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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.

IntroductionS

tructural dynamic response under seismic loading are nonlinearfunctions of many factors, such as structural configurations, materialproperties, occupancy loads, earthquake hazards and incompleteknowledge of the system. Thus, structural dynamic response istypically predicted using nonlinear numerical methods, such as thefinite element method. The random variable for any structural demandfollows a multivariate probability distribution for all related factors overthe integration domain defined by the limit states. Due to the nature of numerical analysis of structures with nonlinear behaviour, a closedform 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 addressthe concerns at targeted performance levels within the life time ofthe 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 levelof intensity measure [1-6]. A fragility analysis does not identify any specific limit state taking into consideration the coupling effect of allrandom variables. A seismic fragility analysis is commonly used toexamine the uncertainty of ground motion records at targeted intensitylevels. The fragility analysis is a reasonably accurate method providedthat: 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) isdetermined by seismologists on a regional basis. Determined hazardlevels, such as those specified in the building codes (i.e., the designintensity at 2% in 50 years) are commonly used by engineers. With thedetermined intensity targets, the fragility analysis provides reasonableinformation about the probabilistic behaviour of structures.The conditional probability distribution described by the fragilityanalysis can be integrated with the uncertainty of intensity measurein order to determine the coupling effect between ground motionsand intensity measure [1,7]. If other random variables are considered,multiple integrals can be applied to conditional distributions ofthese random variables. This method can incorporate all sources ofuncertainties into structural probability analysis and thus has beenwidely used in analyzing seismic reliability of structures. It can be usedto develop a simplified design format similar to the conventional loadand resistance factor design [7,8]. This method was implemented inthe response surface method [9]. It can also be used to determine theprobability of failure of components or systems [10,11] and existingbuildings [12]. This method can also be implemented into designoptimization to study the relationship between seismic risk andpotential damage/repair cost [13]. This method is referred to as thetraditional method in the following discussion.In both the fragility analysis and the traditional method, Monte Carlo simulation (MCS) is commonly used to sample variables otherthan those from earthquakes [12-19]. With the samples from MCS, thetraditional method uses data fitting techniques to obtain parametersfrom the results of simulation, which may not be able to produceaccurate results. In order to accurately quantify and examine theprobabilistic seismic behaviour, two numerical methods were usedhere to produce cumulative probability distributions of structuraldemands. One method is the numerical format of the traditionalmethod. Compared with the traditional method using aggregatedparameters from data-fitting techniques, the numerical procedure isaccurate, especially when the coupling effect from different sourcesof uncertainties is interested. The other method is the MCS thatapplies to all sources of uncertainties, including the intensity measure.The background and rational of this method can be found fund in aprevious study [20]. Both methods have been employed in analyzingseismic reliability analysis of structures.Using numerical procedures to examine seismic reliability ofstructures requires a significant number of nonlinear time historyanalysis (NTHA), which was considered to be a bottle-neck usingtraditional personal computers. It is noted that NTHA for seismicreliability analysis has its parallel characteristics and can be executedby multiple computers connected in parallel. Two parallel computersystems are reported here to discuss their applications. One system isbased on multiple PCs in typical university computer labs. This systemwas used to analyze the probabilistic seismic behaviour of a two-storeywood frame building. The other system is to use a specialized softwarerunning on high performance computer clusters. A three-storey steelmoment frame building was analyzed using this system to studyits seismic reliability. The results of both systems were reported anddiscussed, and some recommendations were made.MethodologiesReliability methodsThe traditional method: Two seismic reliability methods wereused to examine the application of parallel computational systems. Thefirst method is the traditional method, which estimates the exceedingprobability of drift demand from conditional distributions givenintensity 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 coefficientsdata-fitted from limited NTHA [1]. In order to obtain an accurateresult 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 IM x [()] ≤ = , with uncertainties from ground motion recordsand seismic weights were used to compare the influence of differentfactors. This calculation produces multiple probability distributioncurves at different levels of intensity at IM x = .The numerical procedure illustrated in Eq. (4) was originallydeveloped to study seismic reliability of wood frame structures [20].This procedure is more accurate than the original work [7], in whichEq. (3) was used to obtain some simplified algebra equations withparameters obtained from data-fitting techniques. However, thisprocedure requires significant amount of NTHA, which is consideredto be time-consuming and thus needs parallel computing technology.The Monte Carlo simulation: The probability distribution ofground motion records can be viewed as a uniform distribution.Each record is a natural sample representing the ground motioncharacteristics. Considering that the distribution of intensity andseismic weights can be defined with statistical data, the drift demandfollows a joint multivariate distribution of resistance, records andintensity. If other uncertainty sources are considered, the jointdistribution will have more random variables. The MCS may be usedas a benchmark to account for the uncertainties from different sources.This method is an extension of the traditional MCS to engagethe uncertainty from ground motion records, based on the discretenature of ground motions. If there are an infinite number of groundmotion records, the ground motion characteristics can be sampled as aregular random variable and thus be combined with other variables asillustrated by MCS. Since the ground motions available for a particularanalysis are always limited, a special sampling technique is needed. Itis noted that the occurrence probability of each record is 1/N, where Nis the total number of records. Then, all random variables are dividedinto two groups, one for ground motions and the other for the restof variables. The other group is regularly sampled with the numberof combinations denoted as T. All T combinations are mixed with Nground motions to generate T × N grid samples, each of which is aset of input for NTHA. The results of the demand measure from theT × N NTHA forms data points for the CDF [20].It is well-known that iterations are typically required for nonlinearproblems. As the input for NTHA generated by pseudo-randomnumbers typically requires a significant number of iterations, thecomputational 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 innumerical integration to obtain results of the MCS. The computationalefficiency using grid based samples or sequence samples are predictablecompared with pseudo-random samples, which makes the MCSrelatively efficient. This type of MCS is commonly cited as the quasiMonte Carlo simulation [22].A computational procedure with multiple PCsUsing the discrete format of the traditional method or the MCSrequires repeatable NTHA. These repeatable calculations are for thesame system with different vector inputs to consider their uncertainties.On one hand, the process of each calculation itself is performed step bystep in the time domain. In each time step, the iteration to achieve theconvergence involves some algorithms, such as the Newton-Raphsonmethod. All of these iteration steps are to be performed in a serialmanner, the order of which cannot be alternated easily. Therefore,each NTHA is in a sequence-based calculation, which efficiency isprimarily dominated by the processor's speed. The parallel computingtechnology cannot be directly applied to speed up the computationalprocess of any individual NTHA, except some systems have a largeamount of elements or degree-of-freedoms. On the other hand, allNTHA are independent from each other, all of which do not needany communication with other NTHA during the execution. Sinceonly the final results are needed for probabilistic analysis, the demandfor information communication during the calculation is minimum.Therefore, these NTHA can be viewed as parallel and can be executedby different processors on any parallel computing system, regardlesswhether the computer processors are located locally or remotely.This computational procedure aims to utilize the resource ofmultiple personal computers (PCs) that are commonly available inuniversity computer labs. These PCs are typically idle in the evenings,weekends and non-instructional seasons. NTHA for the discussedprobabilistic analysis can be performed on these PCs without anycapital investment.Several attempts were made to utilize the computer resources inthe labs. The procedure shown in Figure 1 was developed for NTHAprograms using traditional computational languages, such as Fortran77/90 and C. Examples of these programs include CASHEW [23] andDRAIN-2DX [24], which are typically programed with modules forsimplicity. But these programs are not object-oriented and are difficultto be controlled via the network. Therefore, these numerical programsare compiled separately as executable files, so that they can be executedremotely when needed. These executable programs are stored onmultiple processors, as indicted by "PC-1", "PC-2" and so on, in Figure 1.In order to feed input to and extract output from the processors, acontrol program, as shown in Figure 1 needs to be developed. The mainfunction of this control program is to pre-process the input and postprocess the output as required for the reliability analysis. In the preprocess stage, this program generates the combinations of inputs fromall random variables for the reliability methods as discussed above.Then these inputs are sent to the processors through the network forNTHA. After NTHA is finished, the results are sent back to this controlprogram to generate probability distribution functions and visualizeresults. This control program was written in Microsoft Excel withVisual Basic Script and run on "PC-0" as shown in Figure 1.In order to send the input to remote processors, check theirexecutable status and retrieve the results back to the control program,an interface communicating through the network is needed. At thebeginning, both Telnet and Microsoft PowerShell were tried on a smallnetwork with some success. However, they were not permitted to runon a university network, because of concerns on the network security.Finally, Ultra VNC [25] was used in the analysis. UltraVNC is a remotecontrol program, which enables users to check the running status onremote processors and manually send files to the controller.

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