Risk Analysis of RC Framed Structure using Fragility Curves

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Abstract - The fragility is important tool for evaluating the seismic failure or seismic damage of the structure; these curves are optimising the provisional probability that response of the structure may exceed the certain performance limits of ground motion intensity. There various methods are available for developing fragility curve. The response surface based HDMR technique is one of the method for developing fragility curve. This HDMR method gives input and output relation and this relation can reduce the computational cost of analysis. The Monte Carlo simulation is one of the techniques for developing fragility curve. This is the old method and this method takes a very long time for analysis, on the other hand the HDMR method is more efficient than the Monte Carlo simulation. At present study the HDMR technique is use for development of fragility curves. As per HDMR method the metamodels are used in this study, for creating metamodels the RC frame is considered with some input variables and for analysis ETABS-2013 is used finally as per HDMR technique the Monte Carlo simulation is performed on the metamodels and plotting fragility curves.

Keywords – Monte Carlo simulation, Fragility curves, High dimensional model representation, Metamodel.

1. INTRODUCTION

A fragility curve is a curve which expresses the probability of failure of a defence as a function of loading. These fragility curves are employed for evaluation of seismic safety of nuclear power plants, and later situations these curves are accepted successfully as reliability method of analysis of civil structures like bridge, buildings etc.

The probability of a damage of structure due to earth quake is estimated as a function of peak ground acceleration (PGA). The fragility curve is important tools for evaluating the seismic failure or seismic damage of structure, and these curve are optimize the provisional probability that the response of structure may exceed the performance limit for ground motion intensity. A fragility curves shows the probability of exceedence of failure with respect to peak ground acceleration.

METHODS FOR DEVELOPMENT OF FAGILITY CURVES

In the development of fragility function there is no policy. An amount of uncertainties involved in each step of procedure. This uncertainty is due to changeability in ground motion intensities and features, analytical modelling, uncertainties in the characteristics of material. The various methods of vulnerability assessment that have been proposed in the past. And it is classified into two categories, they are

1. Empirical method

2. Analytical method

The empirical fragility curves are developed based on statistics of the observed damage from post-earthquake such as data collected from past earthquake survey the use of observational data is the most realistic way to model fragility but the incompleteness and deficiencies in the survey forms and the error produced in the computation of the data might lead to notable reduction of the size of the data base during post processing.

The analytical method consist of four types, they are

- Monte Carlo Simulation technique (MCS)
- Cornell *et al* (2002)
- Response Surface Method
- ATC-63

Monte Carlo Simulation is a method used to understand the collision of risk and uncertainty in financial, project management, and other forecasting models. The Monte Carlo Simulation says when we have range of input variables as results; we are launch to understand the risk and uncertainty in the model. The input future of Monte Carlo Simulation can says, based on how we create range of approximation, how likely the results conclusion.

The Monte Carlo Simulation is works like an arbitrary value is selected each of the tasks, based on the range of estimates. The model is calculated based on this arbitrary value. The result of the model is traced, and the process is repeated. A classical Monte Carlo Simulation calculates the model hundreds or thousands of time, every time using random selected value. When simulation is complete, we have large numbers of results from the model. Each based on random input variable. These results are used to illustrate probability of reaching various results in the model. This tactic requires fairly 5 large numbers of models to attain a satisfactorily reliable evaluation of fragilities which makes it computationally pricey and also time overriding

Cornell *et al.* (2002) proposed a methodology to characterize the fragility function as the probability of exceedence of the designated Engineering Demand Parameter (EDP) for a selected physical limit state (DS) for a particular ground motion intensity quota (IM). Fragility curve reaching a specified damage state or more is represented as a function of that particular demand.

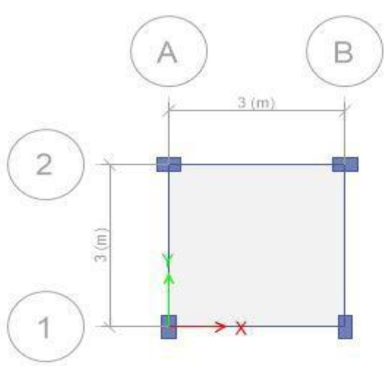
2. MODEL CONSIDERED

Beam size – 230 x 300mm

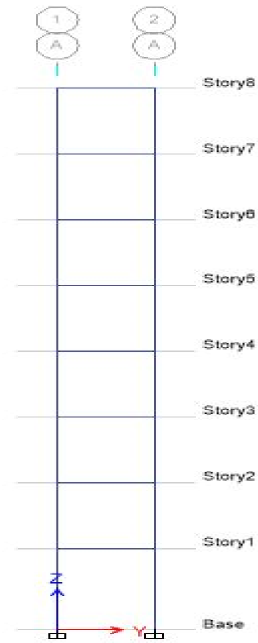
Coloum size – 230 x 400mm

Storey ht – 3.2mt

Bottom storey ht – 4.0mt



PLAN OF MODEL (ETABS model)



ELEVATION OF THE MODEL (ETABS model)

3. PREVIOUS WORK

Towashiraporn et. al. (2004) has proposed a method to formulate the Metamodel for fragility curve generation using response surface method, in which, the input variables are composed of two components: random variable and a control variable. Random variables are those that define uncertainties in structural properties, while the control variable is deterministic with its fixed values characterizing different response prediction models.

U, Vipin unnithan *et. al.* (2008) has proposed the HDMR technique for development of fragility curve. The HDMR method is a one of the important tool developed for the input and output relation of multifaceted, computationally oppressive models in provisions of expansion of hierarchical concurrent functions.

HDMR method in general

The N elemental vector $x=\{x_1, x_2, ...x_n\}$ be the inut variables and the last term 'N' is ranging upto order 10^2 *to* 10^3.and the output variable is considered as a *f(x)*. In HDMR method, the output variable can be expressed as heirahical correlated functions and expanded in terms of input variable as given in equation 3.1

$$F(x) = f_0 + \sum_{i=1}^{n} f_i(x_i) + \sum_{1<i_1<i_2<N} f_{i_1 i_2}(x_{i_1}, x_{i_2}) + \sum_{1<i_1<i_2<i_3<N} f_{i_1 i_2 i_3}(x_{i_1}, x_{i_2}, x_{i_3})$$

$$+ \ldots\ldots\ldots\ldots\ldots + f_{i_1 i_2 i_3 \ldots\ldots i_n}(x_{i_1}, x_{i_2}, x_{i_3} \ldots\ldots\ldots x_n) \quad (3.1)$$

Where

1. 'f_0' is represent the rejoinder (f(x)) as the allusion point ,generally the mean point and which is constant.
2. '$f_i(x_i)$' is the 1st order term and express the consequence of variance 'x_i' performing unaccompanied ,while generally non-linear on the output 'f(x)'.
3. $f_{i_1 i_2}(x_{i_1}, x_{i_2})$' is the 2nd order term portraies the mutal property of the variable 'x_{i_1}' and 'x_{i_2}' on output variable f(x).
4. The elevated order term gives the supportive effects of incresing no of input variable substitute together to authority the output f(x).
5. The preceding term '$f_{i_1 i_2 i_3 \ldots\ldots i_n}(x_{i_1}, x_{i_2}, x_{i_3} \ldots\ldots\ldots\ldots\ldots x_n)$' consists any outstanding dependence of all the input variable sheltered together in a cooperative way to influence the output 'f(x)'.

There are two methods HDME technique depending on the method approved to calculate the factor function in equation (3.1), ANOVA – HDMR and cut – HDMR. the ANOVA – HDMR is usefull for gaugeing the involvement of discrepancy of indivisual module function to the over all discrepancy of the output. And in cut – HDMR expansion is an faithful depiction of the output f(x).

During cut – HDMR first reference point

$C=\{C_1, C_2, C_3 \ldots\ldots\ldots\ldots C_n\}$ is defined in variable space and which is mostly at the mean value of the input variables. the expansion functions are calculated by evaluating the input and output response of the system relative to the define refrence point 'C' along the coupled lines surfaces,subvolume etc in the input variable space.The component function in the equation (3.1) is diminish the following relationship.

$$f_0 = f(c) \quad (3.2)$$

$$f_i(x_i) = f(x_i, c^i) - f_0 \quad (3.3)$$

$$f_{i_1 i_2}(x_{i_1}, x_{i_2}) = f(x_{i_1} x_{i_2}, c^{i_1} c^{i_2}) - f_{i_1}(x_{i_1}) - f_{i_2}(x_{i_2}) - f_0 \quad (3.4)$$

But

$$f(x_i, c^i) = f(c_1, c_2 \ldots\ldots\ldots\ldots c_{i-1}, x_i, c_{i+1} \ldots\ldots\ldots\ldots\ldots c_n)$$

and it represents all input variable except 'x_i' are at the reference points and the next step of function is given by

$$f(x_{i_1} x_{i_2}, c^{i_1 i_2}) = f(c_1, c_2 \ldots\ldots\ldots\ldots c_{i_2-1}, x_{i_1}, c_{i_1+1} \ldots\ldots\ldots\ldots\ldots c_{i_2-1}, x_{i_2}, c_{i_2+1} \ldots\ldots)$$

and it represents all input variable except '$(x_{i_1} x_{i_2})$'are at the reference points.

The 'f_0' is the output response of the system estimate at reference mean point 'C'. each first order term in the equation is estimate by the side of its input variable space through the reference point. In this study first order cut – HDMR is used.

4. PROPOSED METHODOLOGY

The methodology includes:

- Firstly a detailed introduction regarding the fragility curves, methods for developing the fragility curves are presented along with organization of thesis.
- A detailed literature survey is carried out on development of fragility curve for RC framed structure.
- For fragility analysis the input variable are considered as a compressive strength of concrete (fck), young's modulus of concrete (Ec) and yield strength of steel bars(fy). At present study M20 concrete and Fe415 steel is used for non-linear time history analysis.
- Uncertainties is considered in input variables and called as random variables, the statistics of random variables are obtained from Ranganathan (1990). And as per HDMR technique three point sampling method is used for the selection of values of input variable.

Table1- Statistics of random variable

Materials	Variable	Mean(Mpa)	Standard deviation	Distribution
Concrete	fck	19.54	4.1	Normal
Concrete	Ec	34100	7024.6	Normal
Steel	fy	469	46.9	Normal

Table 2 - Range of input variable from three point sampling

Variables	$\mu - 2\sigma$	μ	$\mu + 2\sigma$
f_{c_k}	11.33	19.54	27.75
E_c	20050.8	34100	48149.2
f_y	375.2	469	562.8
PGA	0.1	0.55	1.0

- Uncertainties is also considered in the earth quake ground motion. For non-linear time history analysis 11 no's of scaled ground motion records are considered.
- The non-linear time history analysis is conducted on RC frame for selected values of input variables for 11no's earthquake ground motion records using ETABS-2013.
- **Table 4 - Set of input variable by three point sampling with roof displacement**

Sl no	'f_{c_k}' in mpa	'E_c' in mpa	'f_y' in mpa	PGA in 'g'	'y_μ' in mm	'y_σ' in mm
1	19.54	34100	469	0.55	76.12	21.01
2	27.75	34100	469	0.55	70.78	17.68
3	11.33	34100	469	0.55	69.10	21.38
4	19.54	48149.2	469	0.55	49.6	43.09
5	19.54	20050.8	469	0.55	104.81	36.28
6	19.54	34100	562.8	0.55	68.918	21.47
7	19.54	34100	375.2	0.55	68.92	21.48
8	19.54	34100	469	1.0	138.4	36.38
9	19.54	34100	469	0.1	13.84	3.64

- By the use of response (roof displacement) from the analysis result formulate the Metamodel.
- FEMA 356 gives limit states for three structural performance level.

Table 3 - limit linked with various structural performance levels

Structural performance level	Permissible top storey drift
Immediate occupancy (IO)	1%
Life safety (LS)	2%
Collapse prevention (CP)	4%

- The Monte Carlo simulation is performed on the overall Metamodel by randomly generating values for the input variable based on their probability distribution. The probability of chosen response exceeding certain damage limit state were taken out from the simulation result.
- This probability value corresponds to one specific earthquake intensity and characterizes one point in the fragility curve. The process was repeated for different levels of earthquake intensity and fragility curve is plotted.

5. EXPERIMENTAL RESULTS

This research work is carried out to develop the fragility curve for considered RC frame and observe the risk of the structure. The fragility curve for the RC frame is shown below.

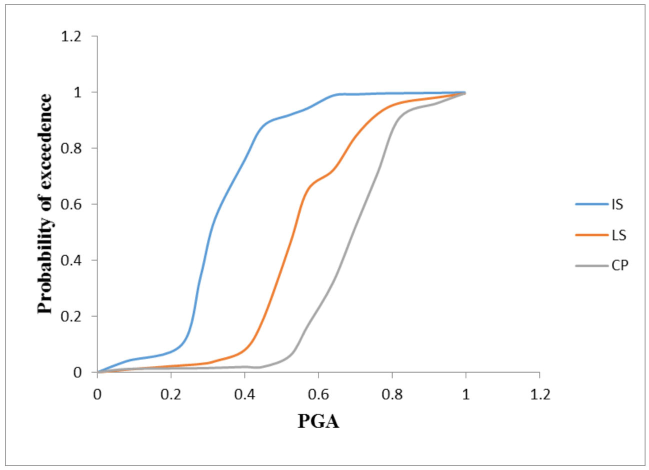


Fig.1─ Fragility curves for three different limit states.

From the study accomplished, it is obvious that the HDMR method for the fragility evaluation is computationally easy. The accurate method for fragility evaluation is Monte Carlo simulation method but it takes a very long time compare to HDMR method. In HDMR method, by three point sampling method only 9 set of input variables is used and results from the non-linear time history analysis for those 9set of input variable, the Metamodels are calculated, and the Monte Carlo simulation is performed on the overall Metamodel, this will take few hours. On the other hand the overall Monte Carlo simulation is used for the generation of fragility evaluation; it requires minimum 10000 to 100000 sets of input variables and perform the non-linear time history analysis for those sets, this will take a very long time.

In HDMR method, for sampling input variable three point sampling and five point sampling is used. For three point sampling, the sampling point is considered as a μ, μ+2σ and μ-2σ. The five point sampling is appropriate for more accuracy and the sampling points are considered as a μ, μ+σ, μ-σ, μ+2σ, μ-2σ.

6. CONCLUSION

The fragility curve is an important tool to recognize the probability of failure of structure when the structure subjected to seismic load. In present study, for generation of fragility curves response surface based HDMR technique is used. By the use of this technique reduce the complexity of analysis like reduce the total number of time history analysis compare to other conventional methods. And in the HDMR method three point sampling is used for selection of values of input variables. In metamodels relation the coefficient of input variable denotes dependency of response on that variables and it proves that the response is more dependent on 'PGA' compare to other variables.

i.e. $E_c < f_c < f_y < PGA$

- In HDMR method, the three point sampling is used for the selection of the values of input variable are obtained. And also sometimes five point sampling are used for more accuracy than the three point sampling. In HDMR method only 9to 18 numbers of time history analysis is sufficient for fragility curve generation.
- The Cornell's method is proposed by Cornell in the year of 2002. In this method the Latin hypercube sampling is used for selection of values of input variables. This method requires 30 no's of time history analysis and expected time is 7 days.
- This is direct method used for fragility curve generation. This method take long time for generation of fragility curve , i.e. minimum 10000 numbers of non-linear time history analysis required and it takes expected time is 70 months but accuracy is more in this method.

The above three discussion proves the HDMR method is more efficient than the other two methods.

7. FUTURE SCOPES

1. In the present study, a single RC 3D frame without footing, basement, plinth beam and shear walls is considered.
2. uncertainties is considered in material properties like chacteristic strength of concrete, modulus of elasticity of concrete, and yield strength of steel bars, and seismic loading is captured by applying an earthquake ground motions.
3. The soil structure interface effects are not considered in this study.
4. The Colum bases are assumed to be fixed, the strength and stiffness of infill walls is not taken into account in this study.
5. The floors diaphragm is considered as a stiff diaphragm.
6. The geometric nonlinearity P-Delta is not considered. And the software ETABS-2013 is used for the analysis of large number of computational models for fragility evaluation.
7. The non-linear time history analysis can be carried out for different grade of concrete.
8. Analysis can be extended by using P- Delta non-linear geometry conditions.

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