OnLine Journal of Earth Sciences 4 (1): 56-62, 2010
ISSN: 1991-7708

Sequence Analysis of Ground Accelerated Earthquake Wave for Studying Geology of the Earth

[1]Omar Faruk, [2,3]Syed Mustafizur Rahman, [4]Abul Hashem and [4]Mumnunul Keramat
[1]Science Workshop, University of Rajshahi, Rajshahi-6205, Bangladesh
[2]School of Physics, University Sains Malaysia, Malaysia
[3]Geophysical Research Divison, Department of Applied Physics and Electronic Engineering, University of Rajshahi, Rajshahi-6205, Bangladesh
[4]Department of Applied Physics and Electronic Engineering, University of Rajshahi, Rajshahi-6205, Bangladesh

Abstract: The present research is an approach of studying the sequences as time frequency to amplitude analysis of the recorded ground accelerated earthquake seismic wave which is being propagated from source to receivers. Sequence can be derived from the various analyses of wave properties and it is realistic to be considered that the properties of the recorded seismic wave is related with subsurface in which the wave propagates. Time frequency to amplitude analysis is a way of studying seismic wave properties. The analysis deals with both amplitude and frequency effects instantaneously. Synthetic earthquake ground accelerated waves have been produced with wide range of variation in amplitude and frequency. Time frequency to amplitude analyses have shown that it can mark better sequences of the wave than time frequency analysis which is also made in this research. The analysis is also applied to the real up down component of ground accelerated earthquake waves and it has well estimated the sequences. It is revealed from the analysis that the technique can be further used for characterization of the geology of the earth.

Key words: Frequency, amplitude, seismic wave, sequence, heterogeneity, geologic sub surface, interpretation

INTRODUCTION

The time frequency concept, one of the signal processing techniques, basically describes the true characteristics of a signal when the frequency content varies with time. The change of frequency content with time in seismic reflection or refraction data as sequences can be taken as an important indicator of geological events. In seismological analysis, amplitude variation with time of the ground accelerated wave is the main basis, however both amplitude and frequency variations with time can provide more valuable information for interpretation of geology of the earth.

The present research is an approach of such study which both the frequency and amplitude as the ratio of frequency to amplitude of seismic wave instantaneously in order to characterize the earthquake wave. Fourier transform is one of the classical signal processing tools, it decomposes a signal into its constituent frequency components (Bracewell, 1965).

Using Fourier spectrum it can be identified the frequencies, however it can not identify their temporal localization (Rahman, 2006; Rahman *et al*., 2005; Steeghs and Drijkoningen, 2001). On other hand time frequency distributions map, a one dimensional signal into a two dimensional function of time and frequency and describe how the spectral content of the signal changes with time. There are number of time frequency representation exists (Chakraborty and Okaya, 1995; Rahman *et al*., 2008, 2007, 2005; Taner *et al*., 1979; Steeghs and Drijkoningen, 2001). The most straightforward approach would be to divide the signal into short time segments and determine the local spectrum by means of a Fourier transformation of the segment.

The result of this operation is a widely used time frequency representation. The short time or sliding-window Fourier transform of a signal inherently suffers from a trade off between the length of the window and resolution of the representation. Improvement of the resolution of the sliding-window Fourier transform has been found the motivation behind the development of other techniques for the analysis of non-stationary signals. However, the search for the physical significance of the time varying spectrum has been the main impetus behind all efforts to formulate better ways to characterize the non stationary behavior of a signal. In

Corresponding Author: Omar Faruk, Science Workshop, University of Rajshahi, Rajshahi-6205, Bangladesh

exploration seismology, seismic attributes analysis (Rahman *et al.*, 2005, 2007, 2008) or simply time frequency analysis plays many important roles, however it does not seem very effective tool for studying the ground accelerated earthquake wave (Faruk *et al.*, 2008).

The difficulties of sliding time windows in short time Fourier based analysis and the lack of instantaneous amplitude uses in complex trace based analysis of time frequency representation of a seismic wave might be important reason. That is why, the present work is approach of the addition of instantaneous amplitude with time frequency analysis which is based on complex trace analysis and the extension of time frequency to amplitude analysis instantaneously to obtain better sequences.

MATERIALS AND METHODS

Synthetic data: As amplitude is considered as the prime factor with time in earthquake wave analysis and observed earthquake waves are generally found decaying exponentially. In this research, synthetic earthquake waves are implemented for studying the effects with the application of roposed technique frequency to amplitude analysis. The synthetic waves are decaying exponentially with varying aplitude and frequency as shown in Fig. 1 and 2.

Figure 1a-c shows three waves changing amplitude with constant frequency (16 Hz), multiple amplitudes with constant frequency (20 Hz) and multiple amplitudes ad frequencies, respectively. Figure 2a-c shows anothr set of three waves changing amplitudes with varying frequencies, changing amplitudes with frequencies and complicated change of amplitudes and frequencies along with few abrupt changes in the waves.

Seismological data: The magnitude of 6.6 earthquake occurred on July 16, 2007 at 10:13:22 AM local time (01:13:22 UTC) along the West coast of Honshu, Japan (37.570°N, 138.478°E) at a depth of 10 km. F-net, a full range seismograph of the National Research Institute for Earth Science and Disaster Prevention (NIED) is currently operating high density observation network of seismic stations in this region (Hamada *et al.*, 1982). Installed three components (up-down, East-West and North-South) high sensitivity and short period seismographs are being provided digitally recorded waveform data in each station of the total 24 stations.

The data of four stations amongst twenty four stations are used for the present study. The station codes are ADM, KZK, SBT and WJM (NIED, 2007). The up-

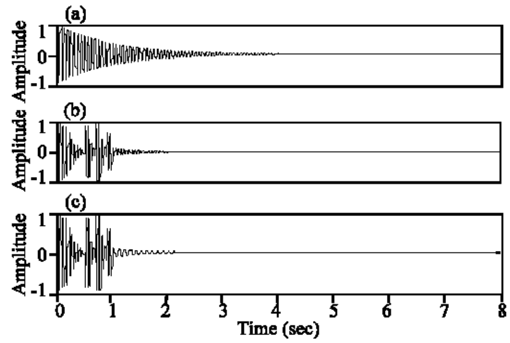

Fig. 1: Synthetic earthquake seismic wave, changing amplitude; a) with frequency of 16 Hz; b) with frequency of 20 Hz and c) with frequency of 10, 20, 25 and 30 Hz

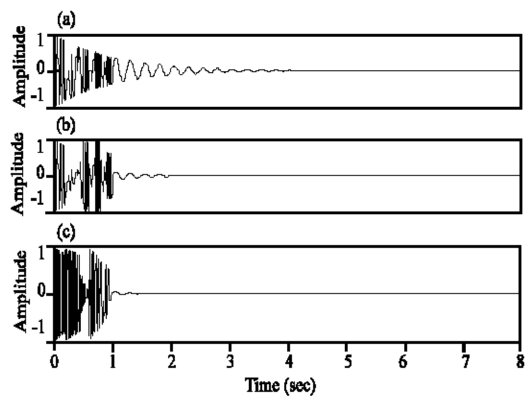

Fig. 2: Synthetic earthquake seismic wave, changing amplitude; a) with varying frequency; b) with varying both frequency and amplitude and c) with varying both frequency and amplitude in a more complicated way

down component of waveform data with BHZ channel are intended for the present analysis of one hour (Fig. 3-6). These data compiled by the NIED may enable us to study the crustal structure with the application of instantaneous frequency to amplitude analysis defining as sequences of the ground motion. The real seismic trace, u(t) can be expressed in terms of a time dependent amplitude, a(t) and a time dependent phase, θ(t) as (Rahman, 2006; Taner *et al.*, 1979):

$$u(t) = A(t)\cos\theta(t) \qquad (1)$$

The quadrature trace u*(t) can be written as:

$$u^*(t) = A(t)\sin\theta(t) \qquad (2)$$

Hence, the complex trace U(t)can be written as:

$$U(t) = u(t)+ju^*(t) = A(t)e^{j\theta(t)} \qquad (3)$$

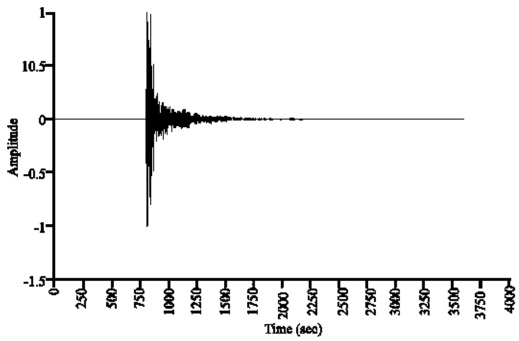

Fig. 3: Up-down ground accelerated seismic wave recorded at station ADM of M 6.6 earthquake from 01:00:00 to 02:00:00 h (UTC) on 16 July 2007

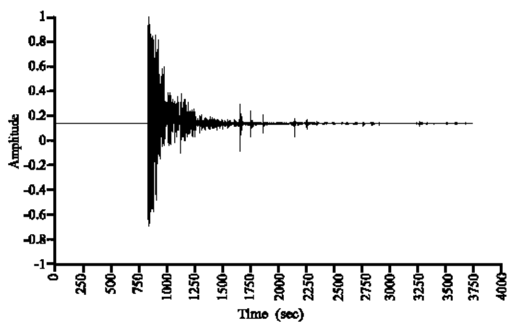

Fig. 4: Up-down ground accelerated seismic wave recorded at station ADM of M 6.6 earthquake from 01:00:00-02:00:00 h (UTC) on 16 July 2007

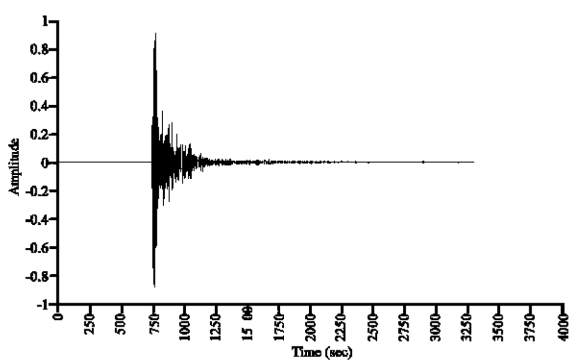

Fig. 5: Up-down ground accelerated seismic wave recorded at station SBT of M 6.6 earthquake from 01:00:00-02:00:00 h (UTC) on 16 July 2007

On other hand, quadrature trace u*(t) can be obtained from real seismic trace u(t) using Hilbert transform as:

$$u^*(t)=\frac{j}{\pi}\times\int\frac{s(\tau)}{t-\tau}d\tau \quad (4)$$

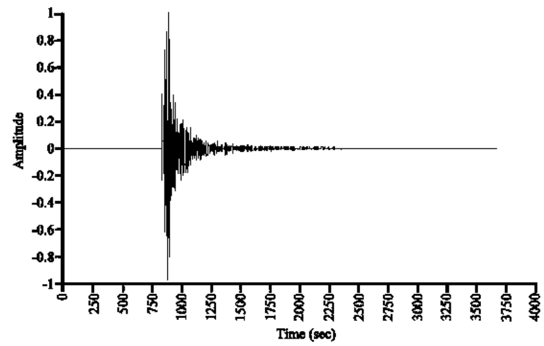

Fig. 6: Up-down ground accelerated seismic wave recorded at station WJM of M 6.6 earthquake from 01:00:00-02:00:00 h (UTC) on 16 July 2007

Now u(t) and u*(t) are known therefore, the solution for A(t) and θ(t) can be obtained as:

$$A(t)=\sqrt{u^2(t)+u^{*2}(t)}=|U(t)| \quad (5)$$

$$\theta(t)=\tan^{-1}(u^*(t)/u(t)) \quad (6)$$

A(t) is called the instantaneous amplitude and θ(t) is the instantaneous phase (Bracewell, 1965). The rate of change of time dependent phase gives a time dependent frequency:

$$\frac{d\theta(t)}{dt}=\omega(t)=2\pi f(t) \quad (7)$$

$$f(t)=\frac{d\theta(t)}{2\pi dt} \quad (8)$$

Which is one of the relations of time frequency analysis. The ratio of instantaneous frequency and amplitude provides the desired frequency to amplitude analysis with time as shown:

$$g(t)=\frac{f(t)}{A(t)}=\frac{d\theta(t)}{2\pi A(t)dt} \quad (9)$$

Therefore, Eq. 9 can provide instantaneous frequency to amplitude ratio of a wave. Instantaneous frequency to amplitude analysis along with time frequency analyses has been made for synthetic and real earthquake data in this research.

Synthetic wave analysis

Time frequency analysis: Using Eq. 3-8 time frequency analysis of the synthetic earthquake waves (Fig. 1 and 2) are made. The analyzed waves are shown in Fig. 7 and 8, respectively. Analyses have estimated the frequency contents with time of the waves.

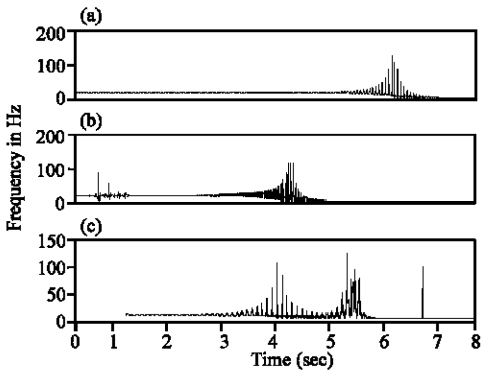

Fig. 7: Time frequency analysis of synthetic earthquake wave respectively of Fig. 1a-c

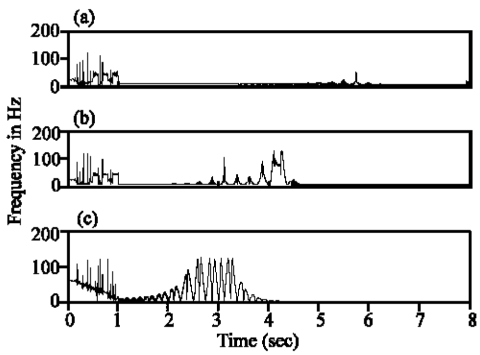

Fig. 8: Time frequency analysis of synthetic earthquake wave respectively of Fig. 2a-c

Traditional seismic processing involved only with time amplitude plot but in many cases very poor amplitude impression might be present in the practical seismological wave due to higher absorption and/or attenuation by the subsurface. Very poor amplitude impression in seismic wave can be efficiently visualized frequency effect using time frequency analysis in an way to observe the local effects (Rahman *et al.*, 2005, 2007, 2008; Steeghs and Drijkoningen, 2001).

This is one of the most important features of time frequency analysis and this local variation can be used in the interpretation of subsurface geology. However, the analysis has shown some limitations as at the time of transition amplitude or frequency, it can not estimates exact values but close to actual values (Rahman, 2006). Few smoothing techniques can be added further for exact attributes computation.

The present analysis is done without smoothing, however as amplitude is the prime variable of the wave, instantaneous amplitude is added in the following analysis as the ratio of frequency to amplitude to obtain better sequences is explained.

Time frequency to amplitude analysis: Using Eq. 3-9, time frequency to amplitude analysis of the synthetic earthquake waves (Fig. 2 and 3) are also made as shown in Fig. 9 and 10, respectively. The instantaneous frequency to amplitude effects or the amplitude to frequency ratios have estimated the better sequences which might be used further in the localization of the seismological wave. The analyzed technique might be better approach as it estimates both amplitude and frequency effect with time rather than amplitude or frequency.

Ground motion earthquake waves analysis: Time frequency and frequency to amplitude analyses of the up-down ground accelerated motion of the earthquake of magnitude 6.6 occurred at 1:13:22 UTC on July 16 2007, near the west coast of Honshu, Japan has been made in the present reasearch. Figure 11-18 show the time frequency and frequency to amplitude analyses. From the analyses, it has found that frequency to amplitude effect with time is different from time amplitude and time frequency representations. Analyses also show that the frequency to amplitude effects are almost same pattern as recorded the amplitude with time having one peak value in each cases.

However, the time position of the peak frequency to amplitude ratio has been shifted to a new time position. Sometimes the peak effects are found delayed or earlier. It is realistic to be considered that solely time amplitude plots are not enough to be used for detailed interpretation of the geology. It needs more analysis and/or further work to attain better interpretation from the point of the characterization of seismic wave.

As time frequency to amplitude analysis of synthetic earthquake waves shown in Fig. 9 and 10 can be used for the characterization as sequences according to frequency to amplitude effects. As amplitude is changed with time in the recorded seismic waves, another variable frequency of a seismic wave may be changed as medias are thought to be dispersive. In exploration seismology while poor amplitude impression is present in the recorded seismic waves, time frequency analysis is shown as an effective way to observe the changes of frequency with time (Rahman *et al.*, 2007).

However, time-frequency analysis is not found more applicable in earthquake seismic wave because of very low frequency and little changes in frequencies. In the present analysis frequencies change are found in between 0-5 Hz. But we believe there must be relationship of crustal geology with frequency in which the wave propagates. Since we want to see the variation

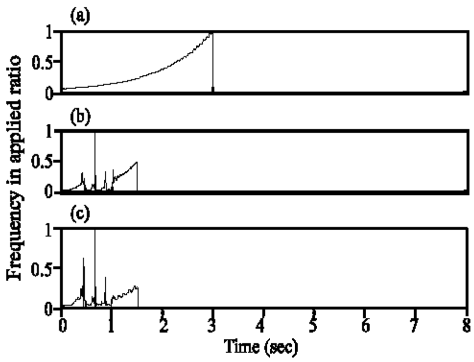

Fig. 9: Time frequency to amplitude analysis of synthetic earthquake wave respectively of Fig. 1a-c

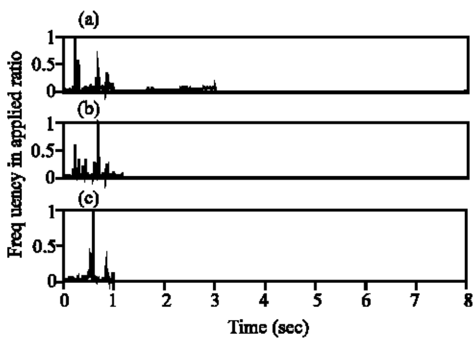

Fig. 10: Time frequency to amplitude analysis of synthetic earthquake wave, respectively of Fig. 2a-c

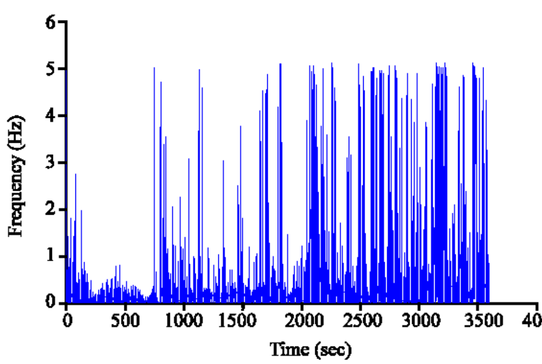

Fig. 11: Time frequency analysis of M 6.6 earthquake at ADM station

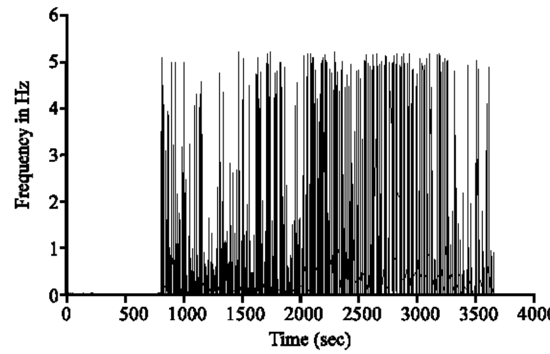

Fig. 12: Time frequency analysis of M 6.6 earthquake at KZK station

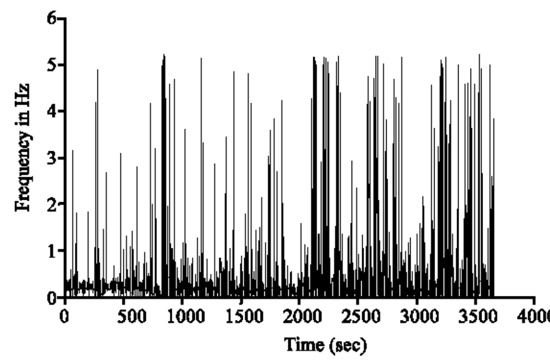

Fig. 13: Time frequency analysis of M 6.6 earthquake at SBT station

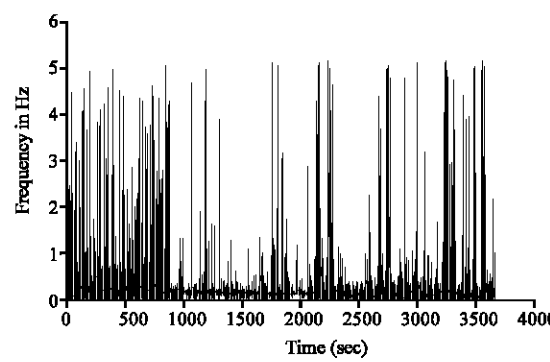

Fig. 14: Time frequency analysis of M 6.6 earthquake at WJM station

of frequency along with the variation of amplitude, up-down ground motion seismic waves have been normalized to a unique maximum value to see uniform time frequency to amplitude effects. It has found that the peak time frequency to amplitude effect can be marked easily (Fig. 15-18). The investigations show that the positions (in time) have been shifted to new times for peak effect in time frequency to amplitude analyses in 6.6 M waves. The peak amplitudes of the up-down ground motion seismic wave of 6.6 M earthquake are found at approx 825, 815, 840 and 875, respectively at stations ADM, KZK, SBT and WJM (Fig. 3-6). However, exception has been found for the KZK station in 6.6 M analyses (Fig. 16). Besides peak frequency to amplitude effect,

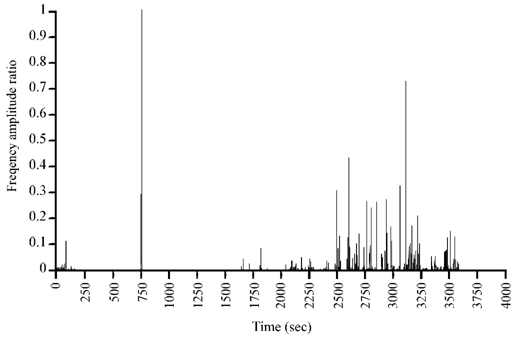

Fig. 15: Time frequency to amplitude analysis recorded at station ADM of M 6.6 earthquake from 01:00:00-02:00:00 h (UTC) on 16 July 2007

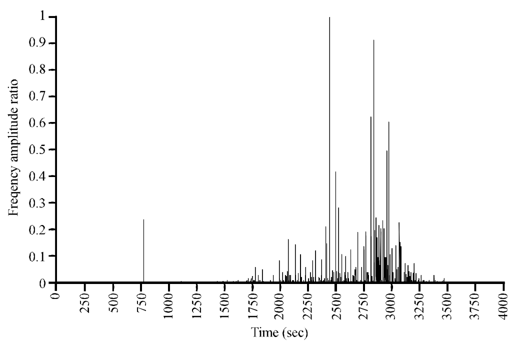

Fig. 16: Time frequency to amplitude analysis recorded at station KZK of M 6.6 earthquake from 01:00:00-02:00:00 h (UTC) on 16 July 2007

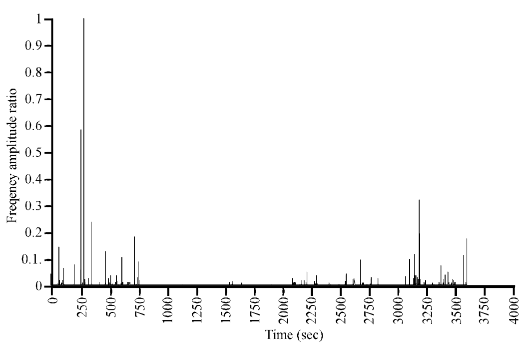

Fig. 17: Time frequency to amplitude analysis recorded at station SBT of M 6.6 earthquake from 01:00:00-02:00:00 h (UTC) on 16 July 2007

there is reasonable number of frequency to amplitude effects found in the total time (1 h) of the analyses. Therefore, two distinct type findings are observed as: peak effect shifted to a new time position and) the presence of a number of reasonable frequency to amplitude ratios with time, in the time frequency to amplitude analyses of the earthquake waves.

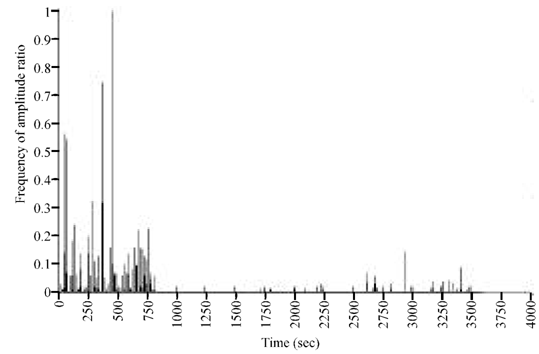

Fig. 18: Time frequency to amplitude analysis recorded at station WJM of M 6.6 earthquake from 01:00:00-02:00:00 h (UTC) on 16 July 2007

These are the sequences of the analyzed earthquake wave. Time frequency analysis does not seem as attractive sequences particularly in the earthquake wave analysis. However, time frequency to amplitude analyses of the earthquake waves have estimated better sequences which can be used further to relate with the crustal structure of an area.

Amplitude, frequency and time are the fundamental variables of a wave. Interfaces can be marked little easily in the reflected time amplitude plot, as usually made in exploration seismology but the work becomes complicated for solely the transmitted wave (e.g., earthquake wave) particularly for the unknown type source. At the receiver, up-down ground motion is found as the amplitude decreases exponentially with time having little fluctuations of amplitude and frequency.

While a wave propagated a long distance through subsurface, amplitude of the wave is absorbed according to absorption coefficient of the media and at the very far end amplitude becomes very close to zero. Hence, it can be thought that for the poor amplitude variation, frequency of the wave can be considered better parameter on such occasion for characterization of earthquake wave. Frequency might be represented the changes of phases of the propagated wave.

Phase change can be taken place when medias are changed during the propagation of seismic wave. It is further considered that the changes of frequency with time are ultimately representing the changes of phases of the propagated wave. Gradual decrease of amplitude and instantaneous frequency with time have been integrated to observe both the changes in a ratio of frequency to amplitude with time in the present analysis. Therefore, frequency to amplitude ratios can used to study the number of interfaces passed by the ground motion seismic wave which is recorded at the receiver. Similarly, the degree of heterogeneity of the crustal structure can be obtained according to the magnitude and successive number of frequency to amplitude ratios found in the time frequency to amplitude analysis. From the time frequency to amplitude analyses of 6.6 M earthquake, strong heterogeneity obtained (Fig. 15 and 16) in between time 2500-3550 sec and 2000-3250 sec, respectively at the stations ADM and KZK.

Second investigation in TFA analyses show that peak effect of frequency to amplitude shifted to a far distances in time scale at KZK station for the earthquake waves. It can be said from our analysis that at the instant while maximum TFA found, seismic wave faces maximum acoustic impedance contrast during propagation. This contrast might be indicated the strongest boundary of two geologic sub surfaces.

CONCLUSION

Seismic waves propagated in the subsurface carry the information about the geological structure. The ultimate objective of the geophysical techniques is to interpret the subsurface geology and this job can be done in various ways. Seismic waves are considered as the most fundamental and prime parameters in the interpretation process. Present analysis is an approach of characterizing seismic wave as sequences which can be further used in the interpretation of subsurface geology. Time frequency to amplitude analysis is the extension of time frequency analysis and an effect of instantaneous amplitude.

It has seen advantages of the time frequency analysis in the exploration seismic processing however, the research does not seem very effective in earthquake seismological wave analysis. Sliding time windows in short time Fourier based analysis and or the lack of instantaneous amplitude uses in complex trace based analysis might be the reason. In order to obtain better localization of the recorded seismological wave, time frequency to amplitude analysis might be the good technique. Analyzed synthetic and ground accelerated earthquake waves are successfully localized and obtained time frequency to amplitude effects as sequences.

ACKNOWLEDGEMENTS

Researchers acknowledge F-net Broadband Seismograph Network of National Research Institute for Earth Science and Disaster Prevention (NIED), Japan for providing seismological data.

REFERENCES

Bracewell, R.N., 1965. The Fourier Transform and Its Applications. McGraw-Hill Book Co., New York.

Chakraborty, A. and D. Okaya, 1995. Frequency-time decomposition of seismic data using wavelet-based methods. Geophysics, 60: 1906-1916.

Faruk, M.O., S.M. Rahman, M.A. Hashem and M. Keramat, 2008. Time frequency analysis of earthquake seismic wave. Proceedings of the ICECC, June 27-29, University of Rajshahi, Bangladesh.

Hamada, K., M. Ohtake, Y. Okada, S. Matsumura and F. Yamamizu ***et al.***, 1982. Kanto-Tokai Observation network of crustal activities of national research center for disaster prevention. J. Seism. Soc. Jpn., 35: 401-426.

Rahman, S.M., M.R. Islam, M. Keramat, M.M. Alam and M. Kimura, 2005. Frequency attributes study of seismic data. Bull. Fac. Sci. Univ. Ryukyus, 80: 1-8.

Rahman, S.M., 2006. Complex seismic attributes analysis for the characterization of subsurface geology. Ph.D. Thesis, Rajshahi University, Rajshahi, Bangladesh.

Rahman, S.M., M.R. Islam, M. Keramat and M. S. Islam, 2007. Seismic attribute analysis for the characterization of Tibetan bright spots: INDEPTH seismic profiles Tibet 9 and 10. J. Geo. Soc. India, 69: 739-745.

Rahman, M.A., S.M. Rahman, M.R. Islam and M. Keramat, 2008. The study of geological constituents of mid-atlantic oceanic crust with the application of attributes in seismic profiles. J. Geological Soc. India, 71: 717-723.

Steeghs, P. and G. Drijkoningen, 2001. Seismic sequence analysis and attribute extraction using quadratic time-frequency representations. Geophysics, 66: 1947-1947.

Taner, M.T., F. Koehler and R.E. Sheriff, 1979. Complex seismic trace analysis. Geophysics, 44: 1041-1041.