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THE NONLINEAR ANALYSIS OF THE SEISMIC RESPONSE OF A REINFORCED CONCRETE STRUCTURE, SUBJECTED TO A STATICALLY EQUIVALENT ACTION

BY

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Abstract. The objectives of this paperwork are the linear and nonlinear analysis of the seismic response of a considered reinforced concrete frame structure and the analogy of the results achieved by both methods. We have observed the successional materialization of plastic hinges at every calculation point and we have identified the lateral force-top displacement curve, as resulted from the software. The analysis of the lateral displacements at Ultimate Limit State (ULS) and Serviceability Limit States (SLS) has been.

Keywords: plastic hinges; nonlinear analysis; lateral displacement.

1. Introduction

Generally, for the structural analysis, when designing a reinforced concrete building, the following methods are available:

Elastic methods: the equivalent seismic forces procedure; modal spectral calculation(Response Spectra); linear dynamic computation by usig the direct-time integration of the decoupled modal differential equations.

Inelastic methods: the incremental nonlinear analysis (pushover); nonlinear dynamic computation by using the direct-time integration of the coupled motion differential equations.

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The advantage of the nonlinear analysis methods are about: the seismic evaluation of structures depending on the most important parameter regarding the characteristics of the seismic ability of a structure, the lateral displacement pointing out its effective behavior.

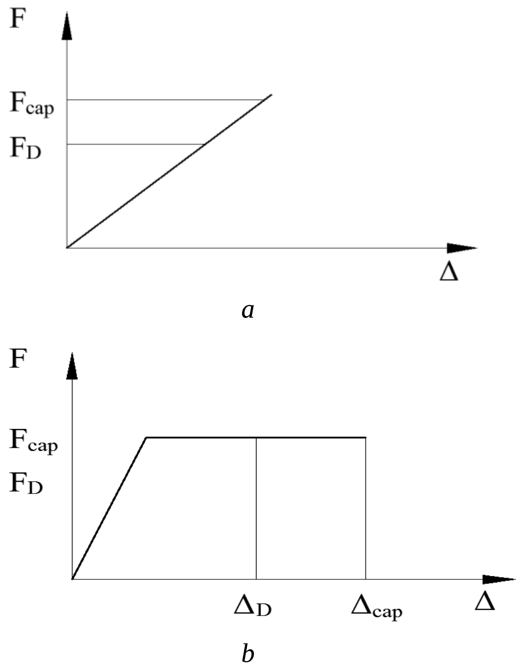


Fig. 1 – *a* – force-based analysis ($F_D \leq F_{cap}$); *b* – displacement-based analysis ($\Delta_D \leq \Delta_{cap}$).

The modeling of beams with plastic hinges on points is the most efficient way of representing the behavior of these elements, in the post-elastic area. The beams are elements that are solicited, in the presence of slabs, to one-sided bending, with no axial forces, thus resulting the plastic moment hinges. (Fig. 2).

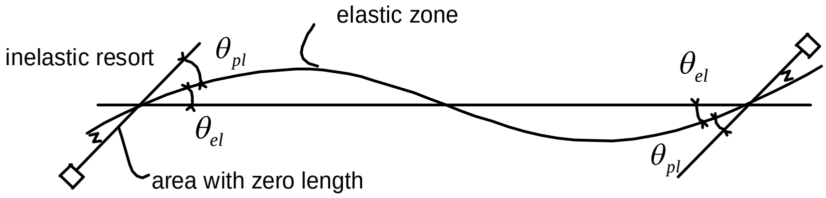


Fig. 2 – Beam model with series elements.

1.1. The Modeling of Columns with Plastic Hinges at Points

When it comes to columns, modeling is not as simple as when modeling beams. In this case, the resistance depends on the axial stress, which can alter during an earthquake, thus the modeling is mostly based on the theory of plasticity. So, flow functions can be used, $f(N,M) = 0$.

2. Presentation of the study. Push over Analysis

The Push-over analysis is a way of checking the structural post-elastic strengths, by progressively imposing some structure displacements, until a plastification mechanism is created, pursuing the registered horizontal forces.

If the stuctural displacements are growing, plastic hinges are being progressively developed, until forming a plastification mechanism (local or global), thereby achieving a graph, known as structural capacity curve or as a pushover curve.

The pushover curve is not associated to seismic actions, it forms as a feature of the analysed structure. It shows different characteristic moments of the post-elastic stuctural behavior (the formation of plastic hinges, out of work elements etc).

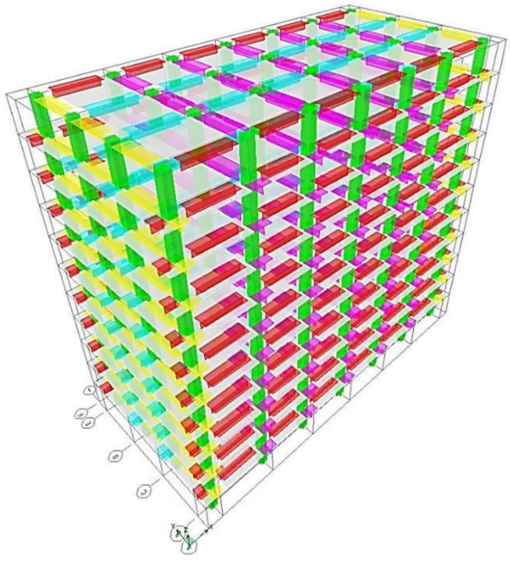


Fig. 4 – 3-D viewing of the designed structure.

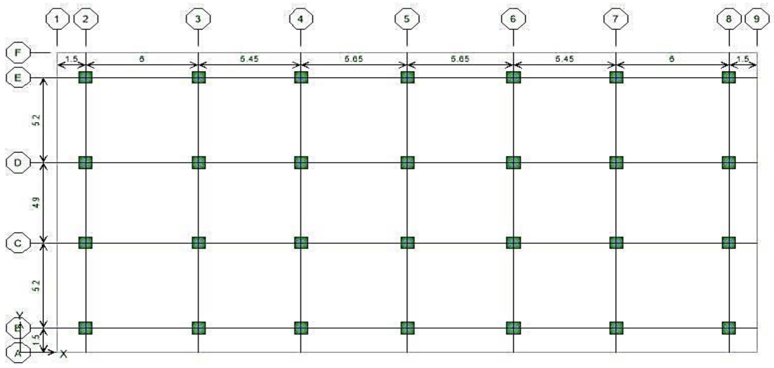


Fig. 5 – Top view of the designed structure.

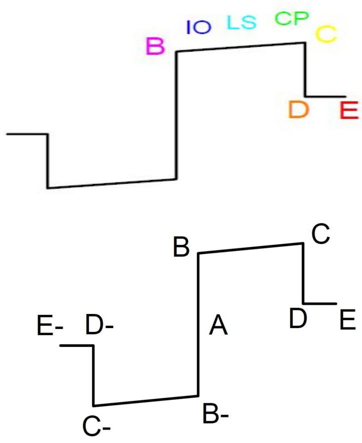
The post elastic analysis firstly involves a linear analysis, while the pushover analysis is made. The analysed structure (Figs. 4 and 5) is a ten-storey bulding, placed in Constanta city. The section dimensions of the columns are 70 × 70 cm and for de beams, 30 × 60 cm.

Regarding the nonlinear analysis, the structure is vertically loaded, according to the seismic loads and horizontally progressively loaded on both, transverse and longituidinal directions. The medium streghts are: concrete – 1.5 f_{cd}; steel – 1.35 f_{yd}.

Tabel 1

The Constructive Moment-Rotation law In Nonlinear Analysis

Point	Moment/SF	Rotation/SF
E-	-0.2	-7
D-	-0.2	-5
C-	-1.25	-5
B-	-1	0
A	0	0
B	1	0
C	1.25	5
D	0.2	5
E	0.2	7



Where: B – beginning of yielding; IO – performance level FEMA, immediate occupancy –without evicting the building; LS – performance level FEMA, life safety – assuring the lives of the residents; CP – performance level FEMA, collapse prevention – collapse prevention; C – ultimate point of the section (maximum moment); D – the section has suffered irreversible major degradations and keeps only a residuual streght; E – the sections is completely out of work; * performance level FEMA: considered by the software or defined by the user.

Fig. 6 – Lateral force- top displacement curve, the case of progressive horizontal loads on the *X* direction.

Fig.7 – Lateral force- top displacement curve, the case of progressive horizontal loads on the *Y* direction.

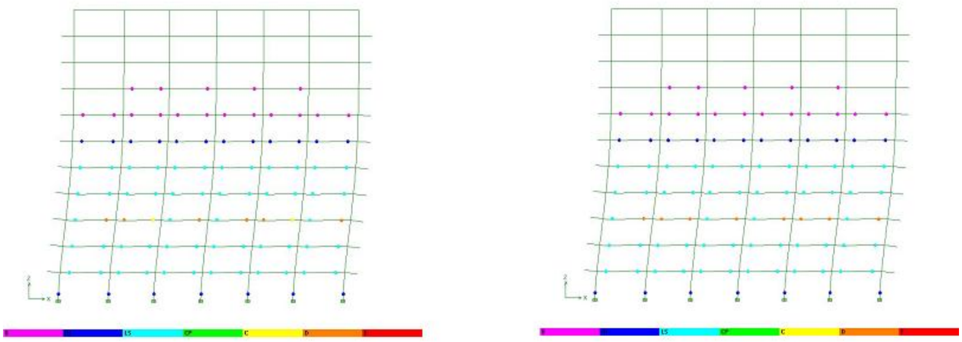


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Fig. 8 – Formation of plastic hinges on points, the case of progressive horizontal loads on the *X* direction.

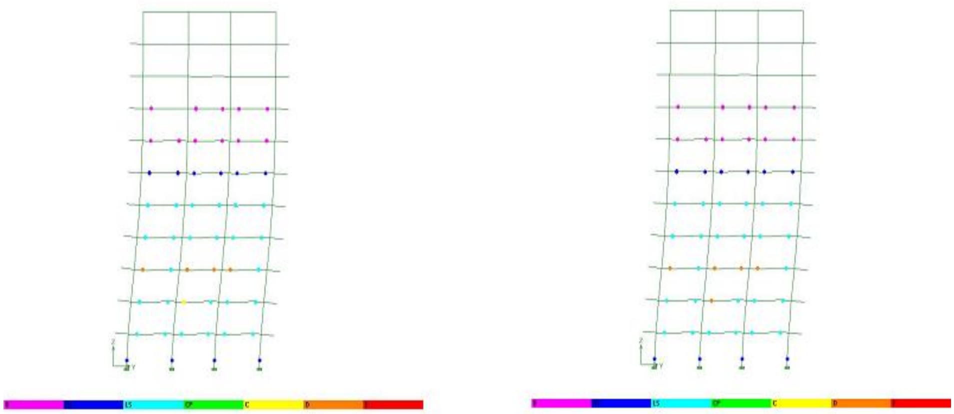

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Fig. 9 – Formation of plastic hinges on points, the case of progressive horizontal loads on the *Y* direction.

5. Conclusions

Analysing the results, an encouraging total behavior can be seen, by forming plastic hinges at the ends of every beam and by plasticizing the columns at the level of their foundation supports.

In case of progressively horizontal loads on the *X* direction, regarding the forming of plastic hinges in the beams, they first develop on the first floor, then the ground floor and second floor. The most affected beamsthat are going to collapse are those on the first and second floors.

In columns, plastic hinges are initially forming in the fifth step, at the level of their foundation support.

On the last calculation step, the plasticization of the beams has reached the seventh floor and on the second floor the beams are turning into out of work elements.

In case of progressive horizontal loads, on the *Y* direction, the behavior is similar, the plasticization of the beams has reached the sixth floor, the beams on the second floor are degrading and the plastic hinges at the bottom of the columns are developing at the sixth calculation step.

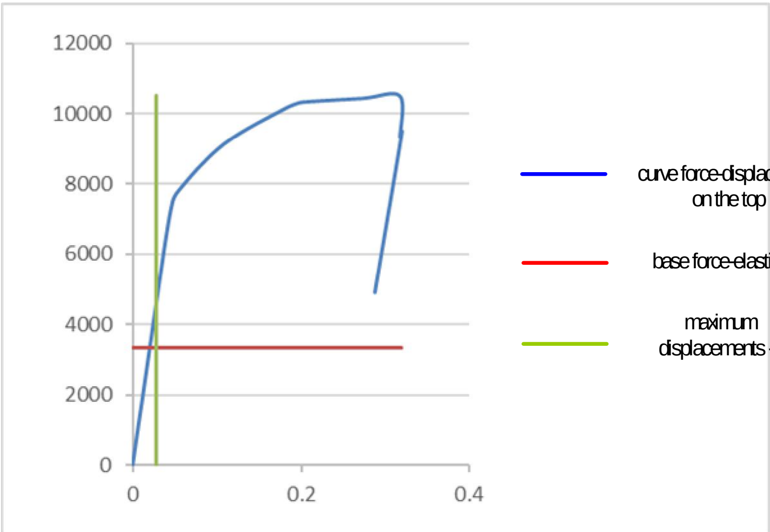

Fig. 10 – Pushover curve for the seismic loads on the longitudinal direction (*X*).

If the maximum values for the basic load and displacement, from the elastic calculus, are overlapping the pushover curve,the following strenght backup is shown: F_{b_cap} = 10,491 KN, F_b = 3,320.8 KN

Regarding the linear displacements, it resulted to be 2.70 cm and the nonlinear displacement resulted to be 31.5 cm, therefore, on this direction can be considered a strenght backup of the structure, by developing plastic hinges (68.35%).

In case of transverse direction (Y): F_b = 3,320 KN, F_{b_cap} = 9,597 KN. Linear displacements : 3.35 cm , nonlinear displacements: 31.5 cm.

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ANALIZA NELINIARĂ A RĂSPUNSULUI SEISMIC PENTRU STRUCTURILE ÎN CADRE DE BETON ARMAT, SOLICITATE LA O ACȚIUNE STATIC ECHIVALENTĂ

(Rezumat)

Obiectivul prezentei lucrări este de identificare a rezervei de rezistență, la acțiunea seismică, a unei structuri în cadre de beton armat. Obiectivul este îndeplinit prin analiza liniară şi neliniară a răspunsului seismic al unei structuri propuse din cadre de beton armat solicitate la o acțiune static echivalentă şi compararea rezultatelor obținute prin cele două metode. A fost urmărită ordinea aparației articulațiilor plastice în structură la fiecare pas calculat şi identificată curba forță laterală – deplasare la vârf rezultată din program. S-a realizat verificarea deplasărilor laterale la cele două stări limită, stare limită de serviciu (SLS) şi stare limită ultimă (SLU).