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Seismic Analysis in Linear or Nonlinear Domain, Using Two or Three-Dimensional Modelling.

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Abstract.
Three-Dimensional dynamic analysis is required for a large number of different types of structures, specially constructed in seismic region. Design of structures is done through linear analysis, but taking in consider the nonlinear behavior depending on plastic properties presented by the structural behavior structures. General guidelines for reinforced concrete structures are those given in EC-2, and more explicit are given in EC-8.
It’s convenient to run the linear analysis in 3-D model using the finite element approach, but it is rather difficult to use 3-D modeling for nonlinear behavior. A simplified 2-D model can be used for such analysis based on a strong engineering experience.
For traditional structures, the use of shear walls in combination with frame structures forming a dual structures, wide spread for the sake of they performance. The positioning of shear walls in plane and the shape of their cross-section has a crucial importance in behavior of the whole structure. Their influence can be observed in stiffness, strength and ductility of the structures. Based on soil properties to the site, to avoid the resonant condition, the engineer can choose the right position and amount of shear walls besides the alternative solution.
The following study illustrates by numerical analysis the behavior of dual structures depending to the shear wall position and their shapes. Also, a change of building stories is observed as well. As outputs the fundamental periods, lateral displacements, base forces and ductility are provided. Based on these parameters, some comments and conclusions are derived.

Keywords: *shear wall, dual structure, frame, nonlinear analysis.*

1. INTRODUCTION

Albania is a country placed in a hazard seismic area. Special efforts are point in implementations of Euronorms and provisions in structural designing. Most of the new building design and constructed in Albania are based on mixed structure with variation in height of 8-24 stories. In this paper are shown the results from different analyses taken over linear and nonlinear models for mixed structures. The design rules are those described in Eurocode 2 prEN 1992-1-1-2002 and Eurocode 8-prEN 1998-1-2003. A design procedure is done even with the Albanian Design Code (ALC) for comparison evaluations. The ALC are rather old and the last upgrade is done on 1989. The basic evaluations and improvement are taken upon the effects of Montenegro earthquake, happened in 1977. Attention is shown for the influence of finite element formulation of shear wall element. Two type of finite element are used, shell element and membrane one. Nonlinear Pushover analyses are used to judge on the structural characteristics for the different structures. The structures are design for high ductility class “DCH”. The influence of reinforced detailing has been check by modelling the concrete behaviour as unconfined or confined. It will be seen that the behaviour of overall structure is ruled by the behaviour of shear wall. Also it will be shown that the frame accompanying the walls have a moderate demand and they do not need to develop higher ductility then the main shear walls.

2. STRUCTURES

Three types of structural systems are selected for this case study as can be shown in Figure 1. They have a variation of 8, 14, and 20 stories.

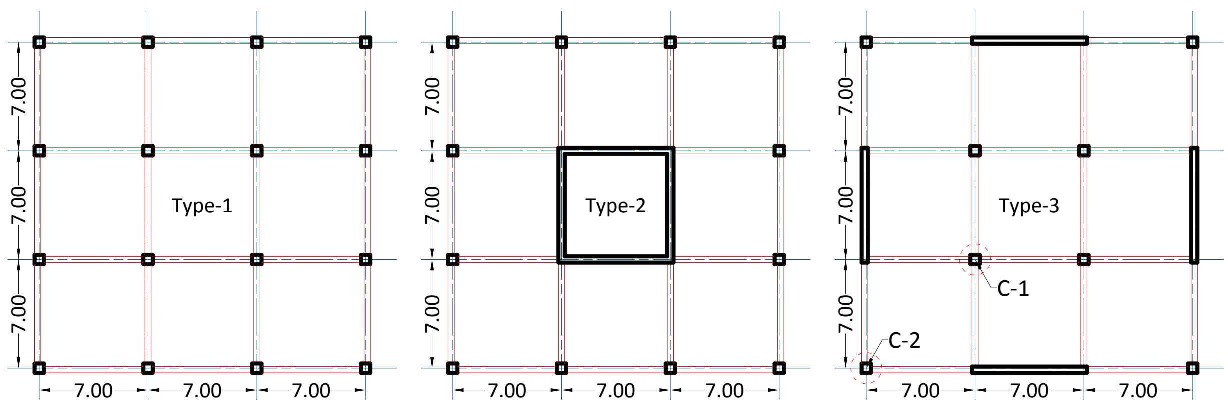


Figure 1. Structural configurations.

The structures belong to the class of: Type-1 to frame system, Type-2 to wall system and Type-3 to dual systems. All the types are studied for variation with 8, 14 and 20 stories. The ground story is 4m high and the other stories with equal height of 3m. The structures are taken symmetric and no torsion effect is included.

3. LINEAR ANALYSES

3.1. Materials Properties

Materials properties are those specified in Eurocode-2 prEN 1992-1-1 for concrete class C25/30 and reinforcing steel S500s.

3.2. Design spectra.

The design loads includes self-weigh, imposed loads (EN 1990) and seismic action. The design value of the effects of actions in the seismic design situation is determined in accordance with EN 1990:2002. The structural behavior factor is q=4 for wall structure, and q=4.5 for frame and dual structure. Buildings are design for PGA=0.3g and soil grade=B.

According to ALC the design spectra is given by:

$$S(a) = k_E \cdot k_r \cdot \psi \cdot \beta \cdot g$$

where: k_E - seismic coefficient, taken equal to 0.3

k_r - importance coefficient, taken equal to 1

ψ - plasticity coefficient, taken equal to 0.3 and 0.25 ($\psi \approx \frac{1}{q}$)

β - dynamic coefficient, taken $0.65 \leq \beta = \frac{0.8}{T} \leq 2.0$

3.3. Load combination.

Table 3.1. Load combination according Eurocode.

Load Combination	Loading		Earthquake	
	Dead	Live	X-dir.	Y-dir.
DCON1	1.35	(---)	(---)	(---)
DCON2	1.35	1.5	(---)	(---)
DCON3	1	0.45	1	0.3
DCON4	1	0.45	0.3	1
DCON5	1	(---)	1	0.3
DCON6	1	(---)	0.3	1

Table 3.2. Load combination according Albanian Code.

Load Combination	Loading		Earthquake	
	Dead	Live	X-dir.	Y-dir.
MAIN	1.15	1.3	(---)	(---)
ACCIDEN.-1	0.9x1.15	0.4x1.3	1	0
ACCIDEN.-2	0.9x1.15	0.4x1.3	0	1

3.4. Structural Elements Geometrical Data

Table 3.3. Members Data

Nr. stories	Building type	Beams [cm]	Columns [cm]	Wall thick. [cm]
8	Type-1	30x70	70x70(3), 60x60(5)	---
	Type-2	30x50	50x50	25
	Type-3	30x50	50x50	25
14	Type-1	40x80	90x90(5), 70x70(9)	---
	Type-2	30x60	60x60	30
	Type-3	30x60	60x60	30
20	Type-1	50x90	100x100(5), 90x90(6), 70x70(9)	---
	Type-2	40x70	70x70	40
	Type-3	40x70	70x70	40

The cross-sections of structural elements are taken based in the condition for preliminarily evaluation according the EC-8 and in design practice.

3.5. Computer Model

Beams and columns are modelled as frame element with six DOF per joint. Slabs are modelled as shell thin-element. Shear walls are modelled with shell element with six DOF per joint (thin or thick depending on their thickness) and as membrane with three DOF per joint.

3.6. Result from linear analyses.

In table 3.4 are given the values of the first fundamental period, top displacement and spectral acceleration taken from spectral analyses. It can be easy seen that there are sufficient differs in displacements given by the two codes.

Table 3.4 Periods values and displacements in function of building types and stories

Nr. stories	Building type	First Mode [s]	Top Displacement[cm]		Spectral Acceleration[m/s^2]	
			EC	ALC	EC	ALC
8	Type-1	0.85	2.87	1.66	1.19	0.69
	Type-3	0.63	2.39	1.35	1.65	0.94
	Type-2	0.41	1.35	0.86	2.25	1.44
14	Type-1	1.23	4.30	3.60	0.78	0.65
	Type-3	1.19	4.38	3.35	0.85	0.65
	Type-2	0.84	3.59	1.84	1.37	0.70
20	Type-1	1.79	6.70	7.20	0.60	0.65
	Type-3	1.63	6.05	6.19	0.60	0.65
	Type-2	1.23	5.28	3.84	0.89	0.65

In table 3.5 are given the values of the top displacement depending from the finite elements formulation. It can be easy seen that there are differs in displacements, influenced by the manner of load distribution through the structure elements.

Table 3.5. Displacements in function of shear wall model (finite element formulation)

Nr. stories	Building type	Top Displacement[cm]		Top Displacement[cm]	
		EC (shell)	EC (membrane)	ALC (shell)	ALC (membrane)
8	Type-3	2.26	2.39	1.28	1.35
	Type-2	1.34	1.35	0.86	0.86
14	Type-3	3.99	4.38	2.30	3.35
	Type-2	3.55	3.59	1.83	1.84
20	Type-3	5.28	6.05	5.00	6.19
	Type-2	5.22	5.28	3.77	3.84

In table 3.6 are given the values of internal forces in the base of shear wall depending from the finite elements formulation and design code. It can be easy seen that axial loads are more sensitive due to finite element formulation. The ALC gives reduced internal loads in comparison to Eurocode.

Table 3.6. Internal forces in the base of shear wall for model Type-3 (14 story)

Model	Axial Force [kN]	Bending Moment [kNm]	Major Shear [kN]	Minor Shear [kN]
EC (membrane)	8289.8	26986.8	2247.1	0
EC (shell)	9493.7	26479.9	2302.7	66.5
ALC (shell)	8755.4	19161.8	1793.9	56.4

In table 3.7 are given the values of longitudinal reinforcement for the corner and internal column for the 14-story building Type-3. Modelling of shear walls with membrane elements, overestimate the longitudinal reinforcement in columns. This yield from inadequate support of beams to the shear walls.

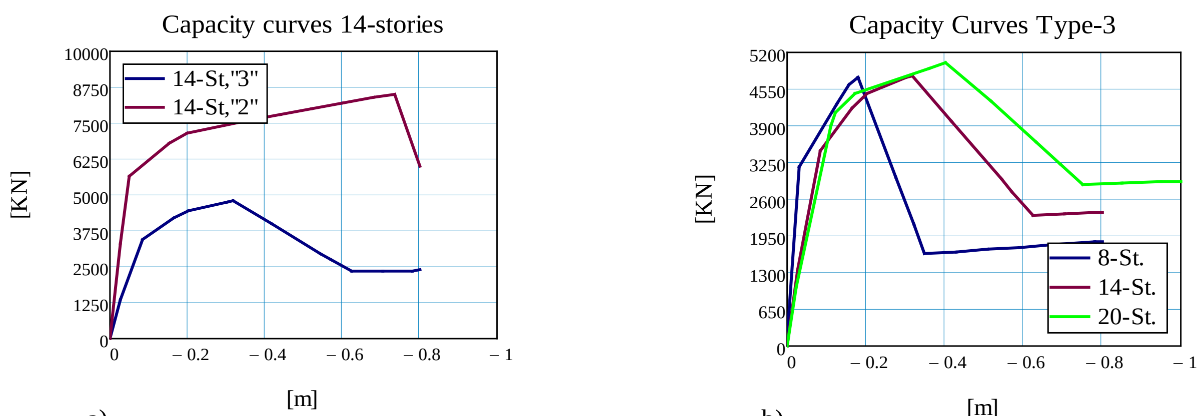
Table 3.7. Longitudinal reinforcement in columns for model Type-3 (14 story)

Story Level	Gross area of reinforcement in cm^2					
	Column C-1			Column C-2		
	EC (memb.)	EC (shell)	ALC (shell)	EC (memb.)	EC (shell)	ALC (shell)

0	94	29	22	8.0	8	7.2
1	66	23	20	7.2	7.2	7.2
2	73	21	18	7.2	7.2	7.2
3	44	19	16	18	7.2	7.2
4	81	27	15	22	10	7.2
5	55	15	13	24	16	7.2
6	28	13	11	25	19	7.2
7	15	12	10	26	20	7.2
8	13	10	8	27	21	7.2
9	11	8	7.2	27	22	7.2
10	9	7.2	7.2	27	23	9
11	7.2	17	7.2	27	24	15
12	14	26	17	27	24	17
13	37	38	31	37	32	29

4. NONLINEAR ANALYSES

Three load cases are taken in consideration. Nonlinear vertical load case, Modal and nonlinear modal static “Pushover”. Pushover analyses starts from the end stage of vertical load case to take into account the stress stage of structural members. A plot of capacity curves are given in Fig.2.

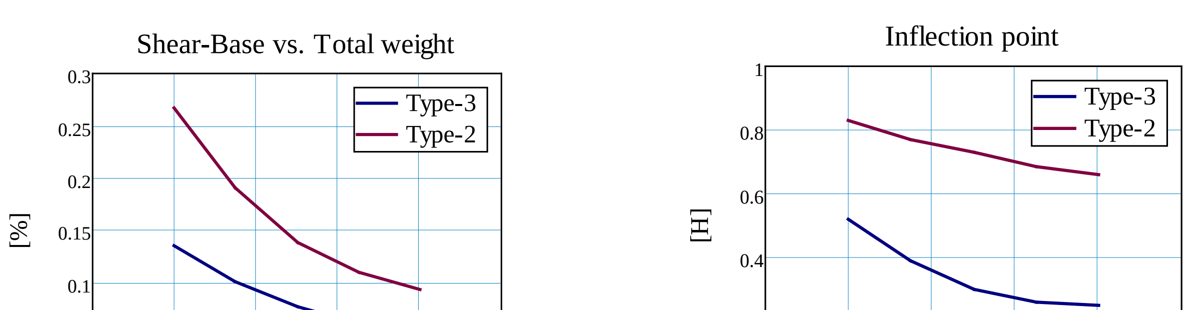


a) b)

Figure 2. Capacity curves for different structures types and number of stories.

In fig.2.a), is presented the capacity curves for Type-2 and Type-3 “14-story” structures. Type-2 structures have higher capacity since it face higher spectral accelerations. In fig.2.b) are compared the capacity curves of the same types of structures but with variation of stories number. It can be seen that the shear-base forces are not differing essentially. There is a small higher displacement capacity with increasing of the stories number. From the above charts can be seen that the shape of shear wall is predominant in structure behavior.

In fig.3 are given the tendency of ratio shear-base vs. total weight of the structure and inflection point height vs. building height in dependence of stories number. Both shear-base and inflection point attempted to decrease as number of stories increase. The gradient is more sensitive for low number of stories and decrease with increase of stories number.



a) b)

Figure 3. a) Shear-base ratio over the total weight; **b)** Inflection point ratio over building height.

5. CONCLUSIONS

From the above analyses and results can be derived the preceding conclusions:
The reinforcement detailing rules are very important to achieve the desired ductility and capacity. This means that the corresponding class detailing restrictions are obligatory to satisfied or overcome.
The shapes of shear-walls cross-sections indicate directly the stiffness and capacity of the structure. So, to achieve the desired stiffness and capacity, the designer can chose the structure type or possible combinations of structural elements.
The building height is of important influence in structures behaviour and performance. Thus, the tall buildings for design purposes, nonlinear analyses must be performed for a better understanding and safety.
The structural behaviours in nonlinear range have shown good correlations with the excepted criteria in design procedure. The structural behaviour factor given by EC-8 is lightly smaller then the ductility results from nonlinear analyses.
Based on the results can be concluded that the Albanian Codes gives a lower reliability and is obligatory to be improved.
According to the finite element model used for the design, the way of shear wall modelling is of very importance. So, the role of structural engineer is fundamental.

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