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COMPARATIVE LINEAR AND NON-LINEAR TIME-HISTORY ANALYSIS OF AN EXPERIMENTAL PROTOTYPE STRUCTURE USING ADVANCED TECHNIQUES

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ABSTRACT

This paper presents some of the results obtained from research program on Shear Wall RC building under torsional effects using Advanced Techniques developed within ENISTAT tasks activities of SERIES project of FP7 program, http://www.series.upat.gr. The overall purpose of this study was to investigate the influence of input accelerations' amplitudes on crack development in the prototype of an irregular reinforced concrete wall structure, which actually shall be experimentally tested in the seismic experimental campaign in C.E.A. Saclay in January 2013. For the ENISTAT prototype a synthetic accelerogram used in the numerical experiments has been designed, considering various scenarios of influence of boundary conditions on this experimental structure. For the numerical investigations, a series of comparative linear and non-linear time-history analyses have been executed based on linear behavioural, respectively nonlinear laws for materials, in order to determine the influence of cracks development on the absolute and relative values of joint displacement, velocity and accelerations respectively. The results of linear and non-linear time-history analyses revealed significant differences between the two sets of analyses proving once again the importance of the inelastic effects consideration when applying a performance based design procedure.

Keywords: time-history analysis, non-linear effects, performance based design.

INTRODUCTION

Within the ENISTAT task activities executed at CEA, Saclay, France within the SERIES FP7 European Project, a prototype of an experimental structure has been designed, based on actual European code provisions, consisting of mixed structural system of both structural concrete walls and concrete frame in order to study the high degree of non-linear effects for high seismic loading (http://www.series.upat.gr). The geometry of the structure is asymmetric one, in horizontal plane, but symmetric in vertical plane, with three storey's of equal height, as it is represented in Figure 1. For numerical investigations of ENISTAT prototype, the dynamic analysis of FE model has been performed, in linear and nonlinear domain. The final goal is to compare the numerical results with the experimental ones which are developed at CEA, Saclay, illustrated by (Yakut et al., 2010).

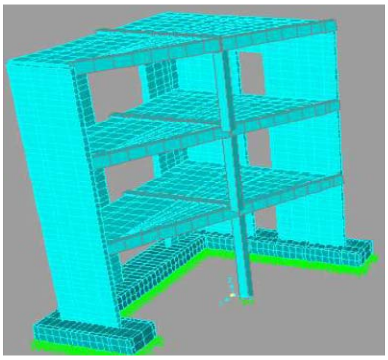

Fig.1 ENISTAT FE model

In the present work, the nonlinear analysis has been performed considering an artificial accelerogram of 1.5g considering 2D model for concrete and steel. For comparison reasons, a linear T-H analysis for an artificial acceleration of 1.5g has been supplementary also executed.

The synthetic accelerogram for a PGA of 1.5 g has been obtained by multiplication of the reference artificial accelerogram of 0.1g PGA, represented in Figure 2, respecting the Eurocode 8 requirements. This input was considered as reference accelerogram by (CEA, 2012), in order to study the cracks developing mechanisms in RC wall irregular type structure.

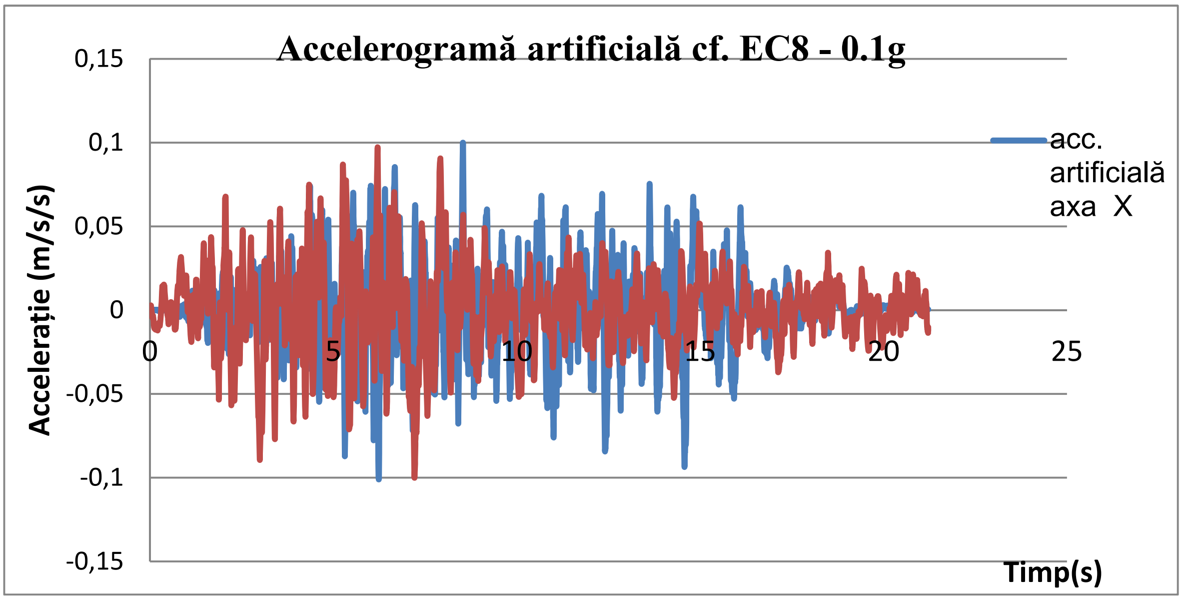

Fig.2 Artificial accelerogram -input for simulations on ENISTAT FE model

RESEARCH METHODOLOGY

The design of ENISTAT project has been realised based on European requirements for seismic design, given in (Eurocode 8, 2006). The finite element modelling of the prototype has been performed based on SAP2000 computational software, (SAP2000 v.14.3.2, 2011).

For numerical investigations of ENISTAT prototype the corresponding FE model presented in Figure 1, the modal analysis and the history analysis respectively, in linear and nonlinear domain has been developed.

The finite element (FE) model for the linear and nonlinear dynamic analysis has been built (Crijanovschi et al., 2012) consisting of 15 frame elements, 8562 shell elements and 624 solid FE elements, respectively.

For modelling purposes the 2D material for both components of the reinforced concrete FE model of ENISTAT have been used based on numerical data considered by (Crjanovschi et al., 2012).

First the Modal Analysis of the FE model has been performed. Next, a set time-history analyses linear and nonlinear respectively, have been developed, considering the input accelerations values up to 1.5g applied upon both on X and Y direction of the prototype FE model. The maximum response of FE model developed during time histories analysis, presented in this paper, has been evaluated at the top of the structure in node #11.

The non-linear material 2D behaviour of reinforced concrete in the shell elements is considered by the use of a layer model with arrangement of the crosswise reinforcement layers in their correct positions near the surfaces. The non-linear behaviour of the components of reinforced concrete is defined by:

- non-linear uniaxial stress-strain laws of concrete (increase of strength due to biaxial compressive behaviour regarded),
- some tests value, which have been conducted on concrete specimens and on steel bar specimens on axial load until failure point;
- time non-dependent factors to characterize the material behavior, for concrete elements as Creep, shrinkage, for example, have been applied and no damping factors for the material definition.

Concrete used is of Class C25/30, with the compression strength on cube, f_{ck} of 25 MPa,the average compression strength, fcm of 33 MPa, average tensile strength, f_{ctm} of 2.6 MPa and the Elasticity modulus, E_{cm} of 31 GPa, with damping coefficient constant, of 5 %.
The concrete and steel material's properties are presented in Figure 3.

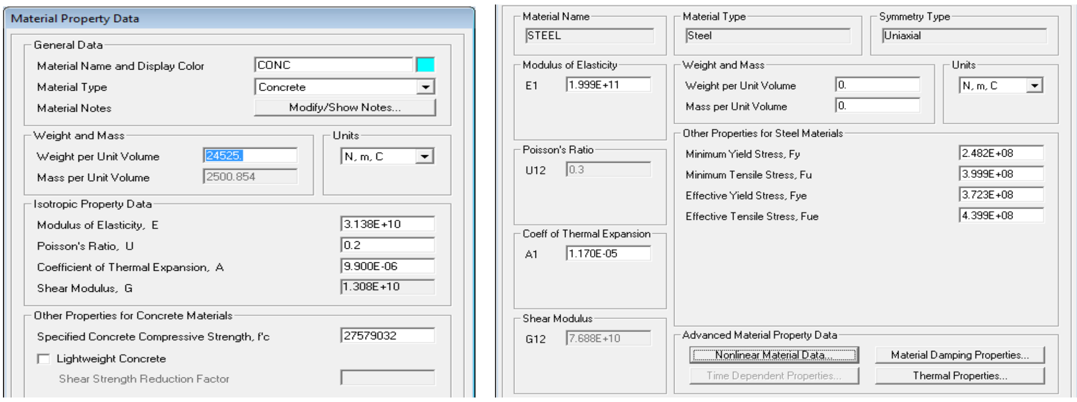

Fig.3 Material characteristics of ENISTAT numerical models

RESULTS

The results of comparative linear and non-linear time history analyses respectively have been analysed and discussed.

In table 1 – 3 the results of relative values of accelerations and displacements obtained at the top level of the structure are presented.

Table 1 Relative displacements in node #11 for an input acceleration of 1.5g

Value	Linear TH Analysis			Nonlinear TH Analysis		
	UX [m]	UY [m]	UZ [m]	UX [m]	UY [m]	UZ [m]
Min.	-0.00174	-0.00306	-0.00052	-0.00705	-0.01359	-0.00237
Max.	0.001604	0.003437	0.000443	0.006664	0.012964	0.001948

Table 2 Relative velocities in node #11 for an input acceleration of 1.5g

Value	Linear TH Analysis			Nonlinear TH Analysis		
	VX [m/s]	VY [m/s]	VZ [m/s]	VX [m/s]	VY [m/s]	VZ [m/s]
Min.	-0.0656	-0.1206	-0.0238	-0.315	-0.5966	-0.1105
Max.	0.0668	0.1356	0.0211	0.323	0.5918	0.1109

Table 3 Relative accelerations in node #11 for an input acceleration of 1.5g

Value	Linear TH Analysis			Nonlinear TH Analysis		
	AX [m/s^2]	AY [m/s^2]	AZ [m/s^2]	AX [m/s^2]	AY [m/s^2]	AZ [m/s^2]
Min.	-3.25848	-6.66183	-1.33878	-16.7425	-28.5114	-7.78876
Max.	2.92948	5.96709	1.50642	16.51691	32.12129	7.78738

Some representative values of the absolute displacements and velocities at top structure's level are reproduced in Figure 4 considering and applied acceleration of 1.5g.

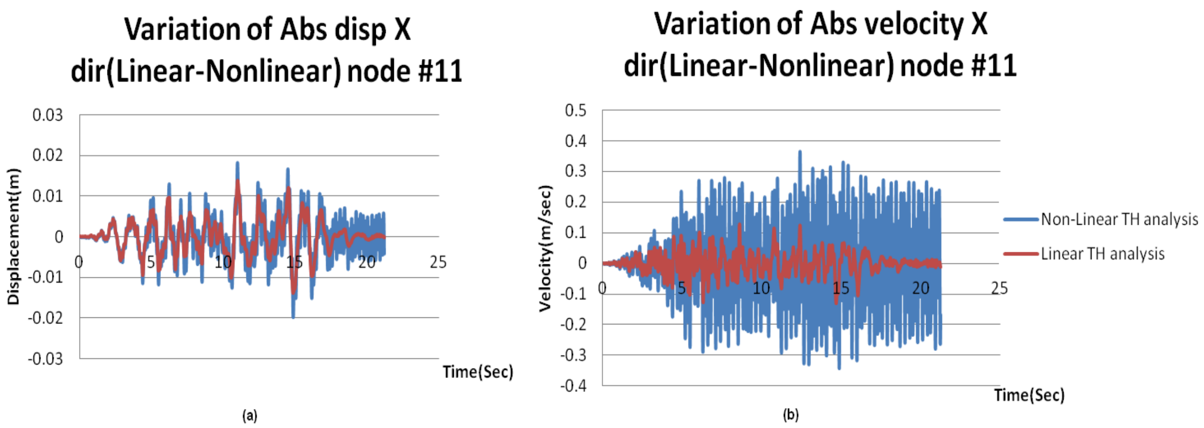

Fig.4 Absolute displacements (a) and velocities (b) at top of structure (node #11), for an input acc. of 1.5g

The variation of absolute accelerations is presented in Figure 5.

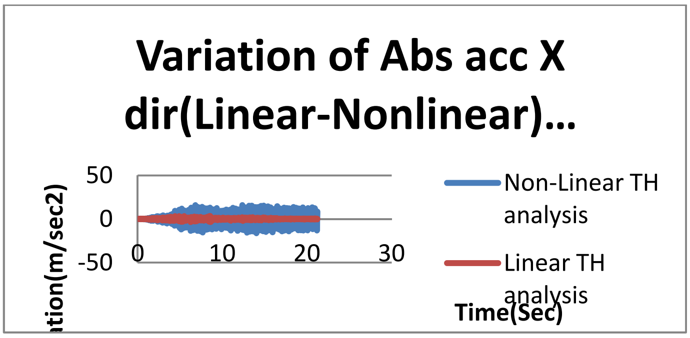

Fig.5 Absolute accelerations at top of structure (node #11), for an input acceleration of 1.5g

The stress values have been developed especially at top side of the finite element #3480, as can be identified in Figure 6.

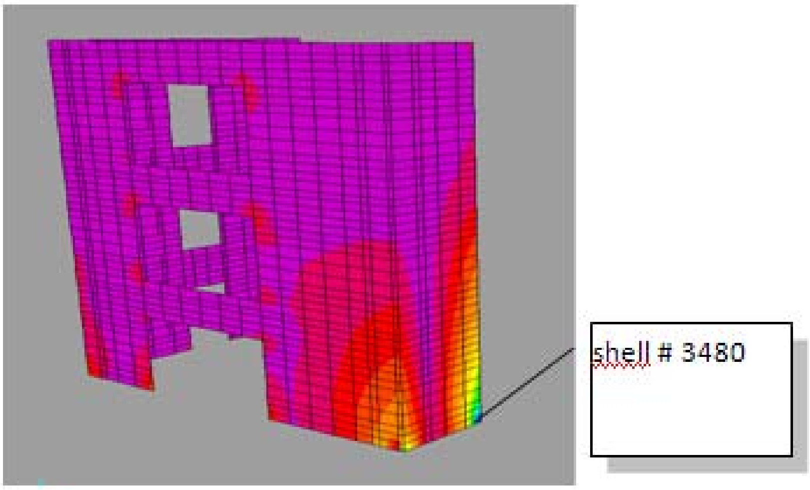

Fig.6 Shell #3480 illustrating the maximum stress values, within the TH analysis of 1.5g input

A study of the effects in the model while performing the nonlinear time history analysis for an applied acceleration of 1.5 g, leads to identification of relevant cracks due to significant values of tensile strength, exceeding the allowable value for the concrete. The represrntation of these maximum stress values is reproduced in Figure 7.

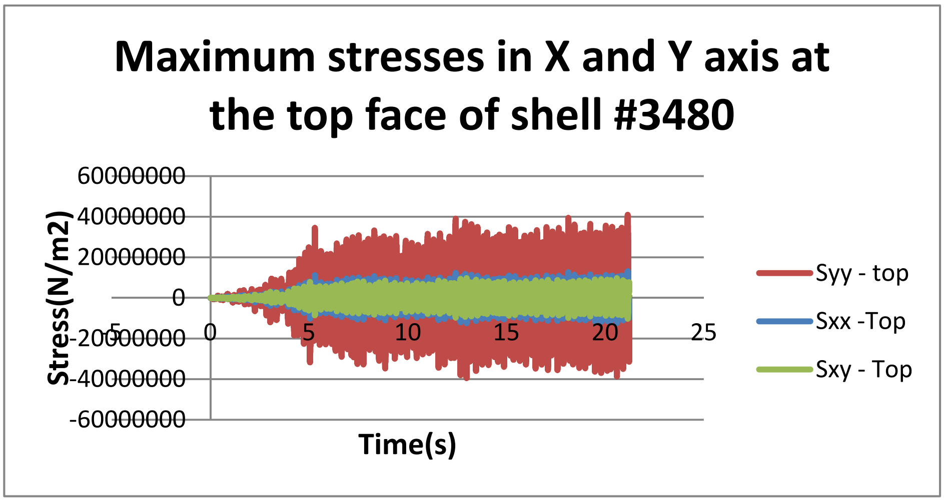

Fig.7 Maximum stresses values, identified at top face of shell FE#3480, in nonlinear T-H analysis, 1.5g input

CONCLUSIONS

This study illustrated a numerical simulation based on time history responses of FE model for an irregular structure, executed in benchmarking liner versus nonlinear domain. The procedure highlighted that these class of simulations ca constitute a valuable instrument to evaluate and predict the structural behaviour during life time cycle. The results obtained are relevant for classes of asymmetric structures located in high seismic hazardous areas. It can be noticed that the analysis of cracks development in FE model which consider non-linear materials behaviour within the nonlinear tie histories analysis, are especially visible in case of absolute velocities development.

The results of linear and non-linear time-history analyses revealed significant differences between the two sets of analyses, proving once again the importance of the inelastic effects consideration when applying a performance based design procedure.

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