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WEB APPLICATION FOR GENERATION OF SHAKE MAP: A CASE STUDY ON VIJAYAWADA CITY, INDIA

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Abstract

Strong earthquakes cause a great damage to buildings and other infrastructure. It is difficult to get an overview of the situation immediately after an earthquake, to facilitate the initiation of appropriate emergency and rescue measures. Shake map provides early information on the intensity of ground shaking in a location. This data will be useful to help authorities and rescue workers for planning their work.

For the purpose of study, Vijayawada city, India has been selected to generate shake map. Peak ground accelerations (PGA) are generated using ground motion prediction equations (GMPE) and the shaking intensities are also estimated for Vijayawada city. A tool for shake map has been generated using php applications. Map generation is automatically triggered by any earthquake in the vicinity of Vijayawada region and the map will be available for the public and government for post-earthquake decision making.

Keywords: Shake map; GMPE; Vijayawada; Attenuation relationships; Site correction;

1. Introduction

Just after the event of an earthquake the most important information required is the damage pattern in areas of influence for the mitigation purpose. Currently government has to rely on media coverage to provide rescue and relief to the areas which sustain most amount of damage by an earthquake. Shake maps prove to be vital in those situations providing a rapid access to the extent of shaking and its damage to particular area. Shake map is designed to rapidly produce shaking and intensity maps for use by emergency response organizations, local, county, State and Federal Government agencies, public and private companies and organizations, the media, and the general public.

A shake map is a representation of ground shaking produced by an earthquake. With the help of magnitude, epicenter of an earthquake a shake can be generated immediately. Shake map focuses on the ground-shaking produced by the earthquake, rather than the parameters describing the earthquake source. So, although an earthquake has one magnitude and one epicenter, it produces a range of ground shaking levels at sites throughout the region depending on distance from the earthquake, the rock and soil conditions at sites, and variations in the propagation of seismic waves from the earthquake due to complexities in the structure of the Earth's crust.

In this study a tool is created which generates shake map for Vijayawada city which involves generation of ground motion estimation maps and a separate seismic intensity map using the available data epicenter and magnitude of the earthquake. These maps can serve to direct the search and rescue teams to the areas most needed and assist civil protection authorities in emergency actions.

These maps allow the portrayal of the extent of potentially damaging earthquakes in the Vijayawada region. Map generation is automatically triggered by any earthquake in Vijayawada region and the map is available for the public and governmental for post-earthquake decision making and they are made available immediately after an earthquake over the Internet.

Recent development in the area of Ground Motion Prediction Equation has made possible generation of such maps. These equations use the earthquake defining parameters to provide with the ground shaking. These GMPEs gives the shaking at bed rock level. So in order to get the shaking at surface level, site based corrections are also applied in the equation.

2. Study area

The study is on preparation of shake map for Vijayawada city, which is the second most populated city in Andhra Pradesh. It is one of the commercial hubs of Andhra Pradesh. Also, it is at a distance of approximately 40 km from the upcoming city capital Amravati, so the same study stands valid for Amravati also.

Vijayawada is also the only city falling under Seismicity Zone III, while all others fall under Zone II in Andhra. In the proximity of 150 km radius of Vijayawada city there are four major sources of earthquakes as per the Geological Survey of India (GIS). There have been more than 160 earthquakes in the Vijayawada region till date. Table 1 shows some of the faults and lineaments around Vijayawada city at 300km radius as taken from SEISAT 2000[1].

3. Attenuation of ground motion in South India

Ground Motion Prediction Equations or attenuation relationships, provides mode of predicting level of ground shaking and its associated uncertainty at any given site or location, based on an earthquake magnitude, source-to-site distance, local soil conditions, fault mechanism, etc. GMPEs are efficiently used to estimate ground motions for use in both deterministic and probabilistic seismic hazard analyses.

In order to find out the Peak ground acceleration (PGA) at any point, attenuation equations are used. They are crucial in generation of shake maps in absence of field instruments; the accuracy of these equations determines how accurate the results of shake map will be. Contour plots of these ground motion tells us about the ground motion variability in the area. It is also used to create the intensity map.

Out of several GMPEs we selected GMPE proposed by Raghukanth and Iyenger[2] as it gave the best results when compared with some actual PGA values for Vijayawada region using earthquake catalogues[1],[3],[4]

$$\ln(y) = c_1 + c_2(m-6) + c_3(m-6)^2 - \ln r - c_4 r + \ln(\varepsilon_{br}) \tag{1}$$

Eq.1 is the proposed equation for PGA for South India region; where *y* refers to PGA in *g*, *m* refers to magnitude of earthquake and *r* is the hypocentral distance of the earthquake. $\ln(\varepsilon_{br})$ represents the error associated with the regression done for obtaining the equation. The value of *r* is calculated as:

$$r = \sqrt{r_{ep}^2 + d^2} \tag{2}$$

It is clear from the above equation that we also need the focal depth for calculating the PGA value of the earthquake along with the latitude and longitude of the epicentre and magnitude of the earthquake. The value of the constants c_1, c_2, c_3, c_4, and, $\ln(\varepsilon_{br})$ are proposed as 1.7816, 0.9205, -0.0673, 0.0035 and 0.3136 respectively according to the Raghukanth and Iyenger.

As show in Fig. 1 the curve for GMPE equation used in our study is compared with other GMPEs with similar site conditions for moment magnitude of 6. For the comparison, 4 other relations by Atkinson and Boore(1995)[5], Hwang and Huo(1997)[6], Dahle, Bungum and Kvamme(1990)[7] and Campbell(2003)[8] have been used. They are almost similar as they all are derived in similar manner and shows that for similar site conditions the equation followed by us is also satisfactory.

Table 1 – Faults and Lineaments in 300km around Vijayawada

S.No	Faults/lineaments	Length(km)	Lat(start)	Long(start)	Lat(end)	Long(end)
1	Kaddam fault	301	76.618	20.678	79.324	18.827
2	Musi lineament	296	78.337	17.526	80.997	17.245
3	Kinnerasani godavari fault	188	79.305	18.718	80.993	17.354
4	Godavari valley fault	211	79.651	19.746	80.972	17.849
5	Kolleru lake fault	72	80.868	17.026	80.487	17.672
6	Chandragutti-kurnool lineament	332	74.996	14.593	77.983	16.163
7	Bennihalla lineament	271	75.523	15.766	77.964	16.566
8	Raichur-nagar karnool fault	181	77.354	16.368	78.977	16.576
9	Gani-kalva fault	91	77.597	15.508	78.409	15.751
10	Pyapalli fault	25.5	77.711	15.319	77.944	15.233
11	Karkambadi-swarnamukhi fault	93	79.283	13.654	80.112	14.101
12	Karempudi-nakirekallu lineament	145.4	79.533	16.195	80.84	16.124
13	Bhavanasi river fault	82.14	78.092	16.18	78.831	15.947
14	Tirumala fault	24	79.315	13.653	79.414	13.865
15	Gundla kamma fault	76	79.51	16.473	80.066	15.788
16	Addanki-nujividu fault	45.51	80.064	15.746	80.35	16.153
17	Badvel fault	44.4	79.342	14.659	78.942	14.928
18	Nallavagu fault	41	78.611	16.379	78.985	16.295
19	Papaghani fault	39	78.61	14.43	78.957	14.763
20	Kadiri fault	35.52	78.003	14.031	78.321	14.323
21	Armakur fault	32	78.47	15.874	78.751	15.761
22	Rudravagu fault	26	78.811	16.052	79.046	16.055
23	Nekkantivagu fault	22	78.591	16.284	78.788	16.233
24	Gulcheru fault	20	78.494	14.251	78.668	14.337
25	Nizampatnam nagayalanka fault	27	80.561	15.939	80.802	16.008
26	Vasishta-godavari fault	59	81.439	16.405	81.969	16.633

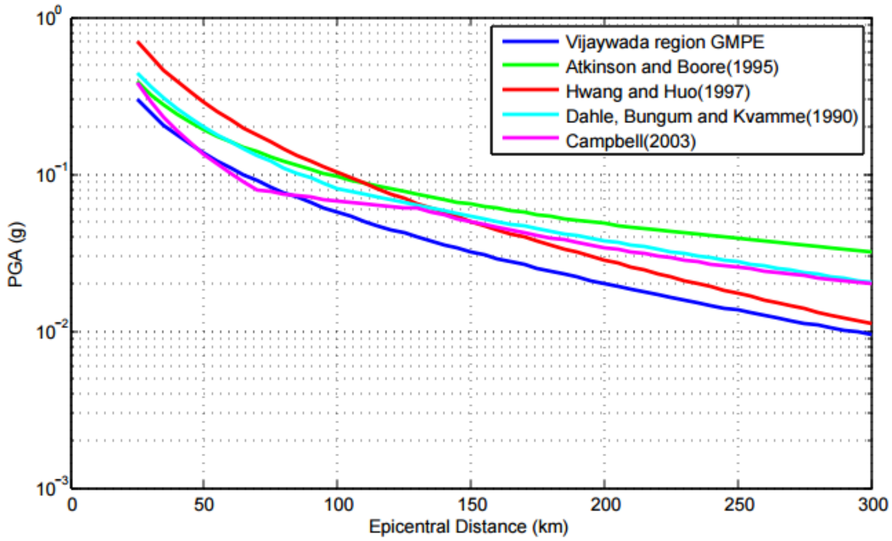

Fig. 1 – Comparison of attenuation relationships (at bedrock level).

Comparison of the Iyengar and Raghukhant attenuation relationship was carried out with three other attenuation relationships for Peninsular India and its nearby region (Dunbar et al (2003)[9], Amit and Narayan (2012)[10], and NDMA technical report (2011)[11]). It can be observed from the Fig. 2 that the predicted PGA values are almost similar for all the attenuation relationships. Thus the Iyengar and Raghukhant attenuation relationship is considered to create shake map in this study.

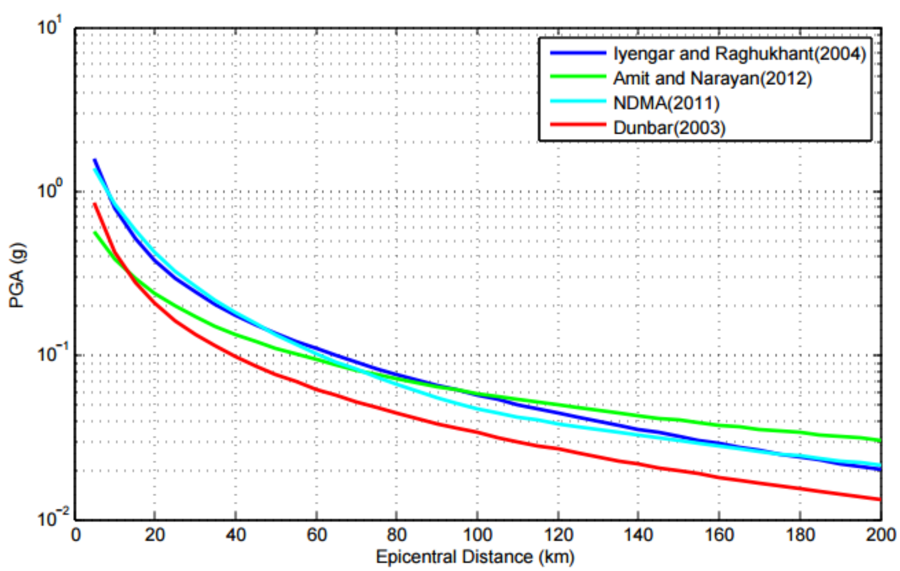

Fig. 2 – Comparison of attenuation relationships for PI (at bedrock level).

4. Site Correction

Generally GMPEs give the PGA value at bedrock level, whereas the surface peak acceleration is affected by local site conditions. These site effects for different site categories can be considered with the help of their respective site coefficient.

Borcherdt et al. (1991)[12] demonstrated the correlation between the average shear wave velocity of the upper 30m of site (V_{30}), and ground motion amplification. This has been in practice as per NEHRP program[13], and the current approach categorizes the soils into class A, B, C, D, E and F on the basis of average shear wave velocity of the upper 30m of site. Table 2 shows the site classification used by NEHRP (BSSC 2003). Class E and F have least average shear wave velocity and they are most prone to liquefaction and failure.

Table 2 – Soil type classification

Site Class	**Description**	**Average shear wave velocity (V_{30} in m/s)**
A	Hard rock	> 1500
B	Rock	Between 760 and 1500
C	Very dense soil and soft rock	Between 360 and 760
D	Stiff soil	Between 180 and 360
E	Soft Clay	≤ 180
F	Soils requiring site-specific evaluations	-

Raghukanth and Iyenger established a relationship between these site categories and their site coefficient except for class E and F because they are prone to liquefaction and failure. The site coefficient F_s (s = A, B, C, and D) which is the ratio of the spectral acceleration value of a site category to that of the bedrock site. Eq. (1) is the proposed equation for the site coefficient (F_s) where y_{br} is the peak bedrock acceleration in unit of g, a_1 and a_2 are regression coefficients.

$$\ln(F_s(T)) = a_1(T)y_{br} + a_2 + \ln\delta \tag{3}$$

The site coefficient values for different site conditions are shown in Table 3. For a given site category the surface PGA value is calculated by multiplying the bed rock level PGA with the respective site coefficient (F_s). We calculate the surface PGA values for all the sites where soil data is available and then using these PGA values the final contour with site correction is generated.

An option to accept the site borehole data provided by the verified users is included. The entire user provided data is checked and stored in the database for future site corrections.

Table 3 – Site coefficient values for Vijayawada Region[2]

Site Class	a_1	a_2	$\sigma(\ln\delta)$
A	0	0.36	0.03
B	0	0.49	0.08
C	-0.89	0.66	0.23
D	-2.61	0.80	0.36

5. Web application

The web application is written in php, HTML, and CSS. Users can subscribe, to get any latest earthquake shake map. In case of an earthquake, map is automatically generated and made available for the mitigation purpose which can be downloaded or previewed on site itself.

It provides an option to submit an earthquakes epicenter, magnitude and depth for which shake map will be generated and will be available for download. So, using this we can generate shake map for any past earthquakes with known epicenter, magnitude and depth.

The web application is user-friendly. A user can find the PGA and intensity value of any point in the Vijayawada city region by selecting that point on a map displayed on the web page or either by specifying the place name or even also by giving its latitude and longitude.

5.1 Shake map creation

The web application generates the shake map in the following manner:

i. A mesh over the Vijayawada region is created.

ii. It takes input the earthquake parameters i.e. magnitude, epicenter and depth.

iii. Computes the PGA at bedrock level using the GMPEs at every grid point.

iv. Applies site correction to all the grid points for which data is available.

v. Finally, peak acceleration and intensity contours are generated.

6. Examples

Shake map of some past earthquakes at bed rock level as we are in process of collecting the soil data for the city. Fig. 2 and Fig. 3 show the variation of PGA value at bedrock level for 1969 Bhadrachalam earthquake and 1987 Ongole earthquake respectively.

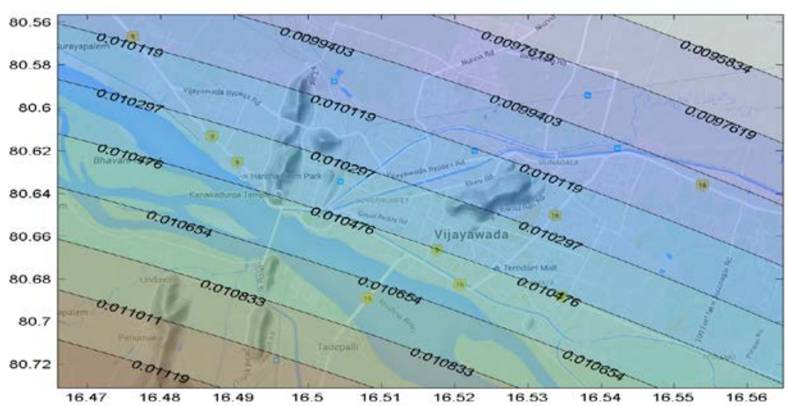

Fig. 2 – Example of Vijayawada city shake map: PGA(g) map for Ongole earthquake (1987), Mw = 4.6, Epicenter at 15.525, 80.246, Depth = 20 km. The PGA values shown in fig are in g m/s2 (9.81 m/s^2).

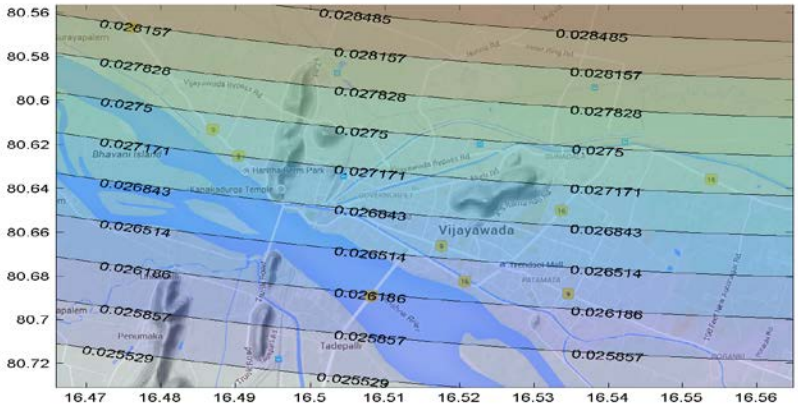

Fig. 3 – Example of Vijayawada city shake map: PGA(g) map for Bhadrachalam earthquake (1969), M_w = 5.7, Epicenter at 17.747, 80.775, Depth = 20 km. The PGA values shown in fig are in g m/s2 (9.81 m/s^2).

In both the examples the variation of the peak acceleration is not significant. For Ongole earthquake the PGA values varies around 0.01g and for Bhadrachalam earthquake it is 0.026g. Instrumental intensity of these two earthquakes comes out to be III and IV for Ongole and Bhadrachalam earthquakes respectively. The potential damage because of such low intensity is negligible and even there was no damage recorded because of these earthquakes in Vijayawada city.

7. Conclusion

Vijayawada is an area of moderate seismicity with very few strong motions and somewhere 26 faults and lineaments in its surrounding. In the absence of instruments to measure the ground motion, the study stated and implemented a method to create shake maps using attenuation relationships with appropriate site corrections. This tool provides an interactive UI for generation of shake map showing approximate damage pattern in Vijayawada city in absence of any on-site instruments for recording and transmitting the real time data.

This methodology for generation of shake map can be generalized to be used to generate shake maps for any place alongside with on-site instrumental data also. We could have instruments on sites and get real time data from there and since instruments can't be present at all the points we could generate the PGA or PGV values using attenuation relationship for those inaccessible areas with adequate site corrections. This will provide a more reliable source showing extent of damage in an area. The same system can be used to implement shake map generation for any other area also in case if instrumental ground motion is also not present there with the change in GMPEs and site coefficients.

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