Bulletin of the New Zealand Society for Earthquake Engineering, Vol. 50, No. 2, June 2017

THE 2016 M_W7.8 KAIKŌURA EARTHQUAKE: AN INTRODUCTION

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(Submitted *March 2017*; Reviewed *April 2017*; Accepted *May 2017*)

SUMMARY

The 2016 Mw7.8 Kaikōura earthquake struck the north-eastern region of the South Island of New Zealand on November 13th 11:02 (UTM). The damaging earthquake generated extreme surface displacements, land deformations and surface ground motions (Figure 1), as well as a regional tsunami and triggered major slow slip events on the Hikurangi subduction zone interface. This special issue of the Bulletin for the New Zealand Society for Earthquake Engineering presents a compilation of papers focussing on reconnaissance observations and preliminary analysis of a range of extensive datasets collected following the Kaikōura earthquake.

The Kaikōura earthquake occurred in a complex tectonic regime characterized by the Hikurangi subduction zone to the north and the transform region to the south marked by the Alpine fault, a major tectonic feature in central South Island. The earthquake involved many shallow crustal fault segments that belong to the dominantly strike slip region of Marlborough and the compressional fault system of North Canterbury. It ruptured (up to) the surface over a distance of 150 km, initiating onshore and extending offshore. Geologists have recorded extreme rupture displacements, including vertical motions of more than 10 m and horizontal displacements over 11 m. Geodetic, geological and marine geophysics data suggest that more than 13 major faults were involved in the earthquake rupture [1]. Stirling et al. [2] summarise the mapping of the faults that ruptured during the Kaikōura earthquake, and provides an overview of the impact of these fault ruptures on the built environment.

GeoNet's extensive strong motion and broadband networks captured ground motion across the country (www.geonet.org.nz). Kinematic source modelling using near-source stations suggest the earthquake ruptured more or less continuously along multiple segments from south to north and went on for more than 90 seconds. This is also supported by back-projection of regional data and detailed 3D wavefield simulations using the multiple-fault source model combined with New Zealand's 3D velocity and attenuation models [3, 4]. At this stage, kinematic models do not indicate a significant contribution of the subduction interface in the rupture process, but a smaller subduction interface component remains possible. The dominant energy release actually occurred in the northern part of the rupture area, between the KEKS and SEDS strong motion stations, around ~60-70 s after rupture initiation. Regardless, direct impact from the earthquake onto the interface is not negligible. The Kaikōura earthquake was followed not only by regional aftershock triggering, with over 8,000 aftershocks recorded up until April 2017 (Figure 1), but also widespread triggering of seismicity, especially throughout the North Island, and unprecedented slow slip events on the Hikurangi subduction zone. The impact of the slow slip events on aftershock forecasts and future behaviour of the subduction interface is currently being assessed.

The earthquake was felt widely across whole of New Zealand and especially strongly in towns closest to the rupture, including Waiau, Ward and Seddon as well as in larger towns in the region including Kaikōura, Hanmer Springs, Blenheim and Wellington. An overview of the ground motion across the country is summarised in Bradley et al. [7]. The epicentre was located about 100 km north of Christchurch but the rupture extended 200 km further north and appears to have stopped about 50 km south of Wellington [3]. GeoNet stations recorded extreme ground motions of over 1 g at both ends of the rupture in Waiau, Ward and Kekerengu, and ground motions exceeding design levels across a range of spectral periods in the Wellington region. The influence of site effects on the ground motion characteristics in Wellington is the focus of the Bradley et al. [8] paper.

GNS estimates that 80,000 to 100,000 landslides were triggered by the earthquake and subsequent aftershocks, with 50 of them yielded significant landslide dams (lakes & ponds). Dellow et al. [9] provide an initial overview of the development of the landslide and landslide dam database that continues to be collated. The earthquake triggered liquefaction throughout the north eastern region of the South Island, the extent and severity of which is summarised in Stringer et al. [10]. The amplified ground motions in Wellington also resulted in liquefaction related impacts. Orense et al. [11] provide a reconnaissance summary of the relatively minor impacts or good performance of the ground along the Wellington Waterfront, while Cubrinovski et al. [12] present a summary of the severe liquefaction induced damage at CentrePort in Wellington.

Henry et al. [13] summarise the building damage in Wellington City; at some locations the demands on concrete moment frame buildings of 5-15 storeys, in a period range of 1-2 s exceeded design levels leading to varying degrees of beam hinging, beam elongation and damage to floors diaphragms. Baird and Ferner [14] documented the damage to non-structural elements in Wellington commercial buildings; in particular damage to the following: suspended ceilings, suspended services, glazing, precast panels, internal linings, seismic gaps and contents, including the effectiveness of seismic bracing.

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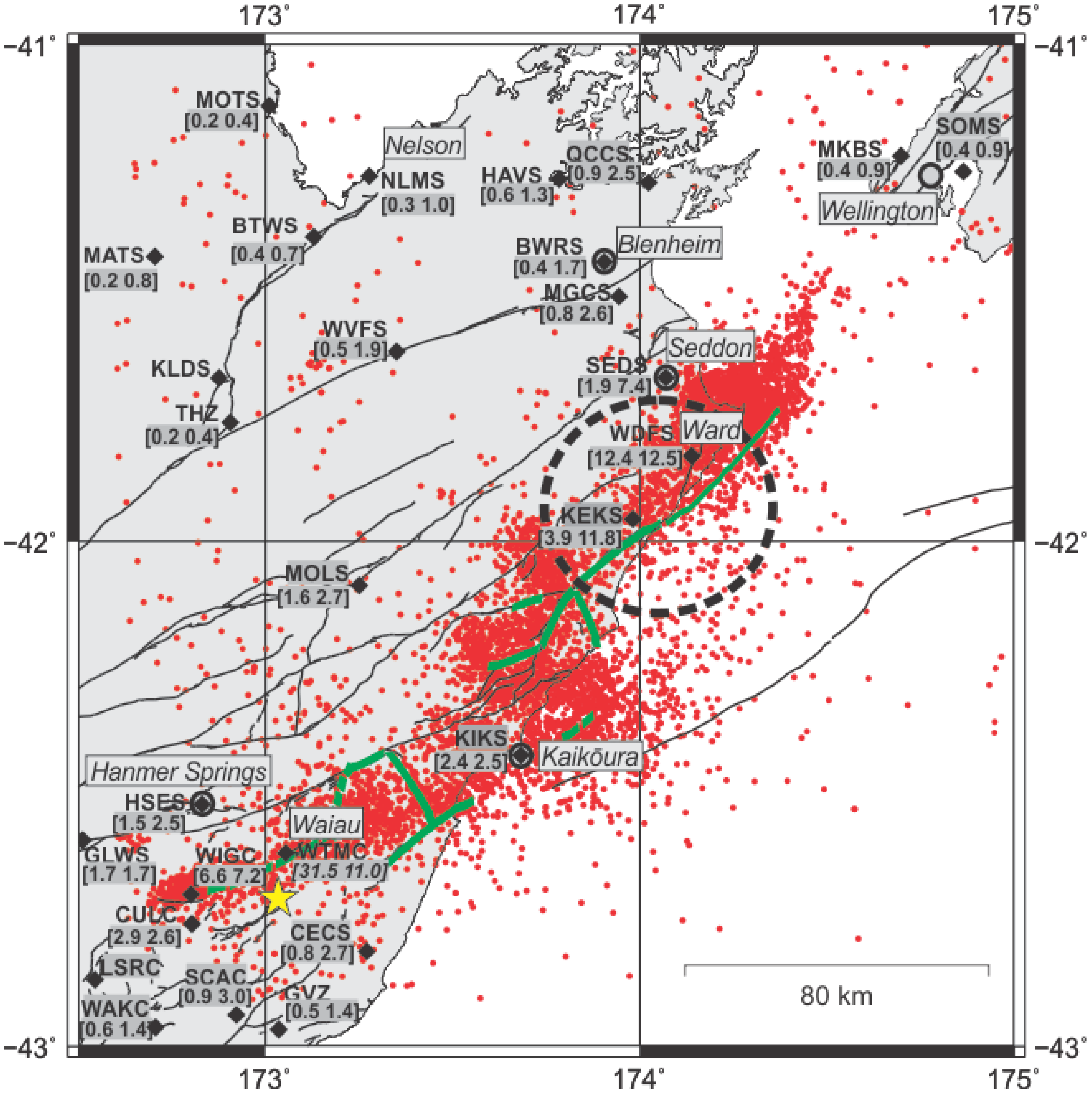

Figure 1: The Mw7.8 Kaikōura earthquake: hypocentre location (yellow star), aftershock locations (M2.5+) up until April 2017 (red dots), inferred coseismic surface fault ruptures (green lines) from Stirling et al. [2] and GeoNet strong-motion stations (with associated peak accelerations [vertical horizontal] in m/s/s). The dashed line circles the area that released the most energy during the earthquake [1, 3-6]; Note that the vertical value of over 3g recorded at station WTMC has unusual characteristics which warrant further investigation, as discussed in Kaiser et al. [3]. For clarity not all GeoNet stations are represented on this figure for Nelson, Blenheim and Wellington. In particular, refer to Bradley et al. [8] for more detailed on ground motion in Wellington.

In the South Island, as reported in Dizhur et al. [15] seismically retrofitted stone and clay brick masonry buildings and cob cottages exhibited good performance, while some vintage concrete structures and partially strengthened cob cottages suffered moderate to extensive levels of damage. Buchanan and Moroder [17] showed that log houses in the area of Mt Lyford performed very well considering the proximity to fault ruptures and very few were damaged beyond repair. The post-earthquake performance observations of winery facilities in the Marlborough region, New Zealand, are documented in Dizhur et al [16]. The damage greatly varies from site to site and includes land damage to vineyards and the performance of winery infrastructure (tanks, catwalks, barrel racks, sheds).

The building stock in Wellington and South Island had different variety of damage which was triggered by a combination of different demand and construction typologies. A number of buildings were instrumented with accelerometers as part of GeoNet's Building Instrumentation Programme (www.geonet.org.nz). The recorded response of a range of building typologies and site classes are presented in Chandramohan et al. [18].

The Kaikōura earthquake impacted a wide region of New Zealand, affecting a range of distributed infrastructure networks and multiple providers. Electricity distribution, telecommunications and 3 waters networks were affected across the lower North and upper South Islands, with extended outages in the region of the most intense shaking. The most significant impact of this event was the damage to the transportation infrastructure, including road, rail and seaports. Palermo et al. [19] provide a summary of the performance of the bridges across the upper South Island, highlighting the good overall robustness of the bridge stock. Davies et al. [20] discuss the significant impact to transportation networks, particularly road and rail, over the first 100 days following the Kaikōura earthquake. Liu et al. [21] highlight the good performance of electric power networks in the upper South Island from transmission through to distribution. Hughes et al. [22] summarise preliminary observations for the damage and performance of the three waters networks in Wellington, Marlborough and Kaikōura. Giovinazzi et al. [23] present an overview of the physical and functional performance of the telecommunication network, highlighting the strong collaboration across the telecommunication industry following this event.

The final set of papers in this special issue focus on the initial learnings around governance, economic and societal aspects of the earthquake impacts and the response. Woods et al. [24] provide a review of the coordination of the science response across New Zealand research institutions and the interface with emergency management structures. Brunsdon et al. [25] summarise the initial engineering response in Wellington and the development of the process for building assessment in the absence of a declared state of emergency. Stevenson et al. [26] present an initial reconnaissance level overview of the economic and social impacts of the Kaikōura earthquake. Finally, Goded et al. [27] provide a comparative analysis of macroseismic intensities (MMI) for the Kaikōura earthquake derived from detailed online questionnaires and newly implemented "Rapid" GeoNet online questionnaire. Robust MMI interpretations are also very important to enhance the extensive dataset of recorded ground motions.

Recent New Zealand earthquakes have brought new observations and understanding of seismic hazard and the impact of earthquakes on our natural and built environment. The Mw7.1 2010 Darfield multi-fault rupture earthquake brought attention to directivity effects, liquefaction impact and the societal impact of aftershock sequences. The ML6.3 2011 Christchurch earthquake showed the destructive power of a shallow earthquake in close vicinity to an urban area, leading to severe building damage and loss of life. This earthquake generated strong vertical motions, triggered extensive rockfalls, landslides and cliff collapses and triggered extensive liquefaction. The 2013 Mw6.6 and Mw6.5 Seddon and Lake Grassmere earthquakes impacted industry in Marlborough and tested Wellington's infrastructure along the waterfront, particularly non-structural elements and stairways. As summarised here the 2016 Mw7.8 Kaikōura earthquake has impacted a large region of New Zealand, with significant land damage through multiple surface faults ruptures, coastal uplift, landslides and liquefaction. The built environment was affected over a 200 km long region and has highlighted the need for further research across the range of disciplines that these special issue papers cover, from seismology through to the socio-economic impacts on society.

We would like to thank the authors who pulled together a number of excellent papers in a very short timeframe, and the reviewers and stakeholders who gave up their valuable time in an effort to publish this issue as soon as possible after the Kaikōura earthquake.

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