APPLICATION OF PERFORMANCE-BASED DESIGN IN DEVELOPING FRAGILITY CURVES

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Abstract - *In our country the general procedure is to incorporate code confirming design. Where as in developed countries a lot of research has taken place in seismic design of mid-rise to high-rise buildings. They have developed many new methodologies to efficiently design best performing buildings with the help of stochastic structural dynamics. This helps predict the hazard intensity, structural response, damage and loss. Based on which fragility curve and loss curves are developed which help better communicate with the different stake holder about the building which has better efficiency and economy. This sort of practice has been implemented in professional field in developed countries since last two decades but in our country the technical know how about this is limited. This paper will show implementation of performance-based design using different fragility curve fitting method. The curve fitting method used in this fragility curve plot will include conventional analytical plot of log normal curve and non-parametric method such as kernel density and kernel density method and maximum entropy kernel density method. The results will provide the information regarding the damage state with respect to different intensity measures on probabilistic manner. These results will better show the performance of the building in different scenarios. The study will include analysis and design of a building will be based on IS 456, IS 13920, FEMA P-58 and HAZUS MANUAL 2013.*

Key Words: Performance Based Earthquake Engineering, Stochastic Structural Dynamics, Fragility curves, Log-Normal Curve, Kernel Density Plot

1.INTRODUCTION

According to Earthquake engineering is at once very old and a very new subject. If EE is considered as just the conscious attempt made to improve the earthquake resistance of man-made structures, then it is an old subject as testified by a 3000-year history of earthquakes in China. If on the other hand, it is considered as the result of scientifically based multidisciplinary effort, then it is a relatively new subject (Hudson 1992).

In this multidisciplinary effort a wide range of knowledge that includes geophysics, geology, seismology, vibration theory, structural dynamics, materials dynamics, structural engineering and construction techniques are necessary for this new scientific study.

All these entities have intrinsic uncertainty present like the source of earthquake, distance, intensity, response of structure, material properties so a probabilistic performance-based design is more adequate approach.

Indian earthquake problem cannot be overemphasized. More than 60% of the land is prone to shaking of intensity VII and above (MMI scale). In fact, the entire Himalayan belt is considered prone to great earthquakes of magnitude exceeding 8.0 and in short span of 50 years (S.K. Jain 2000). Earthquake engineering developments started rather early in India. For instance, development of the first seismic zone map took place in 1930's, and formal teaching and research started in 1950's. Despite early start, the seismic risk in the country has been increasing rapidly in the last few decades. The following data shows that there is need of application of developed new techniques in day-to-day projects for more efficient and economical design.

There is much more research going on in the developed countries, and based on this research they have developed some of the probabilistic approach in earthquake engineering. This field is known as Performance Based Earthquake Engineering.

To achieve these new objectives the structural engineering community, particularly in regions with high seismic hazard, is exploring the concept of performance-based earthquake engineering (PBEE). PBEE implies the design or assessment of structures to withstand, as economically as possible, the uncertain future demands that users and nature will put upon them. It is based on the premise that performance objectives can be defined in a quantitative manner and that performance can be predicted. Its objective is to provide stakeholders with the necessary information to make rational and informed decisions based on life-cycle considerations

1.1 EARTHQUAKE ENINGINEERING

Earthquake Engineering begin to take proper form in late 19th century and early 20th century in different nations due to some great earthquakes like San Francisco USA (1906), Messina Italy (1908) and Kanto Japan (1923). These made the nations to start Earthquake Engineering related study and research work for which major institutes were also started.

Due to such steps equivalent static load method came into picture.

Later-on due to events like Santa Barbra earthquake motivated countries like USA and Japan begin to develop code to reduce the number of casualties and attain life safety performance of the structure.

More recent earthquakes, such as Alaska, USA (1964); Mexico City, Mexico (1985); Loma Prieta, USA (1989); Northridge, USA (1994); Kobe, Japan (1994) and Koceali, Turkey (1999) have continued to push engineering knowledge further, leading to more refined and better designs. Yet later earthquakes caused much damage to the structures occurring which incurred much economic loss as repair cost or replacement cost. These motivated professionals and researchers to focus on this new issue and develop new methodologies to overcome economic loss.

Finally, in the last few decades, the advance in computer technology has facilitated the use of more sophisticated techniques in building design and a sizable reduction in the amount of time required to analyse a structure. This has led to increased productivity and more efficient designs (Bozorgnia and Bertero 2004).

Because of this Performance Based Earthquake Engineering was developed. The concept of PBEE is about predicting the performance of the structure in different scenarios so as to design based on the performance the stakeholder wants. This will give more clarity on the decision variables like the construction cost, repair cost and replacement cost based on the decided performance level the stakeholder wants.

The current scenario in India is too confining to IS code. Its main aim is to achieve Life Safety performance level by a prescriptive based design. It has classical approach of base shear equation which take into consideration factors like Response reduction factor (R), spectral Acceleration (Sa/g) and Zone factor (Z). Earlier these factors were based on empirical engineering judgement. Later more scientifically appropriate values developed but still the response reduction factor is empirical value; to ensure life safety and prevent collapse.

1.2 PERFORMANCE BASED EARTHQUAKE ENGINEERING

In an effort to develop more reliable seismic standard and code provision and their stringent application was much required. The promising approach toward the above development has been proposed by SEAOC Vision 2000 Committee in 1995 in its report "Performance Based Seismic Engineering of Buildings". The various other guidelines then developed later on are FEMA 273/356 (FEMA 273 1996; FEMA 356 2000), ASCE-41 (ASCE/SEI 41-06 2007) and ATC-40 (ATC-40). These guidelines are all very similar to one another but they do have minor changes in them. Most of these guidelines concentrate on the existing buildings performance evaluation whereas the Vision 2000 is different.

Performance Based Seismic Design is a procedure for design of new structures or seismic upgradation of existing structures, which has a specific intent to achieve well defined performance objective in future earthquakes. In the present generation procedure performance is expressed in terms of a discrete performance levels identified as Operational, Immediate Occupancy, Life Safety, and Collapse Prevention. These performance levels are applied to both structural and non-structural components, and are assessed at a specified seismic hazard level. There are a number of steps in the performance-based earthquake engineering.

2. LITERATURE REVIEW

2.1. RESPONSE SPECTRUM CODE CONFIRMING PEER PBEE USING STOCHASTIC DYNAMIC ANALYSIS AND INFORMATION THEORY

In this paper author shows the implementation of stochastic structural dynamics in performance-based design using Eurocode. The performance-based design explained in here is divided in four steps namely 1. Defining seismic hazard model providing Intensity Measure (I.M.). 2. The structural model providing the structural response defined through the engineering Demand Parameter (E.D.P.) 3. The damage model the calculates the damage measure (D.M.) 4. The loss model that predicts the decision variable (D.V.). The guidelines used for it is FEMA ATC-58-1.

The seismic hazard is defined by stochastic process using the artificial accelerograms instead of the time history. The seismic hazard is of the gaussian type developed through Power Spectral Density. It includes stationary and non-stationary part. The structural analysis and fragility curves are developed with the use of newly developed method known as kernel density maximum entropy method under the theory of maximum entropy. It gives log normal distribution of probability distribution. Then it is cumulated on damage and loss calculation. The application example taken is a hypothetical five story reinforced concrete office building in Italy is analyzed. The building is of regular plan and elevation. The dimension is as 20m x20m with 5m bays in each direction. The story height taken is 4m. All the beams and columns are section of size 300mm x 500m with 8 reinforced bars of 16 mm diameter.

The hazard analysis has considered location of Messina, Italy. There is analysis carried out for 20, 100 and 1000 artificial accelerograms. The response spectrum curve is taken from the NTC08, 2008. The structural analysis is carried out using OPENSEES software and fragility curves are plotted by log-normal curve, kernel density and by kernel density maximum entropy. They are compared and show that the kernel density maximum entropy curve is better for statistical estimation for small number of samples and also the tail convergence of the kernel density maximum entropy is better. The damage analysis is carved out for four different states slight, moderate, extensive and complete. The corresponding values are taken from HAZUS FEMA 2013. The repair cost is also taken with the help of HAZUS, with 0.4%, 1.9%, 9.6% and 19.2% of the replacement cost is considered for the different damage states.

Thus, the paper illustrates the application of code-based performance-based design by using the Eurocode. It simplifies the process by application of artificial accelerogram, instead of scaled time histories and the results are more refined by the use of kernel density maximum entropy method. Finally, the cost comparison for different damage state is show using different methods like lognormal, kernel density and kernel density maximum entropy method. Showing refinement of the kernel density maximum entropy method.

2.2. A MULTI-STEP APPROACH TO GENERATE RESPONSE-SPECTRUM-COMPATIBLE ARTIFICIAL ACCELEROGRAMS

In this paper the authors show that when there aren't much earthquake acceleration time histories available one can reside to artificially generated accelerograms for non-linear analysis. The author has utilized multi step method to develop response-spectrum compatible artificial accelerograms. The steps involved first the site-specific data will be produced with the help of probabilistic seismic hazard assessment method. In the second step the site-specific characteristics are made known by auto regression moving average analysis. Lastly the generalized non-stationary Kanai-Tajimi model is utilized to simulate the earthquake time history records utilizing the results of both probabilistic seismic hazard assessment and auto regression moving average analysis.

For the purpose of work two different sites are selected in Kabul, Afghanistan. The sites were assessed by the author and seismic hazard and ground motion levels were determined by using PSHA having seismic source within 300km. The probability of exceedance of 10%, 5% and 2% in 50 years is taken into account. The peak ground acceleration is obtained for them. Alongside real time histories are obtained. They are utilized to generate response spectrum with different damping values.

These records are base point spectrum matching analysis. The ARMA method is used to generate several ground motions. Then the Kanai-Tajimi model is used to develop the response spectra from them. Then the IBS code specifications are used to implement them in the design and evaluation of the building.

In conclusion they compared the result of the real time histories with artificial accelerograms and showed the algorithm developed has minimum error. For comparison external software EZ-FRISK is used.

2.1.3. EFFICIENT ANALYTICAL FRAGILITY FUNCTION FITTING USING DYNAMIC STRUCTURAL ANALYSIS

In this paper the author demonstrates the application of fragility curve fitting. The method employed is the statistical method used to develop the fragility curve under non-linear dynamic structural analysis. The approach of analysis is incremental dynamic analysis and the second is multi-strip analysis. In the former approach the intensity measure at which the collapse occur is found, whereas in the second one ground motion are scaled to specific intensity.

The fragility curve is developed for the collapse probability for different intensity measures. The fragility curve is log-normal curve. The probability distribution P (C/ IM =x) =$\varphi(\ln(x/\Theta)/\beta)$, Here the terms Θ denotes the mean value of the function. The β term denotes the standard deviation. Their estimated values are used for the purpose of statistical probabilistic approach.

There are two statistical methods used in this paper. The one is method of moments, where the moments are found such that their value is same as the moments of the observed value. The other is the method of the maximum likelihood method. In this method the parameters are found out such that the value of the likelihood turns out to be maximum. The parameters here are the median and standard devotion of the probability distribution.

In the incremental dynamic analysis, where each ground motion is scaled and increased such that it causes collapse. The estimated values of the median and the standard deviation can be found by the following formulae, $\ln\Theta=(1/n) *\sum\ln(IM)$ and $\beta=\text{sqrt}((1/(1-n)) *\sum\ln(IM/\Theta)^2$.

After the estimation of the parameters one can sought to excel or MATLAB to plot the log-normal fragility curve using the provided two statistical methods of estimation. Here the author uses the actual probability through analysis results obtained from the software. The likelihood for each intensity is found and the maximum likelihood is obtained for the assumed parameters. Later the parameters are changed the optimum value is found.

2.3 DEVELOPMENT OF EMPIRICAL AND ANALYTICAL FRAGILITY FUNCTION USING KERNEL SMOOTHINGMETHODS

This paper introduces the non-parametric method of fragility curve fitting which does not depict to any specific form of function like normal, log-normal, beta etc. This parametric method is kernel smoothing method. A kernel assigns a weight to individual data and it is inversely proportion to distance between the data points. This type of curve fitting methods is more effective when the data is spare, noise or non-homogeneous. The paper is divided into four parts i.e., 1. Introduction, 2. Data type, 3. Kernel Smoothing Methods and 4. Application

The author introduces the kernel smoothing method by describing the latest developed method of gaussian kernel smoothing. In this method at each data point the gausse-normal distribution function is plotted with corresponding weighted average of the distance between the data point. This distance is introduced as bins in conventional method and bandwidth of the kernel density function. The binning in the log-normal curve is used for the cumulative distribution of the damage states of the fragility curve. The bandwidth is more effective to have smoother fragility curve through gaussian kernel smoothing.

The data type used in the fragility, the author describes the two possible data types that can be selected either of the different ground motion time histories with different intensity used for building analytical models or can group the number of building in a given area under the specified damage states. Then he numerically illustrates both the possible approaches. Based on which the cumulative functions are derived.

The third part of the paper views the different kernel smoothing methods. The author has considered the three conditions. First being the one-dimensional discrete damage state and the other two as one- and two-dimensional continuous damage state. There is in-depth description regarding the gaussian distribution kernel function. The optimal band with demonstration for the gaussian kernel and the way the plot is generated by added the overlapping parts of the kernel.

The fourth part includes the application of the kernel smoothing technique to the real-world problem. There are two problems taken, one of the numerical simulations of a four-story steel building and the second includes the field observation after an earthquake. In the field observation the plot is between the P(DS) vs MMI. The building in the locality is observed and the conditions are defined based on the modified Mercalli intensity scale. There is comparison made between the conventional log-normal curve and the kernel density curve. It concludes that the smoothness of the kernel smoothing curve is more. There is the fragility plot formed for the four different damage states and compared with the conventional curve.

The author concludes that the kernel method is more suitable when there is small amount of data, spares, non-homogeneity in all such conditions the kernel estimates are better than the conventional lognormal curve.

2.4 COMPARISON OF PERFORMANCE-BASED ENGINEERING APPROACH

In this paper the author has compared the two approaches ATC-58 and FORM (First Order reliability method). The ATC-58 approach is a second-generation performance-based earthquake engineering approach, it takes into consideration the continuous state of performance as compared to the discrete state in the first-generation approach. The analysis is conducted on an existing building in campus of university of California which is a steel building moment frame. The analysis results from time history analysis and pushover analysis are used to obtain the fragility curve. The fragility plots are developed for structural and non-structural systems under these two different methods. The author has used monte carlo sampling method for the data sampling.

The ground motion data, the model data, the data regarding the repair work i.e., the cost and the time information are taken from the ATC- 58. The building modeling and analysis is conducted on a finite element software program of OpenSees developed by Pacific Earthquake Engineering Research University of Berkley. The coding is done in Tcl language.

The paper perfectly depicts the steps involved in the application of the performance-based earthquake engineering using the first and second generation so it is helpful for the professional engineers to have basic preliminary application-based knowledge regarding the performance-based earthquake engineering.

The main aim of unified approach is that it measures the exceedance of a given performance level on discrete basis. In this method the limit function needs to be developed. So, the failure is considered to have occurred when the repair exceeds a given threshold. So, there is a limit function and no probability functions are developed.

Whereas the hazard model is developed based on proper selecting a good number of time histories and application of the proper scaling tool in-order to properly depict to the ground motion hazard. Then the response model is developed. For this the dynamic nonlinear analysis and static nonlinear analysis is conducted on the model and the engineering response considered is the story drift and the floor acceleration for the structural components and the non-structural components respectively. Based on that the damage states are evaluated and the fragility curves are developed.

Furthermore, cost of the damage is obtained from the experienced consultant and the damage probabilities are found based on which the cost of damage for different damage states are obtained. Finally, the cost curve and collapse fragility curve are developed.

3. CONCLUSIONS

The Literature Review shows that the Kernel density plot which is a non-parametric form of fragility plot is better as compared to the log normal plot. The literature also show some of the prominent works in performance based design

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