Football quakes as a tool for student engagement.

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Abstract

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

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

Introduction to educational seismology

Seismology, the study of seismic waves travelling through the earth, can provide a great context to help school students understand some key science concepts about the nature of waves. Great success has been had by educational programs around the world in using signals from earthquakes to help high school students in their studies of physical and earth sciences. Examples include the IRIS seismographs in schools program in the USA, the Sismo a l'ecole

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

Football quakes

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

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

Leicester City

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

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

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

Data recording system.

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

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

Anatomy of the seismic signals

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

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

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

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

Amplitudes and magnitudes

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

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

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

Media Interest

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

Educational outreach

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

Conclusion

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

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

Data and Resources

Seismic data used in this study is available at http://www.bgs.ac.uk/discoveringGeology/hazards/earthquakes/FootballQuake/home.html

Seismic analysis carried out using the SeisGram2K free software from Anthony Lomax http://alomax.free.fr/seisgram/SeisGram2K.html

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Tables

Table 1 Leicester City football matches recorded by seismic sensors

Date, Kick off time (UTC)	Leicester City Goal scorer and times *Signal amplitude (counts)*	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')

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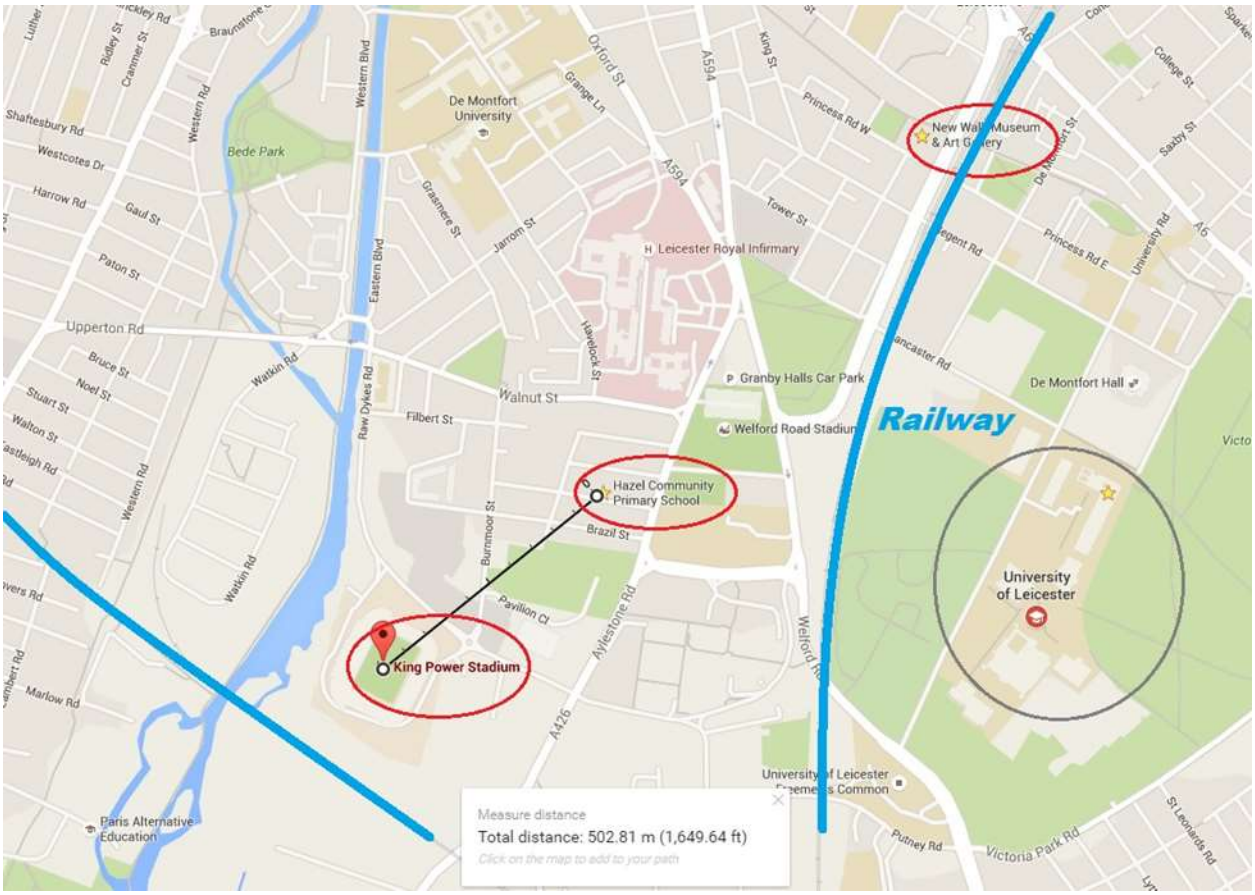
Figure 6 The Leicester Vardyquake story published in the Bangkok Post

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



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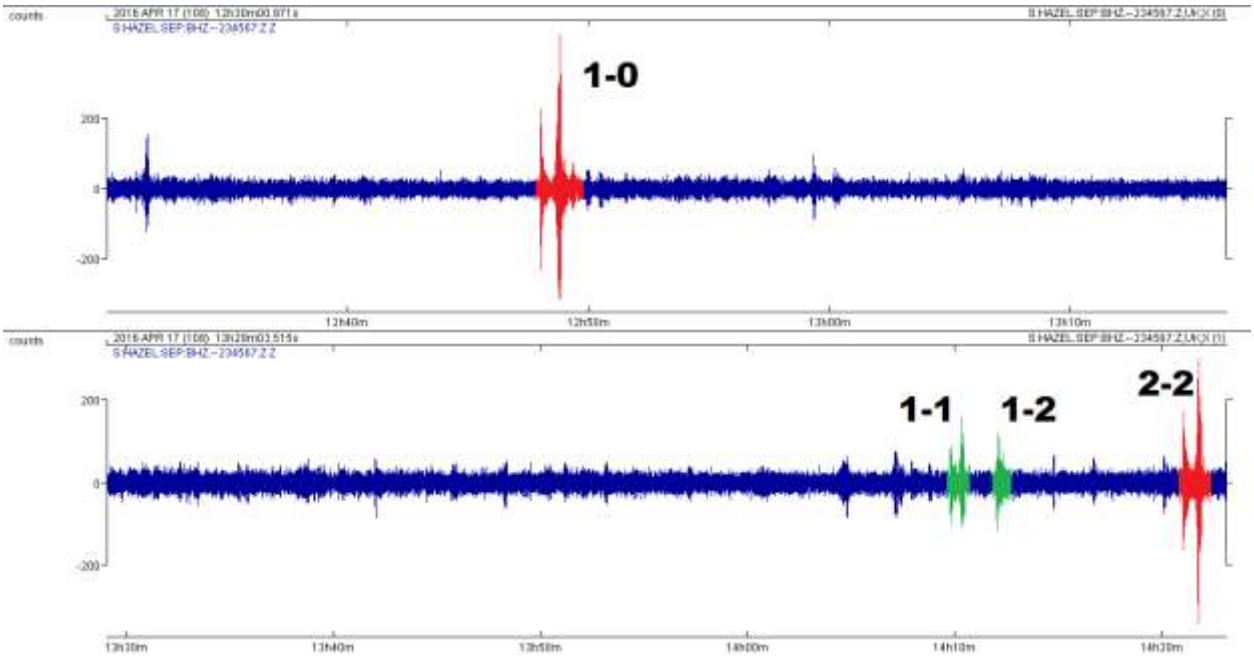

Figure 2 Seismic trace of Leicester City vs West Ham United (2-2 final score)

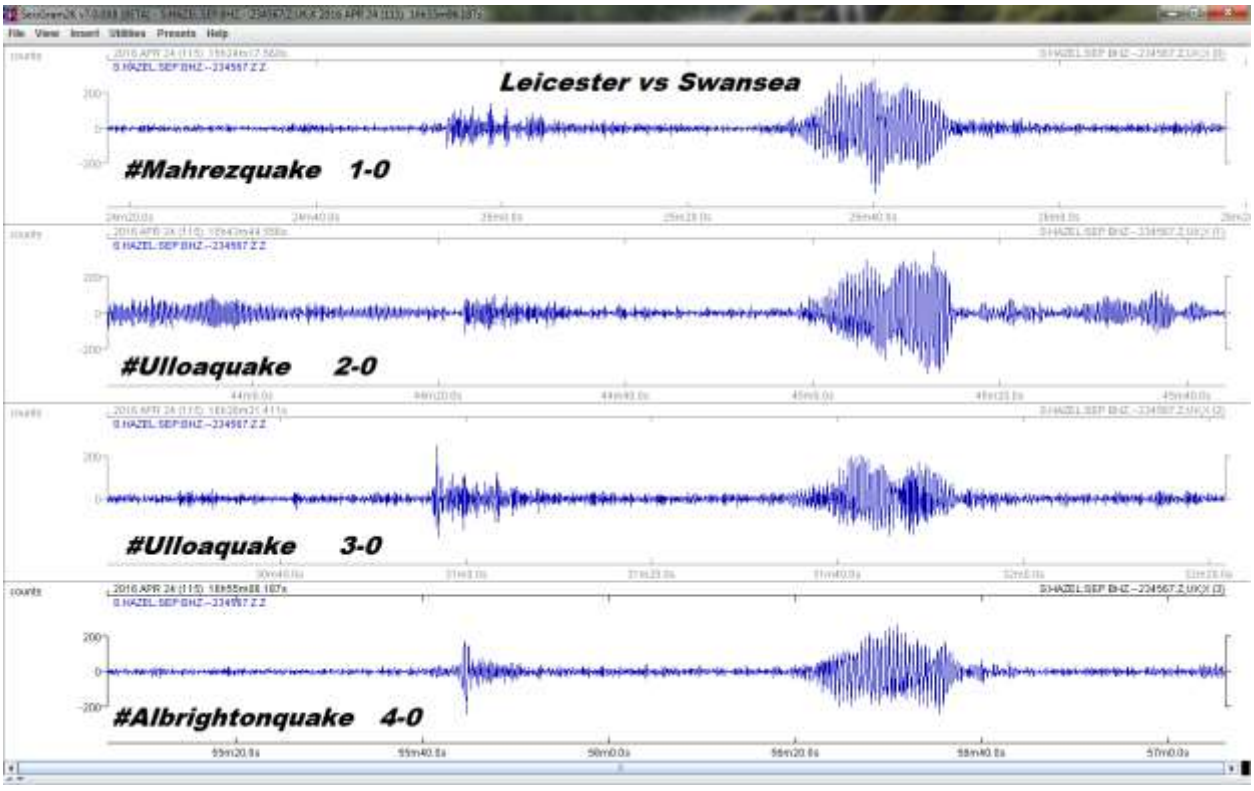

Figure 3 Seismic trace of each goal scored during Leicester City vs Swansea match (4-0 final score)

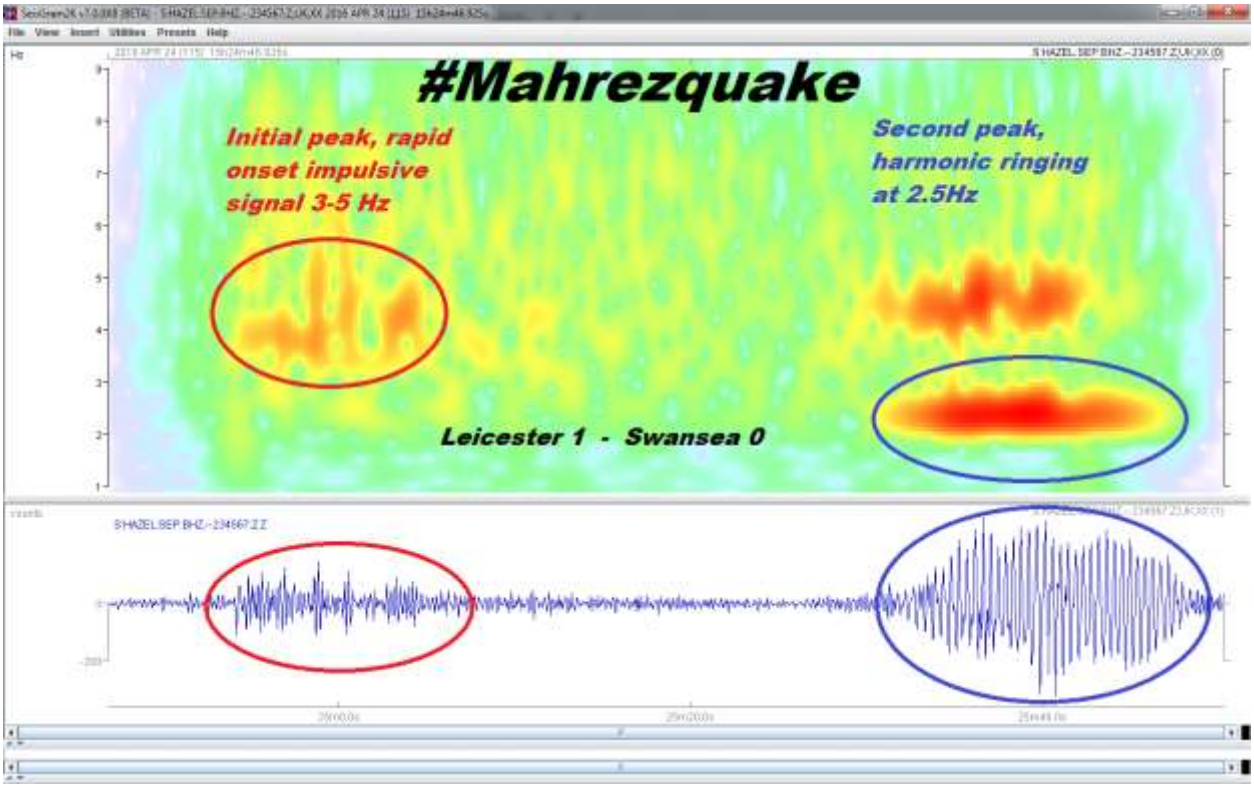

Figure 4 Spectrogram of signal recorded after the first goal in Leicester vs Swansea match

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

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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.

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.

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

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