PROBABILISTIC SEISMIC HAZARD ASSESSMENT METHODOLOGY AND SITE RESPONSE ANALYSIS APPLICATION TO SEISMIC MICROZONATION.

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ABSTRACT: *Seismic hazards are earthquakes and seismically induced natural devastating and sabotage phenomena. Their effect can be horrible on especially man build structure resulting in severe impact on human life. Seismic microzonation is the delineation of areas geographically having dissimilar potential for earthquakes hazardous effects on the basis of site dynamic properties like peak ground acceleration, peak ground velocity or spectral acceleration. The local site conditions strongly influence the dynamic site properties. The probabilistic seismic hazard analysis are carried out to estimate the synthetic ground motion at bed rock. Local soil conditions are incorporated in microzonation studies to obtain local site response at top soil. The soil properties are obtained through site characterization. The methodology for site characterization is comprised of shallow geotechnical and geophysical studies. The most common geophysical techniques for site characterization are based on the inversion of surface wave data. Multichannel analysis of surface waves (MASW) is one of most widely accepted technique. The ground motion at bed rock, soil properties, and strong motion time history serve as input to carry out site response analysis .In case of absence of strong motion database, spectral matching is carried out to generate strong motion time history. The site response analysis provide accurate dynamic site parameters at soil top. These parameters are spectral acceleration at various frequencies and ground amplification factor. The results are interpolated to generate what is called the microzonation maps.*

Key Words: Seismic Hazard Assessment, Site Characterization, Site Response Analysis

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1 INTRODUCTION

Seismic microzonation endeavors to improve seismic hazard estimates by including detailed information on earthquake site response across a city or region because the level of seismic ground shaking is strongly influenced by local site conditions. The variation in spatial distribution of earthquake response can cause dramatic changes in the severity of damage to constructions (1).

The accurate assessment of seismic hazard risk at the local site level is strongly influenced by local geology (2-7). The subsoil structure controls the variation in damage and ground motion over relatively short distances (8). The few of worst historical examples are 1985 Michoacan, Mexico event, 1988Spitak, Armenia event and the 1989 Loma Prieta earthquake (9) and Dinar, Turkey earthquake (10, 11). The local site conditions influence on ground motion and damage pattern is evident from these examples(12).

The basic approach in microzonation actually comprised of three elements, probabilistic seismic hazard assessment, site characterization and site response analysis (Figure 1). The probabilistic seismic hazard assessment (PSHA) provides time series for the specific return period. The site characterization enables to incorporate local soil effects. The ground response analysis provided the soil amplification and acceleration at various spectral periods.

PSHA results are deaggregated to select an appropriate earthquake scenario with specific distance to the site and magnitude. This earthquake scenario is also termed as a controlling earthquake scenario. This information is then utilized to make a spectral matching to obtain strong ground motion record for site compatible with calculated time histories.

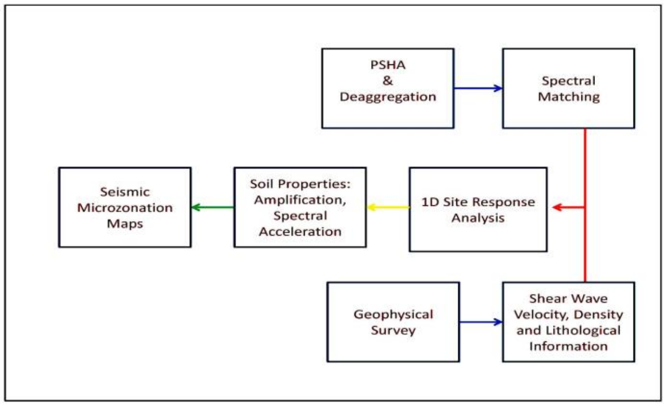


Figure 1: Generalized flow chart for Seismic Microzonation

Beside spectral matching, geophysical and geotechnical techniques are employed for site characterization. Surface wave analysis techniques are mainly used. The first 30 meters shear wave velocity and density information is obtained by surface waves. These three parameters spectral matching results, shear wave velocity, density and lithological information are then combined into software called SHAKE 91.

The shake 91 provides ground motion parameters on top of the soil surface. These parameters include ground amplifications and spectral acceleration at various frequencies. The simplified flow charts is given below.

2 PROBABILISTIC SEISMIC HAZARD ASSESSMENT (PSHA)

Probabilistic seismic hazard analysis (PSHA) is a methodology that provides a basis for the determination of ground motion characteristics by incorporating regressions on ground motion metrics from past recorded earthquakes of known seismic sources, propagation paths and local site conditions(13). Seismic hazard assessment is carried out by the probabilistic scheme is mainly based on the historical seismicity and recorded earthquake motion data (14-16).

The assessment of ground motion probability takes into the account of the earthquake occurrence frequency for diverse magnitudes on the seismogenic zones, the ambiguity of the epicenter locations of these zones, and the attenuation of ground motion together with its uncertainty(17, 18). Cautious thoughtfulness is a requirement also for output utilizations; especially, understanding of employment of PSHA in the present practice of engineering design(19).

A basic approach in calculating ground motion exceedance for a given time can be estimated using the following equation.

$$\lambda(IM > x) = \sum_{i=1}^{n} \lambda(M_i > m_{min}) \int_{m_{min}}^{m_{max}} \int_{0}^{r_{max}} P(IM > x|m,r) f_{M_i(m)} f_{R_i(r)} drdm$$

where:

P (IM> x, | m r) is put from the ground motion model. f_R (r) and f_M (m) are probability density functions dealing with magnitude and distance pairs. IM is the probability of exceedance intensity level given earthquake from large source. Where the rate of occurrence of earthquakes λ (M >m_{min}) is greater than m_{min} from the source, and λ (IM x >) is the rate of IM >x.

The new PSHA methodologies require information on the regarding energetic, kinematic and geometric parameters of the major active faults.. The definition of seismogenic source model constrained by geological and seismotectonic data, was recently introduced for PSHA methodologies enhancement(20). Figure2 summarizes the basic PSHA methodology.

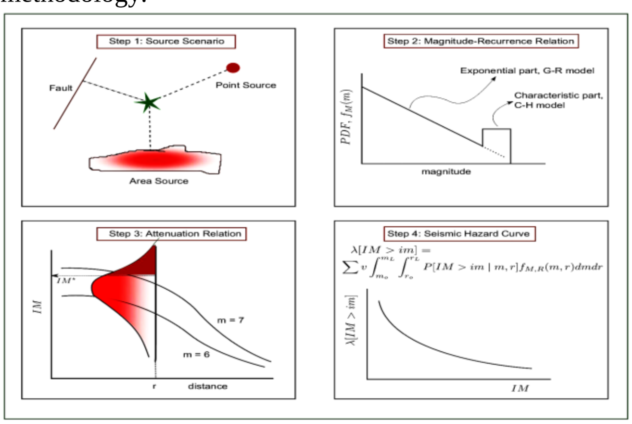


Figure 2: Carton showing various steps of PSHA.

2.1 EARTHQUAKE CATALOG AND RECURRENCE PARAMETER

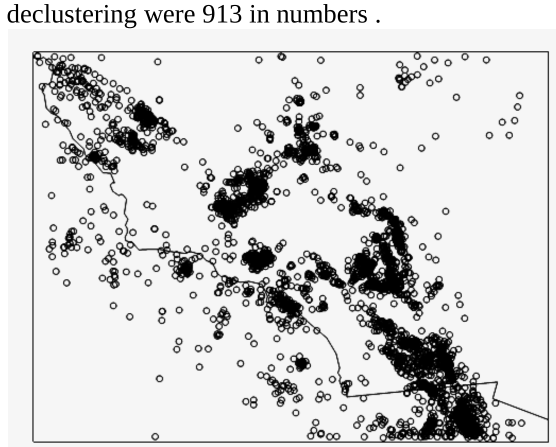
One of the most important products of seismology is earthquake catalogue which provides a broad data set in earthquakes events. This can be used in various analyses associated to seismicity and seismotectonic, hazard assessment and physics of earthquake. The hazard parameters are determined well if the catalogue has longer coverage (21). A homogeneous catalogue is a basic requirement for seismicity analysis in space-time volume and in PSHA (22, 23). Earthquake catalogues are treated by two steps, declustering of earthquake catalogue and determination of the minimum magnitude of completeness. Man-made contaminations and heterogeneity of reporting are present in the catalogue which is strong enough to introduce errors in statistical analyses (24).

Declustering Seismicity is the method to sort out mainshocks, foreshocks and aftershocks in the catalogue and removal of dependent events. Particularly, this technique is applied in earthquake prediction models and seismic hazard assessment (25). The earthquake clusters obscure the analysis, especially statistical for background activity which may emerge as consequent changes in stress field or tectonics (26).

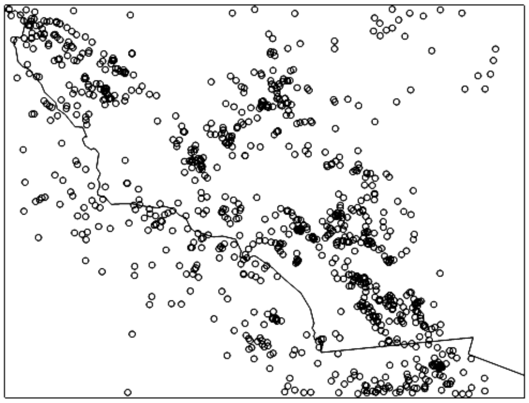
There are several techniques proposed for declustering catalogues. Examples include Knopoff (27), Gardner and Knopoff (28),Keilis-Borok (29),Öncel and Alptekin (30). Reasenberg (31) and Reasenberg and Jones (32) proposed modeling Interaction zone and multifractal analysis techniques formulated by Godano and Caruso (33)and Godano, Tosi (34).

Zhuang, Ogata (26) used a wide-ranging type aftershock sequence (ETAS) model and maximum likelihood to estimate contributions to the total seismicity from the background rate and branching structure. Hainzl, Kraft (35) use the distribution of interevent times to derive a nonparametric estimate of the rate of mainshocks. Barani, Ferretti (36) apply the waveform similarity technique.

Gardner and Knopoff (28) technique is comprised of elimination of contingent events in earthquake catalogue by defining the spatial and temporal coverage of dependent events as dependent on main shock scale. Reasenberg (31) projected a further intricate technique. In this technique, first interaction zone of an earthquake is defined and then an earthquake is considered the element of a cluster if coincide with the previous earthquake interaction zone. The interaction zone size is dependent temporal and spatial elements. This two method is widely used because simplicity in their application. They require a catalogue comprised of fewer parameters such as magnitude location and time. Thus, these methods are applicable to both instrumental and macroseismic catalogues (36). Figures 3a and 3b represent an original and declustered catalogue .SCEC catalogue from1932-2010 having magnitude gretaer than 3.8,comprsied of 3368 events in Southern California was tested byLuen and Stark (37) using Gardner and Knopoff (28). The events left after declustering were 913 in numbers .



(a)



(b)

Figure 3: Declustering using Gardner & Knopoff (1974), a) original b) declustered (Luen and Stark, 2012)

The seismicity of the seismic source zone is described by the means of famous recurrence relationship.

Log N = a - bM

N represents the earthquakes of specific magnitudes (M) or larger per year, *a* is activity rate and defines the intercept of the above equation at M=0. The factor *b* is the slope which depicts the comparative proportion of small and large magnitudes (Figure 4). Beta is the natural log of 10 times the Richter b-value defining the exponential distribution of earthquakes in this source. The overall earthquakes rate in a region is indicated by “a”(38). The numbers of occurrences per years are denoted by lambda $\lambda(X>x)$ when at a site the ground motion parameters X exceeds the given value *x*.

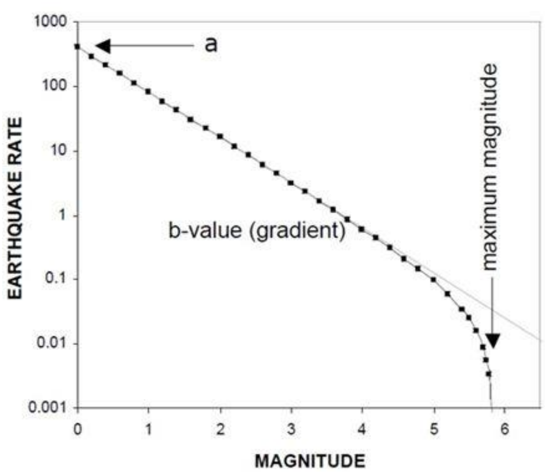


Figure 2.4: Cumulative Magnitude rate (theoretical) plot with presentation of maximum magnitude , a, and b-value.

Two fundamental approaches are used to evaluate the recurrence frequency of earthquake for the particular seismogenic source zone in PSHA. These approaches are termed as historical frequency assessment and geological frequency assessments. The historical frequency assessment utilizes the compiled seismicity catalogue through statistical analysis. Geological frequency assessments are also termed as paleoseismology. The frequency estimation based on seismic moment indeed involves knowledge of average fault slipping rate over a large period of time(39, 40).

A better estimation of the b-value will be inferred when the earthquakes extend over a large compilation of magnitudes. The longer observation episodes will endow with a bigger number of earthquakes reducing the ambiguity in the estimation of recurrence parameters(41).

The Gutenberg and Richter (38) relationship introduces an impractical supposition in which largest size possible earthquake in any zone being studied, is unrestrained and unconnected toward Seismotectonic setting. Kijko and Sellevoll (42), Kijko and Sellevoll (43) extended the Gutenberg-Richter equation from data contain large historical events and recent observation with of different quality and heterogeneity.

2.2 MINIMUM COMPLETENESS MAGNITUDE (MC) AND MAXIMUM MAGNITUDE, (Mmax)

A homogeneous catalogue is a basic requirement for seismicity analysis in space-time volume and in PSHA (22, 23). Man-made contaminations and heterogeneity of reporting are present in the catalogue which is strong enough to introduce errors in statistical analyses (21, 44). Spatial heterogeneity of reported small events occurs because many stations, record small earthquakes that happen near the center of the seismograph and only larger one can be located outside of the network. The detection rate can also change in time and space due to change in configuration and hardware of detecting network (45). In order to overcome this problem minimum magnitude of completeness is mapped. The Completeness Magnitude Mc is defined theoretically as the lowest magnitude at which 100 % of earthquakes are detected in space-time volume. The precise estimation of Mc is critical because higher values of Mc lead to under-sampling, and too low values are erroneous. Mainly catalogue based and network based techniques are applied for Mc estimation (24). Magnitude of completeness is a basic requirement to model seismicity in an area. The maximum curvature (Figure 5) technique mainly used (46) for the completeness magnitude.

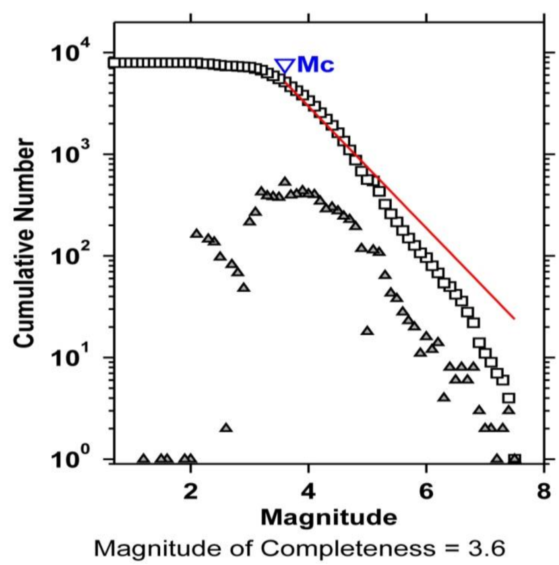


Figure 5: Maximum curvature technique for completeness magnitude determination

Another most important parameter beside recurrence parameters is maximum expected magnitude (Mmax).The seismic hazard assessment is strongly influenced by choice of M_{max}, especially long return period and short distance. No widely accepted methods exist for estimating M_{max}. Several techniques were used in previous hazard studies or estimation of M_{max} among them, regression strain based(47), global statistical models(48). Kikjo (YEAR) proposed techniques which based on numerical approaches to observed seismicity (42, 43, 49, 50). The M_{max} value in probabilistic approach is anticipated solely based upon site area seismological history by using catalogs of a seismic event and suitable statistical assessment process(49).

Kijko (51) discussed defects related to the application of Bayesian method to determine maximum possible magnitude earthquake. Alternatively, the author proposed generic equation based on iterative method. The capabilities of the generic equation include generation of solutions in different forms depending on the historical seismicity available information and/or assumptions of the statistical model. The method advantages also include an application to the incomplete catalogue.

2.3 ATTENUATION RELATIONSHIPS AND PARAMETERS

The next step in hazard evaluation after calculation of recurrence parameters is a selection of ground motion prediction equations (GMPE). GMPE basically describes the parameters of ground motion as a function of various seismological parameters. These parameters include the earthquake magnitude, distance between source and site and conditions at the local site, which are of paramount importance in the seismic hazard assessment (52-54). The GMPE are generally empirically relationships are derived from available data. The majority of work for GMPE based upon Joyner and Boore (55) functional form. This functional form accounts geometrical spreading intended for all distances (56-60). In the case when there are fewer amounts of data available than stochastic techniques are used to derive GMPE model. The stochastic simulation method was applied by Boore (61), Boore (62),Toro, Abrahamson (63) , Raoof, Herrmann (64)and several scientists in many regions worldwide in relation to North America.

New Generation Attenuation project for GMPE yielded in building five latest ground motion models which include Abrahamson and Silva (65), Boore and Atkinson (66),Campbell and Bozorgnia (67), Chiou and Youngs (68) and Idriss (69). These models stand for a noteworthy improvement in the empirical ground-motion modeling (53). Douglas (70) concluded that the utilization of well-constrained models, perhaps generated by other regions data are much defensible than take into consideration equations from weakly constrained and local models.

2.4 EFFECT OF RHEOLOGY

The crustal rheology is primarily a function of mechanical properties, the presence and distribution of various lithologies, fluids and their temperature. Rheology pedals largely the strength and deformation style of the lithosphere (71). Yield Strength Envelope (YSE) is a curve to illustrate the dispersal of various stress regimes with respect to depth. This technique has been utilized widely used broadly for lithosphere's mechanical strength estimation (72, 73).

Depth distribution of earthquakes with YSE can be used to predicate the dry or wet character of crust and mantle (74). The focal depth distribution of earthquakes and the potent deviation in elastic thickness have been used to portray the lithospheric rheological structure and its characteristic deformation (75). Also, the direct interpretation can be made over seismic data collected in a region over many years for deviation in rheological, or frictional, properties with depth (76). Depth Distribution in seismicity is clearly indicative of changes in the geological framework and the variety of seismicity peaks and earthquake cut off depths can be directly indicative of significant rheological changes (72). The thickness of the seismogenic layer can be defined by the cut off seismicity depth. Ito and Nakamura (77) described the methodology to for estimation of cut off the depth of seismogenic layer. This technique follows the focal depth cumulative frequency distribution. The marker for lower cut off the depth of seismogenic layer is put at 90% of the cumulative frequency curve. Figure 6 represents the estimation for the thickness of the seismogenic layer. The upper and lower cutoff seismicity depth is taken from 10 % and lower cutoff depth to 90 % of cumulative frequency (77-79).

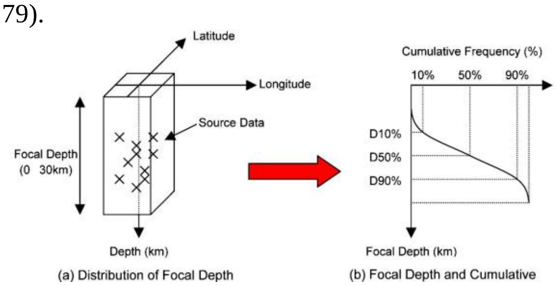


Figure 6: Seismogenic Layer Upper and Lower Cutoff Depths Estimation (Upper Depth :D10% and Lower Depth :D90%) (77)

2.5 A LOGIC TREE AND UNCERTAINTY

In Hazard calculation, uncertainties are caused by imperfect understanding for a system that direct intricate procedure of earthquake generation and propagation of seismic wave and control on quality and availability of data(80). It is vital to discriminate between uncertainty in knowledge (epistemic uncertainty) and randomness in the process (aleatory uncertainty) (81). The natural randomness in a process is termed aleatory variability. It is the effect of simplified modeling for complex process and probability density functions parameterizes it. Epistemic uncertainty is characteristic of alternative models utilized in simple models for scientific analysis (82). Kulkarni, Youngs (83) first introduced the logic tree in PSHA as a tool to capture and quantify the uncertainties related to PSHA. The logic tree is basically comprised of a succession of branches which portray the alternative models and parameter values (Figure 7). The weights assigned to each branch are based on relative confidence for each model or parameter. Abrahamson and Bommer(19, 84, 85).

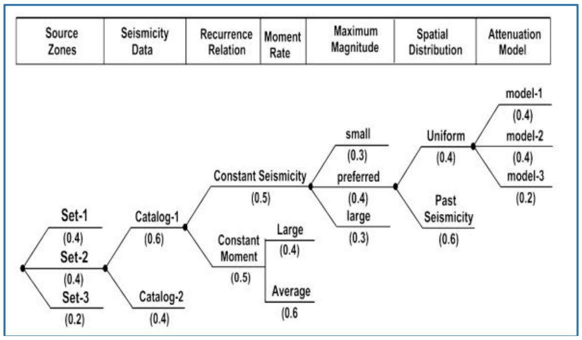


Figure 7: A typical logic tree to account for the epistemic type of uncertainties in the PSHA formulation(86).

2.6 THE SENSITIVITY ANALYSIS (SA)

The hazard calculations include various inputs. The Sensitivity Analysis (SA) is indispensable step for seismic hazard analysis used to determine the significance of input parameters and the uncertainty being introduced the parameters to the outcome (87-92). The SA point, it is the major contributors in the variability of seismic hazard (80, 93). The basic goal of SA is to recognize the input parameters that encompass the maximum impact on risk estimation and its uncertainty (41, 94, 95). Epistemic and aleatory uncertainties are taken into account for the purpose of testing.

3. SITE CHARACTERIZATION

The site characterization is carried out by detailed geological (engineering), geotechnical investigation and geophysical studies (96, 97). The engineering geological and Geotechnical investigation for subsurface exploration are comprised of in-situ and laboratory techniques. The main purpose of in-situ testing is to identify subsurface layers and their physical properties. On the basis of primary engineering geological investigations, the decision is made to go for detailed in-situ testing and laboratory analysis or a combination of both techniques (98).

3.1 GEOTECHNICAL AND GEOPHYSICAL TECHNIQUES

The Geotechnical and geophysical techniques are applied for subsurface investigations. Both techniques have their advantages and disadvantages. The geophysical techniques are rapid and the most cost-effective way to obtain subsurface characteristics, particularly when study area is large (99). The geophysical methods can be employed to pick suitable borehole locations and provide trustworthy information regarding the nature and inconsistency of subsurface strata in-between already present boreholes. For examples, a local geologic anomaly like limestone pinnacle (Figure 8) might not be anticipated by routine drilling program (100).

The geotechnical techniques applied commonly include standard penetration test (SPT) (101) cone penetration test for subsurface investigations, dynamic Cone penetrometer (DCP) and flat plate dilatometer Test (DMT) (102). The SPT and CPT have been adopted in ASTM standards and became industry standards for subsurface Geotechnical studies (103).

The geophysical techniques adopted worldwide for site characterization generally involve the study of seismic waves. The engineering application of seismic signals deals with surface waves which started in 1950's, but extensive utilization started in last two decades. The non invasive nature, rapid and being economical to make these methods advantages over other techniques for site characterization (104).

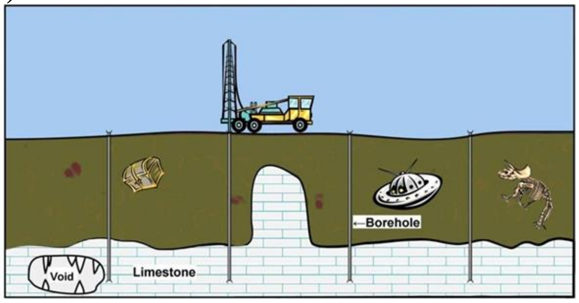


Figure 8: Conventional drilling and limestone pinnacle (Anderson et al., 2008).

Conventionalities in seismic reflection experiment surface waves are regarded as unnecessary singles in records. The surface wave's frequency dependence can be utilized to calculate elastic properties of the material at near surface for engineering, geotechnical and groundwater applications (105-109).

The two kinds of surface ways, Rayleigh and Love waves, are observed in earthquake seismology and seismic prospecting. The two third of the energy generated by the seismic source is consumed by surface wave generation phenomena (110). Body waves lack characteristic dispersion property which surface wave owns. This property defines propagation with different velocities and depth penetration for different wavelengths. Thus, shear wave velocity can be obtained by analyzing surface wave's dispersion (111). Rayleigh wave is most effectively generated by using the vertical source in a seismic survey. Surface wave techniques using Rayleigh waves consisting of , SASW: Spectral Analysis of Surface waves (112), MASW: Multichannel Analysis of Surface Waves: (106), MSOR: Multichannel Simulation with One Receiver(113) .

3.2 MULTICHANNEL ANALYSIS OF SURFACE WAVES MASW)

MASW has been effectively applied in many studies(11, 109, 114-116).MASW is one of quick and rapid technique to estimate shear wave velocity (Vs) for near surface and overcame several disadvantages of other techniques which lead to the delusion of phase velocities (111). The only fundamental mode, which is the highest energy among all wave types, is used often.

The identification of ground roll on multichannel record can be done easily on the basis of their arrival time coherency difference and reliable data processing technique can improve accuracy in results (111). Each wavelength has its own characteristic velocity, also termed as phase velocity (117). There is a basic assumption that around 92% of phase velocity of ground roll, is that of Vs (118). The ground rolls or Rayleigh waves can be generated by a hammer or vibrosis source. Rayleigh wave motions are considered as vertical. It is considered that normal depth penetration of ground roll is approximately equal to its wavelength (119). Although the depth calculation is carried outreaches nearly half of the wave length recorded. The depth of penetration can also be determined by lowest frequency analyzed (120).

The data processing for MASW varies with the type of source used. Non-Impulsive source processing is carried out in the time domain (111). The frequency domain method is applied to impulsive sources (121). The most critical steps is a dispersion curve generation (Figure 9 a, b) which ultimately produces shear wave velocity (122). Dispersion curve is comprised of phase velocity among frequency (121). The inversion of dispersion curve is a crucial step for shear wave's velocity reconstruction in vertical (122). The Vs is calculated by applying inversion iteratively and can be achieved by many methods like least-squares approach (120) or Genetic Algorithms (11).

3.3 GENETIC ALGORITHMS (GA) FOR DATA PROCESSING

Nowadays Genetic Algorithms are popular for inversion. The GA procedure is accurate, quick, stable, and has several advantages over the other traditional techniques (123). A plausible solution is produced by genetic algorithm inspired by Darwin's theory of evolution (124). Three basic Operations of biological evolution process selection, crossover and mutation (125, 126). Initially, individual possible solution population is created at random. The next generation offspring is generated by combining these individual pairs. The poor solutions are replaced by better individual recombination. The genetic structure of some members of each generation is randomly modified by an active mutation to ensure diversity (127).

In fact, the interesting characteristics of GA are that a simple procedure which require random decisions can lead to an effective type of search mechanism (128). Geophysical parameters are wave velocity, layer thickness and their density, which can be treated as genes. The reliability of the inversion can be enhanced significantly for GA, being global optimization method, by using most appropriate initial input model (11).

Several researchers applied GA for inverse problem solution in geophysical methods. Boschetti, Dentith (126) used GA for Inversion of seismic refraction data, Qiu, Liu (129) utilized GA in Geophysical Potential Field Data. The surface wave inversion through a genetic algorithm requires the least information and is independent of the details required in the forward problem(130). The process is accurate and stable, having numerous advantages judged against traditional optimization techniques. One of the main GA's advantages includes the elimination of derivative calculations which leads to avoiding numerical problems typically related with traditional measures are eradicated (123).

4 SITE RESPONSE ANALYSIS

The most important step in microzonation is site response analysis, which yield site based ground vibration characteristics resulting from earthquake excitation. The site response analysis is carried out principally to calculate site peak ground acceleration (PGA), peak ground velocity (PGV) or spectral acceleration (SA) and most important ground amplification factor (3, 8, 131). The devastating earthquakes of Michoacan, Mexico, 1985, and Loma Prieta California, 1989 brought consideration for these effects which could be a direct outcome from site amplifications.

The amplification character of ground motion is strongly influenced by the geotechnical properties of soil deposits and the associated uncertainties. Soft soil sediments can cause amplifications to earthquake vibrations passing from rock to soil deposits. (Figure 10). Some serious amalgamation of geotechnical factors and seismic input may provoke considerable ground amplification (3, 7, 8, 96, 131).

Field (132) presented a soil amplification map for Southern California by collecting, processing, analyzing and compiling multi-source information. Several parts of southern California have five times amplification of earthquake vibrations (Figure 11). These amplifications characteristics are a representation of soil geotechnical properties.

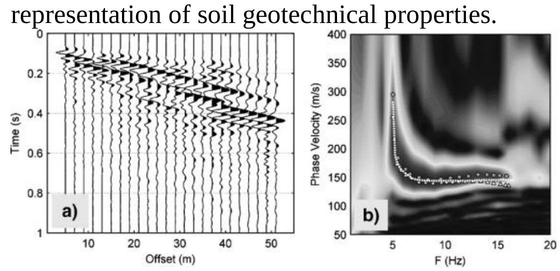


Figure 9 : Illustration of MASW data and dispersion curve(130).

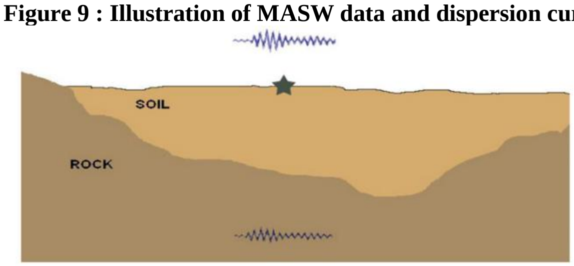


Figure 10: Carton illustrating the propagation of seismic waves from rock site to soil.

In 1989 San Francisco earthquake seismograms from rock site Yerbna Island and soil site Treasure Island are shown in Figure 12. There is distinct amplification observed in both records. These amplifications depict consideration of soil properties in the account for safety purpose.

Engineering geologists and geotechnical earthquake engineers are putting effort to pick up most suitable and realistic solution methodologies for ground response under earthquake loadings. The characteristics of ground are strongly dependent upon soil properties, although the seismic waves travel approximates less than 100 meters in the soil as compared to rock tens of kilometers (133). The easiest way for ground response analysis is to adopt attenuation relationships formulated source and site classifications (65). The detailed site characterization is a most comprehensive technique for site response studies. Empirical relations like Borcherdt (134) also exist and could be implemented for amplification factor calculations. The detailed site characterization technique is adopted preferably because empirical relations may not always be on the conventional side (135).

The Prior essential input information used for site response analysis includes subsurface soil model and strong motion record at the site. The soil model depicts the various physical parameters of soil layers variation with depth. The MASW results and available borehole provide this information which is comprised of subsurface soil lithology, thickness, density, and shear wave velocity (136). The real earthquake record at site mostly lacks. This problem is solved by deaggregation of PSHA results and using the deaggregation results in a spectral match to obtain real earthquake records compatible with PSHA results at the site(137).

4.1 EARTHQUAKE INPUT FOR SITE RESPONSE ANALYSIS

A controlling earthquake with the specific magnitude and epicentral distance are required for input in site response analysis. This process of selecting an earthquake with specific magnitude and distance to site is carried out by deaggregation. The earthquake with the specific magnitude and epicentral distance which contribute the maximum to hazard at a site is selected by deaggregation of hazard results (137).

4. 2 DEAGGREGATION OF HAZARD RESULTS

Deaggregation technique turned out to be significant and essential means for seismic hazard understanding. This process helps to identify the magnitude size and distance range hazard to site stems(17, 138, 139). This deaggregation has become a more basic practice for answering the question related to sources which significantly contribute to the hazard (140). This process enables to identify the attributes of seismicity accountable for seismic hazard in term of distance, magnitude and azimuth (141-143). Normally seismic hazard is deaggregated in provisions of two variables: magnitude and source to site distance (Figure 13) (144).

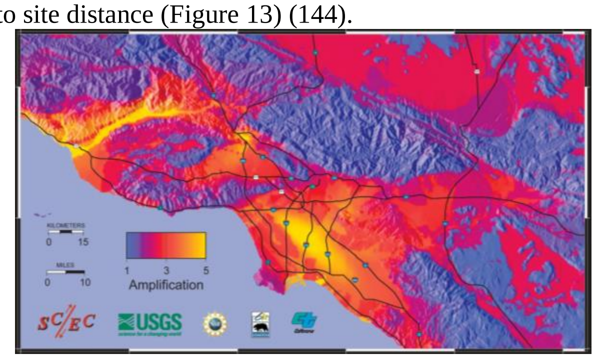


Figure 11: Ground motion amplification map for southern California (Edward H. Field 2001).

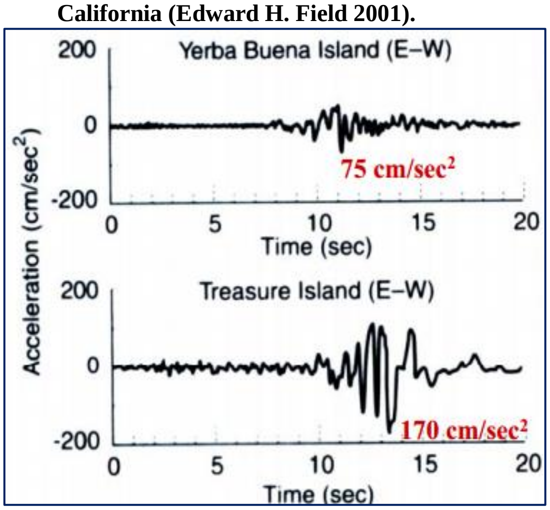


Figure 12: Seismogram from San Francisco 1989 earthquake at two sites (Bouckovalas G., 2010).

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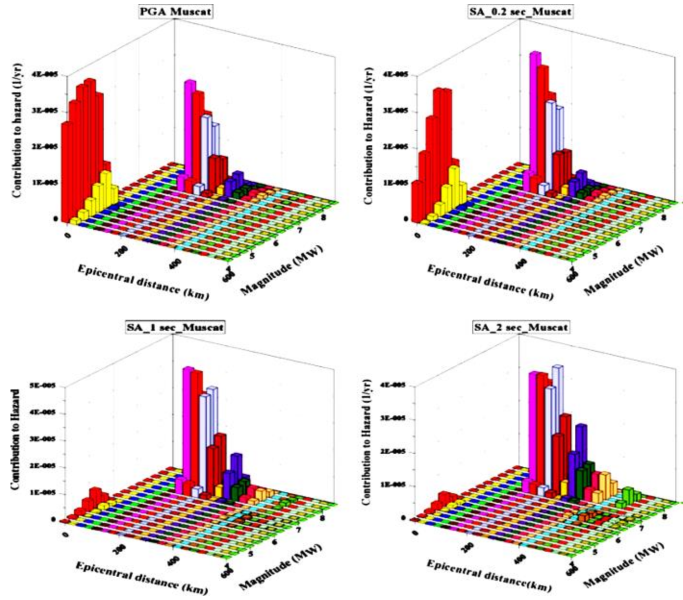

gure 13 : Deaggregation results on magnitude and source to site distance for Muscat city at different spectral periods for 2475years return period(137).

4.3 SPECTRAL MATCHING

Spectral Matching is the procedure for generation of synthetic/artificial ground motion acceleration time histories having shapes nearly identical to the predetermined target spectrum. This technique is used for the estimation of nonlinear structural response. It is generally accepted that spectral matching produces results which in most of the cases present somewhat lower dispersion. The generation of artificial accelerogram can be done iteratively in two major groups: Time-Domain-based (TD)and Frequency-Domain-based (FD) matching (145).

Time Domain Method: The time domain method is generally considered better techniques for spectral matching. This method the adjustment of acceleration time histories is done by adding wavelets in the time domain. A wavelet is a mathematical function that defines a waveform of limited duration which has a zero average. The wavelet amplitude typically starts out at zero, increases, and then decreases back to zero. Adding discrete length wavelets to the acceleration records tends to better preserve the non-stationary character of the original time histories (146). The fundamental scheme for the time-domain alteration of earthquake records presumes that the peak response time will not be disturbed through the addition of small modification to the real time history. In such way, the modification of observed response relative to indicated value of the response spectrum is carried out by, taking into consideration the observed difference between both original and response spectra generated (145). Figure 14 is an example of time domain spectral matching carried out by current authors in RspMatch 2009 code by Al Atik, Abrahamson (146).

Frequency Domains Methods: One common way to perform spectral matching using real earthquake ground motions is an adjustment of Fourier amplitude spectra in the frequency domain(147). The frequency domain approach keeps the Fourier phase of the reference time series fixed and amends the Fourier amplitude spectrum, which is the ratio between target response spectrum and actual response spectrum. The generation of artificial accelerograms of available frequency domain existed for many years. An early scheme, which is still somewhat popular today, makes use of code SIMQKE of the computer (148); it is based on the relationship between expected response spectral values and the spectral density function of a random process representation of ground motions.

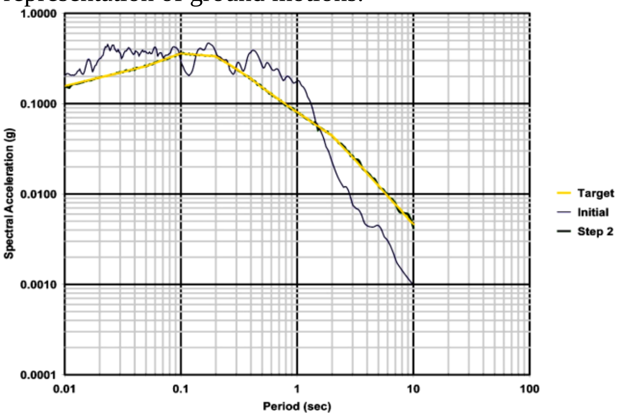

Figure 14: Time domain spectral matching

4.4 1D SITE RESPONSE ANALYSIS

The 1D response analysis, dynamic characteristic of seismic wave propagation in soil deposits, is taken into account, but time history is requires to input ground motion. The input time history is determined from PSHA. Kramer (149) stated that soil response towards strong motion can be calculted by the transfer function of damped layered soil on an elastic rock. The models of 1D site response are valuable to a leveled or gently sloping sites with parallel material boundaries.

One dimensional site response analysis is performed either for equivalent layer analysis in the frequency domain or using non-linear hysteretic soil models in the time domain (150). First Seed and Idriss (151) postulated the equivalent layer linear technique based upon linear approach methodology which calculates approximately nonlinear site response. The frequency domain implementation of this technique is carried out by Schnabel (152).

The simplicity, low computational power, robustness and flexibility of frequency domain methods make them more practicable, but also with some limitations. The analysis is linear process in the frequency domain. The nonlinear behavior of the soils is achieved by the iterative procedure (153). There are cases in which the soil column behavior over a seismic event of complete duration cannot be accurately represented for equivalent soil stiffness and damping in each layer. In such cases, the time domain solution is done (154).

The time domain method discretizes soil column using multi-degree-of-freedom lumped parameter into individual layers using finite elements (149). In many time domain solutions, the single layer is symbolized by a nonlinear spring, equivalent mass, and a viscous damping dashpot for time domain solutions. The model of vertical soil column layered horizontally layer is presented schematically in Figure 15.

The one-dimensional propagation of shear wave's model in layered media is carried out by Nonlinear and equivalent linear methods. Nonlinear analyses showed good agreement with earthquake observation (133).

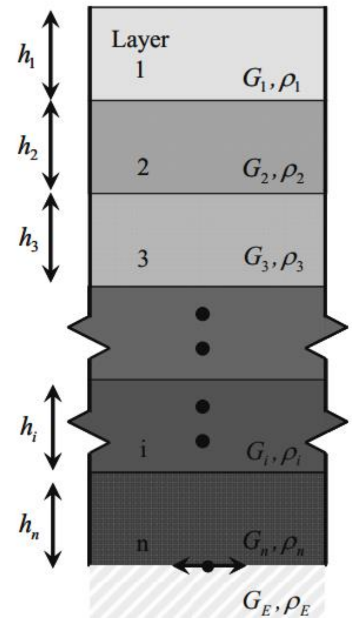

Figure 15: Model for soil column with shear modules (G) and density (ρ) at horizontally layered soil deposit.

MICROZONATION MAPS

The site response analysis provides the dynamic properties of soil deposits. The results are than plotted to obtain microzonation maps. These maps are used to serve the land use and town planning. These maps provide understanding to the natural hazards risk in developing urban.

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