

1 **Football quakes as a tool for student engagement.**

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10 **Abstract**

11 In 2016 students from the Geology department at Leicester University used simple low  
12 frequency geophones and low cost seismic dataloggers set up in a primary school and local  
13 museum within Leicester city to record crowd induced vibrations from the King Power Stadium,  
14 home of Leicester City Football Club, a professional soccer team in the English Premier League.  
15 Clear signals were detected every time the home team scored a goal, which the students named  
16 “vardyquakes” on social media after the team’s star striker. After a student-led social media  
17 campaign the story was picked up by the press and turned into a viral news story, leading to  
18 hundreds of newspaper articles in papers around the world together with dozens of TV news  
19 stories and interviews with the students.

20 However the true success of this project was in finding an engaging and reliable tool for  
21 encouraging university students to participate in outreach activities with local schools. The  
22 football-quakes provided a regular, and predictable seismic signal which was easy to understand  
23 and gave the opportunity to explain to school students how seismic waves are created and can  
24 travel through the ground.

25

26 **Introduction to educational seismology**

27 Seismology, the study of seismic waves travelling through the earth, can provide a great context  
28 to help school students understand some key science concepts about the nature of waves. Great  
29 success has been had by educational programs around the world in using signals from  
30 earthquakes to help high school students in their studies of physical and earth sciences.

31 Examples include the IRIS seismographs in schools program in the USA, the Sismo a l’ecole

32 program in France, and similar school seismology projects in the UK, Ireland, Switzerland,  
33 Portugal, Romania, Australia and New Zealand (Denton 2008). The school seismology program  
34 in the UK is run by the British Geological Survey ([www.bgs.ac.uk/sfp](http://www.bgs.ac.uk/sfp)) and has had great success  
35 helping schools to set up long period horizontal pendulum seismograph stations (with a 20  
36 second natural period) . These stations are ideal for detecting P, S and Surface waves from large  
37 earthquakes around the world. Successful use of such resources in a school setting relies on a  
38 flexibility of timetabling and the ability to quickly mobilise resources to coincide with the  
39 occurrence of significant events. Initiatives like the IRIS “teachable moments” resources  
40 ([www.iris.edu/hq/retm](http://www.iris.edu/hq/retm)) help greatly with this although their effective use still relies on schools  
41 and outreach teams having flexible enough timetables. Making use of seismic signals from  
42 scheduled events within an educational context makes it much easier to plan activities and  
43 schedule school visits.

44

#### 45 **Football quakes**

46 Seismologists have long known that crowds of people moving together create seismic signals  
47 that can be detected at some distance from the event. Seismic signals recorded near large sports  
48 stadiums have been noted before, e.g. in Seattle Seahawk Football games (Vidale 2011) and  
49 more recently at Barcelona Nou Camp stadium in Spain (Jordi 2017). In exceptional  
50 circumstances seismic signals coinciding with a home team scoring a goal have been detected  
51 across an entire country, in the 2006 African Cup of Nations the Cameroon Lions scored eight  
52 goals across four matches all of which were televised live across the country. For each goal  
53 scored an associated “footquake” was detected on broadband seismometers deployed on a 32

54 station, 1200km aperture IRIS-PASSCAL temporary array (Euler et al 2007) as the whole nation  
55 danced and celebrated.

56

## 57 **Leicester City**

58 Leicester is a medium sized city in the English midlands with a population of about 300,000, a  
59 vibrant university geology department and a strong sporting tradition with a well-supported  
60 football team, Leicester City Football Club (the Foxes), who have a relatively new 32,000 seater  
61 city-centre stadium. The Foxes have historically always been a mid-ranking team in the English  
62 football leagues, never having won the top title in their 132 year history. At the start of the  
63 2015-16 football season they were distinct underdogs, the team had only just missed relegation  
64 from the top flight of English Football, the English Premier league, the previous season.  
65 Bookmakers were offering unprecedented odds of 5,000-1 against the Foxes winning the Premier  
66 League title (a title awarded over the course of a season of 38 matches played against the other  
67 top 20 clubs in English football). However with a remarkable run of wins at the start of the  
68 season, helped by a record-breaking goal scoring run by their star striker, Jamie Vardy, Leicester  
69 City were sitting at the top of the league at the season mid-point in January. At this time the  
70 British press started taking an interest in the “Leicester story” and were starting to have an  
71 increased presence at home matches. The Foxes went on to win the Premier League Cup at  
72 the end of the season in May 2016 ensuring a continual press interest in all things Leicester City  
73 football related which spilled over into the football quakes recorded by Leicester University  
74 students.

75 The British Geological Survey and Leicester University Geology department have a long record  
76 of collaboration on education and outreach programs so together decided to capitalise on this  
77 new found interest in footballing success to launch an outreach program with a city centre  
78 school. A team of 20 undergraduate student volunteers from the geology department were  
79 recruited to run the project, with the objective of installing a sensor in a city centre school,  
80 recording some football quakes during home matches and using the opportunity to talk to the  
81 school students about waves, earthquakes and university life. With such a large group of  
82 undergraduates keen to become involved, sub-teams were created with responsibilities for  
83 technical work, educational visits and social media/publicity.

84 The head teacher at Hazel Community Primary School, located 0.5km from the football stadium,  
85 (figure 1) was approached and was keen to get involved. Hazel Road is a small school with 400  
86 pupils aged 4-11 serving a relatively impoverished inner city district of multi-ethnic populations  
87 (80% of school pupils start school speaking English only as a second language). Inner city  
88 schools like this often have relatively poor records for their pupils eventually studying at  
89 university and so introducing these pupils to current undergraduates as potential role models can  
90 be a boost to pupil's personal aspirations.

91

## 92 **Data recording system.**

93 Seismic signals from local sources tend to have relatively high frequency content, previous work  
94 at rock concerts (Denton 2014, Green and Bowers 2008) suggests that a crowd of several  
95 thousand people simultaneously jumping up and down should produce a seismic signal with a  
96 peak at about 2Hz. This is a little too low for most geophones to register, however a supply of

97 obsolete 2Hz sensors (Geo-Space model HS-10 sensors from the 1970's) was rescued from the  
98 scrap heap. The digitiser and recording system used was a single channel 16 bit USB digitiser  
99 made by [www.mindsetonline.co.uk](http://www.mindsetonline.co.uk) with datalogging done on a Raspberry Pi single board  
100 computer running a variant of Linux and running the IRIS jAmaseis datalogging software as  
101 used on school seismology programs around the world. The geophone was set up in a storage  
102 shed in the school playground and connected to the school wi-fi system for real-time monitoring  
103 using the IRIS jamaseis networking options. The location of the sensor was approximately  
104 0.5km from the football stadium. During the daytime when the school was full, the signal  
105 recorded was very noisy, however football matches are always played at the weekend or in the  
106 evenings when the school is empty and background noise is quite low. A second sensor was also  
107 being monitored as part of a city museum exhibit approximately 1.1km from the stadium (figure  
108 1), however daytime visitors at the museum cause so much noise that it was only able to record  
109 usable signals during evening kick-off matches. For one match a professional quality broadband  
110 sensor (Guralp CMG-6TD) was deployed alongside the 2Hz geophone at Hazel school by the  
111 SEIS-UK instrument facility to check on calibration values.

112

### 113 **Anatomy of the seismic signals**

114 Signals were recorded at Hazel school from the last 7 home matches of the season, in which  
115 Leicester scored in every match at least once and the opposition scored in 3 of these matches  
116 (table 1). The stadium was full for each match with 29,000 home supporters and only 3,000  
117 visiting supporters so goals from visiting teams hardly registered at all on the seismic systems.  
118 Figure 2 shows the seismic record for the whole match between Leicester City and West Ham  
119 United (first half 12:30-13:15, second half 13:30-14:20). The Leicester goals at 12:48 and 14:20

120 show up clearly as double spikes, the West Ham goals at 14:09 and 14:11 show up with much  
121 smaller amplitudes, other spikes in the data correspond to near misses by Leicester or referee  
122 decisions that the home crowd disagreed with.

123 Looking at a number of the Leicester goals together the seismic signals show a remarkable  
124 similarity of character, with a double spike separated by about 40-50 seconds (figure 3). The  
125 first spike is impulsive and coincides with the goal being scored, about 40 seconds later an  
126 emergent signal appears which has very different frequency characteristics. Inspection of the  
127 spectrogram for this signal (figure 4) shows that the second peak has a distinct spectral peak at  
128 2.5 Hz. Ground truth investigations at the stadium indicate that these two peaks can be  
129 explained by analysis of the crowd behaviour. When a goal is scored the crowd immediately  
130 stand up at the same time and start cheering, this produces an impulsive seismic signal (the first  
131 peak), for the next 30-40 seconds the crowd are standing and cheering, making lots of noise but  
132 not moving about much. After 30-40 seconds the stadium public address system will announce  
133 the goal scorers name and a vocal section of the crowd begin to chant and dance, this dancing  
134 generates the harmonic 2.5Hz signal, a similar frequency signal has been noticed from crowds  
135 dancing at rock concerts, Denton (2014), Bowers (2008). However it appears that at the  
136 stadium that Leicester play at the design of the stadium (cantilevered steep tiers of seats  
137 surrounding the pitch) has a natural oscillation frequency close to this frequency and what we are  
138 measuring is the seismic signal created by the stadium resonating to the rhythmic dancing of a  
139 section of the crowd. This resonance phenomenon in sports stadia is well known and has been  
140 studied and reported on by structural engineers (Ellis et al 2000, Reynolds et al 2004, Salyards  
141 and Hanagan 2007). In the case of the Leicester City stadium local licensing regulations restrict  
142 the capacity of the crowd allowed in the stands (only the lower 17 rows can be filled with the rest

143 of the crowd on the pitch) when the stadium is used for large rock concerts and rhythmic dancing  
144 is expected, and encouraged.

145

### 146 **Amplitudes and magnitudes**

147 With seismic signals recorded on the same sensor from events occurring at a fixed distance it is a  
148 straightforward matter to rank the magnitude of events and identify which one is largest. For  
149 the seismic signals recorded at Hazel school the results indicated that the largest seismic signals  
150 when the goals scored were the most important, and also the most unexpected. The largest  
151 signal was from a goal scored in the last minute of a 1-0 match against Norwich city (table 1).  
152 Goals scored in open play tended to give higher amplitude signals than those from penalties (the  
153 crowd are already standing up when the penalty is taken so you get a less intense impulse when  
154 the goal is scored)

155 Although the seismic signal from a crowd induced event is very different to that produced by an  
156 earthquake it is sometimes useful to make a comparison between the amplitudes of the vibrations  
157 recorded with the amplitudes of vibrations that would have been recorded if an earthquake had  
158 occurred at the same location. This allows seismologists to assign discrete seismic events with  
159 an equivalent earthquake magnitude, such calculations have often been used for assigning  
160 magnitudes to explosive events (Booth 2009). Being able to associate an equivalent earthquake  
161 magnitude to each individual foot-quake event also greatly increases the press appeal of the  
162 subject. Rigorous calculation of event magnitudes rely on being able to convert recorded  
163 signals into true ground displacement signals and applying an appropriate magnitude formula.  
164 Unfortunately the low-cost and reclaimed equipment used in this experiment was not provided



165 with precise transfer functions or even accurate sensitivities. A more empirical approach was  
166 called for. Fortunately on the 6<sup>th</sup> March the Hazel school seismograph recorded the seismic  
167 signal from a small local earthquake which occurred in the middle of the night near Oxford, 102  
168 km away. The British Geological Survey national seismic network registered this event and  
169 assigned it a local earthquake magnitude value  $M_l=2.3$  using their modified local earthquake  
170 magnitude formula (Booth 2007). By making use of this event and a simplified form of the same  
171 BGS local earthquake as a calibration event it was possible to make an empirical estimate for the  
172 sensitivity of the Hazel school seismograph system and make an equivalent magnitude estimate  
173 for the largest event recorded, the last minute goal by Ulloa against Norwich City which  
174 registered as the same amplitude as a  $M_l 0.3$  event occurring in the stadium.

175

## 176 **Media Interest**

177 As soon as the outreach program began the undergraduate team involved in media started a  
178 social media campaign based around Twitter with a @VardyQuake account posting images and  
179 information about each match as it happened. The idea of their local team causing mini  
180 earthquakes raised some interest in the local newspapers. The press office from Leicester  
181 University put out a press release about the project which was picked up by the Associated Press  
182 news agency and the story became a global viral hit. The story was tracked on over 340 news  
183 outlets worldwide including 50 broadcast outlets, both TV and radio (fig 5) in over 50 countries  
184 around the world (figure 6).

## 185 **Educational outreach**

186 During the spring term of 2016 a team of undergraduate students from Leicester University  
187 Geology department made visits to Hazel road primary school and ran education sessions for the  
188 pupils there. They talked about how the seismic waves had travelled from the stadium to the  
189 school, using slinkies as visual aids, and making comparisons and contrasts with sound waves  
190 through the air which the school pupils had been studying in their curriculum. However the  
191 most valuable part of this interaction for the undergraduates was gaining experience of talking  
192 about their science and for the school pupils it was being being exposed to potential role models  
193 for a future life in higher education.

#### 194 **Conclusion**

195 Football matches provide seismologists with a regular scheduled event which can produce  
196 seismic signals capable of being measured with simple seismic monitoring systems up to a mile  
197 from the stadium (assuming that the home team score a goal during the match). This enables  
198 university outreach programs to schedule activities with local schools in a predictable manner.  
199 The seismic signals generated are small but readily identifiable above background noise and  
200 have sufficient complexity and structure to allow for some interesting analysis. The amplitude  
201 of the signals can be compared to those recorded by the same systems of local or regional  
202 earthquake events and comparisons can be made with magnitude calculations for earthquakes.  
203 Exotic seismic signals will usually capture the imagination of school and university students and  
204 lead to questions about the nature of seismic waves and how sensors work, providing a perfect  
205 opportunity for university students to practice their outreach science communication skills to a  
206 receptive audience of school pupils. It is generally possible to interest the local press in such  
207 novel stories (“Local school records earthquake signals from football match !”) in exceptional  
208 circumstances (as with Leicester’s remarkable 2015-16 season) these stories can have wider

209 appeal and lead to significant press engagement for the schools and university students involved.  
210 While not the primary purpose of the activity, such press coverage does make it much easier to  
211 keep students and schools interested in the project.

212

### 213 **Data and Resources**

214 Seismic data used in this study is available at

215 <http://www.bgs.ac.uk/discoveringGeology/hazards/earthquakes/FootballQuake/home.html>

216 Seismic analysis carried out using the SeisGram2K free software from Anthony Lomax

217 <http://alomax.free.fr/seisgram/SeisGram2K.html>

### 218 **Acknowledgements**

219 Thanks to the teachers and pupils from Hazel Community Primary School in Leicester for  
220 helping with the data recording and putting up with the numerous newspaper, radio and  
221 television reporters who descended on the school in vast numbers, staff at the New Walk  
222 Museum in Leicester and the Leicester Literary and Philosophical Society for installing an  
223 educational seismograph in the museum gallery. Professional seismic recording instruments  
224 were supplied by SEIS-UK, a NERC funded seismic instrument facility based at the University  
225 of Leicester. Undergraduate students in the geology department at the University of Leicester  
226 for giving up their free time to work with pupils at Hazel Community Primary School and for  
227 giving numerous interviews to the press, on radio and on television.

228

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257

258 Tables

259 Table 1 Leicester City football matches recorded by seismic sensors

Date, Kick off time (UTC)	Leicester City Goal scorer and times <i>Signal amplitude (counts)</i>	Score	Visiting team (goal times)
27-Feb 15:00	Ulloa 89' (1335)	1-0	Norwich City
1-Mar 19:45	Olsson 30' (497), King 46' (855)	2-2	West Bromwich Albion (11', 50')
14-Mar 20:00	Okazaki 25' (409)	1-0	Newcastle United
3-Apr 12:30	Morgan 38' (356)	1-0	Southampton
17-Apr 12:30	Vardy 19' (427), Ulloa 95' (282)	2-2	West Ham United (84', 86')

24-Apr 15:15	Mahrez 10'(238), Ulloa 30'(228), 60'(282), Albrighton 85'(230)	4-0	Swansea City
7-May 16:30	Vardy 5'(817), 65'(599), King 33'(828)	3-1	Everton (88')

260

261 List of figure captions

262 Figure 1 Location map of Football stadium and seismic monitoring sites in Leicester.

263 Figure 2 Seismic trace of Leicester City vs West Ham United (2-2 final score)

264 Figure 3 Seismic trace of each goal scored during Leicester City vs Swansea match (4-0 final  
265 score)

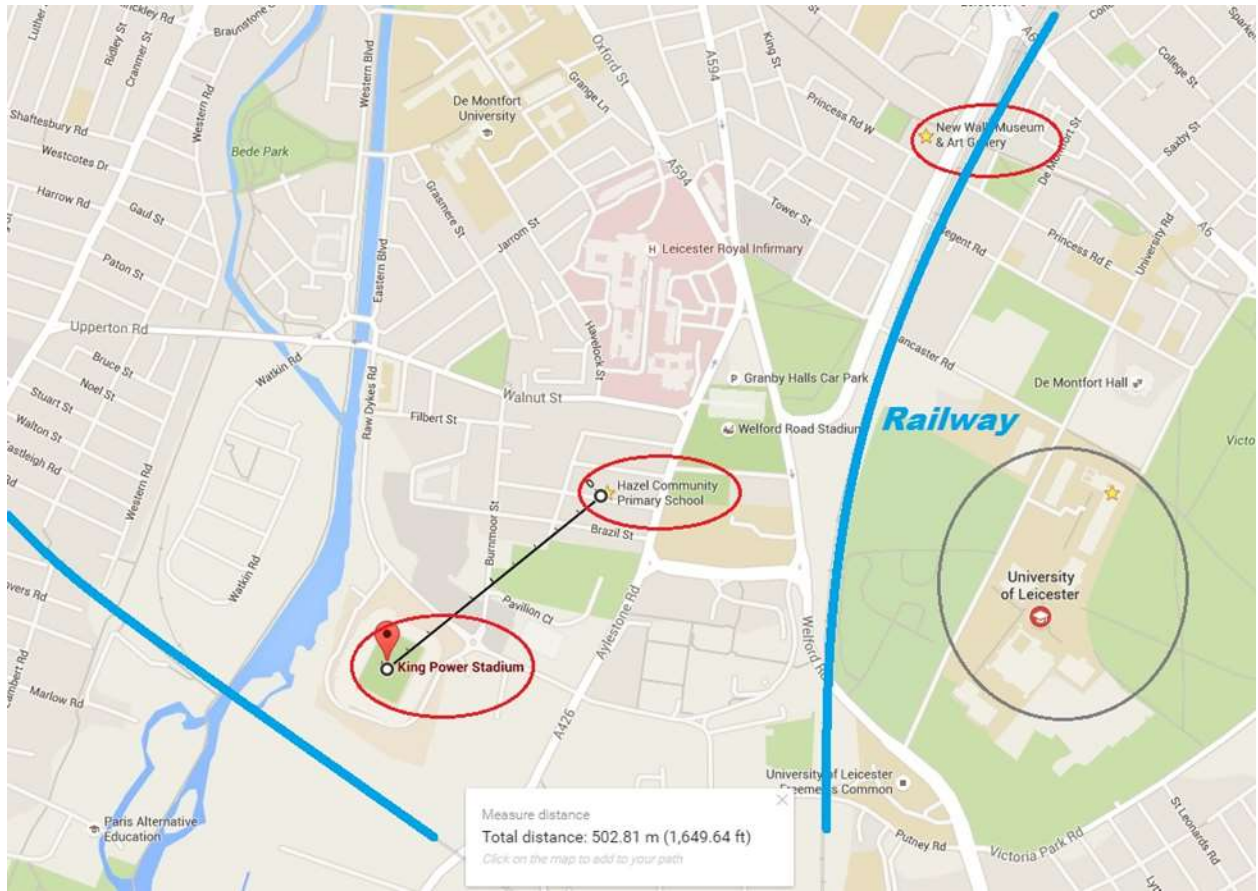
266 Figure 4 Spectrogram of signal recorded after the first goal in Leicester vs Swansea match

267 Figure 5 Pupils at Hazel road primary school demonstrating a celebratory dance for visiting TV  
268 news crews.

269 Figure 6 The Leicester Vardyquake story published in the Bangkok Post

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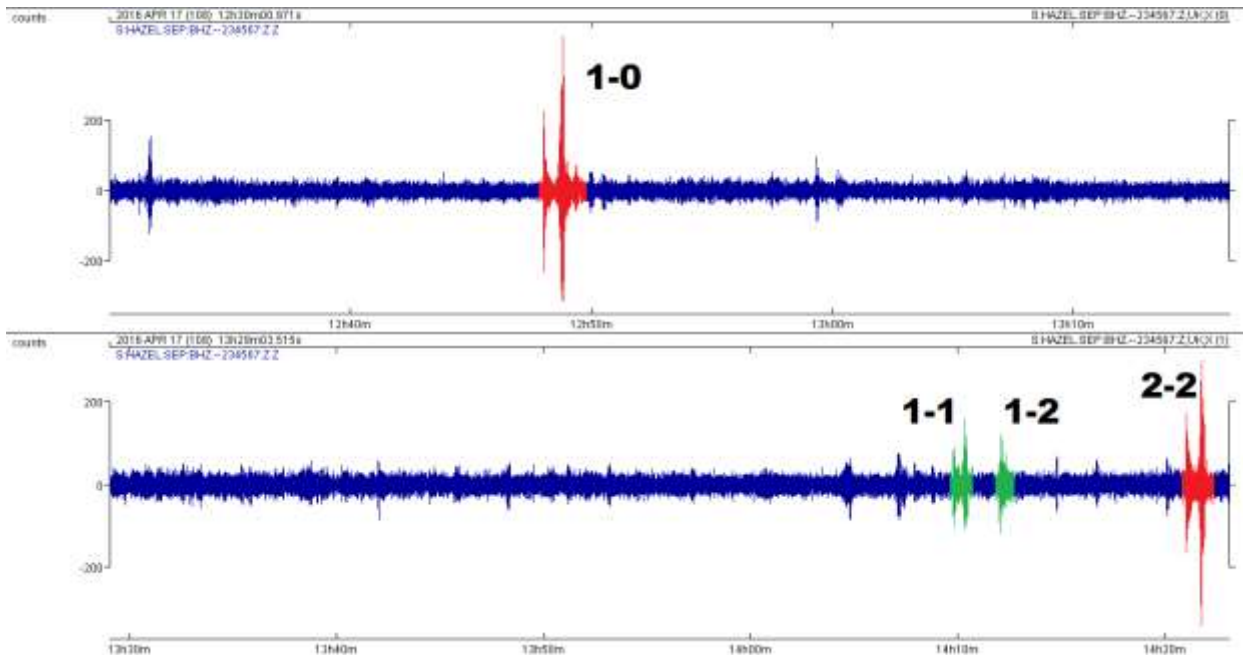
271 Figures (TIFF, Native Adobe Photoshop, (300dpi CMYK) Jpeg (no compression) , GIF



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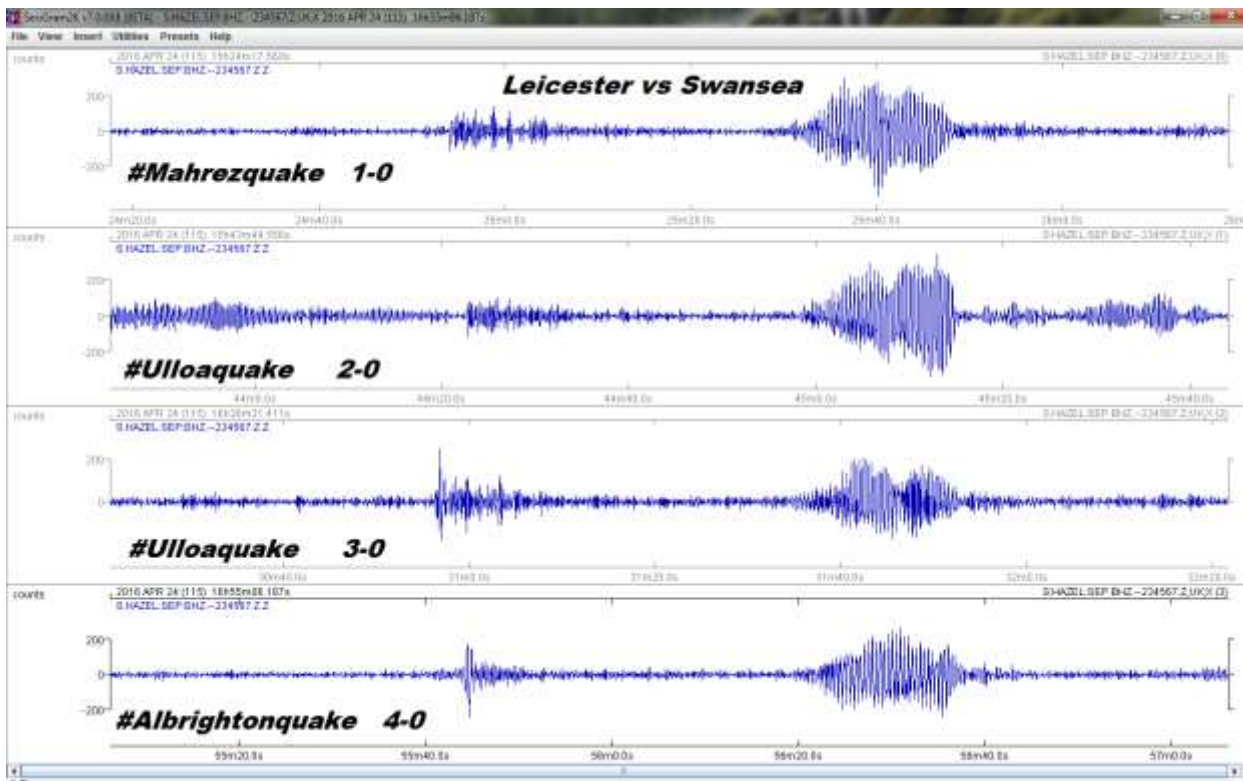
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274 Figure 1 Location map of Football stadium and seismic monitoring sites in Leicester.



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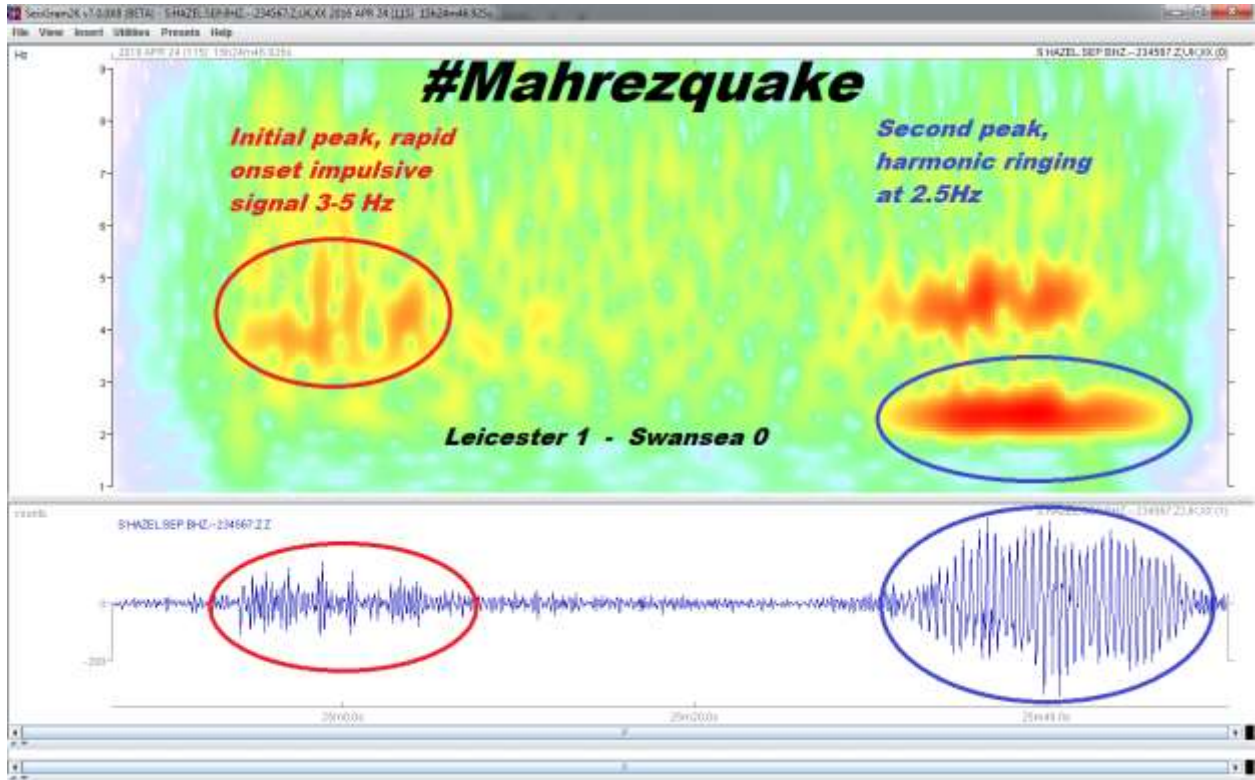
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278 Figure 3 Seismic trace of each goal scored during Leicester City vs Swansea match (4-0 final  
279 score)



280

281 Figure 4 Spectrogram of signal recorded after the first goal in Leicester vs Swansea match



282

283 Figure 5 Pupils at Hazel road primary school demonstrating a celebratory dance for visiting TV  
284 news crews.

NEWS > SPORTS

# Earth moves for jubilant Leicester City fans

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LONDON - Leicester City's supporters celebrated a recent goal so jubilantly that a minor earthquake was detected in the city, a group of geology students said on Tuesday.

A- A+



When Leicester's Leonardo Ulloa scored an 89th-minute winner in last month's win over Norwich City, fans' celebrations sparked a mini-earthquake with a magnitude of 0.3 on the Richter scale

The group from the University of Leicester recently placed earthquake-monitoring equipment at a school close to Leicester's King Power Stadium.

When Leonardo Ulloa scored an 89th-minute winner in last month's win over Norwich City, fans' celebrations sparked a mini-quake with a magnitude of 0.3 on the Richter scale.

"A few days after we installed the equipment at the school and were analysing data collected, we noticed large peaks on the seismogram during football matches being held in the stadium nearby," said first-year student Richard Hoyle.

285

286 Figure 6 The Leicester Vardyquake story published in the Bangkok Post

287

