# ABSTRACT

The objective of the present work is the investigation of the response variation with the incident angle under two horizontal translational components of ground motion without the use of the Penzien – Watabe model (i.e. these components can have any degree of correlation). For this purpose an extensive parametric study was carried out. This investigation is necessary because none of the present antiseismic codes clarifies the ground motion's components orientation. It is only mentioned that the recorded accelerograms can be applied along the two orthogonal axes of the building (structural axes). For buildings that these axes do not exist, no orientation is recommended. In addition, a parametric study was carried out in order to compare three different design methods. This is also of great importance, because the antiseimic codes do not impose a certain design method when the time history analysis is used.

In the parametric analyses the following buildings were studied: symmetric (single-story, five-story and ten-story), one-way asymmetric (single-story, five-story and ten-story), two-way asymmetric (five-story and ten-story), irregular in plan and elevation (five-story and ten-story). For the linear analyses the program SAP2000 Nonlinear v7.44 was used.

The aforementioned buildings were analyzed due to the following earthquake records by using the linear time history method: El Centro, Loma Prieta, Kobe, Northridge, Landers, Mexico, Aigio και Kalamata.

The recorded accelerograms were applied along two orthogonal directions for incident angle varying from 0 degrees to 180 degrees and the maximum values of specific response quantities were computed for each value of the incident angle. These response quantities were the axial force N, the bending moments $M_x$ and $M_y$ (i.e. $M_2$ and $M_3$) computed at the base of a specific column and the horizontal translation δ computed at the top of the same column. For each response quantity exists a critical orientation which is the orientation that yields the maximum value. The results are at first presented in matrix form and finally the curves of the variation of the maximum response quantity vs incident angle are plotted. Also the variations RVX (Relative Variation X) and MRV (Maximum Relative Variation) were calculated and then in chart form presented. RVX is equal to the variation percentage between the response quantity's maximum value (critical angle) and the value of the same response quantity when the recorded accelerograms are applied along the two orthogonal axes of the building (0 degrees angle). MRV is equal to the variation percentage between the response quantity's maximum value (critical angle) and the minimum value of the same response quantity (incident angle).

The results (critical angle and maximum value which corresponds to this angle) calculated by the parametric analyses were verified with the use of theoretical formulas. Especially for four building types more analyses were carried out in order to examine the effect of the natural frequency and the accelerograms multiplier c variation on the critical angle and maximum value of the response quantities.

For the four five-story building types three different design methods were compared. The $1^{st}$ and $2^{nd}$ methods use the response quantities' time histories ($N(t)$, $M_2(t)$, $M_3(t)$) when the orientation of the ground motion components is parallel to the structural axes of the building (0 degrees angle). In particular, for the $1^{st}$ method the stresses' time histories for the four corners of the frame section were calculated. The response quantities' values with which the design was performed, were concurrent with the maximum and minimum stresses. For the $2^{nd}$ method the maximum and minimum values of the response quantities (maxN, minN, max$M_2$, min$M_2$, max$M_3$, min$M_3$) were combined in order to obtain the design forces. For the $3^{rd}$ method the critical angle of every stress was calculated as well as the stress which corresponds to this angle. The design forces which are determined, correspond to the time instant that the maximum and minimum stresses are attained. The results for every design method are presented in matrix form and the variations RVX and MRV in chart form.

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

- Different earthquake records have different critical angles for the same response quantity.
- The same earthquake records have different critical angles for different response quantities.
- The critical value for a response quantity can be up to 180% larger than the response produced when the seismic components are applied along the structural axes (RVX≈180%)
- The critical value for a response quantity can be up to 340% larger than the minimum response produced for an incident angle. (MRV≈340%)
- RVX and MRV are independent to the number of stories and degree of asymmetry of the building.
- The natural frequency modification causes random variation on the critical angle and the maximum value of the response quantities.
- The maximum value of the response quantities is modified in proportion to the variation of the accelerograms multiplier c, while the critical angle remains constant.
- The demanded longitudinal reinforcement depends greatly on the design method used. The results of the three methods can vary up to 100%.
- The 3rd design method is the most rational because it refers to the stresses' critical angle. The percentage of the longitudinal reinforcement calculated by the 3rd method is in every case greater than the one calculated by the 1st.
- Between the 2nd and 3rd design method it is not certain which of the two will produce greater percentage of the longitudinal reinforcement. Therefore, the 2nd method which is more compatible to the antiseismic codes can either be conservative or unconservative.