Utilizing Parallel Computer Systems to Examine Seismic Reliability of Constructions

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Abstract Primary reaction under seismic loadings is ordinarily nonlinear and identified with numerous components, for example, underlying designs, material properties, inhabitance loads, quake risks and fragmented information on the framework. As every one of these components have their wellsprings of vulnerabilities, underlying reaction under seismic stacking has its probabilistic nature. Along these lines, the irregular variable for any primary interest follows a multivariate likelihood dispersion over the reconciliation space characterized by the breaking point states. Inspecting the probabilistic conduct of constructions under quake loadings needs to think about the wellsprings of vulnerabilities from all components. It is likewise realized that mathematical strategies, for example, the limited component strategy, are generally used to anticipate nonlinear primary reaction. The probabilistic primary interest is a discrete likelihood capacity of its connected factors.

Introduction Structural dynamic response under seismic loading are nonlinear functions of many factors, such as structural configurations, material properties, occupancy loads, earthquake hazards and incomplete knowledge of the system. Thus, structural dynamic response is typically predicted using nonlinear numerical methods, such as the finite element method. The random variable for any structural demand follows a multivariate probability distribution for all related factors over the integration domain defined by the limit states. Due to the nature of numerical analysis of structures with nonlinear behaviour, a closed form solution of the probability distribution may not be available. A quantitative assessment of the implied reliability level of the designed structures under earthquake loads is needed to address the concerns at targeted performance levels within the life time of the structures. In the past decades, much research work have been conducted to examine risk-based procedures toward performance based earthquake engineering and design. The fragility analysis determines the exceeding probability of demand conditioned on a specific level of intensity measure [1-6]. A fragility analysis does not identify any specific limit state taking into consideration the coupling effect of all random variables. A seismic fragility analysis is commonly used to examine the uncertainty of ground motion records at targeted intensity levels. The fragility analysis is a reasonably accurate method provided that: 1) the source of uncertainties is dominated by earthquake loads; and 2) no uncertainty is associated with targeted intensity measures. The occurrence probability of earthquake intensity measure (IM) is determined by seismologists on a regional basis. Determined hazard levels, such as those specified in the building codes (i.e., the design intensity at 2% in 50 years) are commonly used by engineers. With the determined intensity targets, the fragility
analysis provides reasonable information about the probabilistic behaviour of structures. The conditional probability distribution described by the fragility analysis can be integrated with the uncertainty of intensity measure in order to determine the coupling effect between ground motions and intensity measure [1,7]. If other random variables are considered, multiple integrals can be applied to conditional distributions of these random variables. This method can incorporate all sources of uncertainties into structural probability analysis and thus has been widely used in analyzing seismic reliability of structures. It can be used to develop a simplified design format similar to the conventional load and resistance factor design [7,8]. This method was implemented in the response surface method [9]. It can also be used to determine the probability of failure of components or systems [10,11] and existing buildings [12]. This method can also be implemented into design optimization to study the relationship between seismic risk and potential damage/repair cost [13]. This method is referred to as the traditional method in the following discussion. In both the fragility analysis and the traditional method, Monte Carlo simulation (MCS) is commonly used to sample variables other than those from earthquakes [12-19]. With the samples from MCS, the traditional method uses data fitting techniques to obtain parameters from the results of simulation, which may not be able to produce accurate results. In order to accurately quantify and examine the probabilistic seismic behaviour, two numerical methods were used here to produce cumulative probability distributions of structural demands. One method is the numerical format of the traditional method. Compared with the traditional method using aggregated parameters from data-fitting techniques, the numerical procedure is inaccurate, especially when the coupling effect from different sources of uncertainties is interested. The other method is the MCS that applies to all sources of uncertainties, including the intensity measure. The background and rational of this method can be found in a previous study [20]. Both methods have been employed in analyzing seismic reliability analysis of structures. Using numerical procedures to examine seismic reliability of structures requires a significant number of nonlinear time history analysis (NTHA), which was considered to be a bottleneck using traditional personal computers. It is noted that NTHA for seismic reliability analysis has its parallel characteristics and can be executed by multiple computers connected in parallel. Two parallel computer systems are reported here to discuss their applications. One system is based on multiple PCs in typical university computer labs. This system was used to analyze the probabilistic seismic behaviour of a two-storey wooden frame building. The other system is to use a specialized software running on high performance computer clusters. A three-storey steel moment frame building was analyzed using this system to study its seismic reliability. The results of both systems were reported and discussed, and some recommendations were made. Methodologies Reliability methods The traditional method: Two seismic reliability methods were used to examine the application of parallel computational systems. The first method is the traditional method, which estimates the exceeding probability of drift demand from conditional distributions given intensity levels. Considering the nature of NTHA, a closed-form solution to Eq. (3) may not exist. With certain assumptions for the random variables, this method was used to obtain an algebra equation with its coefficients data fitted from limited NTHA [1]. In order to obtain an accurate result from this method, Eq. (3) can be...
rewritten using the discreteWhere M is the number of intensity levels and L is the numberof capacity levels. The discrete samples of seismic weight have beenincorporated in the conditional CDF. In this study, the conditional probability distributions, P \[ D a y | I M x \leq \] , with uncertainties from ground motion records and seismic weights were used to compare the influence of differentfactors. This calculation produces multiple probability distribution curves at different levels of intensity at IM x = . The numerical procedure illustrated in Eq. (4) was originally developed to study seismic reliability of wood frame structures [20]. This procedure is more accurate than theoriginal work [7], in which Eq. (3) was used to obtain some simplified algebra equations with parameters obtained from data-fitting techniques. However, this procedure requires significant amount of NTHA, which is considered to be time-consuming and thus needs parallel computing technology. The Monte Carlo simulation: The probability distribution of ground motion records can be viewed as a uniform distribution. Each record is a natural sample representing the ground motion characteristics. Considering that the distribution of intensity and seismic weights can be defined with statistical data, the drift demand follows a joint multivariate distribution of resistance, records and intensity. If other uncertainty sources are considered, the joint distribution will have more random variables. The MCS may be used as a benchmark to account for the uncertainties from different sources. This method is an extension of the traditional MCS to engage the uncertainty from ground motion records, based on the discreteneature of ground motions. If there are an infinite number of groundmotion records, the ground motion characteristics can be sampled as a regular random variable and thus be combined with other variables as illustrated by MCS. Since the ground motions available for a particular analysis are always limited, a special sampling technique is needed. It is noted that the occurrence probability of each record is 1/N, where N is the total number of records. Then, all random variables are divided into two groups, one for ground motions and the other for the rest of variables. The other group is regularly sampled with the number of combinations denoted as T. All T combinations are mixed with N ground motions to generate T × N grid samples, each of which is a set of input for NTHA. The results of the demand measure from the T × N NTHA forms data points for the CDF [20]. It is well-known that iterations are typically required for nonlinear problems. As the input for NTHA generated by pseudo-random numbers typically requires a significant number of iterations, the computational efficiency may be compromised. On the other hand, the MCS can be viewed as a numerical integration in its domain. Therefore, grid based samples or sequence samples can be used in numerical integration to obtain results of the MCS. The computational efficiency using grid based samples or sequence samples are predictable compared with pseudo-random samples, which makes the MCS relatively efficient. This type of MCS is commonly cited as the quasi Monte Carlo simulation [22]. A computational procedure with multiple PCs using the discrete format of the traditional method or the MCS requires repeatable NTHA. These repeatable calculations are for the same system with different vector inputs to consider their uncertainties. On one hand, the process of each calculation itself is performed step by step in the time domain. In each time step, the iteration to achieve the convergence involves some algorithms, such as the Newton-Raphson method. All of these iteration steps are to be performed in a serial manner, the order of which cannot
be alternated easily. Therefore, each NTHA is in a sequence-based calculation, which efficiency is primarily dominated by the processor’s speed. The parallel computing technology cannot be directly applied to speed up the computational process of any individual NTHA, except some systems have a large amount of elements or degree-of-freedoms. On the other hand, all NTHA are independent from each other, all of which do not need any communication with other NTHA during the execution. Since only the final results are needed for probabilistic analysis, the demand for information communication during the calculation is minimum. Therefore, these NTHA can be viewed as parallel and can be executed by different processors on any parallel computing system, regardless whether the computer processors are located locally or remotely. This computational procedure aims to utilize the resource of multiple personal computers (PCs) that are commonly available in university computer labs. These PCs are typically idle in the evenings, weekends and non-instructional seasons. NTHA for the discussed probabilistic analysis can be performed on these PCs without any capital investment. Several attempts were made to utilize the computer resources in the labs. The procedure shown in Figure 1 was developed for NTHA programs using traditional computational languages, such as Fortran 77/90 and C. Examples of these programs include CASHEW [23] and DRAIN-2DX [24], which are typically programmed with modules for simplicity. But these programs are not object-oriented and are difficult to be controlled via the network. Therefore, these numerical programs are compiled separately as executable files, so that they can be executed remotely when needed. These executable programs are stored online on multiple processors, as indicated by “PC-1”, “PC-2” and so on, in Figure 1. In order to feed input to and extract output from the processors, a control program, as shown in Figure 1 needs to be developed. The main function of this control program is to pre-process the input and post-process the output as required for the reliability analysis. In the pre-process stage, this program generates the combinations of inputs from all random variables for the reliability methods as discussed above. Then these inputs are sent to the processors through the network for NTHA. After NTHA is finished, the results are sent back to this control program to generate probability distribution functions and visualizer results. This control program was written in Microsoft Excel with Visual Basic Script and run on “PC-0” as shown in Figure 1. In order to send the input to remote processors, check their executable status and retrieve the results back to the control program, an interface communicating through the network is needed. At the beginning, both Telnet and Microsoft Power Shell were tried on a small network with some success. However, they were not permitted to run on a university network, because of concerns on the network security. Finally, Ultra VNC [25] was used in the analysis. UltraVNC is a remote control program, which enables users to check the running status on remote processors and manually send files to the controller.

References