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DOES THE SEISMICITY OF THE AREA HAVE AN IMPACT ON THE CONSTRUCTION COST OF THE LOAD-BEARING STRUCTURE OF R/C BUILDINGS?

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Abstract

In the present research work, an attempt is made to investigate the possible influence of the seismic acceleration on the construction cost of the load-bearing anti-seismic structure of reinforced concrete (R/C) buildings. It is not uncommon for the design engineer to be confronted with the question of dimensioning a building for seismicity greater than that provided by the relevant seismic regulations. More specifically, the Greek Seismic Code (EAK 2000) provides for three different seismic hazard zones. Will the choice of the engineer, then, affect the construction cost and if so, to what extent does it influence it? A fifteen-storey building with a standard floor plan per floor was used for this study. The building simulation took place using the SAP2000 analysis and dimensioning software. The seismic regulation used is Eurocode 8. The study of the influence of seismicity takes place by measuring the quantities of concrete and steel reinforcement construction materials. Analyses of the results and comparisons between them are made for all three seismic zones. Useful conclusions are drawn regarding the influence of seismicity on the construction cost of the load-bearing structure of R/C buildings.

Keywords: Cost, Seismicity, Load-bearing structure

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1 INTRODUCTION

Construction cost is an issue that has troubled engineers, consultants and contractors worldwide [1], [2]. The basic problem has to do in achieving the best technical solution in terms of safety along with the best solution possible in terms of economy; meaning a techno-economical best solution for the design of a structure that should take into account the influence of the soil properties, too [3], [4]. In simple words, the goal is to achieve both safety [5]–[14] and economy at the same time when the consultant engineers design a structure. This issue has troubled engineers for all types of structures: (a) Buildings [15]–[17], (b) bridges [18], [19], (c) other types of structures [20]–[22]. Thus, this analytical study investigates the influence of seismicity to the construction cost of the load-bearing structure of reinforced concrete (R/C) buildings.

2 CONSTRUCTION DESCRIPTION

In the present work, the study of a load-bearing structure of a R/C building in the three seismic hazard zones is carried out. This is a fifteen-storey building, double symmetrical that has a rectangular plan with dimensions of 25 x 25 m, which corresponds to a total area of E=625 m^2, without a basement. In the center of the floor plan, there is a strong core consisting of 8 walls of different dimensions, 6 along the Y axis and 2 along the X axis. At the perimeter of the plan, there are two walls along the Y axis, which have enlarged boundary edges at their ends. The cross-sections of the columns of the building are the same for the 1st (ground floor) and 2nd floor, while after they are gradually reduced to the other floors, except for the walls T3 and T10, whose cross-sections are reduced as they depend on the enlarged boundary edges of their ends. Below is a summary table with the geometric elements of the floor plan (Table 1), as well as a top view of the floor plan of the building (Figure 1).

FLOOR	HEIGHT (m)	BEAM DIMENSIONS		WALL THICKNESS (cm)	COLUMNS (cm)
		PERIMETER	INTERIOR		
1st (Ground)	4.5	25x70	25x70	50	100x100
2	3	25x70	25x70	50	100x100
3	3	25x70	25x70	50	95x95
4	3	25x70	25x70	50	90x90
5	3	25x70	25x70	50	85x85
6	3	25x70	25x70	37.5	80x80
7	3	25x70	25x70	37.5	75x75
8	3	25x70	25x70	37.5	70x70
9	3	25x70	25x70	37.5	65x65
10	3	25x70	25x70	37.5	60x60
11	3	25x70	25x70	25	55x55
12	3	25x70	25x70	25	50x50
13	3	25x70	25x70	25	45x45
14	3	25x70	25x70	25	40x40
15	3	25x70	25x70	25	35x35

Table 1: Geometric plan elements

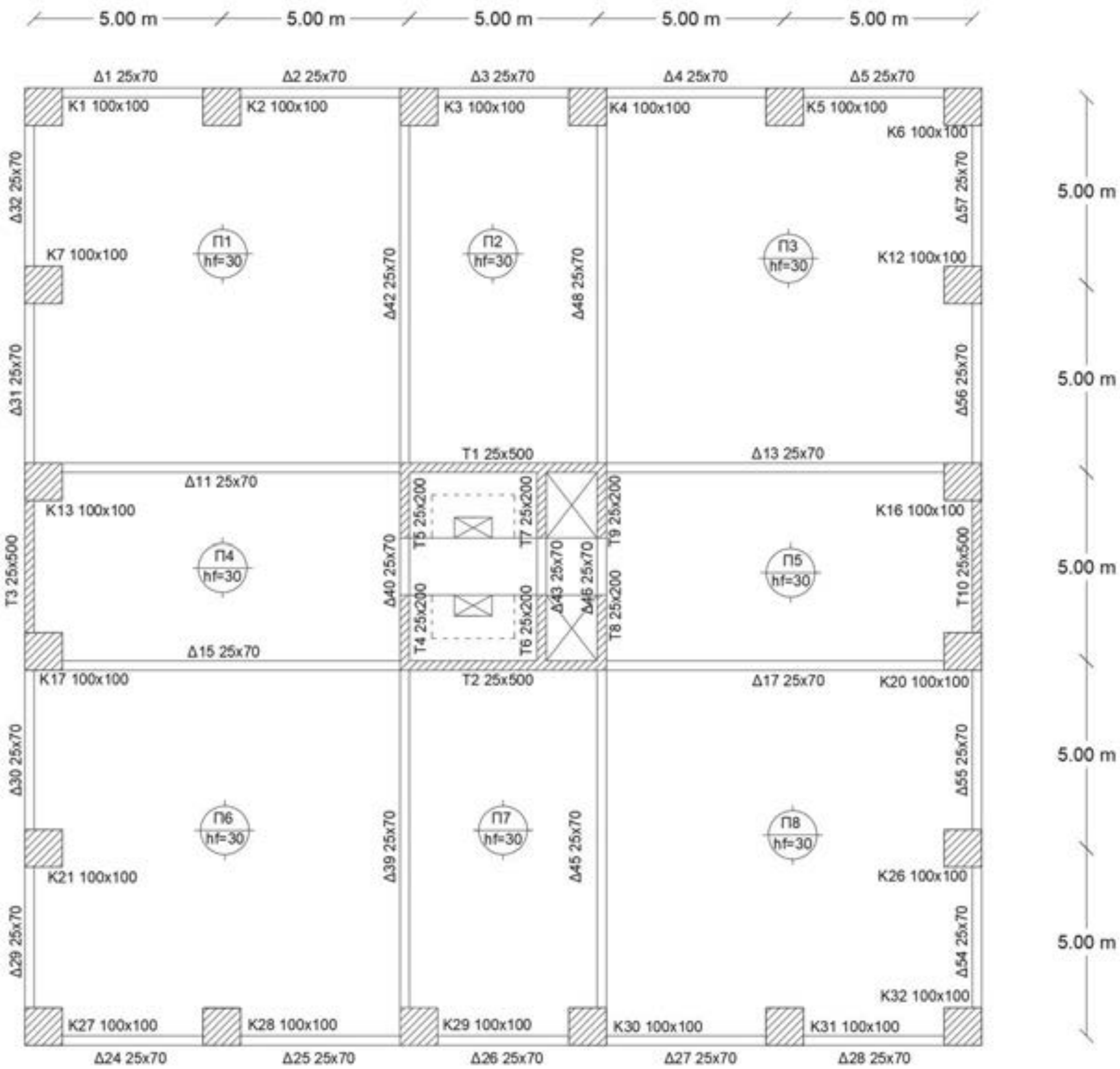

Figure 1: Floor plan of the building

3 BUILDING MODELING

The construction materials of the load-bearing body are:

- Concrete quality C30/37
- Steel quality B500C

According to Eurocode 2 [23] the measure of elasticity is equal to E_{cm} = 32 GPa. The value of the Poisson ratio is considered to be zero, according to the specifications of the code for cracked concrete sections.

The beams are simulated using a linear finite element in space placed on the centripetal axis of the structural element. Due to the diaphragm action of the slabs, they are considered to have a T-type cross section. The columns are modeled in the same way as the beams, using linear finite elements and with reduction of their properties due to cracked concrete cross section (stage II). The modeling of the walls is done with the help of the "equivalent frame model". It has to do with the replacement at each level using a linear element that is placed on the center of gravity of the wall with reduced properties for cracked sections. The wall is connected to the neighboring beams by means of rigid bodies. The building 3D model is displayed on Figure 2.

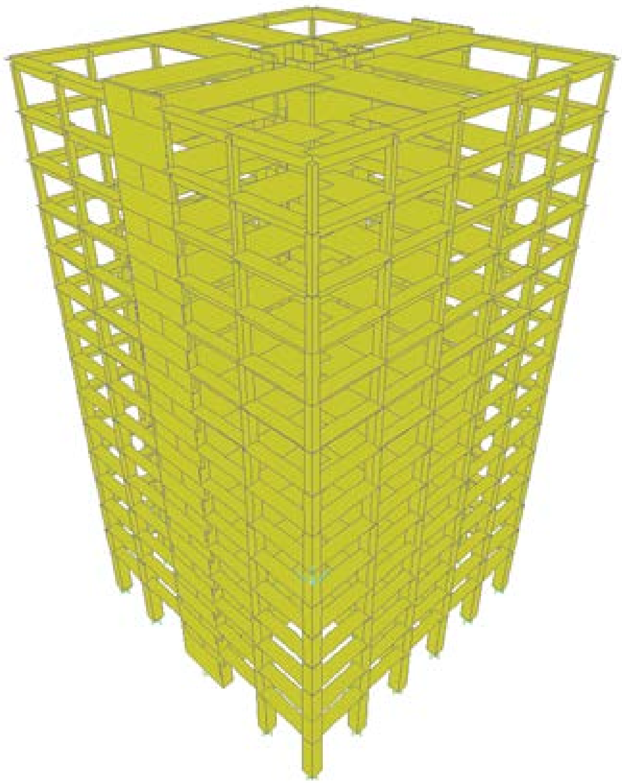

Figure 2: 3D illustration of the building

4 LOADS

The dead loads of the structure according to which the building is dimensioned, are presented below in Table 2:

DEAD LOADS		
N/A	Type	Value
1	Flooring	1.40 kN/m^2
2	Partition brick walls	1.00 kN/m^2
3	External brick walls	8.00 kN/m
4	Roofing	3.50 kN/m^2
5	Parapet roof load	3.60 kN/m^2

Table 2: Dead loads

- The load of the partition brick walls is considered to be evenly distributed over the entire surface of the floor plan.
- The load of the external brick walls is applied only on the perimeter beams and directly on them.
- On the roof of the top floor around the perimeter, it is considered that there is a parapet with a height equal to 0.90 m.

Table 3 shows the live loads of the construction.

LIVE LOADS		
N/A	**Type**	**Value**
1	Ground floor	2.00 kN/m^2
2	Other floors	2.00 kN/m^2
3	Top roof	2.00 kN/m^2

Table 3: Live loads

The spectrum data used according to Eurocode 8 [24] are shown below in Table 4:

EC8 SPECTRUM DATA		
N/A	**Type**	**Data**
1	Spectrum	Type 1
2	Soil Category	B
3	β	0.20
4	Seismic acceleration factor a	For all three categories i.e., a = 0.16, 0.24, 0.36
5	Gravity acceleration g	9.81 m/sec^2
6	Behavior factor q	Calculations based on EC8

Table 4: Spectrum data

Based on the results of the dynamic analysis of the building for each seismic zone, for the two seismic combinations along the X and Y axes, the percentage of the seismic force received from the walls was determined. In this way, it is proved that the static system under consideration is a wall system in every direction and for every seismic zone.

ZONE I		
	G+0.3Q+Ex+0.3Ey	**G+0.3Q+0.3Ex+Ey**
Base shear force	429.76	887.01
T1, T2 (X-axis)	379.75	
T3, T10 (Y-axis)		460.21
T4, T5, T6, T7, T8, T9 (Y-axis)		415.97
Percentage of shear force by walls	**88.36% > 65%**	**99.91% > 65%**

Table 5: Indicative percentages of seismic force carried by the structural walls (Zone I)

5 DYNAMIC ANALYSIS

Table 6 displays the sum of mass activated in each eigenmode. According to EC8 [24], dynamic spectral analysis requires activation of a mass percentage of at least 90% of the total mass of the building per direction.

Eigenmode	Participating mass			Eigenmode	Participating mass		
	SumUX	SumUY	SumRZ		SumUX	SumUY	SumRZ
1	0.679	0.000	0.000	**24**	0.998	0.992	0.989
2	0.679	0.690	0.000	**25**	0.998	0.995	0.989
3	0.679	0.690	0.712	**26**	0.998	0.995	0.989
4	0.877	0.690	0.712	**27**	0.998	0.995	0.993
5	0.877	0.865	0.713	**28**	0.999	0.995	0.993
6	0.877	0.867	0.852	**29**	0.999	0.997	0.993
7	0.942	0.867	0.852	**30**	0.999	0.997	0.993
8	0.942	0.922	0.860	**31**	0.999	0.997	0.995
9	0.942	0.929	0.917	**32**	0.999	0.998	0.995
10	0.969	0.929	0.917	**33**	1.000	0.998	0.995
11	0.969	0.959	0.918	**34**	1.000	0.998	0.997
12	0.969	0.960	0.951	**35**	1.000	0.999	0.997
13	0.982	0.960	0.951	**36**	1.000	0.999	0.997
14	0.982	0.977	0.951	**37**	1.000	0.999	0.997
15	0.989	0.977	0.951	**38**	1.000	0.999	0.997
16	0.989	0.977	0.971	**39**	1.000	0.999	0.998
17	0.993	0.977	0.971	**40**	1.000	0.999	0.998
18	0.993	0.987	0.971	**41**	1.000	1.000	0.998
19	0.993	0.987	0.982	**42**	1.000	1.000	0.999
20	0.995	0.987	0.982	**43**	1.000	1.000	0.999
21	0.995	0.992	0.982	**44**	1.000	1.000	1.000
22	0.997	0.992	0.982	**45**	1.000	1.000	1.000
23	0.997	0.992	0.989				

Table 6: Percentage of mass activated in each eigenmode

The results of Table 6 show that:

- In the first eigenmode, 68% of the mass is activated and is translational by X.
- In the second eigenmode, 69% of the mass is activated and is translational by Y.
- In the third eigenmode, 71% of the mass is activated and a torsional result is obtained.
- The requirement of the code for 90% of the mass to be activated for movements in X and Y directions arises in the ninth eigenmode.

6 DIMENSIONING OF BUILDING

Building has been dimensioned for all three seismic zones based on the reinforcement calculated for the ground floor slab. Figure 3 shows the plan view of the layout and the quantity of the reinforcement of the ground floor slab which resulted based on the necessary calculations for seismic zone I.

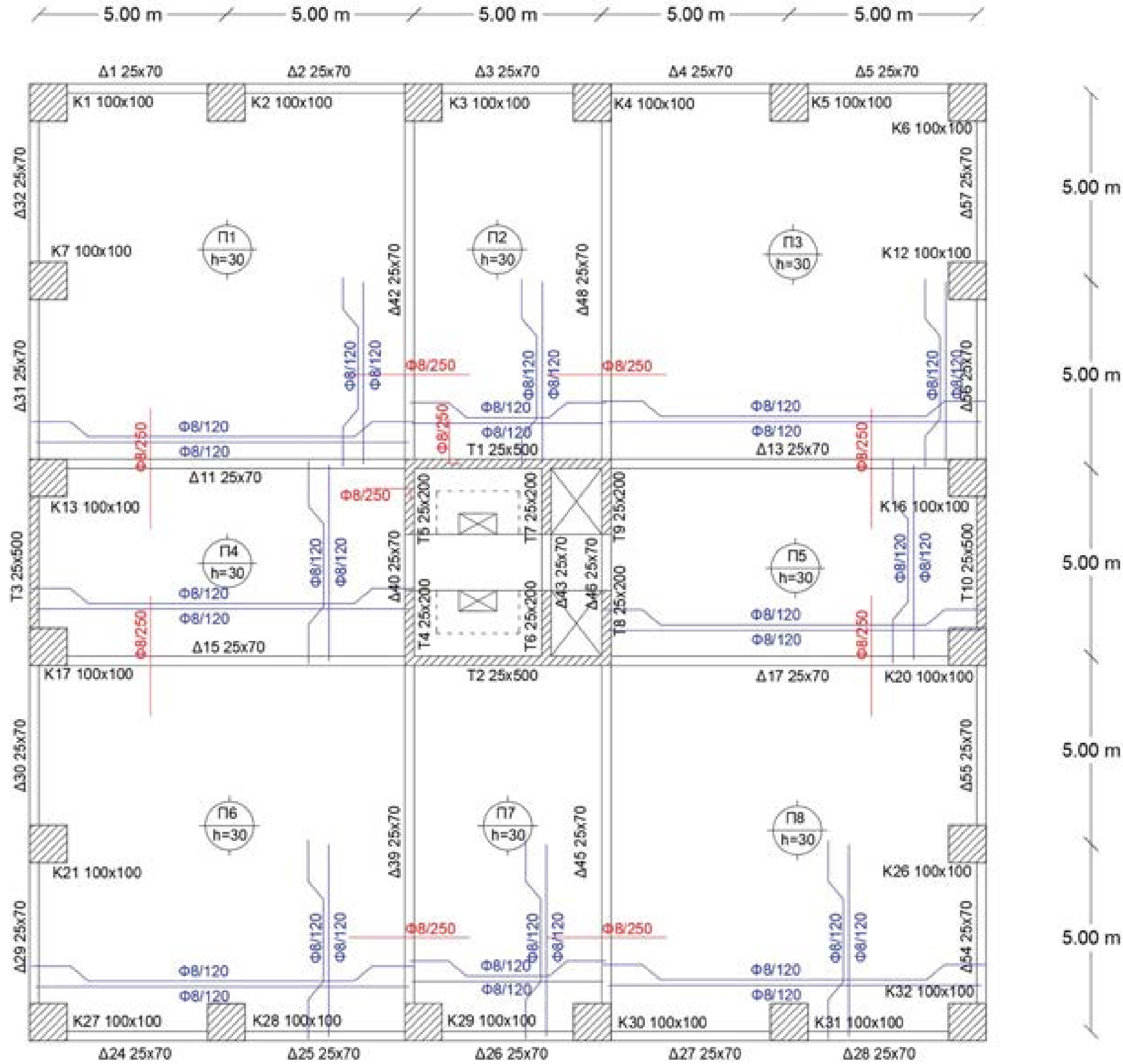

Figure 3: Ground floor slab reinforcement arrangement

7 CALCULATION RESULTS AND ANALYSIS

The engineering study of a building, in addition to the construction plans and the static calculations, also includes the pre-measurement of the project for the estimation of the construction costs. This section presents the measurements of the quantities of concrete and steel for the construction that has been studied, analyzed and dimensioned for all three seismic zones.

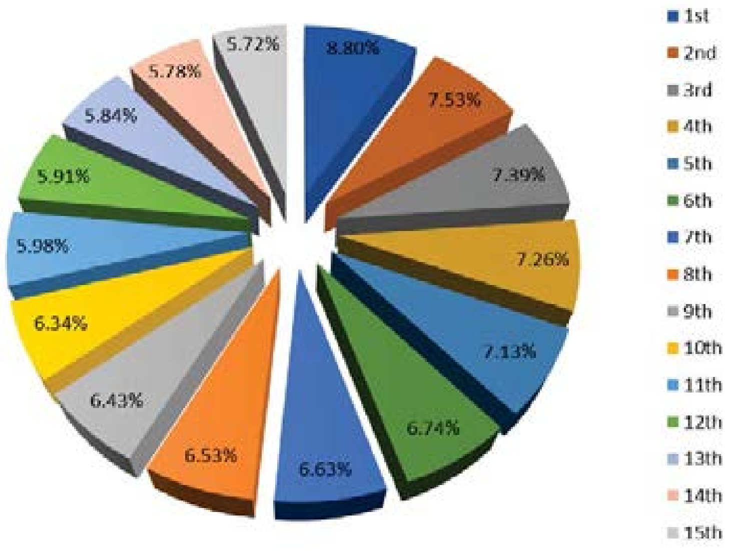

Figure 4: Percentage of concrete per floor

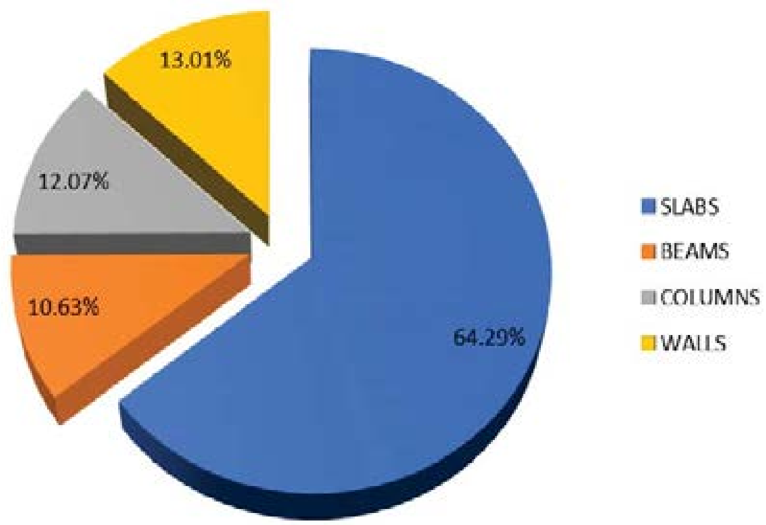

Figure 5: Percentage of total amount of concrete per structural element

It is therefore concluded that the first floor has the largest percentage of concrete while at the same time the percentage of the concrete is reduced from floor to floor (Figure 4). Also, the slabs occupy by far the largest percentage of the total amount of concrete with a percentage of 64.29%, followed by the seismic walls with 13.01%, the columns with 12.07% and finally the beams with 10.63% (Figure 5).

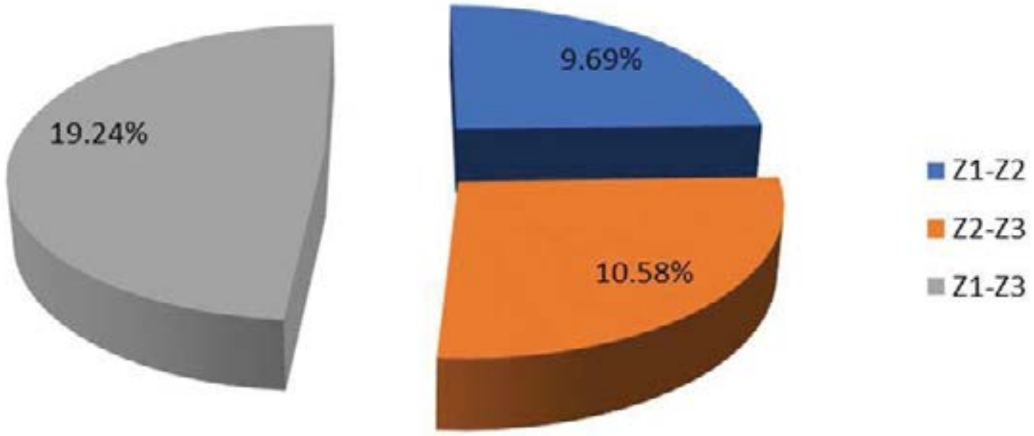

Figure 6: Percentage increase in total steel weight of ground floor seismic walls' steel (Zones I-III)

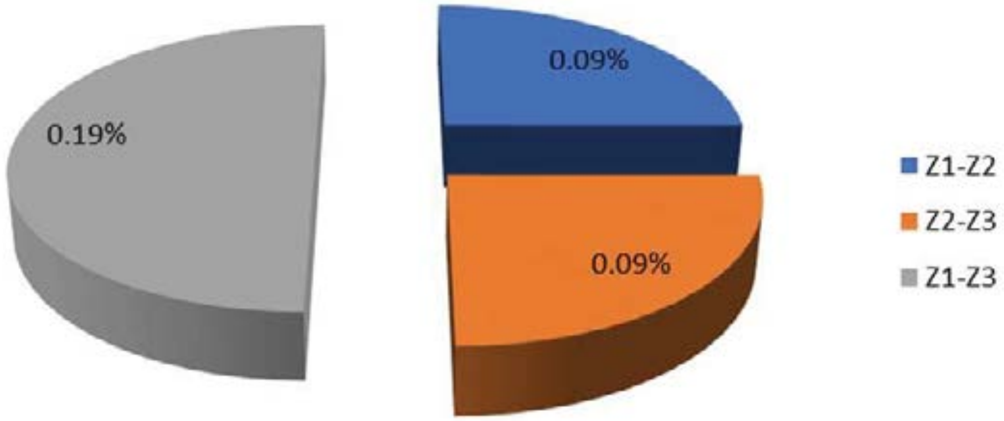

Figure 7: Percentage increase in total steel weight of ground floor beams' steel (Zones I-III)

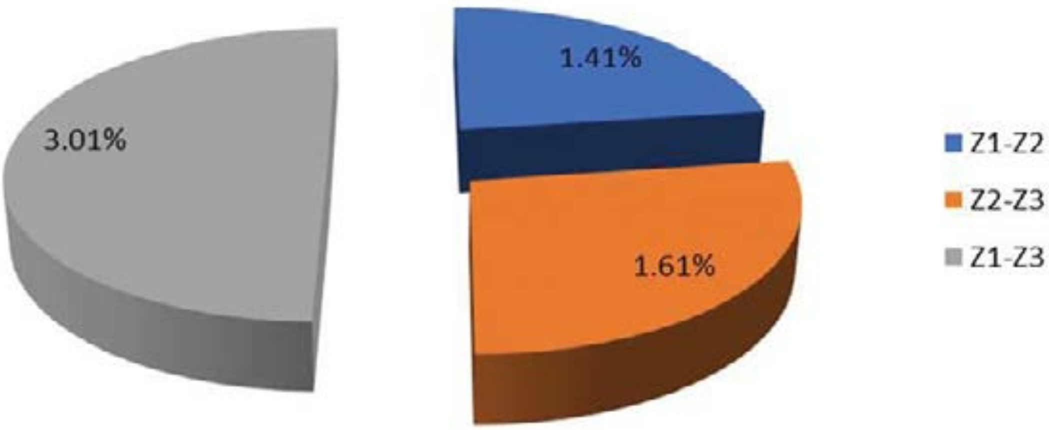

Figure 8: Percentage increase in total steel weight of ground floor structural components (Zones I-III)

From the above diagrams that emerged from the measurements of the building materials for each seismic zone, it is observed that:

1. During the increase of the seismic acceleration in the building in question, it is observed that the steel of the seismic walls has the largest percentage increase of its weight. Specifically, during the passage from (Figure 6):
   - Zone I ($a_g = 0.16g$) → Zone II ($a_g = 0.24g$) percentage increase of 9.69%
   - Zone II ($a_g = 0.24g$) → Zone III ($a_g = 0.36g$) percentage increase of 10.58%
   - Zone I ($a_g = 0.16g$) → Zone III ($a_g = 0.36g$) percentage increase of 19.24%

   The steel of the beams increases by much less (Figure 7):
   - Zone I ($a_g = 0.16g$) → Zone II ($a_g = 0.24g$) percentage increase of 0.09%
   - Zone II ($a_g = 0.24g$) → Zone III ($a_g = 0.36g$) percentage increase of 0.09%
   - Zone I ($a_g = 0.16g$) → Zone III ($a_g = 0.36g$) percentage increase of 0.19%

   Therefore, the walls have a dominant position in the load-bearing structure, as the static system is governed by the wall behavior.

2. The increase in seismic acceleration from (Figure 8):
   - Zone I to Zone II is of the order of 50% while the percentage increase in the total amount of material is only 1.41%, i.e., many times smaller.
   - Zone II to Zone III is of the order of 50% while the percentage increase in the total amount of material is only 1.61%, i.e., many times smaller.
   - Zone I to Zone III is of the order of 125% while the percentage increase in the total amount of material is only 3.01%, i.e., many times smaller.

8 CONCLUSIONS

In conclusion, in a reinforced concrete building, with strong structural walls, designed and dimensioned according to modern seismic codes, the influence of seismic hazard on the construction cost of the building is not significant, due to the small percentage increase in total material costs in comparison to the drastic percentage increases of the respective seismic accelerations.

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