 2020/21
Stavroula Kontoe to report.
TREASURER'S REPORT AND MEMBERSHIP FEES
Barnali Ghosh to report.
RESOLUTIONS
ELECTION TO THE COMMITTEE
Results of nominations/elections to be reported.
ANY OTHER BUSINESS
DATE OF NEXT MEETING

Wednesday 27 April 2022 at the Institution of Civil Engineers.

Any resolutions duly supported by not less than five members of the Society and notified to the Secretary not less than seven days before the date of the Annual General Meeting shall be dealt with at the meeting.

The SECED AGM is preceded by the EEFIT AGM at 5pm and followed by the evening meeting, The significance of liquefaction in earthquake disasters, at 6.30pm.

Nominations

This year two candidates have been nominated for one vacancy among the elected members on the Committee. An election has been called to select one of the two candidates. All members should have received via email a ballot form with the names of the candidates and their biographical details. The ballot forms should be returned to the SECED Secretary (seced@ice.org.uk) by Tuesday 27 April 2021 before 4.30pm. Ballot forms received after this deadline will not be counted. If you are a member of SECED – either an individual member or a nominated representative of a corporate member – and you have not received the ballot form, please contact the SECED Secretary and request a form.

Further information

This AGM will be chaired by Stavroula Kontoe (Imperial College). The meeting will take place online via Microsoft Teams.

The significance of liquefaction in earthquake disasters

Robert Muir-Wood

28 April 2021 (6:30 pm) , online event

Synopsis

The importance of liquefaction as a principal agent of fatalities and destruction in earthquake disasters has had to be re-considered following two recent earthquakes: the February 22nd 2011 Christchurch earthquake and the September 28th 2018 Sulawesi earthquake. In the former, more than half the damage has been attributed to the consequences of extreme liquefaction, while in the suburbs of Palu, well over half the total fatalities were the consequence of liquefaction-driven low-angle landslides. We now fully appreciate how liquefaction is a separate damage mechanism to earthquake vibration. These examples of extreme liquefaction, flooding streets and ripping buildings apart, demand their own name: 'ultra-liquefaction'. This experience opens up a series of research questions. It allows us to go back into historical accounts of earthquakes and find evidence for comparable ultra-liquefaction, swallowing up people and buildings. It also helps us understand how attempts to create earthquake intensity scales struggled to include the impacts of liquefaction. If half of the damage or fatalities can be driven by liquefaction what does that tell us around the priorities in modelling earthquake impacts? Where else can we anticipate comparable disasters, and what actions can we take to highlight the risks ultra-liquefaction brings to life and property?

Dr Robert Muir-Wood

After a first class degree in Natural Sciences and a PhD in Earth Sciences from the University of Cambridge, Robert Muir-Wood has worked on the development of methodologies for catastrophe impacts, originally focused on earthquakes. His 1993 paper (with Geof King), 'Hydrological Signatures of Earthquake Strain' has 475 citations, while his 2000 paper on 'Deglaciation Seismotectonics' has 127 citations. He has been head of research at Risk Management Solutions since 2003 with a mission to explore new applications for catastrophe modelling and develop models for new areas of risk. He has been technical lead on a number of Catastrophe risk securitizations, was Lead Author for the 2007 4th IPCC Assessment Report and for the 2011 IPCC 'Special Report on Extremes'. He has written scientific papers on earthquake, flood and windstorm perils and published more than 200 articles. His latest book, 'The Cure for Catastrophe – How we can stop manufacturing natural disasters', was published in 2016, receiving positive reviews in the New York Times, Science, and Nature. He is Chair of the OECD High Level Advisory Board of the International Network on Financial Management of Large Catastrophes, and a Visiting Professor at the Institute for Risk and Disaster Reduction, University College, London.

Further Information

This evening meeting will be chaired by Chris Browitt (ABConsulting). Non-members of the society are welcome to attend. Attendance at the meeting is free. The meeting will take place online via Microsoft Teams.

National Seismic maps for the UK

Ilaria Mosca

26 May 2021 (6:00 pm) , online event

Synopsis

The British Geological Survey published the 2020 national seismic hazard maps for the UK in November 2020 to update the previous maps published in 2007. The work was partly funded by the Institution of Civil Engineers, and the sub-committee B/525/8 of the British Standards Institution provided the overall guidance on the design requirements for the seismic hazard maps and regularly reviewed its progress.

Two factors prompted the revision of the hazard maps for the UK. Firstly, since 2007, there have been significant advances in the methodology for seismic hazard analysis, particularly with respect to how ground motion and its uncertainties are modelled. Secondly, updated UK seismic hazard maps will be needed for use with the National Annexes for the revised edition of Eurocode 8: Earthquake resistant design of structures, which is expected to be published in 2025.

The 2020 national seismic hazard model accounts for: 1) the updated earthquake catalogue for the British Isles; 2) a thorough assessment of the catalogue analysis and the seismic source model, including the earthquake recurrence statistics; 3) the validation of the source model against the observed seismicity; and 4) advances in the ground motion modelling, including the host-to-target adjustments for the ground motion prediction equations used in the ground motion characterisation model. The national hazard maps cover the region between 49°N – 61°N and 8.5°W – 2°E and show peak ground acceleration and spectral acceleration at 0.2 s and 1.0 s for 5% damping on rock site conditions and for return periods of 95, 475, 1100 and 2475 years. The results confirm that seismic hazard is generally low in the UK and slightly increases in areas like Wales and north central England due to the higher rates of historical earthquake activity in these regions.

This talk presents the individual components of the 2020 national seismic hazard model, including the seismic hazard maps, how they compare with previous studies, and seismic hazard results for UK.

Dr Ilaria Mosca

Dr Ilaria Mosca is a seismic hazard researcher in the seismology team of the British Geological Survey. She holds a PhD. in seismology from the University of Utrecht (the Netherlands) mapping seismic and thermo-chemical variations in the lower mantle using Monte Carlo approaches. After a PDRA in seismic tomography in Germany, since 2013 she has been working for BGS. Her work with BGS is on probabilistic seismic hazard analysis in terms of software and scientific developments, including catalogue analysis, ground motion modelling, and assessing realistic uncertainties for the various components of the hazard analysis, in the UK and worldwide.

Further Information

This evening meeting is chaired by David Hawthorn (BGS). Non-members of the society are welcome to attend. Attendance at the meeting is free. The meeting will take place online via Microsoft Teams.

For up-to-date details and further information on events organised by SECED,
visit the SECED website or contact Shelly-Ann Russell (020 7665 2147, societyevents@ice.org.uk)

SECED

SECED, The Society for Earthquake and Civil Engineering Dynamics, is the UK national section of the International and European Associations for Earthquake Engineering and is an Associated Society of the Institution of Civil Engineers. It is also sponsored by the Institution of Mechanical Engineers, the Institution of Structural Engineers, and the Geological Society. The Society is also closely associated with the UK Earthquake Engineering Field Investigation Team. The objective of the Society is to promote co-operation in the advancement of knowledge in the fields of earthquake engineering and civil engineering dynamics including blast, impact and other vibration problems.

For further information please contact the SECED Secretary at the Institution of Civil Engineers.

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