ABSTRACT

The objective of the present work is the investigation of the way that frame internal forces should be selected for the design of frame elements within the framework of the linear time history analysis method. This investigation is of great importance because none of the present seismic codes impose a certain design method when the time history analysis is used. In addition, a parametric study was carried out in order to investigate the inelastic response of a building designed with three different methods using the nonlinear time history analysis method.

For this purpose, various analyses were carried out with the application SAP2000 v10.0.1. using the two horizontal records of the following four earthquakes, El Centro, Kobe, Landers and Loma Prieta. For each earthquake two linear time history analyses were carried out in which the components of ground motion were applied along two horizontal orthogonal axes forming 0° and 90° angle with the structural axes of the building.

The design was carried out based on three different methods in which suitable scale factors were applied to the accelerograms so that the demanded longitudinal reinforcement of frame elements does not exceed the maximum requirements of the Greek Reinforced Concrete Code (ΕΚΩΣ 2000). The first and second methods use the response quantities' time histories (N(t), $M_2(t)$, $M_3(t)$) that resulted from an analysis in which the components of ground motion were parallel to the structural axes of the building. More specifically:

- In the first method the stresses' time histories for the four corners of the studied elements' frame section were calculated. The frame internal forces applied in the design are those that correspond to the time moment the maximum and minimum stress values of the above-mentioned stresses' time histories are recorded.
- In the second method the maximum and minimum values of all frame internal forces (maxN, minN, maxM_2, minM_2, maxM_3, minM_3) were determined from the corresponding response quantities' time histories. The design carried out concerned all the potential combinations of these values.
- In the third method the stresses' time histories for the four corners of the studied elements' frame section were calculated for 0 and 90 degrees incident angle. The maximum and minimum stress values derived on the basis of these time histories using the SRSS combination method. What followed was the calculation of each stress's critical angle and the determination of the derived frame internal forces' triads that correspond to the time moment this stress is recorded.

In each case the derived frame internal forces were added to the corresponding static analysis' values for vertical loads G+0,3Q.

Taking the above into consideration, the most significant conclusions that can be drawn are the following:

- The percentage of the required longitudinal reinforcement varies considerably with the design method applied in each case.
- The percentage of the required longitudinal reinforcement calculated with the third method is in all cases greater than the one calculated with the first method, as expected, since the reinforcement in the third method derives from the critical angle which always produces the maximum stress. In the case where the critical angle is equal to 0 degrees, the two methods produce the same percentage of longitudinal reinforcement.
- Comparing the second and third design methods it is not evident which of the two will produce greater percentage of the longitudinal reinforcement. This is differentiated both for each ground motion studied as well as for each frame element separately.

What followed was the investigation of the inelastic response of the building for each design case, as well as the examination of the effect that the direction of the ground motion has on the inelastic response concerning the earthquakes El Centro, Kobe and Landers. For this purpose, nonlinear time history analyses were carried out, both for the initial ground motion in study as well as for bigger ones. The components of ground motion were applied along two horizontal orthogonal directions forming an angle with the structural axes of the building which varies from 0 to 360 degrees per 45 degrees. The calculation of the hinge properties was carried out by the above mentioned program.

Based on the results of the nonlinear analyses, the following useful conclusions can be drawn:

- The building remains elastic in the cases for which it was designed. Specifically, for the first and second design methods no hinges were recorded when the orientation of the ground motion components is parallel to the structural axes of the building (0 degrees angle). In the third method the building remained elastic regardless of the ground motion's orientation angle.
- In the first and second methods hinges were found for the initial ground motion in study, concerning however different ground motion orientation angles from the one applied in the design. Consequently, these methods are inferior to the third one, in which no hinges were found in the building whichever angle applied.
- For earthquakes bigger than the one initially studied, hinges are recorded, as expected, in all three design cases. However, in the third method the building was in a better condition, since considerably less hinges were recorded in comparison with the ones found in the other two methods.