POSSIBLE EXTENSIONS OF THE STRUCTURAL SEISMIC ANALYSES

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SUMMARY

This paper presents the main aspects of a proposed approach to improve the Romanian Earthquake Resistant Design Code. As possible extensions of the structural seismic analyses, besides the current design procedures, this approach has the aim to optimize the structure seismic response using inelastic "time-history" seismic analyses. Concepts of "Imposed Energy Dissipating Mechanism" (IEDM) and of simultaneous seismic actions along both principal axes are involved. The method makes also possible the analysis of structures having non-uniform mass, resistance and stiffness distributions in plane and along the building height, as well as of "dual-type" structures.

DEFINITIONS AND NOTATIONS

M_y = "yielding moment"
ES = "elastic section"
PH = "plastic hinge"
PPH = "potential plastic hinges": the localities where PH may occur during inelastic time-history analyses
EDM = "energy dissipating mechanism": any pattern of "PPH"
IEDM = "imposed EDM"
REDM = "real EDM": pattern of PH involved in EDM for a specified type and intensity accelerogram
EEDM = "envelope EDM": envelope pattern of PH involved in REDM corresponding to a set of accelerograms
CEDM = "collapse EDM": REDM corresponding to the collapse state of the structure

BASIC CONCEPTS AND PHILOSOPHY

In previous studies were established the fundamental concepts of choosing and imposing an energy dissipating mechanism, adequate to a favorable structural behaviour, of "weak beams and strong columns", recommendations for inelastic seismic design and for a draft code based on energy concepts [1], [2].

Due to T. Paulay's studies, the "capacity design" philosophy together with the method of "dynamic magnification factor" for the design actions of regular frames columns have been adopted by the New Zealand standards [7] and Model Code CEB - FIB for Seismic Design of R/C Structures.

Since the use of inelastic time-history computer programs has become

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current in the last years, the following approach was developed as a possible extension of the seismic structural analyses with the purpose to improve the actual Earthquake Resistant Design Code of Romania (8). Instead of the method of the "dynamic magnification factor", the approach offers the means to obtain the envelopes of the internal forces from the inelastic time-history analyses in view of imposing the chosen EDM, for both uniaxial and biaxial loading.

The adopted way to impose an EDM is the following: in the input data, for the localities of "PPH", the M_y values are established on the basis of preliminary design according to the code. For the other end member sections which do not belong to the EDM, the M_y values are fictitionally settled very high so that during the time-history analyses these sections should remain in the elastic stage.

A computer program which combines the features of "ANELISE" (4) and (9) "CASE" - similar in performance to "DRAIN 2D" and respectively "ETABS" - is used in Romania for the inelastic time-history analyses of the two-way frame structures. In order to impose an EDM for biaxial loading (the case of simultaneous seismic actions with dynamic inelastic behaviour along both main axes), a subroutine is used which calculated the interaction surfaces for biaxial bending with axial force, necessary for proportioning and checking the columns so as to maintain it in the desired stage of behaviour. Within the proposed procedure, the structures, which contain structural walls or coupled structural walls, may be calculated in this way by assuming "frame analogy" modelling. The program series "DRAIN TABS" and more recently ANSR II, worked out by Powell, seem to offer the possibility of performing such inelastic seismic analyses of three-dimensional non-linear systems.

Structure optimization involved the most adequate changes of the PPH strength and of the member stiffness providing an improvement of the distribution of energy dissipation in terms of REDM strength and ductility demands. For the assessment of the structural reliability against collapse, it is necessary to study the probable collapse performance i.g. the establishing of the CEDM and of the earthquake characteristics as the type of accelerogram and intensity level. The fundamental criterion becomes the energy dissipation demands. The reliability will be expressed in terms of the probability of the occurence of the earthquake that can provoke the collapse.

In the light of the adopted philosophy, the designer has the possibility to impose a certain uni and biaxial loading CEDM with the aim to improve the collapse performance of the structure.

DESCRIPTION OF DESIGN PROCEDURE

Fig. 1 presents a simplified flow-chart of the proposed approach for the earthquake resistant design procedure.

Preliminary design phase. The main objective of this phase is the initial proportioning.

Step 1. includes the performance of all the static and seismic analyses required by the code.

- 2 accelerograms: Bucharest N-S for Romanian Earthquake 1977 ("BUH") and El Centro N-S 1940 ("EC")
- 2 directions of seismic actions: uniaxial along the main axes ($\alpha = 0$) and biaxial ($\alpha = 45^o$)
- 3 types of IEDM: a pure beam hinging mechanism IEDM-1; hinging of beams and of columns bases IEDM-2; sway mechanism of first storey IEDM-3. Certainly, an optimum design may include any other IEDM in which PH are involved in some columns, but currently with the avoidance of sway mechanism.

Analysis no. 1.: The initial sizes (V-1) of the column bases are not able to support the strength demands for the IEDM-1 and uniaxial loading; also beam ductility demands are too high; it is necessary to adopt the mechanism IEDM-2 (loop "c" fig. 1).

Analysis No. 2 and 3.: For IEDM-2 the column sizes are not sufficiant for biaxial loading. Therefore, it is necessary to increase the column sizes (loop "b" fig. 1) in order to satisfy both strength and ductility demands.

Analysis No. 4 and 6.: The Strength and ductility demands in case of uniaxial loading are more severe for BUH accelerogram (a_{max}=o,22 g) in comparison with E.C. accelerogram (amax= 0,33 g) for which no PH occur in columns. Consequently, the following analyses for this type of structure are carried out only for BUH accelerogram.

Analysis no. 4 and 5.: Due to the fact that the column ductility demands are high, V-3 variant is adopted.

Analysis No. 7 and 8.: For both uniaxial and biaxial loading, the column strength and ductility demands are improved. Therefore, in final design phase V-3 variant is selected for proportioning and detailing. For this variant, fig. 4, 5, 6, 7 present the time-history of the structure displacements, envelope of bending moments on columns, maximum storey shear force, beam and column rotational ductility demands.

Analysis No. 9.: In order to demonstrate that sway mechanism IDEM-3 is very inadequate for seismic behaviour, inelastic response No. 9 is performed. In this case, ductility demands and shear force in the first storey columns are 4 (respectively 2) times greater as compared to analysis No. 7 for mechanism IEDM-2.

The results obtained from this case-study as well as from other analytical parametric studies made in Romania (5), (6) permit us to formulate some findings as follows:

a) The dimensions of the cross sections of the columns of the tall-building designed according to Romanian code seem to be unsatisfactory from the point of view of the strength. It is noticed that in variant V-1, the strenght ratio column-beam is inadequate in relation with the avoidance of column hinging, because it leads to high ductility demands for columns. Fig. 5 shows that to avoid the columns hinging (except for column bases) by imposing IEDM-2, the increase of the strength demands referring to the flexural resistance of the columns is up to 4,5 times greater in comparison with the code values.

b) The analyses made for an earthquake acting on an oblique direction versus principal axes of the building lead to demands of ductility columns which are 10-25% greater than those obtained from plane analyses.

c) The effective internal forces in the columns have great values only at the base section, maintaining an approximately constant distribution along the height of the structure.

d) Concomitently, the proposed approach allows the obtaining of the most unfavorable internal forces which act at the beam column joints.

e) For flexible structure, in the interval period 0,9 - 1,5 s, the BUH accelerogram is much more severe than the E.C. accelerogram in what regards the stiffness, strength and ductility demands. Concerning the storey shear forces distribution, the E.C. earthquake is more unfavorable for the upper storey due to the influence of the higher modes of vibration.

CONCLUSIONS

1) The proposed approach represents a possible extension of the structural seismic analyses, which consist of applying: the philosophy of the imposed energy dissipating mechanism for uni and biaxial loading; the "weak beams-strong columns" concept: and the use of computer programs for inelastic time-history analysis.

2) The final design phase of this approach yields:

- the strength demands of the elastic zones by the envelopes of the simultaneous internal forces;
- the envelopes of both ductility and strength demands for PH zones.

3) Inelastic time-history analyses are used in order to IMPOSE a certain response of the structure and not to CHECK its behaviour.

4) It is emphasized that empirical simple rules cannot be done in order to impose the chosen EDM, namely in the case of irregular structures.

5) The level of the seismic forces and the distribution of the internal forces induced into the structure can be controlled by the type of imposed mechanism (see Table 2).

6) The taking into account of an oblique direction of the seismic action imposes higher strength and ductility demands to the structure. It is also worth mentioning the increasing of the indirect effect through the plastification sometimes concomitent of the adjacent beams of the two directions, as well as the decreasing in this case of the capable rotational ductilities of the columns under biaxial bending with axial force.

7) In comparison with current code design, the approach allows a proper seismic design concerning proportioning and detailing as well as the damage control of the PH zones and of the building as a whole, with improvements of the reliability and of the optimum total cost-benefits characteristics.

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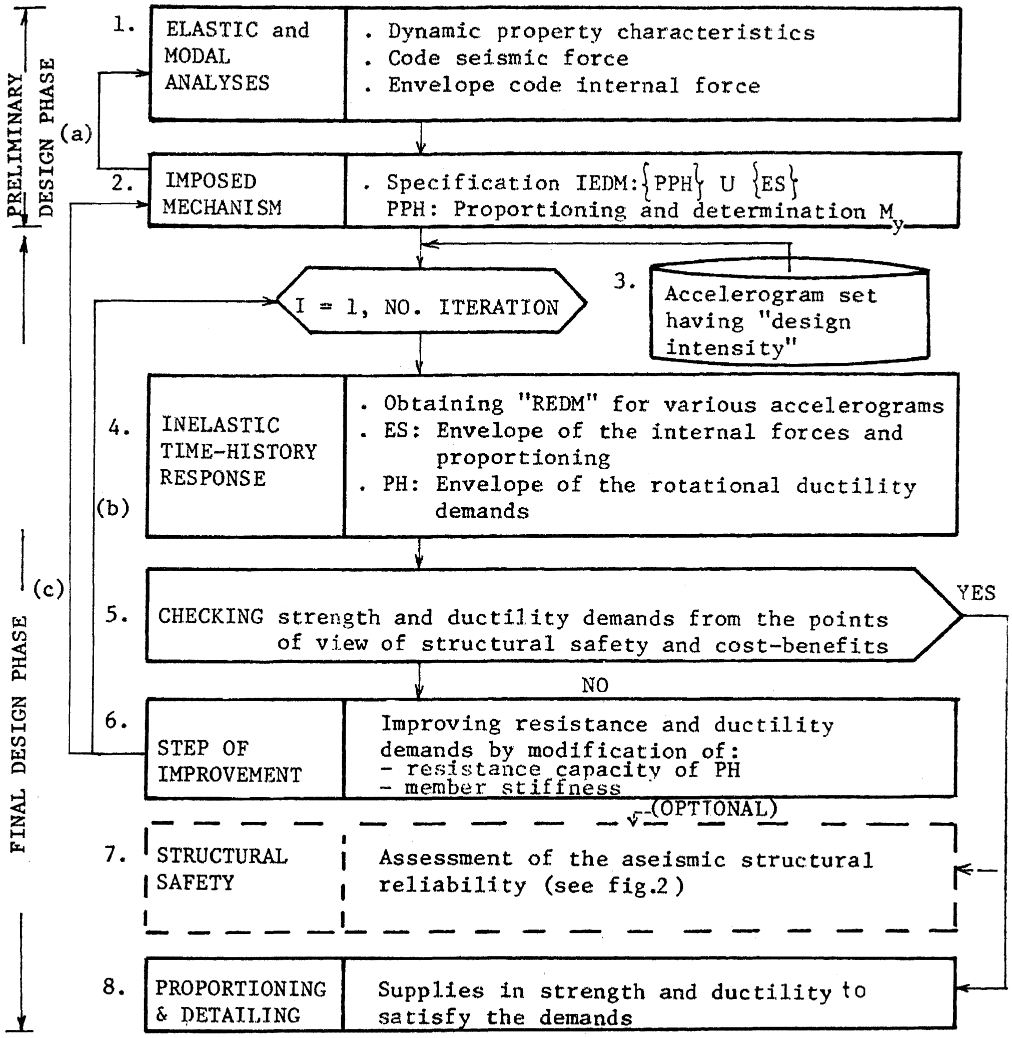


FLOW-CHART FOR ASEISMIC DESIGN PROCEDURE

Fig. 1

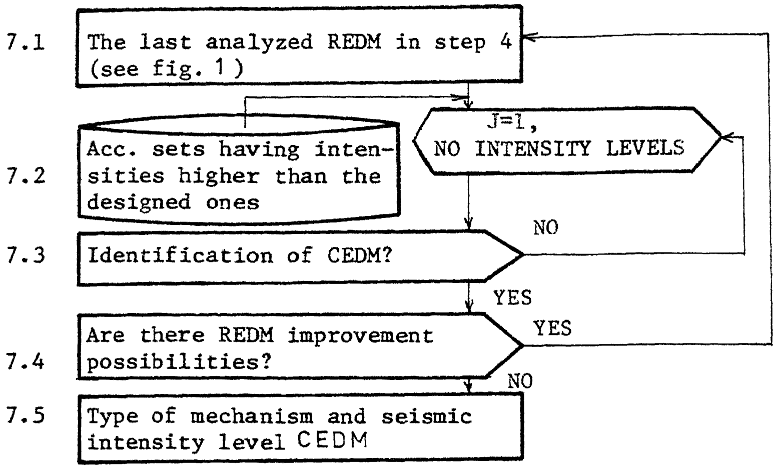
Step 2. points out the application of EDM philosophy for uni and biaxial loading.

Code design is used as a first approximation both as a guideline in imposing EDM and for determining the M_y values of PPH.

The preliminary design phase may also include an iterative procedure (loop "a") depending on the designer's experience and the basic code concepts.

Final design phase: The main objective of this phase is the structural optimization from the point of view of REDM characteristics for uni and biaxial loading.

Fig. 2



Step 3. indicates the specification of design accelerograms as accepted types and intensities within the general aseismic regulations.

Step 4. includes the achievement of certain inelastic time-history analyses; they offer the possibility of obtaining for each accelerogram type the REDM characteristics concerning the critical state from the viewpoint of the PH pattern, maximum and cumulative rotational ductility demands and internal forces.

Step 5. establishes the necessity to improve REDM through engineering judgements of the results obtained in the previous step.

Step 6. aims at obtaining improved REDM from the point of view of balancing the strength and ductility demands by adequate changes of the resistance and stiffness characteristics. This implies, among other things, means for decreasing and/or increasing the strength and ductility demands of some PH in order to obtain an improved pattern of PH and an improved distribution of the strength and ductility demands along the height of the structure. If necessary, the IEDM type may be changed by modifying the PPH patterns (loop "c").

Step 7. is presented in detail in fig. 2. The assessment of the aseismic structural reliability is obtained by identifying the collapse conditions and by comparing them with the design accelerograms and with the seismic risk of the site.

Step 8. represents final proportioning and detailing taking into account the envelope of simultaneous internal forces corresponding to EEDM.

DISCUSSION OF CASE STUDY RESULTS

The plan and elevation of a 9-storey R/C frame structure (fundamental period T = 1,1s) for a residential building, selected as a case study is shown in Fig. 3. Table 1 presents the main results of nine time-history analyses performed within the final design phase.

The variable involved in these analyses are the following:

- 3 structural variants: V-1 according to "code design" (8); V-2 having increased sizes of the columns, V-3 having modified flexural capacities of PPH

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Table 1

No. Analyses	VARIABLES						RESULTS				
	No. Variant	No. Iteration	Accel.	Seism Direction	Type of IEDM	C%	D(cm)	μ_θ^b	μ_θ^c	μ_Δ
1	V1	1	BUH	0°	1	22	19	12	-	-
2		2	BUH	0°	2	18	27	4.1	5.2	3.5
3			BUH	45°	2	24	25	5.3	11	3.7
4	V2	3	BUH	0°	2	22	23	6.2	1.5	1.6
5			BUH	45°	2	26	21	6.5	4.5	2.2
6			E.C.	0°	2	16	12	3.2	1	-
7	V3	4	BUH	0°	2	20	22	6.4	2.4	2.2
8			BUH	45°	2	19	27	8.2	2.6	2.5
9			BUH	0°	3	46	23	-	9.7	2.4

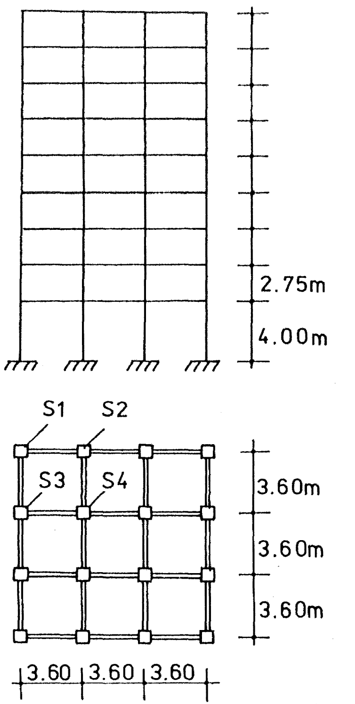
D : maximal top displacement
C% : base shear coefficient (%)
$\mu_\theta^b, \mu_\theta^c$: rotational ductility demands for beams and columns
μ_Δ : ratio between maximum top displacement and that corresponding of the PH occurence at the column bases

Effective base shear coefficients C for BUH acc. $n/n_{cr} = 0{,}05$

Table 2

ASSUMED BEHAVIOUR		C%
RESPONSE TYPE	MECHANISM TYPE	
Elastic	-	50
Inelastic	IEDM 3	46
Inelastic	IEDM 1	22
Inelastic	IEDM 2	20
Inelastic	PP in beams and some columns	18

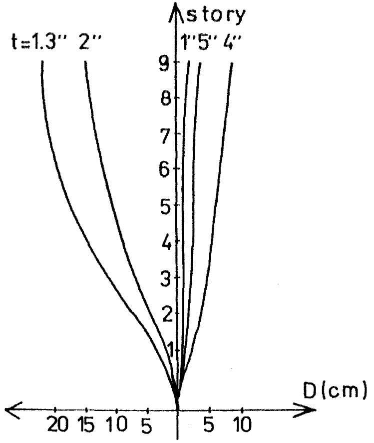
FIG.3
PLAN AND ELEVATION OF STRUCTURE



– gravity load 1,1 KN/m^2

No LEVEL	sq. columns S1	S2	S3	S4	beams G1(G2)
1-4	50	55	55	60	25/40(45)
5-9	40	45	45	55	25/40(45)

FIG.4
TIME-HISTORY OF STORY DISPLACEMENTS



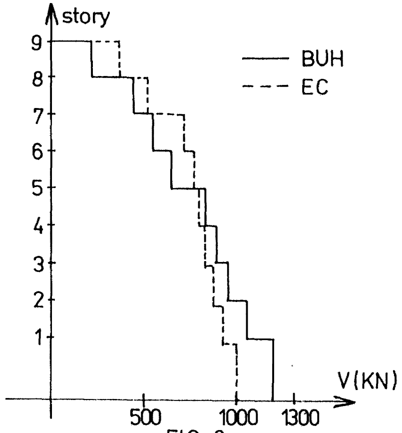
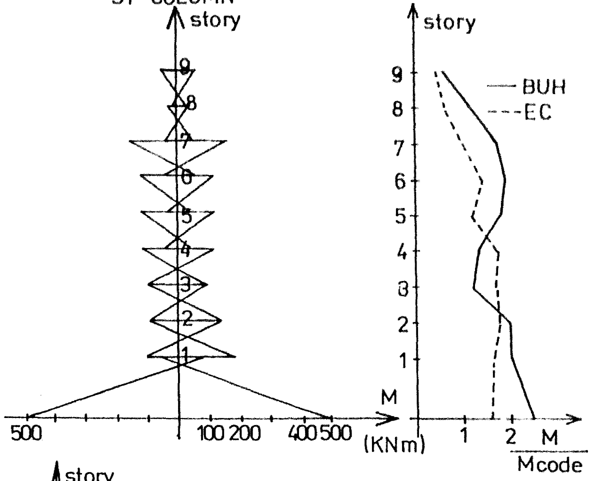


FIG.6
MAXIMUM STOREY SHEAR FORCES

FIG.5
MAXIMUM BENDING MOMENTS FOR S1 COLUMN



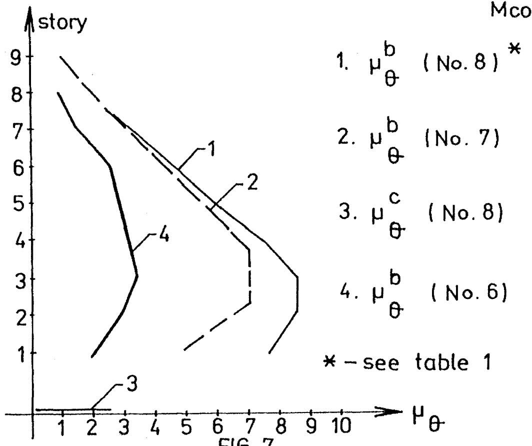


FIG.7
MAXIMUM ROTATIONAL DUCTILITY DEMANDS FOR ANALYSES No. 6÷8