Sectional forces for seismic design of R/C frames by linear time history analysis and application to 3D single-story buildings

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ABSTRACT

The aim of the present paper is to present a rational procedure for the appropriate selection of the sectional forces needed for the calculation of the longitudinal reinforcement to R/C elements within the context of linear time history analysis. The proposed procedure is based on the maximum normal stresses, which occurs in each relevant cross section, and takes into consideration the critical angle of the seismic excitation, i.e., the angle that yields the maximum value of each response quantity of interest. Moreover, in an attempt to realistically interpret pertinent code provisions, three other code compatible methods of selecting the cross sectional forces are presented and compared to the here proposed method. For this purpose, three single-story buildings subjected to 47 bi-directional strong earthquake ground motions are analyzed. For each ground motion, the longitudinal reinforcement at all critical cross sections is calculated using the above four methods. Furthermore, the necessary reinforcement due to 3 and 7 representative earthquake records, required by the seismic code provisions, is determined. Comparison of results clearly shows that methods compatible with current seismic code provisions can significantly underestimate the necessary reinforcement with regards to the proposed method.

1. Introduction

Modern seismic codes [1–5] suggest the linear time history analysis as one of the methods that can be used for the seismic analysis and design of R/C structures. According to this method, a spatial model of the structure is analyzed using simultaneously imposed consistent pairs of earthquake records along each of the two horizontal structural axes (N.b.: with a few exceptions, the vertical component of the ground motion is allowed to be ignored [2,3]). Then the maximum values of the action effects due to such bi-directional excitation, which are determined by time integration, are used to calculate the reinforcement at every relevant cross section.

The application of this method raises a series of questions regarding, among others, the choice of the excitation's incident angle and the proper (i.e., safe but not over the odds conservative) selection of the sectional forces required for the final design of the R/C structural elements, as code provisions are lacking the necessary explicitness with regard to these aspects.

An important issue, which has not yet been thoroughly studied, is the proper combination of the sectional forces required for the design of the R/C structural elements. For example, the determination of the longitudinal reinforcement of a column in a

3D frame depends on three response parameters: the axial force N and two bending moments (M_ξ, M_η) that act simultaneously. For such cases, seismic codes do not provide clear instructions for the proper combination of the values of the sectional forces needed for the calculation of the longitudinal reinforcement.

Another significant issue, closely related to the proper selection of the values of the frame's sectional forces required for the final design of the R/C frame elements, is the orientation of the two horizontal components of the ground motion, as it strongly affects the response quantities and, consequently, the reinforcement steel ratio. It is important of note that none of the seismic codes prescribes clearly the orientation of the horizontal axes along which the accelerograms should be applied; hence it is common practice to apply the horizontal seismic components along the so-called structural axes, i.e., the axes along which the earthquake resisting structural elements are arranged in plan-view. However, it is prudent to perform the seismic analysis for those orientations of seismic motion that yield the maximum response.

Several researchers [6–14] have investigated the critical seismic incident angle and the corresponding maximum response *within the context of response spectrum method.* Lopez et al. [10,13] proved that the critical value for a single response quantity can be up to 20% larger than the usual response produced, when the seismic components are applied along the structural axes. Menun and Der Kiureghian [11,12] and Anastassiadis et al. [14] determined the critical incident angle for the most unfavourable

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