Observations from the 28th April 2007 Kent (Folkestone) Earthquake and Implications for EMS-98 Intensity Evaluation

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KEY WORDS

Folkestone earthquake, Building damage, EMS-98, Intensity evaluation

1.0 INTRODUCTION

On Saturday April 28, 2007 an earthquake of magnitude Mw 4.0 (BGS) shook the county of Kent, United Kingdom. The earthquake was the most damaging event to have occurred in the UK since the 1957 East Midlands earthquake. It mainly caused damage to houses in the town of Folkestone, where five roads were evacuated due to damage after the event and one person was injured. Following the event the authors visited Folkestone to observe the damage caused by the earthquake. This paper summarises the authors' observations and resulting assessed intensities. Discrepancies are seen between these values and the EMS-98 Intensities (Grünthal G. ed, 1998) assigned by the British Geological Survey (BGS, 2007). These are discussed and recommendations are made for the modification of the BGS Intensity assignment and of the masonry damage scale within the EMS-98 Intensity scale.

2.0 THE EARTHQUAKE

The Kent (Folkestone) Earthquake occurred at 08:18 GMT on the 28th April 2007. It's epicentre, initially thought to be offshore of Kent, has recently been determined to be adjacent to the town of Folkestone, at 51.08°N 1.17°E (Figure 1). This is consistent with the observed damage, which is concentrated in a small area of Folkestone. The earthquake was shallow, with hypocentre at 2km depth (BGS, 2007), fault rupture length of approximately 0.6km and a displacement of 3cm (Ottemöller, 2007). The earthquake has been attributed a moment magnitude of M_w 4.0 and local magnitude M_L 4.2.

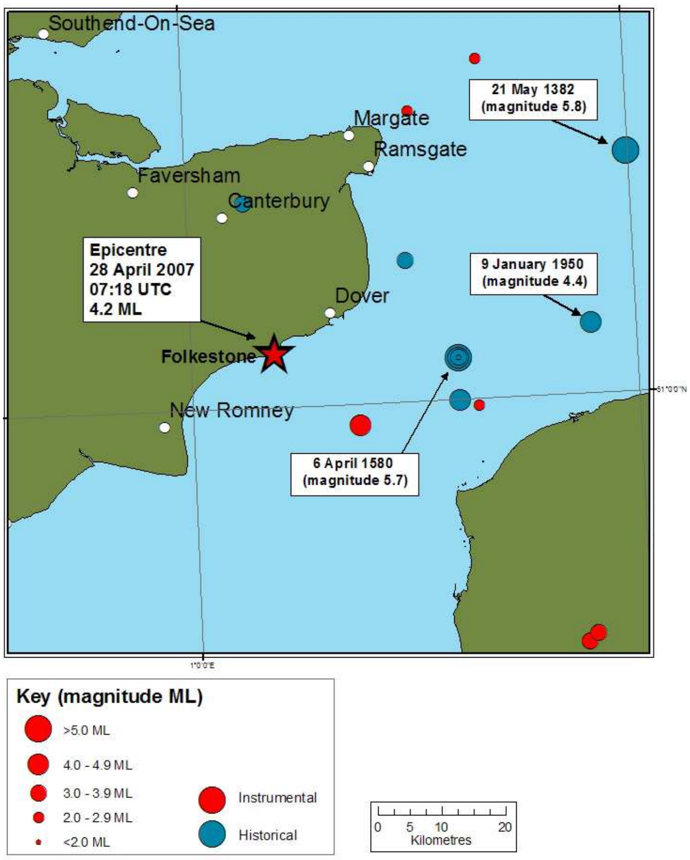

Figure 1: Map of the epicentre of the April 28, 2007 Folkestone earthquake, and other earthquakes with magnitude(M_L) greater than 2 occurring in Kent and the Dover straits (BGS, 2007).

The earthquake is reported to have been felt throughout Kent (BGS, 2007 see Figure 18) and is the most damaging earthquake in the UK since the 1957 East Midlands Earthquake (Neilson et al. 1984). Recordings of the event show a duration of about 2.5s and a horizontal peak ground acceleration (pga) of approximately 0.1g, which is the largest recorded pga for an earthquake in the UK (Musson and Walker 2007).

3.0 DAMAGE OBSERVATIONS

Early reports from Shepway Council revealed that damage had occurred to buildings in Folkestone and that one person had been injured in the earthquake. On hearing news of the earthquake, the authors carried out walk-over surveys of Folkestone on the 28th April and on the 1st May 2007, covering the areas shown with red markers on Figure 2.

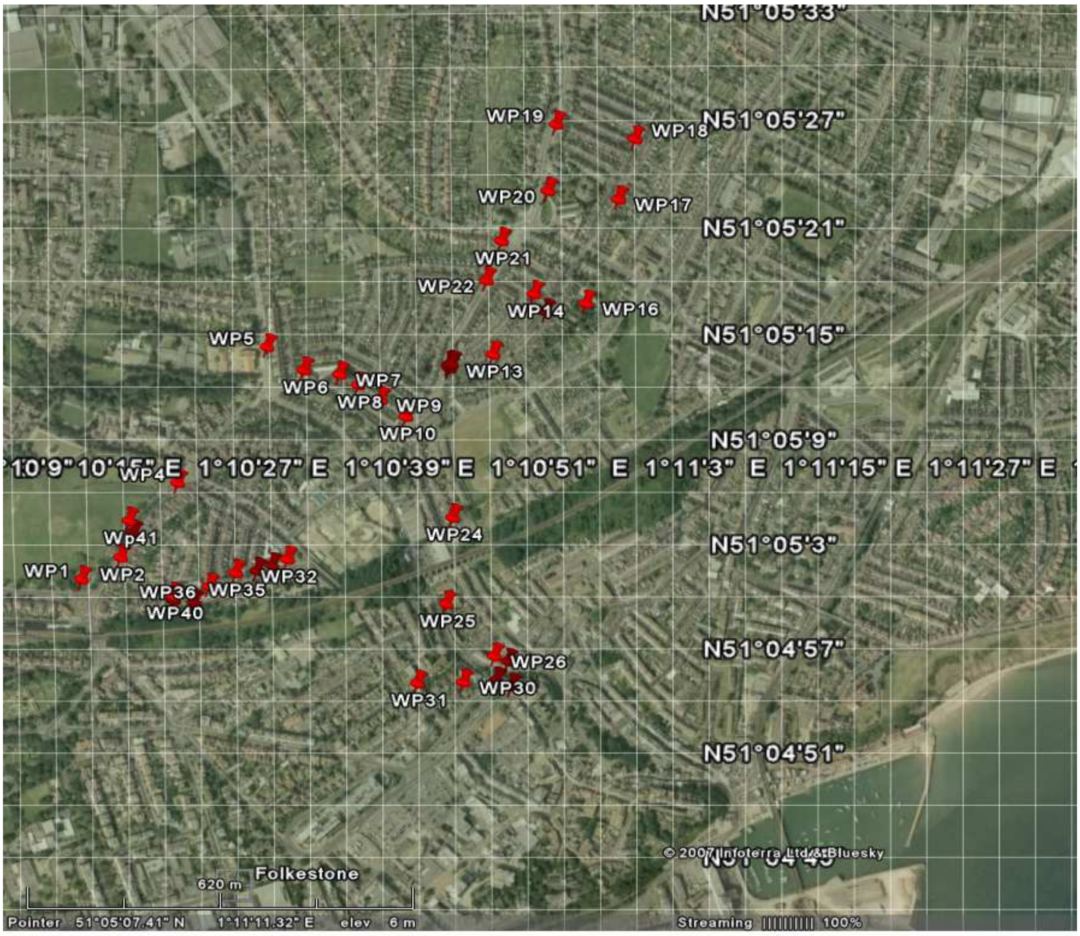

Figure 2: Map of the locations in Folkestone visited by the authors during the walk-over surveys of the 28th April and 1st May 2007, following the Folkestone Earthquake (Base map from Google Earth).

The walk-over surveys revealed the damage to be concentrated over a localised area in the north of Folkestone. Affected houses were predominantly Victorian red-brick masonry houses with timber joist floors, pitched roofs and brick masonry chimneys. The houses ranged between two- and three-storeys in height (above ground), some also having basements. These were mainly built for housing workers and have not been well-maintained.

By far the most common form of damage observed was chimney damage ranging from moderate to partial collapse. In most roads chimney damage was observed in 10-20% of buildings (e.g. in Black Bull Road), however in some roads (e.g. northern end of Marshall Street, Broadmead Road) this damage rate rose to 60-70% (see Figure 7). The pattern of failure of chimneys presented no particular orientation, thus not giving insight into directivity of ground shaking.

The chimneys consist of brick stacks on which multiple cylindrical clay chimney pots are mounted with mortar (see Figures 3). The heavy clay chimney pots were commonly seen to dislodge during the ground shaking, often together with bricks in the chimney stacks. Some chimneys were observed to be damaged more than others despite being of similar type and in close proximity (see Figures 4, 5 and 6). It is interesting to note that in Figure 6 the newer and more slender chimney on the left suffered no damage to the stack.

The majority of damage seemed to occur in chimneys that had not been maintained and had lost mortar or had suffered some sulphur intrusion. However, this was not always true. Some chimneys that had been re-pointed with cement mortar, which tends to be less flexible than the original lime-mortar, were also seen to be damaged.

Figure 3: Examples of typical clay chimney pots (left) and the mortar build-up for chimney pots (right).

Figure 4: Similar chimneys damaged to different extents at two ends of same building on Black Bull Road.

The failure of chimneys was also seen to cause secondary damage to roofs. In most cases this was limited to the removal of roof tiles (commonly seen in the lea of falling chimney pots) and in rare cases damage to the roof structure (Figure 5).

Figure 5: Park Farm Road. Chimney damage causing secondary damage to the roof.

Figure 6: Damage to end of gable-end wall on Black Bull Road (left). No damage observed in the newly rebuilt gable and chimney in Foord Road (right).

Figure 7: Marshall Street. View of scaffolding. Damage to these houses was in the form of non-structural chimney damage as seen in the picture on the right.

Other non-structural damage observed was damage to a gable-end wall in Black Bull Road and the cracking of plaster in some houses. The authors were able to visit the interior of a house in Linden road where minor cracking of plaster was observed. Cracking was mainly seen to occur along joints of ceiling plaster board panels. Diagonal cracking of plaster was also observed to occur above door frames (see Figure 8). This damage will only require minor cosmetic repair.

Figure: 8. Examples of hairline cracks in plaster observed within a house on Linden Road (right). External view of the property (left).

Some light structural damage was seen in a very few locations, mainly on Radnor Park Road (Figure 9) and Broadmead Road (Figure 10 and 12). Here, buildings were observed to have suffered some vertical cracking of walls and lintels. It is interesting that this observation differs from the damage reports given by the news which seem to relate the worst affected areas as being Black Bull road, Marshal Road and Linden gardens where more spectacular chimney failures occurred.

Figure 9: Light structural damage in a house on Radnor Park Road. First floor window sill is tilted, structural vertical crack to door, crack in ground floor lintel, detachment of wooden portico and significant chimney damage.

Figure 10: Broadmead Road. Structural cracking and cracking of render in the façade of a three storey house.

Figure 11: Broadmead Road. Vertical cracks in lintels, window sill and wall.

Figure 12: Broadmead Road. Large crack in the external wall of a house.

In interpreting structural damage to houses in Folkestone, care must be taken to consider their history and the possible presence of existing damage. Folkestone was subjected to bombing in the Second World War and although further investigation is required, it may be that some of the structural cracking may first have occurred during this era, and was aggravated by the earthquake ground shaking. Knowledge of local history proved important when surveying the only school damaged by the earthquake, Harvey Grammar School. This school is located about 2km west of the main areas of damage (at Waypoint 42 on Figure 13). The school was built in 1912 to have symmetrical facades. During WWII the western façade was bombed and later rebuilt in 1945. The “plane of weakness” locally created between the old school building and the newer façade partially explains why this particular section suffered cracking along its height at its connection with the old building. Cracking was also observed in the ceilings of two classrooms on the second floor adjoining this façade.

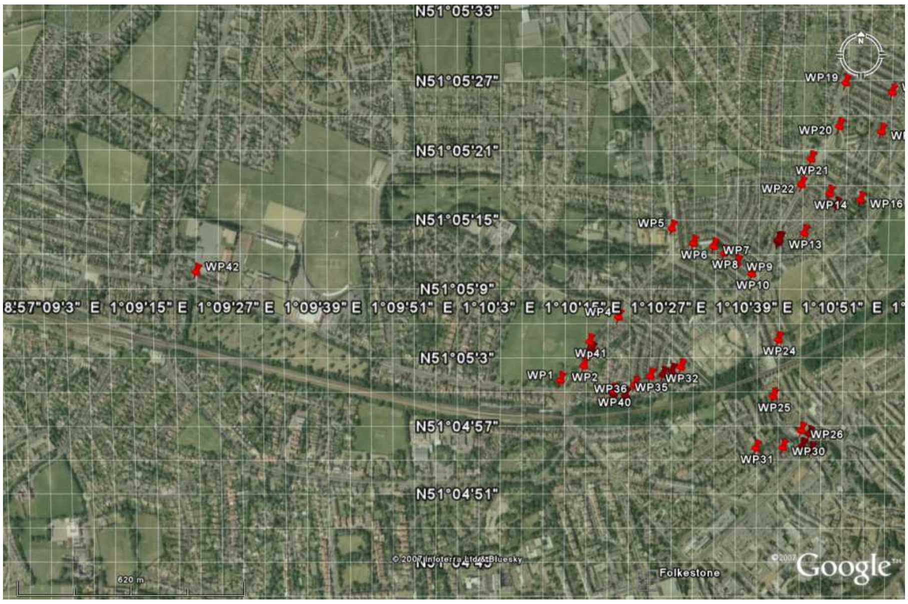

Figure 13: Extended map of the locations in Folkestone visited by the authors during the walk-over surveys of the 28th April and 1st May 2007, showing the location of Harvey Grammar school.

Figure 14: Picture of eastern side of Harvey Grammar School, showing damaged façade. Photo care of Neena Saith and Torolf Hamm of Risk Management Solutions.

Figure 15: Cracks in western façade of Harvey Grammar School. Photos care of Neena Saith and Torolf Hamm of Risk Management Solutions.

The only case of Moderate damage was observed in the building adjoining Grace Independent Baptist Church and School on Grace Hill. This building was cordoned off and condemned as it was reported to have suffered severe internal damage. A vertical crack was observed along the front of the building. Some possible torsion of the building was observed, although its severity was difficult to determine from rapid visual inspection. The authors consider this building to be particularly susceptible to earthquake damage due to its irregularity in elevation and location, (i.e. it is built on a slope so that the front is 3 storeys and the back is 4 storeys high, see Figure 16).

Figure 16: Moderately damaged building on Grace Hill.

No recently constructed masonry buildings were seen to be damaged by the earthquake as illustrated in Figure 17. This is to be expected in a small earthquake and highlights the importance of good construction and maintenance in helping resist strong ground-shaking.

Figure 17: Examples of modern brick buildings with no damage. (left: building located at the junction of Park Farm road and Pavilion road, right: Pavilion Road).

4.0 INTENSITY ASSIGNMENT

Current data from Shepway Council reports that up to 2500 buildings were damaged to some degree during the earthquake, the vast majority having damage to chimneys (data as of 26th July 2006, Nick Lewington, Building Control, Shepway Council). 300 of these buildings required immediate intervention to secure the chimneys. However, no buildings had to be demolished following the earthquake and only one building was found unsafe for immediate habitation.

The walkover survey revealed that most earthquake building damage in Folkestone could be classified as Grade 1 on the European Macroseismic Scale (EMS-98, Grunthall 1998) damage scale for masonry. This corresponds to no structural damage and slight non-structural damage, described by the Scale to consist of hair-line cracks in very few walls, fall of small pieces of plaster only, fall of loose stones from upper parts of buildings in very few cases.

Assigning EMS-98 masonry building damage grade 2 to some buildings in Folkestone requires more judgement from the assessor. Grade 2 damage is defined as slight structural damage with moderate non-structural damage. This is described to consist of cracks in many walls, fall of fairly large pieces of plaster and partial collapse of chimneys. Whilst the partial collapse of chimneys certainly occurred extensively in Folkestone, the criteria of structural cracks in many walls was not observed except for in a small number of properties on Broadmead Road and Radnor Park Road. However, even this damage would be at the lower bound of grade 2.

Based on the definitions of the EMS-98 vulnerability table (Grunthall, 1998), old (circa early 1900s) UK brick masonry houses with timber joist floors and a relatively poor maintenance regime, would fall approximately into the EMS-98 vulnerability class category B.

The part of the definition for EMS-98 Intensity class VI that refers to building damage is defined as (Grunthall, 1998): damage of grade 1 is sustained by many buildings of vulnerability class A and B; a few of class A and B suffer damage of grade 2; a few of class C suffer damage of grade 1. In the areas visited by the Authors where it could be stated that "many" buildings of vulnerability class B suffer damage grade 1 (i.e. Radnor Park Road, Broadmead Road, Linden Crescent, Black Bull Road and Marshall Street), it was observed at best that very few suffered grade 2 and no damage to class C building was observed. These roads would therefore fall within Intensity level VI (Slightly Damaging), but again would lie at the lower bound of this intensity class. The areas immediately surrounding those stated above would fall within Intensity V (Strong), i.e. Damage to Grade 1 in a few buildings of vulnerability class A and B. This would soon attenuate to Intensity IV for the rest of Folkestone.

These observations differ with the intensity maps produced by BGS (reproduced in Figure 18), which peak at Intensity VII in central Folkestone and have wide isoseismals of Intensity VI and V extending far beyond the bounds of Folkestone. The BGS made preliminary assessments based on their online macroseismic questionnaire. However, as it is well-known that such questionnaires are unreliable for assigning large Intensity values, they also sent a team to look at the damage to verify the high levels of intensity being assigned by the questionnaire (Musson and Walker, 2007).

So why the discrepancy? This discrepancy arises from the assignment of grade 2 and 3 damage by BGS to housing in Folkestone where severe chimney damage has occurred. Essentially their interpretation of the EMS-98 Intensity damage scale is that only one element of the description of damage needs to be satisfied (i.e. damage to chimneys) to assign the level of damage. However, the general understanding in earthquake engineering is that all descriptive elements of the damage state should be satisfied in order for the damage state to be achieved. It is clearly wrong to assign intensity values based on one element only, more so if the assessment is made on the basis of a non-structural element such as a chimney. It is simple to see the problem if one thinks what the intensity assignment would be if there had been no chimneys in the affected houses. These values clearly can therefore not be used to compare the effects of the Folkestone earthquake with other European or international earthquake events, which assign EMS Intensity values based on a comprehensive satisfaction of the descriptive criteria in the damage scales.

The BGS intensity assignment would also contradict decisions in seismic hazard assessment being taken for the development of the (advisory) UK national zoning map, to be referred to in the UK National Annexe to Eurocode 8. This is because the Folkestone earthquake magnitude (M_w 4.0) places it below the minimum magnitude (M_w 4.5) value taken in the UK seismic hazard study as contributing to peak ground acceleration. The rationale for the latter threshold is that the ground motions arising from smaller magnitude events have low energy content in the frequency range of engineered structures and short duration, and are therefore unlikely to damage such structures (Booth, 2007). However by assigning an Intensity value of VII to the Folkestone event, the British Geological Survey are essentially stating that this M_w 4.0 earthquake can cause some Grade 2 and Grade 1 damage in buildings of vulnerability class C and D, respectively i.e. in engineered buildings.

In view of these arguments it is the authors' opinion that the BGS mapped intensity levels need to be decreased to values consistent with the observed building damage, as suggested herein.

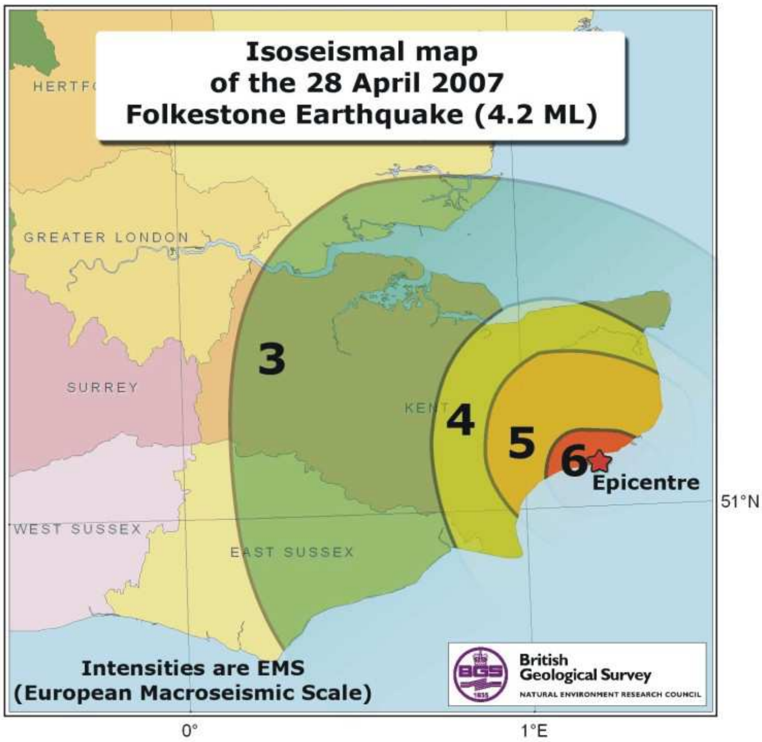

Figure 18: Intensity map produced by the British Geological Survey (http://www.earthquakes.bgs.ac.uk/macroseismics/folkestone_macro.htm).

5.0 CONCLUDING REMARKS

This paper presents damage observed by the authors to have occurred in Folkestone following the April 28, 2007 earthquake. In view of the building damage observations the authors suggest a maximum EMS-98 Intensity value of VI is assigned to Folkestone, with the understanding that this Intensity value covers a very limited area, with the rest of Folkestone being assigned Intensities V and IV. The damage observations do not support the Intensity distribution proposed by the British Geological Survey and it is highly recommended that these values be lowered to be consistent with the Intensities proposed herein. It is also recommended that the European Macro Seismic Scale (EMS-98, Grünthal, 1998), be changed such that reference to chimney damage is removed from its masonry building damage scale descriptions. Furthermore, it is suggested that explanatory text be added to state that all criteria of a damage state and Intensity level description should be satisfied in order for that state or level to be assigned.

The authors of this report also contributed to a paper (Sargeant et al, 2008) that was published on the Folkestone earthquake.

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