Ground Motion Time-Histories Matching Spectrum
Notes

Introduction

With the widespread availability of powerful personal computers and advanced engineering software, dynamic analysis using acceleration time histories can now be readily carried out for many types of structures. However, as always, the quality of the output from a computer analysis depends on the quality of the input information. It is important for the engineering analyst to understand that not only should the numerical model represent the structure well, the acceleration time histories used in the analysis should represent the design earthquake well.

As a starting point it is useful to refer to NBCC requirements on this topic. NBCC 2005 provides the following direction:

> ***4.1.8.12. Dynamic Analysis Procedure***
>
> *1) The Dynamic Analysis Procedure shall be in accordance with one of the following methods:*
> *a) Linear Dynamic Analysis by either the Modal Response Spectrum Method or the* ***Numerical Integration Linear Time History Method using a structural model that complies with the requirements of Sentence 4.1.8.3.(8),*** *or*
> *b) Nonlinear Dynamic Analysis, in which case a special study shall be performed.*
>
> *2) The spectral acceleration values used in the Modal Response Spectrum Method shall be the design spectral acceleration values, S(T), defined in Sentence 4.1.8.4.(6).*
>
> *3)* ***The ground motion histories used in the Numerical Integration Linear Time History Method shall be compatible with a response spectrum constructed from the design spectral acceleration values, S(T), defined in Sentence 4.1.8.4.(6)***

In other words, the ground motion time histories selected for the dynamic analysis must be compatible with the site-specific Uniform Hazard Spectrum developed by the process defined elsewhere in NBCC Subsection 4.1.8.

Commentary J of NBCC 2005 provides the following guidance on selection of ground motion time histories:

> ***Commentary J, Sentence 4.1.8.12.(1)***
>
> ***181*** *The ground motion time-histories used as input should be representative of the seismotectonic environment at the location of the building, i.e. correspond to earthquake ground motions that have been recorded for magnitudes and*

epicentral distances similar to those that dominate seismic hazard at the particular location. In addition to being compatible with a response spectrum constructed from the design spectral acceleration values, S(T), these time histories need to have durations and waveforms that will allow the structural model to respond inelastically with sufficient cycles of load reversal. Also, sufficient time histories need to be used to enable uncertainties in ground motion parameters (e.g. durations) to be reflected in the dispersion of resulting response parameters.

Commentary J, Sentence 4.1.8.12.(3)

183 *The Numerical Integration Linear Time History Method requires dynamic excitations, which are represented as acceleration time histories. Sentence 4.1.8.12.(3) requires that such time histories be compatible with a response spectrum constructed from the design spectral acceleration values, S(T). A time history is deemed to be "spectrum compatible" if its response spectrum equals or exceeds the target spectrum throughout the period range of interest, i.e. the periods of the modes contributing to the response of the particular structure. Spectrum-compatible time histories may be obtained by scaling and/or modifying actual recorded earthquake accelerograms (obtained from earthquakes of similar magnitudes and located at similar distances to those that contribute most significantly to seismic hazard at the site in question) or by creating artificial or synthetic time histories. The latter are often required due to the limited number of actual records available for such purposes; this is particularly the case for earthquake magnitude-distance pairs that dominate seismic hazard in eastern Canada. A stochastically-based approach for obtaining synthetic time histories is given by Atkinson and Beresnev (1998).*

184 *If actual earthquake accelerograms are used, then they should be scaled so that the spectral acceleration at the fundamental period of the structure corresponds to the design spectral response acceleration for the particular site. The spectral acceleration ordinates at the periods below the fundamental period should also be equal to or greater than those of the design spectral response acceleration, S(T), for those periods. If that is not the case for the selected accelerograms, they can be modified to meet that requirement (Naumoski, 2001, describes a simple technique for such a modification).*

185 *Due to the natural aleatory uncertainty arising from the physical variability of earthquake ground motions, it is not feasible to represent the range of possible responses in a single time history. This fact, combined with the sensitivity of time history response calculations to small differences in the characteristics of individual records, means that multiple records must be used so that the realistic dispersion of response parameters due to this variability can be obtained. NEHRP 2000 (Building Seismic Safety Council) requires that a suite of ground motions used for this kind of analysis be made up of at least three records but the NEHRP Commentary recommends that seven or more be used.*

The seminar presentation which these notes accompany provides an overview of the key issues to be considered when selecting earthquake time histories and matching them to a target response spectrum. Additional information on selected topics is provided below.

Selection of Time History Records

Time histories selected for dynamic analysis of a structure should be from seismotectonic & geologic settings comparable to those at the site of interest. The time histories selected should also be consistent with the magnitude/distance/duration scenarios developed for the analyses.

Southwestern British Columbia is located in a tectonically complex region, adjacent to and overlying the Cascadia subduction zone. The region is exposed to seismic hazard from potential earthquakes in both continental and oceanic crustal sources, potential (intraplate) earthquakes within the subducting Juan de Fuca Plate and potential (interplate) major subduction earthquakes. The local strong motion network was quite limited until the last 10 to 20 years and there are few local strong motion records of large magnitude earthquakes. The most recent Cascadia subduction earthquake is interpreted to have occurred in January 1700, long before earthquake recording instruments were developed. Therefore, it is necessary to obtain time history records from other parts of the world for use in dynamic analyses of structures.

California is often viewed as a primary source of earthquake time history records because of that region's history of large earthquakes and seismic research and the fact that numerous earthquakes have also been recorded by strong motion instruments. However, it is important to note that many of those strong motion records have been obtained on deep soil deposits (e.g. the Imperial Valley), or on rock that is of lower quality than some of the rock in southwestern B.C. California is also located along a transform plate boundary (e.g. San Andreas Fault) that is comparable to northern B.C. which is located along the tectonically-similar Queen Charlotte Fault, but only northern California is located close to the Cascadia subduction zone.

Other tectonically active regions of the world should also be considered as sources of time histories that could be applicable to southwestern B.C. This includes other plate boundary regions such as Japan, Taiwan and Chile (subduction zone settings) and Italy, Turkey and Iran.

Many time history records are publically available, and many universities and engineering consultants maintain informal libraries of such records. Variations of the same time histories are sometimes encountered due to different base line corrections and filtering being applied to the raw records by different processing techniques. Such variations may not have significant impact on the results of dynamic analyses based on those records, but an effort should be made to confirm that records selected have been processed by an appropriate and consistent method.

Several key sources of strong motion data are available on the internet, including:

Pacific Earthquake Engineering Research Center (PEER) Strong Motion Database, at http://peer.berkeley.edu/smcat/ . This searchable database currently contains records from 143 earthquakes, selected for their engineering value. All records have been processed in a consistent manner and are referenced to specific ground conditions. These records recently provided the database for a PEER-sponsored project to develop new ground motion attenuation relationships for western USA crustal earthquakes (Next Generation Attenuation relationships).

Consortium of Organizations for Strong Motion Observation Systems (COSMOS) Virtual Data Centre, at http://db.cosmos-eq.org/scripts/default.plx . This site serves as a portal to strong motion databases maintained by approximately 35 COSMOS strong motion program members.

Numerous national institutes, universities and research organizations maintain strong motion databases that are not linked to COSMOS. Links to many of these sources can be found at the following websites maintained by the US Geological Survey (USGS) and the University of Washington:

US Geological Survey - http://pasadena.wr.usgs.gov/info/smdata.html
Seismosurfing the Internet - http://www.geophys.washington.edu/seismosurfing.html

Approaches to Spectrum Matching

There are several approaches to modifying time histories to achieve a match to a target spectrum:

Linear scaling, in which the entire acceleration time history is scaled by a constant factor. The scaling factor is typically selected to achieve a match to target PGA or spectral response acceleration at the fundamental period of the structure. This approach is easy to understand and perform and the frequency content and original phasing of the record are preserved. There are no hard rules for scaling factors, but large factors (e.g. > 2 to 3) should be avoided if possible as the scaled record may not be realistic in terms of relative amplitudes and duration. The scaled spectrum should also be examined critically to determine if it is overly severe or deficient at periods other than the target period.

Frequency content modification approaches, which are generally described as frequency domain or time domain scaling.

Frequency domain techniques generally involve adjusting Fourier amplitudes while maintaining Fourier phases of the time histories. In simple terms, this is similar to the addition or subtraction of sinusoidal waves of different periods to the full length of the original time history. The SYNTH software referred to in the NBCC 2005 commentary (Naumoski, 2001) is an example of the frequency domain approach. Other software of this type includes SIMQKE (Gasparini and Vanmarcke, 1976; Vanmarcke et al, 1997) and RASCAL (Silva and Lee, 1987). Several iterations are usually required to achieve a match. Attempts to match the target spectrum exactly should be avoided as the repeated modifications may produce unrealistic time histories that significantly differ in appearance from the original time histories. In some cases, the acceleration time histories may appear visually similar to the original, but the velocity and displacement histories may exhibit significant changes.

Time domain techniques involve adding or subtracting "wavelets" of finite duration to or from the original time history. The wavelets are selected to provide a match to the target spectrum at specific periods. RSPMATCH (Abrahamson, 1998) is an example of software that is based on a time domain approach. Again, several iterations are usually required to achieve a match to target spectrum. Currently, time domain scaling is the generally preferred frequency modification approach for matching to a target spectrum.

Artificial time histories can be generated based on numerical modeling of the fault rupture process and the source-to-site propagation of seismic waves. Several theoretical approaches are available and are best left to qualified seismologists. This method is sometimes applied in regions where no appropriate scenario earthquake time histories are available, or to provide an alternative to time histories that have been modified by the techniques described above.

For More Details…..

For a more comprehensive review of methodology for matching earthquake time history records to a target spectrum, refer to US Army Corps of Engineers (2003), Section 5 and Appendices B,C, and D. That document is available for download on the internet at http://www.usace.army.mil/publications/eng-manuals/em1110-2-6051/ .

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