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The Use of Modern Computer Software in the Calculation of Seismic Stability of Multi-Story Buildings

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Annotation: This article will talk about the use of modern computer software in the calculation of seismic stability of multi-storey buildings. The author, relying on technical data, analyzed the problem on the basis of available literature and studied the existing peculiarities of the use of modern computer software in the calculation of seismic stability of multi-storey buildings.

Keywords: Multi-storey buildings, seismic stability, modern computer.

Seismic analysis is a tool for the estimation of structural response in the process of designing earthquake resistant structures and/or retrofitting vulnerable existing structures. In principle, the problem is difficult because the structural response to strong earthquakes is dynamic, nonlinear and random. All three characteristics are unusual in structural engineering, where the great majority of problems are (or at least can be adequately approximated as) static, linear and deterministic. Consequently, special skills and data are needed for seismic design, which an average designer does not necessarily have.

Methods for seismic analysis, intended for practical applications, are provided in seismic codes. (Note that in this paper the term “code” is used broadly to include codes, standards, guidelines, and specifications.) Whereas the most advanced analytical, numerical and experimental methods should be used in research aimed at the development of new knowledge, the methods used in codes should, as Albert Einstein said, be “as simple as possible, but not simpler”. A balance between required accuracy and complexity of analysis should be found, depending on the importance of a structure and on the aim of the analysis. It should not be forgotten that the details of the ground motion during future earthquakes are unpredictable, whereas the details of the dynamic structural response, especially in the inelastic range, are highly uncertain. According to Aristotle, “it is the mark of an educated mind to rest satisfied with the degree of precision which the nature of the subject admits and not to seek exactness where only an approximation is possible”.

After computers became widely available, i.e. in the late 1960s and in 1970s, a rapid development of procedures for seismic analysis and supporting software was witnessed. Nowadays, due to tremendous development in computing power, numerical methods, and software, there are almost no limits related to computation. Unfortunately, knowledge about ground motion and structural behaviour, especially in the inelastic range, has not kept up the same speed. Also, we cannot expect that, in general, the basic capabilities of engineers will be better than in the past. So, there is a danger, as M. Sozen wrote already in 2002: “Today, ready access to versatile and powerful software enables the engineer to do more and think less.” (M. Sozen, A Way of Thinking, EERI

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Newsletter, April 2002.) Two other giants in earthquake engineering also made observations which have remained valid up to now. R. Clough, one of the fathers of the finite element method, stated: “Depending on the validity of the assumptions made in reducing the physical problem to a numerical algorithm, the computer output may provide a detailed picture of the true physical behavior or it may not even remotely resemble it” warned: “There are some negative aspects to the reliance on computers that we should be concerned about. It is unfortunate that there has been a trend among the young practicing engineers who are conducting structural analysis, design, and detailing using computers to think that the computer automatically provides reliability”. Today it is lack of reliable data and the limited capabilities of designers which represent the weak link in the chain representing the design process, rather than computational tools, as was the case in the past.

An indication of the restricted ability of the profession (on average) to adequately predict the seismic structural response was presented by the results of a blind prediction contest of a simple full-scale reinforced concrete bridge column with a concentrated mass at the top, subjected to six consecutive unidirectional ground motions. A description of the contest, and of the results obtained, described in the following text, has been summarized from Terzic et al. (2015). The column was not straightened or repaired between the tests. During the first ground motion, the column displaced within its elastic range. The second test initiated a nonlinear response of the column, whereas significant nonlinearity of the column response was observed during the third test. Each contestant/team had to predict peak response for global (displacement, acceleration, and residual displacement), intermediate (bending moment, shear, and axial force), and local (axial strain and curvature) response quantities for each earthquake. Predictions were submitted by 41 teams from 14 different countries. The contestants had either MSc or PhD degrees. They were supplied with data about the ground motions and structural details, including the complete dimensions of the test specimen, and the mechanical one-dimensional properties of the steel and concrete. In this way the largest sources of uncertainties, i.e. the characteristics of the ground motion and the material characteristics, were eliminated. The only remaining uncertainty was related to the modelling and analysis of the structural response. In spite of this fact, the results showed a very wide scatter in the blind predictions of the basic engineering response parameters. For example, the average coefficient of variation in predicting the maximum displacement and acceleration over the six ground motions was 39 and 48%, respectively. Biases in median predicted responses were significant, varying for the different tests from 5 to 35% for displacement, and from 25 to 118% for acceleration. More detailed results for the maximum displacements at the top of the column and the maximum shear forces at the base of the column are presented in Fig. 1. A large dispersion of the results can be observed even in the case of the elastic (Eq. 1) and nearly elastic (Eq. 2) structural behaviour.

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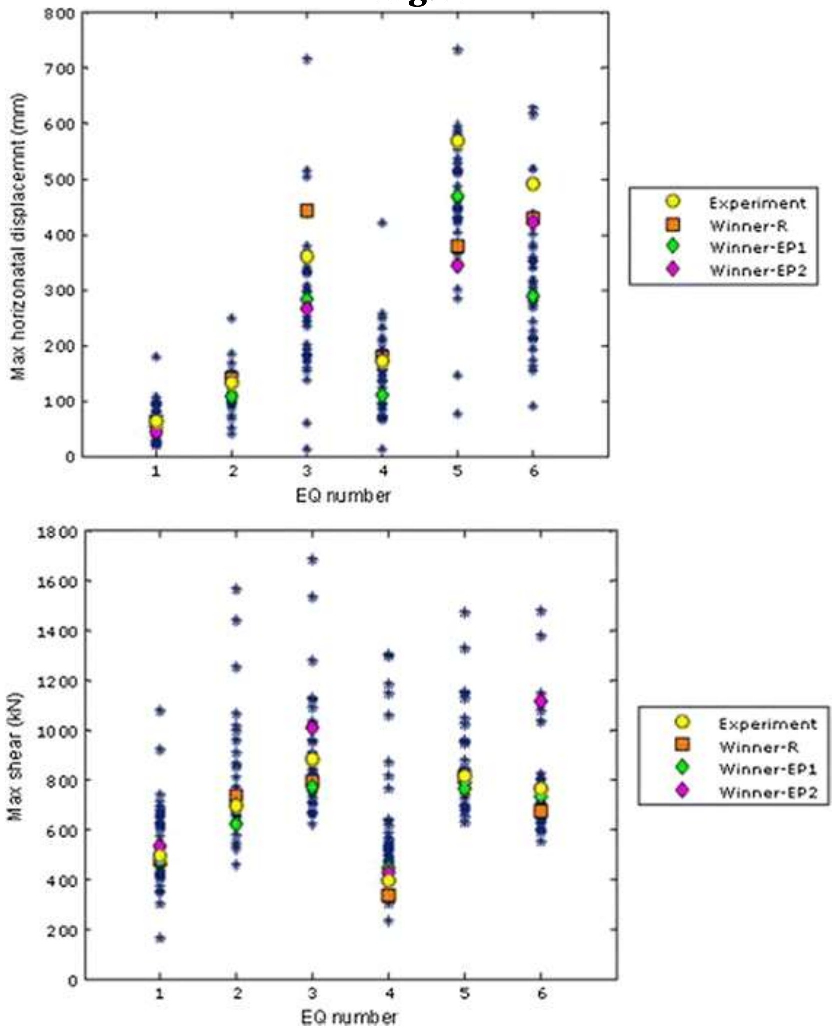
Fig. 1



Predictions of maximum horizontal displacements at the top of the column and maximum base shears versus measured values (Terzic et al. 2015)

The results of the blind prediction contest clearly demonstrate that the most advanced and sophisticated models and methods do not necessarily lead to adequate results. For example, it was observed that a comparable level of accuracy could be achieved if the column was modelled either with complex force-based fibre beam-column elements or with simpler beam-column elements with concentrated plastic hinges. Predictions of structural response greatly depended on the analyst's experience and modelling skills. Some of the results were completely invalid and could lead to gross errors if used in design. A simple check, e.g. with the response spectrum approach applied for a single-degree-of-freedom system, would indicate that the results were nonsensical.

This paper deals with analysis procedures used in seismic provisions. The development of seismic provisions related to the analysis of building structures is summarized, the present state is discussed, and possible further developments are envisaged. Although, in general, the situation in

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the whole world is discussed, in some cases emphasis is placed on the situation in Europe and on the European standard for the design of structures for earthquake resistance Eurocode 8 (CEN 2004), denoted in this paper as EC8. The discussion represents the views of the author and is based on his experience in teaching, research, consulting, and code development work.

Earthquake engineering is a relatively young discipline, "it is a twentieth century development" (Housner 1984). Although some types of old buildings have, for centuries, proved remarkably resistant to earthquake forces, their seismic resistance has been achieved by good conceptual design without any seismic analysis. Early provisions related to the earthquake resistance of buildings, e.g. in Lima, Peru (Krause 2014) and Lisbon, Portugal (Cardoso et al. 2004), which were adopted after the disastrous earthquakes of 1699 and 1755, respectively, were restricted to construction rules and height limitations. It appears that the first engineering recommendations for seismic analysis were made in 1909 in Italy. Apparently Housner considered this date as the starting date of Earthquake Engineering.

The period up to 1978 was dominated by the equivalent static procedure. "The equivalent static method gradually spread to seismic countries around the world. First it was used by progressive engineers and later was adopted by building codes. Until the 1940s it was the standard method of design required by building codes" (Housner 1984), and still today it is widely used for simple regular structures, with updated values for the seismic coefficients. "This basic method has stood the test of time as an adequate way to proportion the earthquake resistance of most buildings. Better methods would evolve, but the development of an adequate seismic force analysis method stands out in history as the first major saltation or jump in the state of the art." (Reitherman 2012, p. 174). From the three basic features of seismic structural response, dynamics was the first to be introduced. Later, inelastic behaviour was approximately taken into account by the gradation of seismic loads for different structural systems, whereas randomness was considered implicitly by using various safety factors.

In the following sections we will summarize the development of seismic analysis procedures in different codes (see also Table 1). It will be shown that, initially, the equivalent static approach was used. With some exceptions, for several decades the seismic coefficient mostly amounted to about 0.1.

Dynamic considerations were introduced by relating the seismic coefficient to the period of the building, indirectly via the number of storeys in 1943, and directly in 1956. The modal response spectrum method appeared for the first time in 1957. The impact of the energy dissipation capacity of structures in the inelastic range (although this was not explicitly stated in the code) was taken into account in 1959. Modern codes can be considered to have begun with the ATC 3-06 document "Tentative provisions for the development of seismic regulations for buildings", which was released in 1978 (ATC 1978). This document formed the basis upon which most of the subsequent guidelines and regulations were developed both in the United States and elsewhere in the world.

When discussing seismic code developments, the capacity design approach developed in the early 1970s in New Zealand, should not be ignored. It might be one of the most ingenious solutions in earthquake engineering. Structures designed by means of the capacity design approach are expected to possess adequate ductility both at the local and global level. In the case of such structures, it is completely legitimate to apply linear analysis with a force reduction factor which takes into account the energy dissipation capacity. Of course, a quantification of the inelastic behaviour is not possible. Since capacity design is not a direct part of the analysis process, it will not be further discussed in this paper.

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