Strong Motion Simulation for Kathmandu by Stochastic Method

Hari Ram Parajuli[*], Pragnyan Ghimire [**]

[*]Associate Professor, Institute of Engineering Pulchowk Campus, Nepal

[**]Earthquake Engineer

Abstract- The strong ground motion simulation of Kathmandu done through stochastic method .Time History of Gorkha Earthquake 2015 was generated using time domain simulation and compared with recorded time history of Kantipath seismological station. The simulation work stopped once the target and generated spectra matched.

The ground motion calculated with consideration of source, site, and path with amplification effect of soil. Then after time domain simulation carried out. The simulation work started from noise generation work with windowing, Fast Fourier Transform (FFT) and Spectra matching (Target and Generated) to obtain Simulated Time History. The simulation work carried out using MATLAB programming language. The Simulated and Measured Time History changed in form of response spectra in the program to compare the result.

The parameter of stochastic method for Kathmandu defined after the comparison of simulated time history to the Kantipath station of Kathmandu.

Index Terms- Gorkha Earthquake, Kathmandu Ground Motion, Nepal Earthquake, Stochastic Method, Time domain Simulation

I. INTRODUCTION

Nepal lies in the earthquake prone region due to two tectonic plates i.e. Indian and Eurasian plate. The Himalayan Mountain range formed by the collision of the Indian and Eurasian plates considered as earthquake prone zone. The Indian Plate under thrusts the Eurasian Plate occurs a number of earthquakes in near zone of India, Nepal, China and other south Asian countries. On 25 April 2015 at 11:56 Nepal Standard time, a massive 7.6 magnitude earthquake occur in Nepal with the epicenter in Gorkha District (north-west) of Kathmandu (Capital city). Hundreds of aftershocks (498 no of aftershocks of size more than 4 magnitude until 1 June 2018). It was the most powerful disaster to strike Nepal since 1934 Nepal-Bihar earthquake.

A simple and powerful method for simulating ground motions based on the assumption that the amplitude of ground motion at a site can specified in a deterministic way with a random phase spectrum modified such that the motion distributed over a duration related to the earthquake magnitude and to distance from the source (Boore, Simulation of Ground Motion Using the Stochastic Method, 2003). This method of simulating ground motions often goes by the name "the stochastic method." (McGuire, 2004). It is particularly useful for simulating the higher-frequency ground motions of most interest to engineers. It is widely used to predict ground motions for regions of the world in which recordings of motion from damaging earthquakes are not available (McGuire, 2004). This simple method has been successful in matching a variety of ground-motion measures for earthquakes with seismic moments spanning more than 12 orders of magnitude. One of the essential characteristics of the method is it distills what is known about the various factors affecting ground motions (source, path, and site) into simple functional forms that can be used to predict ground motions. Stochastic methods (Boore, Simulation of Ground Motion Using the Stochastic Method, 2003) estimate ground motions during an earthquake based on physical properties of the energy release and the travel path of seismic waves. From the characteristics of the process in a time, an estimate can be made of spectral response, peak motion parameters, or any other desired measure (including nonlinear response).
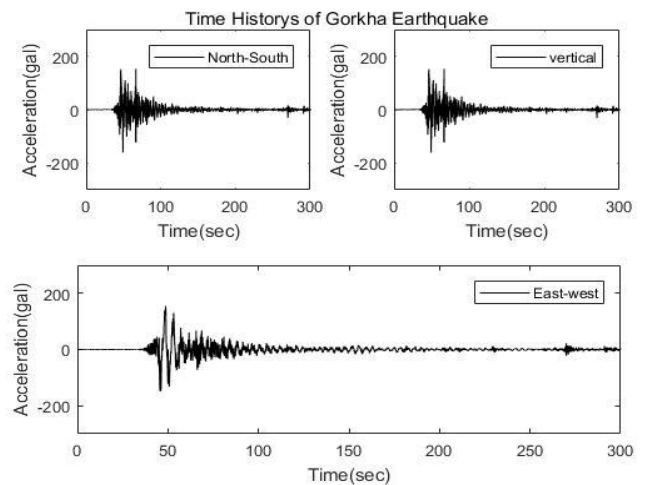

Figure 1 Measured Time History of Gorkha Earthquake at Kantipath Station (Data source USGS)

II.   METHODOLOGY

Stochastic Method prescribed by David M Boore (Boore, Simulation of Ground Motion Using the Stochastic Method, 2003)and McGuire (McGuire, 2004) are the key documents for this research works. MATLAB programing language used to find the result of this research work.
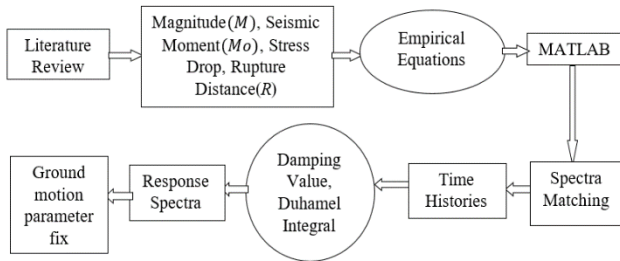

Figure 2 Flow Chart of Methodology Used in this Research

A.   GENERATION OF TARGET SPECTRA

Equation used in this simulation is defined by the David M.Boore (Boore, Simulation of Ground Motion Using the Stochastic Method, 2003).

According to Boore, the Spectrum of ground Motion

$$Y(Mo, f, R) = E(Mo, f)P(R, f)G(f)I(f)$$

Where, f is frequency, $E(Mof)$ is Source Effect, $P(R, f)$ is the Path Effect, $G(f)$ is the site effect and $I(f)$ is Filter control.

a)   Source Effect $E(Mof)$

Different source model described by Boore in his paper.

The model used in the research is w square model.

$$E(Mof) = CMoS(Mof)$$

Where C is constant and value depend on different parameter, $S(Mof)$ is the displacement source spectrum and for w square model

$$S(Mof) = \frac{1}{1 + \left(\frac{f}{fc}\right)^2}$$

$$C = \frac{R_{\theta\Phi}FV}{4\Pi\rho Ro(v_s)^3}$$

$R=$ Distance from rupture point

$R_{\theta\Phi}$ =Effect of radiation pattern (0.55)

ρ =Density of the earth crust

v_s =Shear wave velocity

$Ro = $ $distance\ in\ Km\ generally\ taken\ as$ 1

Mo =   Seismic moment

$$M\quad = \frac{2}{3(logMo)} - 10.7$$

b)   Path effect $P(R, f)$

The path effect is depend on geometrical spreading and q (f) function.

$$P(R, f) = Z(R)\exp(-\frac{\pi f R}{q(f)C_q})$$

Where, $Z(R) = \frac{Ro}{R}$ for R<100 Km

$q(f) = 180f^{0.45}$ Is quality factor

C_q is velocity of soil layer 30m below

f is frequency of wave

c)   Site Effect $G(f)$

The site effect is mainly dependent on frequency of the wave. It also represent the amplification and di-amplification of the soil (McGuire, 2004)

$$G(f) = (2.024 + 0.65\ln(f) + 0.263(\ln(f))^2)$$

$$for\ 0.5 <= f < 5Hz$$

$$G(f) = 3.75\quad for\ 5Hz \leq f$$

d)   Filter control $I(f)$

$I(f)$ Is the diminution factor or filter for ground motion? Generally there are two types of filter are in used and Boore combine both the filter in his research (Boore, Simulation of Ground Motion Using the Stochastic Method, 2003)

$$I(f) = I_1(f) * I_2(f)$$

Where $I_1(f)$ is the Butterworth Filter and $I_2(f)$ is kappa filter

$$I_1(f) = \left(1 + \left(\frac{f}{f_{max}}\right)^8\right)^{-0.5}$$

$$I_2(f) = \exp(-\pi k f)$$

Where, f_{max} is the cut off frequency

k=0.01 to 0.066 for different soil conditions

After applying all parameter correctly the target spectra $Y(Mo, f, R)$ is generated and that should be changed to time history by time domain simulation.

B.   TIME DOMAIN SIMULATION

The cos function $A * cos(wt + 2\pi\theta)$ is used for generation of Time History.

Where, θ is random number between (-π to 2π)

w=circular frequency

t=time in sec

A=constant value for random amplitude spectrum

This will generate the random time history and shaping of the time history is done by the envelop function.

i)   Envelop Function

There are difference envelop function and the envelop Function used by Kanai Tajmi is used for simulation work in this research. The Envelop Function is calculated by equation

$$E_t = a\left(\frac{t}{t_n}\right)^b \exp\left(-c\frac{t}{t_n}\right)$$

Where,

$$b = -eps \frac{\log(T_{90})}{1 + eps(\log(T_{90}) - 1)}$$

$$c = \frac{b}{eps}$$

$$a = \left(\frac{\exp(1)}{eps}\right)^b$$

eps = 0.4 called as normalized duration time when ground motion achieves peak

T_{90} = value of the envelop function at 90 percent of the duration
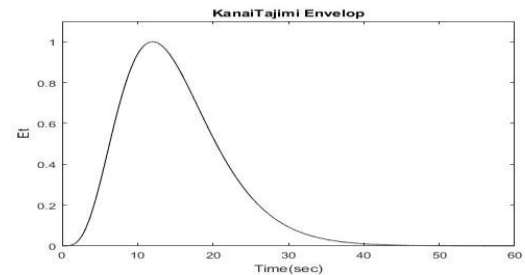
t_n = Time period of the envelop

Figure 3 Shape of Envelop Function used in research, plotted through MATLAB

ii)   Fast Fourier Transfer

The simulated time history then changed to frequency domain by use of Fast Fourier Transform. Thus, the spectrum is named as matching spectra. The time history generation and spectram matching works was done for different value of ground motion parameters until the two spectra and maximum value of time history do not match with target spectra and time history of Kanthipath station.

iii)   Response Spectra

After the completion of simulation of Time History completed the response spectrum of the simulated and Kanthipath station Time History response spectra was calculated for the comparison of the two time histories.

C.   MATLAB

The programing language called MATLAB was used to carry out the simulation, calculation, Figures generation, target and matching spectra generation work.

III.   RESULTS
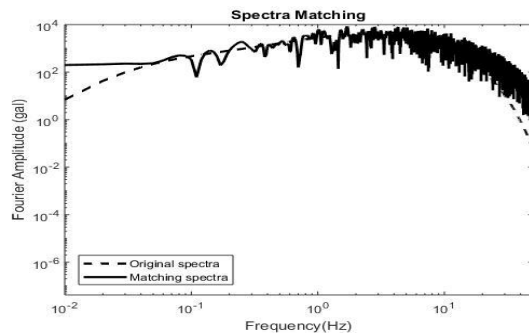
A. SPECTRA MATCHING

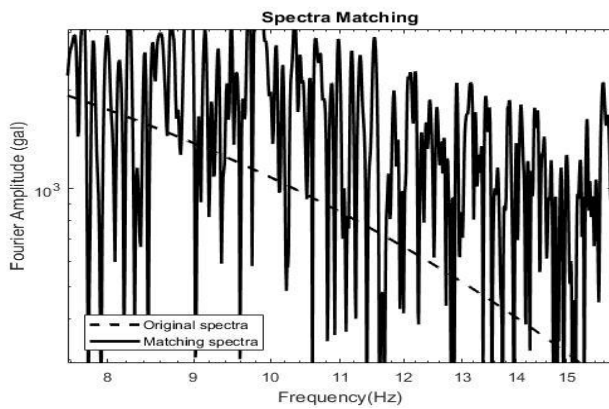*Figure 4 Target and Matching Spectra Matching*

Figure 5 spectra matching work zoomed in 8 to 15 Hz frequency range

In the Figure, 4 generated spectra matched with target spectra. Figure 5 shows the portion of spectra matching work in zoomed form. The maximum value of Time History occur in the time range of 10-15 sec as shown in Figure 3 Since two spectra matched, the result of time history simulation is completed.
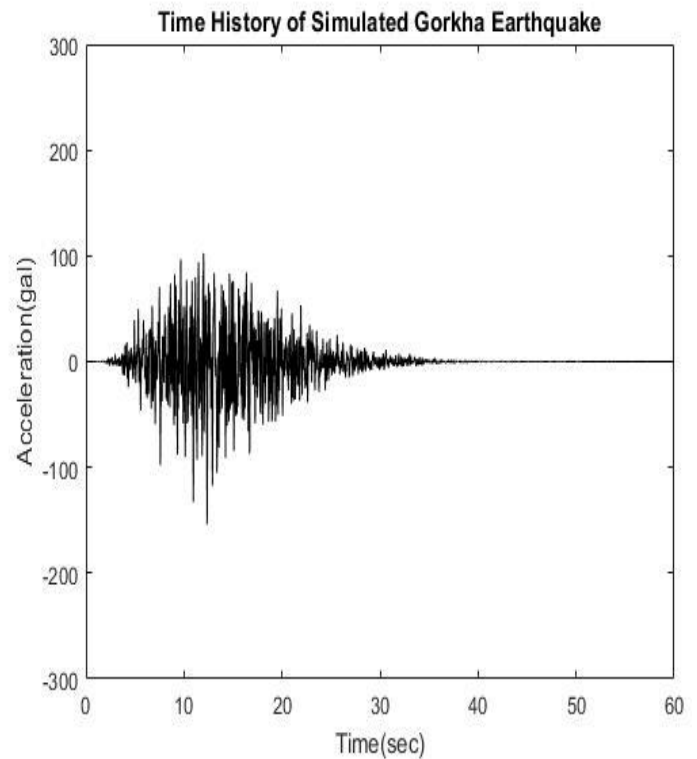
B. SIMULATED Time History

Figure 6 Simulated Time History of Gorkha Earthquake

The simulated Time History of Gorkha Earthquake matches with measured Kantipath stations Time History (see Acceleration vs Time in Figure 7, a and c). The parameters used for this simulation are fixed for Kathmandu.
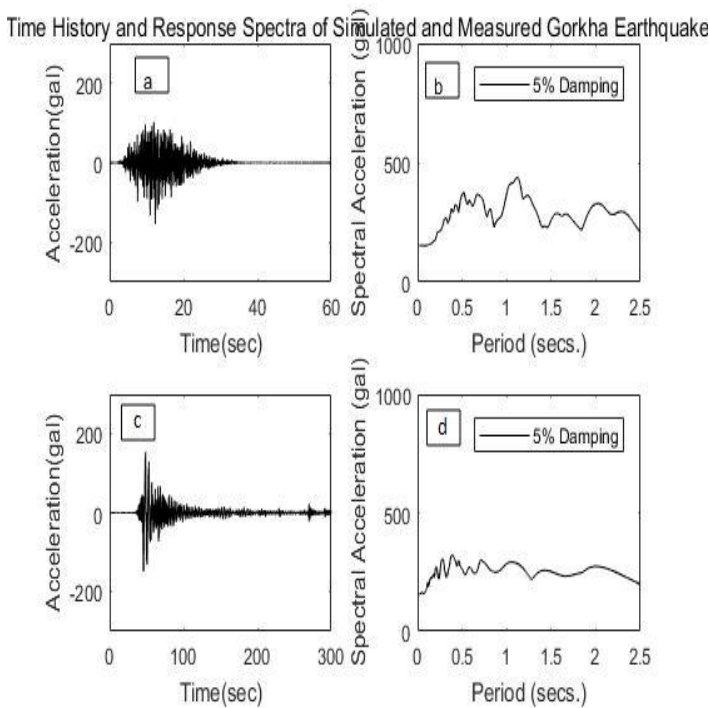
C. RESPONSE SPECTRA COMPARISON

Figure 7 Comparison of Simulated and measured Time History and Respective Response Spectra

The response spectrum describes the maximum response of SDOF system to a particular input motion. Here the simulated time history is the input motion. In addition, 5% damping was used to generate Response Spectra of SDOF and the shape of the response spectra was compared with the generated Gorkha earthquake response spectrum as show on in figure 7.

D. PARAMETERS VALUES USED IN THE TIME HISTORY SIMULATION

The ground motion parameters used in the simulations are as follows:

Magnitude of Earthquake (Mw)   =7.8
Closest Distance Between source to site(R) =82 Km
Stress drop ($\Delta\sigma$)   = 80 Bars
Diminution parameter (Kappa)   = 0.05
Radiation pattern   = 0.55
Maximum frequency   = 30 Hz
Density of Earthquake crust   =2800 Kg/m^3
Shear wave Velocity of rock (v_s) =3.5 Km/sec
Shear wave velocity C_q =0.525 Km/sec
velocity adopted for path effect, which shows that the soil type of the area is Very Dense Soil
Value of quality factor $q(f)$ = $80 * f^{0.45}$

IV. CONCLUSIONS

The research aimed to simulate the Gorkha earthquake Time History through stochastic method. Simulated Time History was compared with the Kantipath station measured Time History of Gorkha earthquake. The comparison showed similarity nature of these two Time Histories, which helped to fix the strong ground motion parameters for Kathmandu. The entire research done using MATLAB programing language to compare, calculate and generation of Figure presented in this research. The different ground motion parameters were used in trial basis to match the generated Fourier amplitude spectra to the target spectra. The time history whose Fourier spectra matched with target spectra is taken as simulated Time History and values used for generation of that time history is the strong motion parameters values for Kathmandu.

V. LIMITATION

Some limitations have been identified during the research work, which are listed below.

1 The matching of spectra and other iteration calculations are based on the judgement rather than is fixed by the program.
2 The Fourier Spectrum and each Time Series realization may diverge from the "target" Fourier spectrum $Y(Mo, R, f)$.
3 In stochastic method, various components of motions and different wave types were ignored.
4 The stochastic method is empirical method, which adopts many assumptions.

VI. Acknowledgment

We thank all those people who directly and indirectly helped us in this research.

REFERENCES

Amod Mani Dixit, A. T. (2015). *Strong-Motion Observations of the M 7.8 Gorkha, Nepal, Earthquake Sequence and Development of the N-SHAKE Strong-Motion Network* . Seismological Research Letters Volume 86, Number 6 .

Boore, D. M. (2003). Simulation of Ground Motion Using the Stochastic Method. *Pure and Applied Geophysics*, 635-676.

Hari Parajuli1, J. K. (2008). Design Earthquake Ground Motions From Probabilistic Response Spectra: Case Study Of Nepal. *Journal of Japan Association for Earthquake Engineering, Vol.8, No.4*, 16-28.

McGuire, R. K. (2004). Estimating Earthquake Ground Motion. In R. K. McGuire, *Seismic Hazard and Risk Analysis* (pp. 71-104). Earthquake Engineering Research Institute.

N. Upreti, A. M. (2012). Raising Earthquake Awareness in Kathmandu Valley:. *15 WCEE,Lisboya 2012*.

Nobup Takai, M. S. (2016). Strong Motion in the kathamndu
    Valley during the2015, Gorkha Nepal, Earthquake.
    Earth Planet and Space.
YoshifumiYamamoto. (2011). *Stochastic Model For Earthquake
    Groundmotion Using Wavelet Packets.*

.

Second Author Er. Pragnyan Ghimire, Master of Earthquake
Engineering, Khwopa Engineering College, Nepal,
pragnyan24@gmail.com

AUTHORS

First Author – Dr, Hari Ram Parajuli, PHD (Engineering),
Associate Professor, Institute of Engineering, Pulchowk Campus,
Nepal, hariparajuli@ioe.edu.np