Prediction of response spectral parameters for Bhuj earthquake (26th January 2001) using a component attenuation modelling technique

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Abstract

The M_w 7.7, Bhuj earthquake that occurred in the north-western fringes of the Indian subcontinent is regarded as one of the most devastating earthquakes of the stable continental regions (SCR). Although the Kutch region has experienced the events of large and moderate magnitude since historic times, yet the estimation of future design basis have remained hampered by lack of ground motion data. A recently developed methodology of Component Attenuation Modelling (CAM) is adopted to estimate the response spectral values. The technique is a modified version of the orthodox stochastically based simulation model, and predicts design structural responses directly by adapting local seismological information, for the regions lacking earthquake records. A dataset of 13 Structural Response Recorders (SRRs) stationed at various location from the epicentre is utilized for purpose of validation, due to absence of Digital Strong-Motion Accelerograph (DSA) records. The stations are categorized in three schemes: Quaternary, Tertiary and Rock; based on NEHRP classification. The wave propagation behaviour of the crust is assumed to resemble with Coastal Region of South China (CRSC), considering the geological setting and wave transmission qualities of both regions. The observed recordings reconcile well with predictions of CAM in the bandwidth of available time periods on the rock sites. The absence of recordings in displacement and acceleration controlled regimes restricts to assess the performance of the technique in all period ranges. The exercise not only helps achieve the design parameters for the subject region, but also assesses the applicability of CAM to the regions of low to moderate seismicity.
Keywords: component attenuation modeling, Bhuj, stochastic simulation, structural response recorders, stable continental regions, design response spectra.

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1 Introduction

Unfortunately January 26th, 2001 Bhuj Earthquake can be registered as one of the most devastating earthquakes in the history books of Indian subcontinent. The earthquake epicenter resided near Bhachau city at 23.40° N, 70.28° E (India Meteorological Department (IMD)), with M_w =7.7 and hypocentral depth of 23.6 km (data by USGS). The event has recurred after a span of one and half century in the vicinity of epicenter, as an earthquake of similar magnitude struck the region on June 16th 1819.

The event is regarded as one of the huge earthquake in the plate-interior settings, though there exists a debate whether the earthquake was intraplate or interplate. The epicenter of the event lied at a distance of 200-400 km from the active plate boundary zone, between subcontinent and Asian plate Lozios et al. [1]. Li et al. [2] developed a viscoelastic finite element model to simulate the stress within the lithosphere of western India to investigate the cause of Bhuj earthquake and concluded that the cause of event can be attributed to the intracontinental thrusting and shearing along the northwestern Indian plate boundary.

Various different methodologies for prediction of peak ground accelerations have been employed by the researchers Singh et al. [3], Hough et al. [4], Cramer and Kumar [5] and Iyengar and Raghu Kanth [6] to develop future design basis for engineering structures. This paper presents the application of Component Attenuation Modeling (CAM) technique to predict design responses of systems with varying natural time periods. The predicted values have been testified with the Structural Response Recorders (SRR) values. CAM provides an edge to the other methods to predict SRR values owing to its simplified input and direct relation with the design response spectra. The research endeavor provides an opportunity to assess the capability and versatility of CAM for evaluation of design basis for the regions with low to moderate seismicity, and also acts as a major step towards the seismic hazard assessment of the Southern Coastal Region of Sindh, (SCRS) Pakistan.

2 Available data

The event remained least recorded in the near vicinity of the ruptured fault, though the broad band velocity records are available from Bhuj observatory. The strong motion recordings are available from the Digital Strong motion Accelerographs (DSA) located in Ahmedabad city which is 238 km away from the epicenter. Even these far-field recording lack the authenticity to be used in the validation of earthquake estimation methodologies, due to expected contamination in the ground motion recordings, as the accelerograph was situated on the 10th floor of a high rise building.

The only reliable source of recordings for the M_w = 7.7 event is Structural Response Recorders (SRR) data. The instrument recorded the acceleration response of the pendulum at varying natural time periods at a fixed damping ratio of 5%. There exist thirteen such instruments recording within the radius of

300 km from the epicenter; the instruments were stationed at the ground floor of one or two story buildings. Data is taken from the Cramer and Kumar, [5] as shown in Table 1; and similar soil conditions are assumed at the recording stations, which are based on the NEHRP recommendations.

Table 1: Showing the SRR values at three time periods having damping ratio of 5%.

Epicentral Distance (km)	Sa-5% Damped			Site Condition
	0.4 sec	0.75 sec	1.25 sec	
44	1.616	0.705	0.423	T
53	0.863	0.571	N. A.	T
97	0.811	0.65	0.300	Q
147	0.72	0.216	N. A.	T
150	0.181	0.065	0.023	R
166	0.220	0.152	0.072	R
188	0.211	N. A.	0.058	Q
207	0.191	0.248	0.054	Q
216	0.187	0.063	0.023	R
225	0.096	0.066	0.028	R
238	0.288	0.230	0.219	Q
266	0.488	0.041	N. A.	Q
288	0.144	0.061	0.045	Q

3 Component Attenuation Modelling (CAM)

CAM is the modified version of the stochastic simulation method which incorporate wave attenuation model developed by Boore [7]; it takes into account various effects that a wave undergoes during its travel from source to site to predict a Design Response Spectrum for direct use of engineering applications, Chandler and Lam [8], Lam and Wilson [9], Chandler et al. [10] and Lam and Wilson [11]. The intrinsic philosophy of CAM is not new, as similar methodology was adopted by Newmark and Hall [12] to develop normalized response spectral model, based on the strong motion observations of Californian earthquakes. The concept was modified to incorporate the source zone models and ground motion attenuation relations to predict the spectral acceleration values by Atkinson [13] but such models are deficient in providing multiple probability of exceedance. Atkinson and Boore [14] also attempted to predict response amplitudes using constant stress parameters for ENA conditions.

CAM is based on the important finding of Atkinson and Boore [15] that there exists a similarity in the average frequency characteristics of seismic waves generated at the source between ENA and WNA. Generic earthquake source behavior is also validated by Beresnev and Atkinson [16], using extended-source models of the ruptured fault. The parametric study indicates that the differences in the ENA and WNA motion primarily results from path-related modifications, namely the mid-crust amplification and the combined effect of the upper-crust amplification and attenuation. The observation led to development of a generic model that forecasts peak spectral ordinates, with simplified input parameters of the subject region. The peak responses are used to develop design response spectra, detailed procedure can be referred from Lam et al. [20]. The concept has been successfully applied for seismic hazard assessment of different regions Chandler and Lam [17, 18] and Lam et al. [19].

$$\Delta = 0.78\Delta^* \alpha(M) G(R) \beta(R) \gamma(crust) \qquad (1)$$

where,

$\Delta =$ Response spectral parameter of interest ($S_{Dmax,}$ S_{Vmax} and S_{Amax})
$\Delta^* =$ Constant pertaining to spectral parameter of interest
$\alpha(M) =$ Source factor
$G(R) =$ Geometric factor
$\beta(R) =$ Anelastic attenuation factor
$\gamma(Crust) =$ Upper crust factor, product of C_m and C_u for mid-crust amplification and combined upper crust amplification and attenuation.

4 Spectral values predictions using CAM

A very simplistic methodology is adopted to estimate the responses due to the earthquake event. Based on the data achieved it can be deduced that the surficial geology of the SRR stations can be grouped into two types viz. rock and surficial soft deposits. Parameters for upper crust attenuation and amplification will vary, whereas other factors affecting the strong ground motion will remain constant. Therefore two separate analyses are performed with different parameters and compared with the recorded data. The results presented hereafter in tabular as well as graphical form are the output of HAZCALc [21]. Software is developed by the authors to predict earthquake ground motion parameters using multiple methodologies including stochastic simulation that incorporate point and finite fault source models, it also possess the capability to perform ground response analysis using linear as well as nonlinear models of soils.

4.1 Prediction for rock sites

The source factor presented in the model is dependent on the magnitude of the earthquake, which is taken as 7.7 and spectral quantity of interest. The mid crust of the region consists of the Pre-Cambrian crystalline basement and exhibits higher frequency content and the upper crust presents a thick Phanerozoic sedimentary sequence Lozios et al. [1], which might lead to amplification due to transmission of waves from hard rock to soft sedimentary formations and simultaneous attenuation in the upper crust can be anticipated, even though literature review reveals that ENA crustal conditions have been assumed explicitly to capture mid crust and upper crust wave propagation behavior. Cm and Cu parameters used to predict spectral values have been found to resemble the crustal condition of CRSC that assumes 30% amplification in maximum spectral parameter as compared to ENA conditions. The thickness of the crust is taken to be 40 km; hence geometric attenuation function for ENA conditions is adopted.

Table 2: Predicted results by CAM at rock sites.

Distance (km)	**Sa/g Values**			**Corner Periods**		**Peak Spectral Parameters**		
	0.4	**0.75**	**1.25**	**T_1**	**T_2**	**SD_{max}**	**SV_{max}**	**SA_{max}**
150	0.192	0.102	0.060	0.17	1.97	37.77	0.12	0.465
166*	0.176	0.094	0.056	0.17	2.03	35.54	0.11	0.411
216	0.144	0.077	0.046	0.190	2.18	30.11	0.09	0.287
225	0.128	0.068	0.041	0.200	2.210	29.31	0.08	0.27

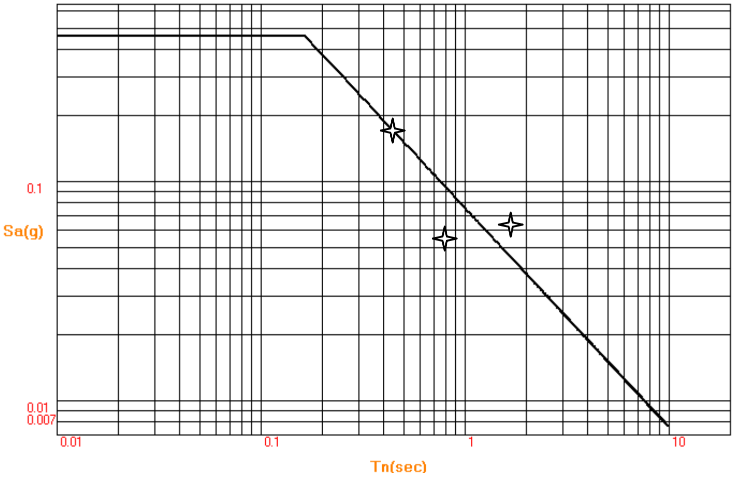

Figure 1: Illustrates the predicted DRS v/s SRR values at the distance of 150 km.

A typical downward trend can be visualized in the recorded spectral ordinates with gradual increase in distance and with increasing time period of response recorders at all distances at the bedrock. Except for the recording at the distance of 166 km away from the fault, this exhibits certain amount of amplification characteristics (as shown in Table 1). CAM forecasts the recorded values to be in the intermediate range i.e. velocity controlled regime characterized by constant velocity in the design response spectrum.

Comparison between the observed and recorded values at the rock site shows that the recorded values are in overall agreement with the predicted values of CAM, except for the distance of 166 km (as shown in Figures 1 and 2). The discrepancy in the observed recordings at this distance may be due to use of the geological map of very large scale i.e. 1:2,000,000; that create a lot of uncertainty Cramer and Kumar [5].

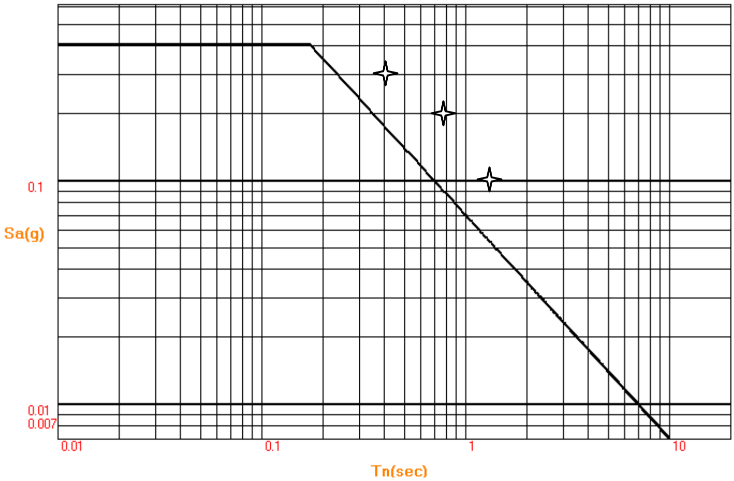

Figure 2: Illustrates the predicted DRS v/s SRR values at the distance of 166 km.

4.2 Prediction for tertiary and quaternary sediments

The overall prediction at the sites classified as Tertiary and Quaternary sediments are under predicted by the applied technique (as presented in Tables 3 and 4). The recorded values are almost five and half times higher than the forecasted values of CAM in certain regions.

Table 3: Comparison of observed and predicted parameters on tertiary sediments.

Distance (km)	**Sa (g) Values Observed**			**Sa (g) Values Predicted**			**Ratio Observed/Predicted**		
	0.4	**0.75**	**1.25**	**0.4**	**0.75**	**1.25**	**0.4**	**0.75**	**1.25**
44	1.616	0.705	0.423	0.416	0.222	0.133	3.88	3.17	3.18
53	0.863	0.571	N.A.	0.336	0.179	0.107	2.56	3.18	N.A.
147	0.72	0.216	N.A.	0.192	0.102	0.061	3.75	2.19	N.A.

Table 4: Comparison of observed and predicted parameters on quaternary sediments.

Distance (km)	Sa (g) Values Observed			Sa (g) Values Predicted			Ratio Observed/Predicted		
	0.4	**0.75**	**1.25**	**0.4**	**0.75**	**1.25**	**0.4**	**0.75**	**1.25**
97	0.811	0.65	0.300	0.272	0.145	0.087	2.98	4.48	3.44
188	0.211	N.A.	0.058	0.16	0.085	0.051	1.46	N.A.	1.26
207	0.191	0.248	0.054	0.144	0.079	0.046	1.32	3.14	1.17
238	0.288	0.230	0.219	0.128	0.068	0.041	2.25	3.38	5.34
266	0.488	0.041	N.A.	0.114	0.061	0.036	4.28	0.67	N.A.
288	0.144	0.061	0.045	0.104	0.055	0.033	1.38	1.11	1.36

The highest value can be seen in Table 4, for the observation at the distance of 238 km that means instrument was positioned in Ahmedabad city, which was the worst affected due to earthquake. The prediction can be compared and confirmed with the ground response analysis study performed by Raju and Sitharam [22]. Moreover ground motion seems to have been amplified appreciably in near source zone. Variety of methods can be applied to incorporate the amplification due to presence of soft soil at the sites, but that is not the focus of this study.

5 Conclusion

Though the strong ground motion data remains at scarce for this region, especially for the earthquake of Bhuj, the SRR values are utilized to validate the technique. The recorded values remain in sound agreement with forecasted values of the modeling technique; adopted in the paper for the rock site in the available period ranges. Where as the prediction on tertiary and quaternary sediments are under predicted by the model, due to amplification of shear waves in the surficial soil deposits.

The most comprehensive method for assessing the applicability of the methodology adopted in this paper could be to use the recorded accelerograms, along with the exact details site geology of the recording station of the instrument. The undertaken research effort is unable to study the design response ordinates at all period ranges of interest and corner periods of the predicted spectrum due to unavailability of strong ground motion accelerographs. In addition to this detailed crustal modeling of the subject region is also envisaged to reduce epistemic uncertainty in the results, by utilizing the most realistic parameters to reasonably account wave path modification factors.

It should also be considered that CAM is based on seismological models based on point-source assumption of fault; where as the length and orientation of the ruptured fault is not taken into account. Therefore method needs to be more rigorsly verified in conjunction with orthodox stochastic simulation of updated source models, before adapting for this region.

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