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Berrak Teymur

Istanbul Technical University, Istanbul, Turkey

S. P. Gopal Madabhushi

University of Cambridge, Cambridge, UK

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Dr. Berrak Teymur
Istanbul Technical University
Istanbul, Turkey

Dr. S.P.Gopal Madabhushi
University of Cambridge
Cambridge, UK

ABSTRACT

In recent years there were several earthquakes in Turkey with magnitudes 7.4, 7.2 and 6 in Kocaeli, Duzce and Pulumur respectively. The first two occurred in 1999 causing the most damage both structurally and economically. The last happened in January 2003. These were all on the North Anatolian Fault and the earthquake occurrence was propagating towards east on the fault. Damage due to surface faulting, slope stability, liquefaction occurred during these earthquakes. In this paper the strong motion data acquired from these earthquakes at various locations are inspected using both the commonly used Fast Fourier transform and more recent harmonic wavelet analysis developed at Cambridge. Harmonic wavelet analysis is applied to some of the strong motion data obtained to observe the variation of frequency contents with time as the earthquake proceeds. With this analysis a comparison of the accelerations on the same fault was obtained. All the earthquakes had their strongest component in east-west direction and this could be seen with peak accelerations occurring in that direction. The contribution from different frequencies at different time instants to the energy of the signal was observed with the wavelet analysis and energy changes in each of the earthquakes could be seen.

INTRODUCTION

In recent years there were several earthquakes in Turkey with magnitudes 7.4, 7.2 and 6 in Kocaeli, Duzce and Pulumur respectively. The first two occurred in 1999 causing the most damage both structurally and economically. The last happened in January 2003. These were all on the North Anatolian Fault and the earthquake occurrence was propagating towards east on the fault. Damage due to surface faulting, slope stability, liquefaction occurred during these earthquakes. The Kocaeli earthquake that happened on August 17, 1999 was 7.4 moment magnitude on Richter scale which was epicentred in Golcuk and caused the north strand of the east-west extension of the North Anatolian Fault Zone (NAFZ) consisting of the Adapazari, Kocaeli, Golcuk segment to rupture. Peak lateral ground accelerations of 0.41g were measured in Adapazari in EW direction. The peak ground accelerations about 10km away from the epicentre at Yarimca Petrochemical Facility were 0.32g in EW, 0.23g in NS and 0.24g in UD. The Duzce earthquake that happened on November 12, 1999 had a moment magnitude of 7.1 and took place near Duzce along the Duzce Fault which is separated from North Anatolian Fault. There was a fault rupture of 30km with right lateral offsets. Peak lateral ground accelerations of 0.02g were measured in Adapazari and of 0.80g in Bolu in EW direction. On January 27, 2003 an earthquake with a moment magnitude of 6 has occurred in Pulumur near Erzincan in the eastern segment of the North Anatolian Fault. Peak lateral ground accelerations of 0.011g were measured in Elazıg in EW direction.

The city of Adapazari is located on an alluvial plain which overlies Quaternary Age alluvial deposits with alternating layers of gravel, sand, silt and clay. The groundwater level is shallow and between 0.5m to 3.0m below ground level. The Izmit city is located on the northern and eastern side of Izmit Bay, on a coastal plain with a gentle slope to the south, towards the sea. It is underlain by Quaternary age deposits with alternating layers of clay, silt, sand, gravel and a dense silty fine sand. Duzce city is located in an alluvial basin approximately 200m above sea level. The geological map points out that Quaternary age alluvial deposits underlie the plain which consists of layers of gravel, sand, silt and clay, and the ground water table is usually shallow varying between 2m to 7m below the ground level, (D'Ayala and Free, 2003). The geological map indicates that north of Pulumur is located on Miocene aged undifferentiated marine deposits and the south of the city on Mesozoic mainly cretaceous aged deposits.

Strong motion data was acquired from the general directorate of disaster affairs webpage (*http://www.deprem.gov.tr*) and department of earthquake engineering of Bogazici University (*http://www.koeri.boun.edu.tr*). Figures 1, 2 and 3 show the acceleration time graphs for these earthquakes. Arcelik (ARC) station was chosen as it was almost 35km away from the epicentre of Kocaeli earthquake and also to show its response to a slightly less strong Duzce earthquake epicentred almost four times the distance of the other one. The acceleration-time history for Kocaeli earthquake is only for the first 80 seconds of the earthquake. The sampling rate of the signal was 200Hz. The acceleration time histories for Duzce and Pulumur earthquakes presented here are for 50 seconds and the sampling rate of the signals was 200Hz and 100Hz respectively.

As can be seen from the record, ARC which has recorded the peak acceleration in NS as 0.211g has two distinctive peaks as seen in Fig.1. The first peak was at 14 seconds, then the second one at 42 seconds yielding the time between the two events of about 30 seconds. ARC has recorded 0.134g in EW and 0.083g in UD directions. Figure 2 shows the acceleration-time history for ARC station during Duzce earthquake, it has registered the peak acceleration in NS and EW directions as 0.008g and 0.007g in UD directions. The peak accelerations were registered at about 33 seconds. Tercan (TER) station has recorded 0.005g in NS, 0.007g in EW and 0.003g in UD directions during the Pulumur earthquake as shown in Fig.3. The peak accelerations were recorded at 21 seconds.

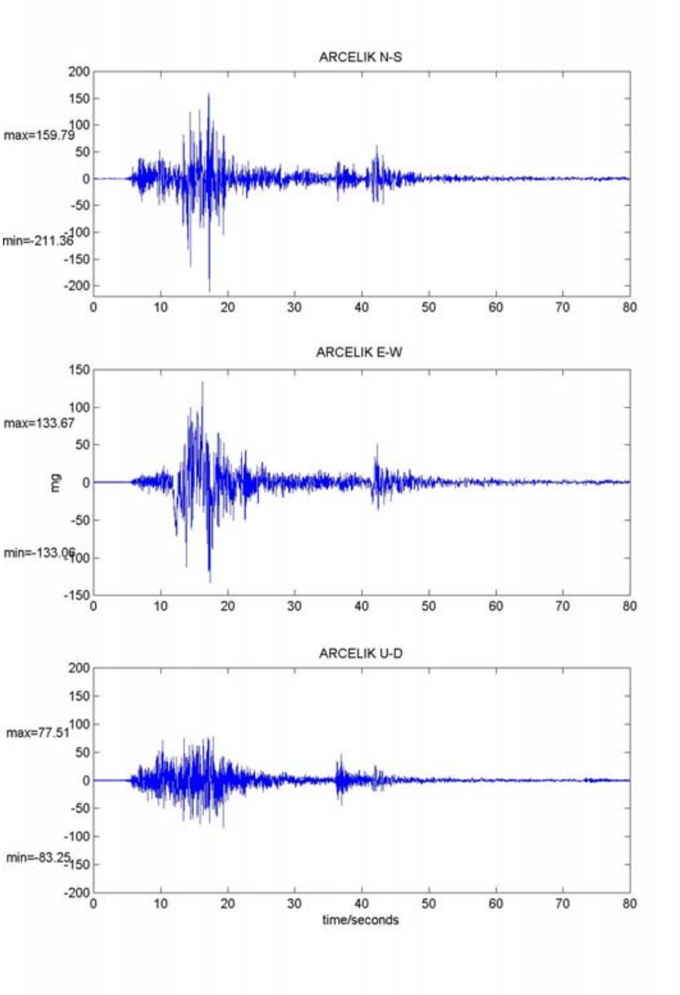


Fig.1 The acceleration time history of ARC station (Kocaeli Earthquake).

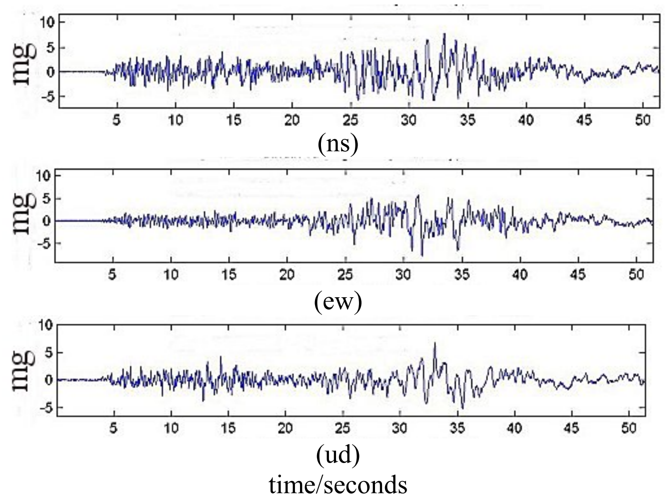


Fig.2 The acceleration time history of ARC station (Duzce Earthquake).

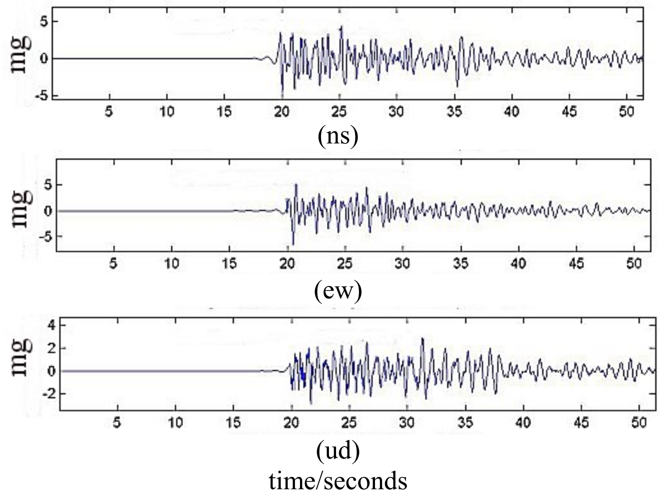


Fig.3 The acceleration time history of TER station (Pulumur Earthquake).

In this paper the strong motion data acquired from these earthquakes at various locations are inspected using both the commonly used Fast Fourier transform and more recent harmonic wavelet analysis developed at Cambridge. Harmonic wavelet analysis is applied to some of the strong motion data obtained to observe the variation of frequency contents with time as the earthquake proceeds. With this analysis a comparison of the accelerations on the same fault was obtained. All the earthquakes had their strongest component in east-west direction and this could be seen with peak accelerations occurring in that direction. The contribution from different frequencies at different time instants to the energy of the signal was observed with the wavelet analysis and energy changes in each of the earthquakes could be seen.

FOURIER ANALYSIS AND HARMONIC WAVELETS

Frequency analysis using FFT method was carried out on N-S, E-W and the U-D components showing various frequencies between 0-10 Hz. Figures 4, 5 and 6 show the results of the frequency analysis of the signals from ARC and TER stations. The frequency contents of the ARC signals for Kocaeli earthquake are seen in Fig.4. It was difficult to pinpoint one significant frequency, various frequencies were observed. ARC signal has similar frequency graphs with significant frequencies present between 3-7 Hz for NS, EW and 0-1Hz for UD. ARC signal for the Duzce earthquake has frequencies between 0-1 Hz as seen in Fig.5. TER signal has the frequencies concentrated below 2Hz as seen in Fig.6. When ARC signals for Kocaeli and Duzce earthquakes are compared, the frequency content of Duzce is concentrated below 1Hz, decreasing in magnitude at higher frequencies, whereas Kocaeli earthquake signal has peak energies at two higher frequencies. Higher frequency component die down quickly for Duzce and Pulumur earthquakes. These graphs show that there are various frequencies present for the duration of the earthquake and that no one dominant single frequency in the signals.

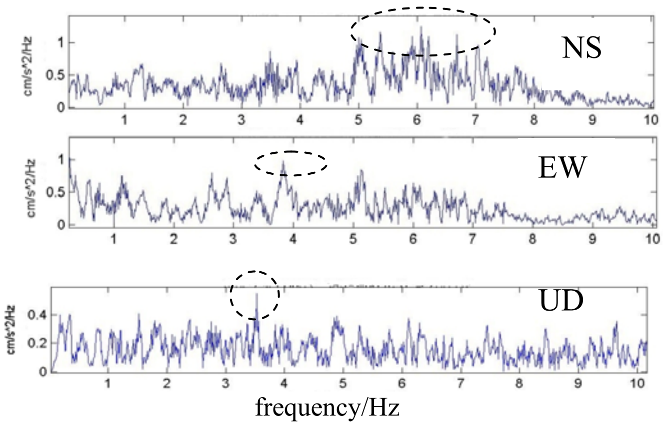


Fig.4 Fourier analysis of ARC signal (Kocaeli Earthquake).

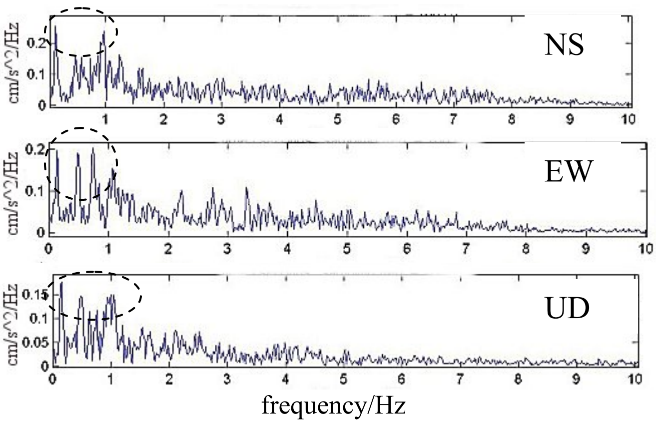


Fig.5 Fourier analysis of ARC signal (Duzce Earthquake).

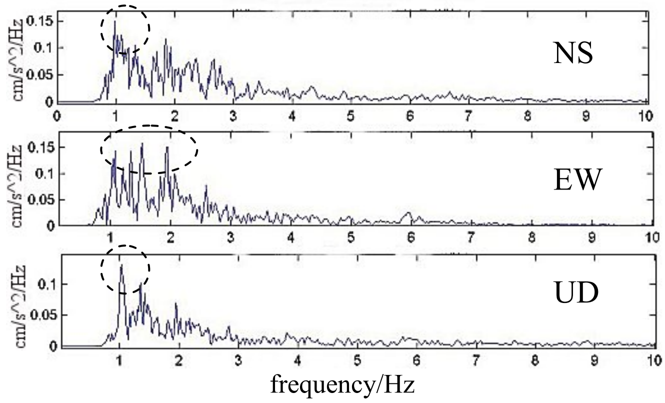


Fig.6 Fourier analysis of TER signal (Pulumur Earthquake).

Many applications of harmonic wavelet analysis were seen in signal processing, geology, vibration analysis and lately in geotechnical earthquake engineering. Harmonic wavelets developed by Newland (1999 a, b) were used to look at the accelerations observed during earthquakes. Acceleration signal is broken into its constituents at different frequency bands and time instants, to give a better localisation of the signal. As a method of time-frequency analysis, harmonic wavelet analysis is done through a system of combining temporal and spectral domains. The signal is broken into a series of local basis functions called wavelets that occupy different times and have different frequency compositions. When they are merged, they completely represent the signal being investigated. Harmonic wavelets have been found to be particularly suitable for vibration and acoustic analysis because their harmonic structure is similar to naturally occurring signal structures and they therefore correlate well with experimental signals, (Newland, 1999b). For further information Newland (1993, 1999a, b) and Haigh et al. (2002) can be referred to. A specimen harmonic wavelet can be seen in Fig. 7.

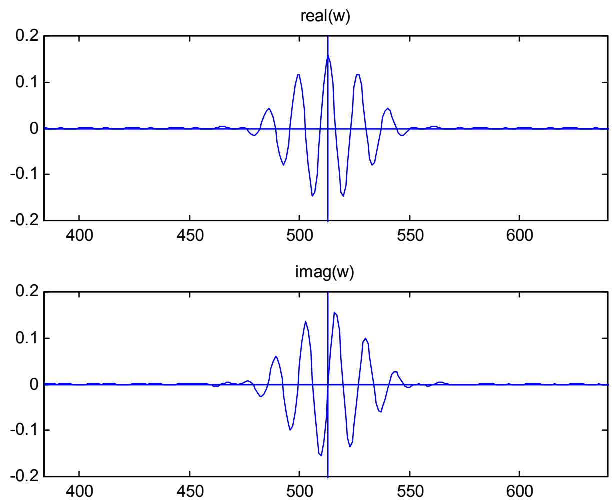


Fig.7 Specimen harmonic wavelet: Real part above, imaginary part below. (Teymur et al., 2001)

Harmonic wavelets have their Fourier transform defined by

$$W_{m,n}(\omega) = \begin{cases} 1/(n-m)(2\pi) & \text{for } m(2\pi) \leq \omega < n(2\pi) \\ 0 & \text{elsewhere} \end{cases} \quad (1)$$

where m and n are real and positive numbers. Inside the band $m(2\pi)$ to $n(2\pi)$ the function has constant magnitude which is normalised to ensure the enclosed area to be unity and outside this band it is zero. The corresponding wavelet function can be defined as follows;

$$w_{m,n}(x) = \{\exp(in2\pi x) - \exp(im2\pi x)\} / i2\pi(n-m)x \quad (2)$$

Level m, n indicate a wavelet in the frequency band $m(2\pi)$ to $n(2\pi)$ where n>m.

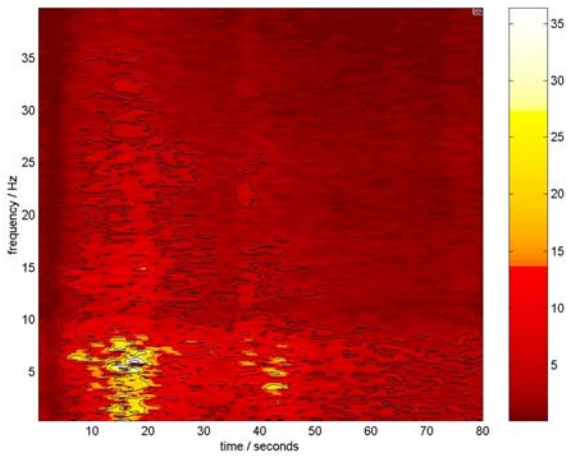
Harmonic wavelet analysis is a tool that has been developed over the past fifteen years for the analysis of non-stationary signals in the time-frequency domain. This technique was used in the investigation of earthquake accelerograms and is shown to be a versatile tool than can reveal information not presented in a classical FFT analysis. Classical FFTs can be used to identify the frequencies at which earthquake energy is concentrated. However FFTs can prove to be less useful when energy at a single frequency is released at different times.

HARMONIC WAVELET ANALYSIS OF STRONG MOTION DATA

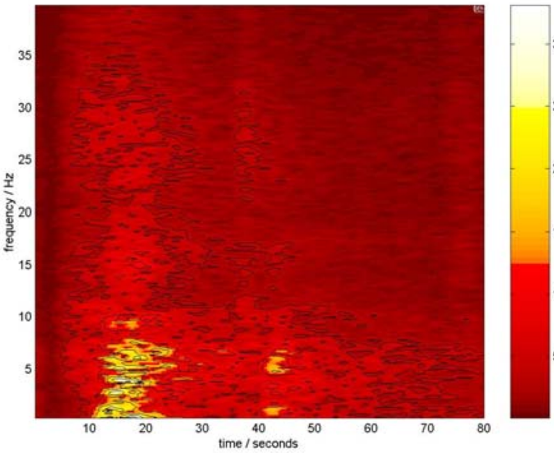
Time-frequency maps plotted here are the two-dimensional contour diagrams of the three-dimensional surface plots created from the harmonic wavelet transform calculations. The axes of the map are time plotted horizontally and frequency plotted vertically. Different colour shadings represent the various contour levels. Figures 8-10 show the results of harmonic wavelet analysis for the signals from ARC and TER stations. It must be pointed out that the colour scale is different for different plots, to maximise the resolution for each plot.

NS and EW components of ARC signal of Kocaeli earthquake has a signal time band between 8-22 seconds as seen in Fig.8. 0-10 Hz frequency band is significant over 8-60 seconds. In UD signal it is a triangular pattern between 0-30 Hz and 5-80 seconds. If UD signal is mainly composed of P-waves, since they arrive quickly, they die down quickly, too. This might be an explanation of this observed pattern (Teymur et al. 2000). As seen in Fig. 9 ARC of Duzce earthquake NS signal is concentrated between 25-35 seconds and 0-4Hz. Though at 25 seconds, frequencies between 0-6 Hz is observed. Towards the end of the earthquake, frequencies concentrate between 0-2 Hz. The EW signal has 0-4 Hz frequencies between 25-40 seconds of the earthquake and for the UD signal 0-2 Hz frequencies is present between 10-40 seconds of the earthquake. For the Pulumur earthquake, TER signal has triangular patterns for all of its components where the frequencies of 0-4 Hz dies down as the earthquake proceeds from 20 seconds to 50 seconds as shown in Fig.10.

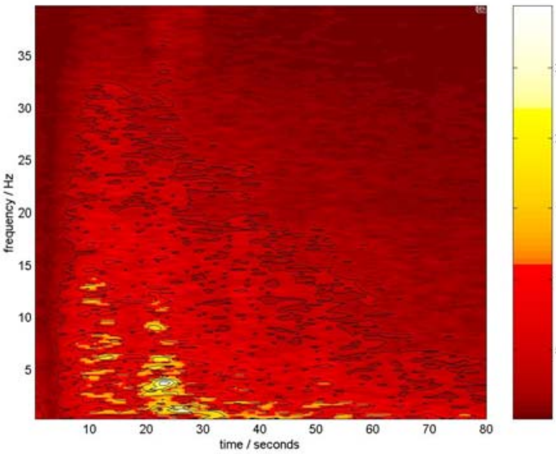
When you compare ARC signals from the two earthquakes, these two signals have different time-frequency patterns which would not be obvious or achieved by acceleration traces or frequency graphs alone. As a result of the Fourier analysis the frequency content of the second peak of Kocaeli earthquake was lost. With the frequency-time maps achieved by wavelet analysis this could be seen. The frequency content of peak accelerations can also be observed. Also as the earthquake gets less strong, energy lessens as well and this could also be observed with the change in the scale on the colour map of wavelets. The frequency content at each time interval could be observed. All frequencies concentrated between 10-20 seconds of Kocaeli earthquake, between 20-40 seconds for Duzce and between 20-50 seconds for Pulumur earthquake. When compared with ARC signal of Kocaeli earthquake, which had two noticeable peaks due to the characteristic of the earthquake having two ruptures occurring consecutively one after the other, the Duzce and Pulumur events are single events.



(N-S)

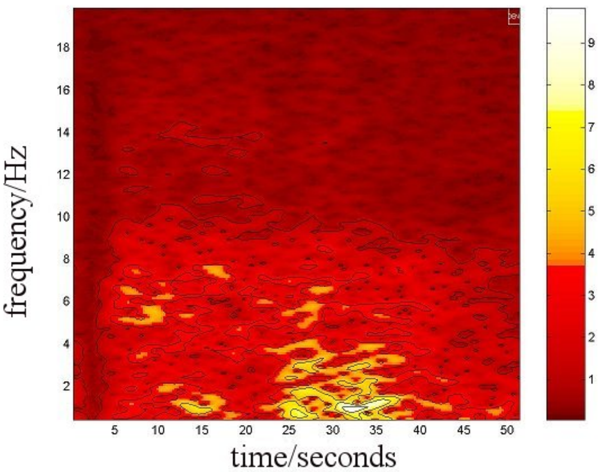


(E-W)

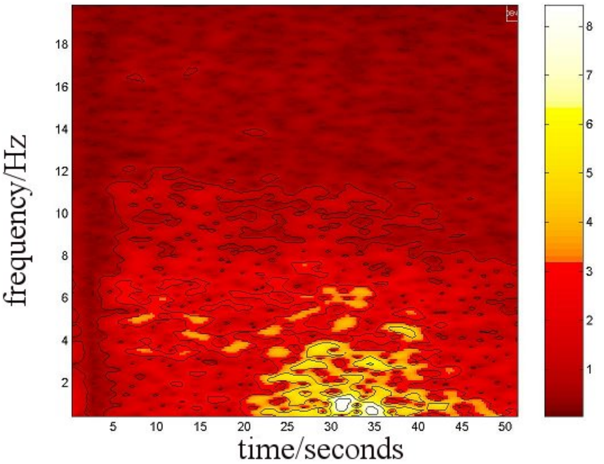


(U-D)

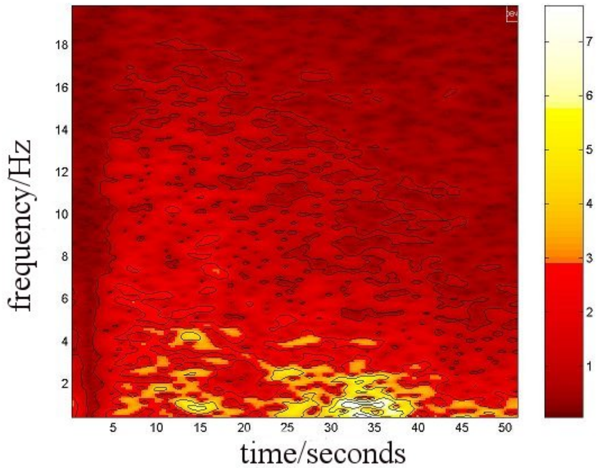
Fig.8 Wavelet analysis of ARC signal. NS, EW and UD components respectively (Kocaeli Earthquake).



(N-S)

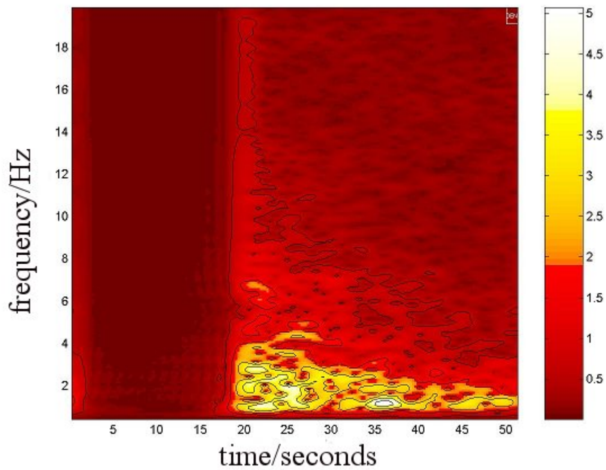


(E-W)

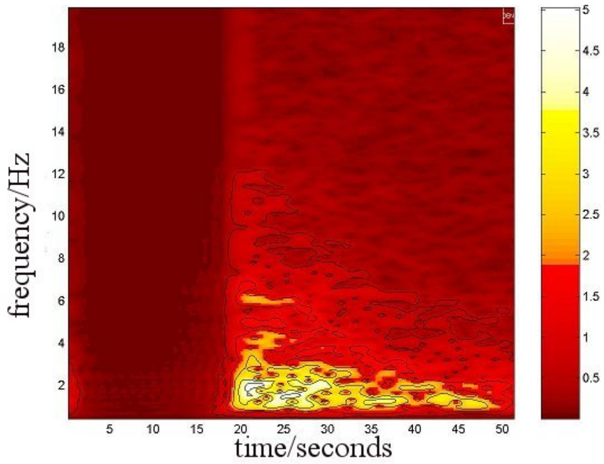


(U-D)

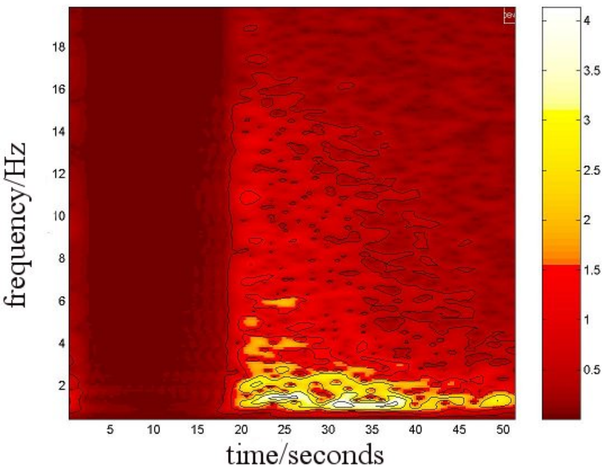
Fig. 9 Wavelet analysis of ARC signal. NS, EW and UD components respectively (Duzce Earthquake).



(N-S)



(E-W)



(U-D)

Fig.10 Wavelet Analysis of TER signal. NS, EW and UD components respectively (Pulumur Earthquake).

CONCLUSIONS

Wavelet transform allows us to see the discontinuities within the signal or the system and zoom in for closer inspection. In this paper, three strong motion recordings from three earthquakes were studied. Methods of analysis used in this paper included the classical FFT method and the new wavelet method. The results of the FFT analysis are that frequency content of the signals changes. With the wavelet analysis, the different time-frequency patterns which could not be seen with the traditional FFT analysis were observed. Most frequencies concentrated between 10-20 seconds of the earthquake for ARC of Kocaeli earthquake. For ARC of Duzce earthquake it was between 25-40 seconds and for TER 20 to 50 seconds. From the wavelet maps, it could be seen that Kocaeli earthquake has more energy than Duzce and Pulumur earthquakes.

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