ABSTRACT

The objective of the present work is the investigation of the way of selecting frame internal forces for the design of structural elements within a linear time history analysis. 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 using the two horizontal records of the following four earthquakes, El Centro, Kobe, Landers and Loma Prieta. For each earthquake there were two linear chronological analyses in which the components of ground motion were applied along two horizontal orthogonal directions (forming an angle of 0 and 90 degrees respectively with the axes of the building).

In this study three different design methods were used. Each method made use of suitable multipliers of the accelerograms so that the following two conditions are satisfied: a) the demanded longitudinal reinforcement of frame elements does not exceed the maximum requirements of the Greek Reinforced Concrete Code (ΕΚΩΣ 2000), b) the produced reinforcement steel area is more than the minimum required. The three design methods used are the following:

- The first method made use of the time histories of the response quantities (N(t), M_2(t), M_3(t)) when the orientation of the ground motion components is parallel to the structural axes of the building. The stresses' time histories for the four corners of the frame section were calculated. The values of the frame internal forces with which the design was performed, were concurrent with the maximum and minimum stresses.
- In the second method the accelerograms were applied along the structural axes of the building. The maximum and minimum values of all frame internal forces (maxN, minN, maxM2, minM2, maxM3, minM3) were estimated on the basis of the respective time histories. The design was performed using all the possible combinations of those values.
- In the third method, the stresses' time histories for the four corners of the frame section were calculated when the angle of ground motion is 0 and 90 degrees. The time histories helped specify the maximum and minimum stresses. Then, the critical angle of every stress was calculated. The design forces which were determined correspond to the time instant that the maximum stress at each corner is attained.

In each case, the response quantities that resulted were combined with the corresponding quantities of static analysis for the vertical loads G+0,3Q through the method of superposition and the required reinforcement steel area was calculated.

The main conclusions that can be drawn in relation to the three design methods are the following:

- The percentage of the demanded longitudinal reinforcement can vary greatly depending on the design method used.
- The percentage of the longitudinal reinforcement calculated by the third design method is in every case greater than the one calculated by the first. That can be easily explained, as in the third method the reinforcement is calculated with reference to the critical angle, where the value of stress is always the highest. In case the critical angle is equal to 0 degrees, then the two methods result in the same percentage of the reinforcement.

- Between the second and third design method it is not clear 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.

The next step in this study was to examine the inelastic response of a building in each design case. The variation of the inelastic response with the incident angle was closely examined in the event of the earthquakes El Centro and Kobe. For the above investigation, nonlinear time history analyses were carried out both for the earthquake conditions for which the building was designed and for earthquakes with a higher scale factor. The components of ground motion were applied along two horizontal orthogonal directions for the incident angle varying from 0 to 360 degrees every 22.5 degrees. A special use of the programme was made in order to estimate the nonlinear properties of the frames of the structural elements (hinge properties). Those properties helped design diagrams of moment – rotation for all the structural elements, which were also incorporated into the properties of the NLLink elements of the building.

Taking into consideration the results of the nonlinear analyses, the following significant conclusions can be drawn:

- The building responds elastically under the earthquake conditions for which it was designed. In particular, when the first and second methods are used, there are no plastic joints detected for an incident angle equal to 0 degrees. With the use of the third method, the building remains in the elastic area for every incident angle.
- In the earthquake conditions taken into consideration in the design, hinges are formed in the building when the first and second design methods are used, but this occurs for incident angles different from the angle used in the design. Consequently, the above two methods are inferior to the third method in which the building behaves elastically for any incident angle.
- For earthquakes with a higher scale factor than the earthquakes of the design, hinges are formed in all three design cases. However, the building designed using the third method shows better response, since there are considerably less hinges in case this method is employed than in the other two cases.
- Examining how elastically the building responded in the analyses that were carried out with the El Centro earthquake, it is observed that the building designed with the third method responds better than the building of the second method, although in the latter there is greater reinforcement in most of its structural elements. Therefore, the over-design in a few structural elements does not always result in a better response of the building.