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Eccomas Proceedia COMPDYN (2021) 1712-1724

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COMPDYN 2021
8th ECCOMAS Thematic Conference on
Computational Methods in Structural Dynamics and Earthquake Engineering
M. Papadrakakis, M. Fragiadakis (eds.)
Streamed from Athens, Greece, 28 - 30 June 2021

STUDY OF THE INFLUENCE OF SEISMIC ACTION ON THE CONSTRUCTION COST OF THE LOAD-BEARING STRUCTURE OF A TEN-STOREY R/C BUILDING

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Abstract

Greece is divided into three seismic hazard zones ZI, ZII, ZIII. In the present research work, the same building in the three seismic zones of Greece is modeled, analysed and dimensioned and then the construction cost of its structural body is estimated. The building modeling was performed in SAP2000 using linear finite elements. The analysis of the building was performed by dynamic spectral analysis methods using the design spectrum of EC8. A ten-storey building with a standard floor plan per floor was used. The purpose of this research paper is through comparative analytical estimation of construction costs to demonstrate whether the cost of construction of the bearing structure of a reinforced concrete building is affected by the area seismic hazard, if this influence is significant and to what extent. Useful conclusions are drawn regarding the influence of seismicity on the construction cost of the load-bearing structure of reinforced concrete buildings.

Keywords: Seismicity, Cost, Reinforced Concrete, Seismic Hazard.

Peer-review under responsibility of the organizing committee of COMPDYN 2021.
doi:10.7712/120121.8593.18667

1 INTRODUCTION

One matter that has troubled consultant engineers worldwide is the correct design and detailing of a reinforced concrete (R/C) building [1]–[16]. However, another matter that has troubled engineers is the economical design of a R/C building, as far as the construction cost of the load-bearing structure is concerned. Several studies worldwide have taken place on this matter in order to find the most economical way of designing and detailing the load-bearing structure of structures, whether these structures are buildings [17]–[19], bridges [20]–[24] or other types of structures [25], [26].

2 DESCRIPTION OF BUILDING

The reinforced concrete structure that is simulated and dimensioned in the three seismic zones is a symmetrical ten-storey building, without a basement. The floor plan of the building is 25 m x 25 m, so its area is E = 625.00 m^2, and is the same for each floor (Figure 1). The height of the ground floor is 4.5 m and the rest of the floors 3 m. In the center of each floor, there is a strong core and two ductile walls around the center of the Y direction.

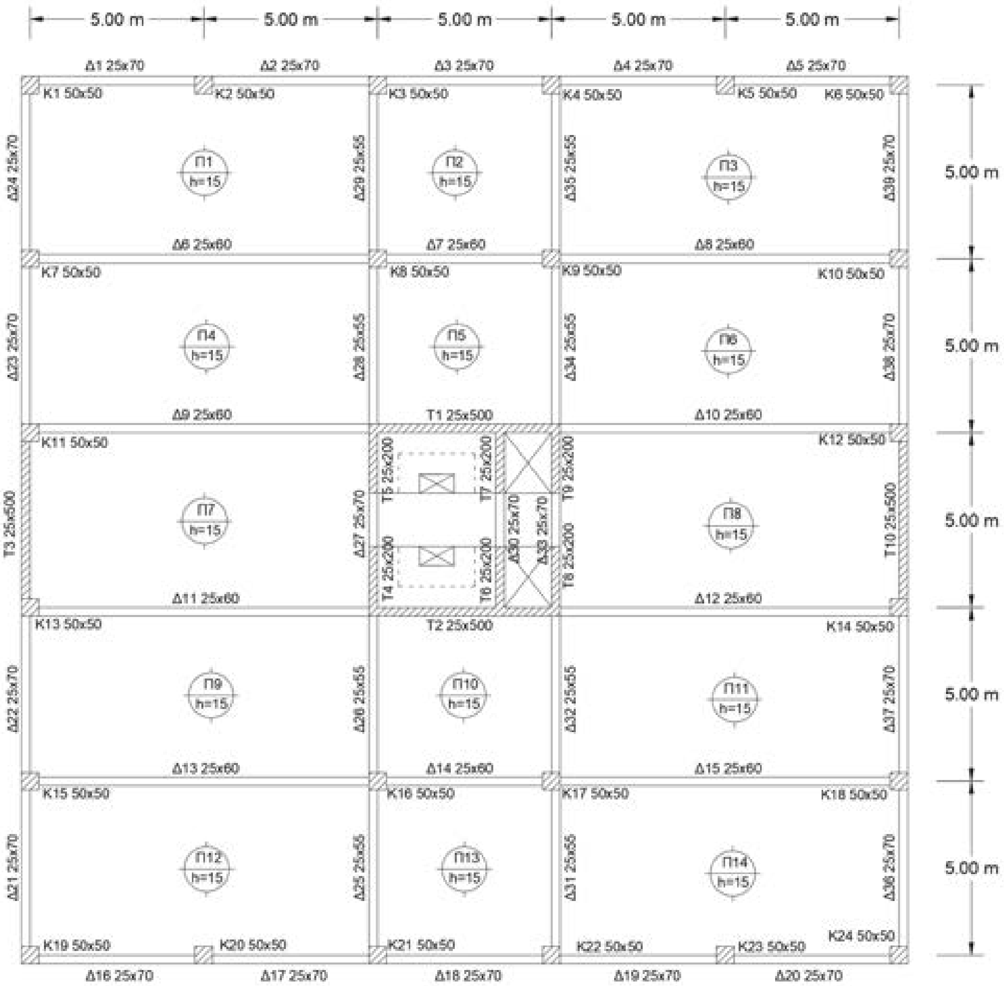

Figure 1: Floor plan.

The dimensions of the beams' cross sections of the building do not change per floor. The perimeter beams have dimensions 25 cm x 70 cm and the inner ones 25 cm x 60 cm in the X direction and 25 cm x 55 cm in the Y direction, apart from the core where they are also 25 cm x 70 cm. The cross section of the columns varies in height; for the first two floors is 75 cm x 75 cm and then decreases by 5 cm per floor. The thickness of the ductile wall sections varies with height and changes every five floors. On the first five floors, it is 37.5 cm and for the last five it is 25 cm. Enlarged boundary elements are used at both ends of the ductile walls T3 and T10 to avoid lateral buckling of structural walls under extreme seismic actions [27]–[34]. The thickness of the slabs is 15 cm.

3 MODEL DESCRIPTION

The modeling of the load-bearing structure is performed with the program SAP 2000. The ductile walls are modeled through the equivalent frame method (Figure 2). A vertical element is used, equivalent to a column, in the center of the wall, which is connected to the other structural elements with horizontal elements; rigid bodies at the level of the floors, with special properties. These bodies have increased values of their characteristics so that they appear as rigid in relation to the neighboring elements. The nodes at the base of the structure have rigid supports so that the superstructure is not affected by the foundation structure [35], [36].

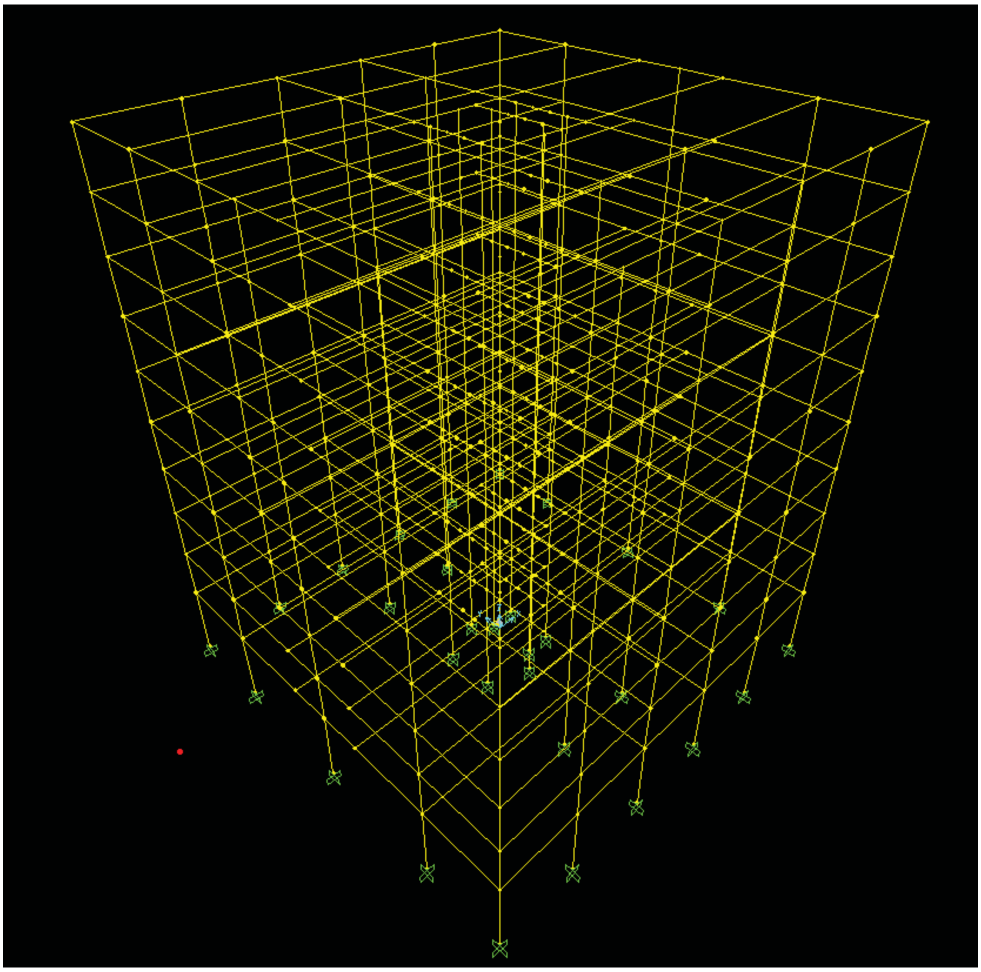

Figure 2: 3D building simulation.

The construction materials of the load-bearing structure have the following characteristics:

- Concrete quality C30/37
- Steel quality B500C

The modulus of elasticity of concrete is 33 GPa, according to Eurocode 2 [37]. The value of the Poisson ratio is set equal to 0, according to the specifications of Eurocode 2 [37], for cracked sections of reinforced concrete. The beams are modeled as linear finite elements in space, placed on the centroid axis of the structural element. As the diaphragm action of the slabs is ensured, the beams are considered as T or L beams. The columns are modeled as linear finite elements in space, placed on the centroid axis of the structural element, like the beams.

4 DIMENSIONING

4.1 Slabs

All slabs are quadrilateral and are reinforced in both directions and the calculation was done with Czerny tables. The maximum torque at middle of the slabs is M = 15.80 kNm. Therefore, reinforcement Ø10/190 (A_s = 4,13 cm^2) is placed in the openings of the slabs. The supports that require additional reinforcement are Π1-Π4, Π3-Π6, Π9-Π12, Π11-Π14, as well as the core support and so additional reinforcement Ø10/250 is placed.

4.2 Beams

The detailing of the beams has been performed in the openings and the supports for the most unfavorable combination and according to the minimum requirements of Eurocodes 2 and 8 [37], [38].

4.3 Columns

Detailing against biaxial bending with axial force is performed according to Eurocode 2 [37]. Similar to the beams, the most unfavorable combinations, the minimum requirements of Eurocodes 2 and 8 [37], [38] and the capacity design were used (Table 1).

ZONE II				
Column	vd	μ1	μ2	Reinforcement
K1, K6, K19, 24	-0.07570	0.01544	0.00564	12Ø25
K2, K5, K20, K23	-0.12780	0.01795	0.00360	12Ø25
K3, K4, K21, K22	-0.17002	0.01773	0.00281	12Ø25
K8, K9, K16, K17	-0.16832	0.01783	0.00273	12Ø25
K7, K10, K15, K18	-0.12499	0.01787	0.00341	12Ø25

Table 1: Longitudinal reinforcement of ground floor columns of Zone II

4.3 Structural walls

The detailing of the ductile walls has been performed according to the provisions of Eurocodes 2 and 8 (Table 2) [37], [38].

ZONE III				
Structural Walls	vd	μx	μy	Reinforcement
T1, T2	0.0690	0.1200	0.0043	12Φ32
T3, T10	-0.1380	0.1750	0.0160	12Φ32
T4, T5	0.2420	0.0805	0.0052	8Φ25
T6, T7	0.1200	0.0755	0.0051	8Φ25
T8, T9	0.2631	0.0772	0.0052	8Φ25

Table 2: Tension reinforcement of ground floor ductile walls of Zone III

5 CONCRETE AND STEEL MEASUREMENTS

The amount of concrete does not change in the three seismic zones, as the dimensions of the elements remain constant. The measurement of the steel reinforcement of the slabs, beams, columns and walls took place after the completion of the detailing for all three seismic zones.

6 ANALYSIS OF RESULTS

6.1 Analysis of concrete results

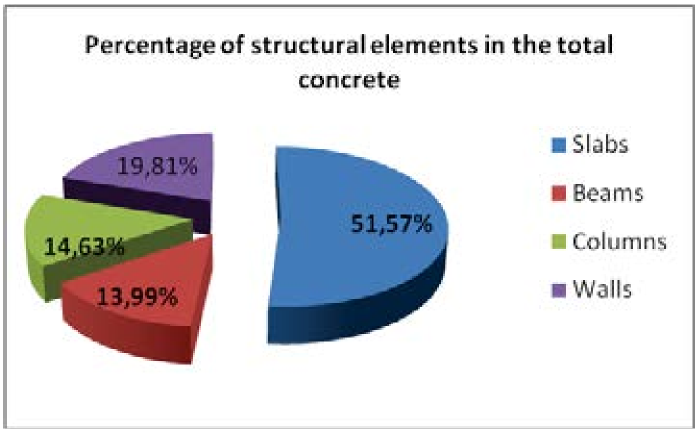

Figure 3: Percentage of structural elements concrete column compared to the total volume of concrete.

From Figure 3, it appears that the slabs have the largest percentage of the structural elements with a percentage of 51.57%. Then there are the walls with a percentage of 19.81%, the columns with a percentage of 14.63% and finally the beams with a percentage of 13.99%.

6.2 Analysis of reinforcement results for the ground floor

The following Table 3 and Figures 4-11 display the weight of steel of the structural elements of the ground floor for each zone.

Zone	Slab steel (kgr)	Beam steel (kgr)	Column steel (Kgr)	Structural wall steel (kgr)	Sum
Z1	10381.83	6739.43	6391.74	5538.13	29051.13
Z2	10381.83	8028.39	6405.58	7573.54	32389.35
Z3	10381.83	8561.27	7370.15	8784.73	35097.98

Table 3: Weight of steel of structural elements

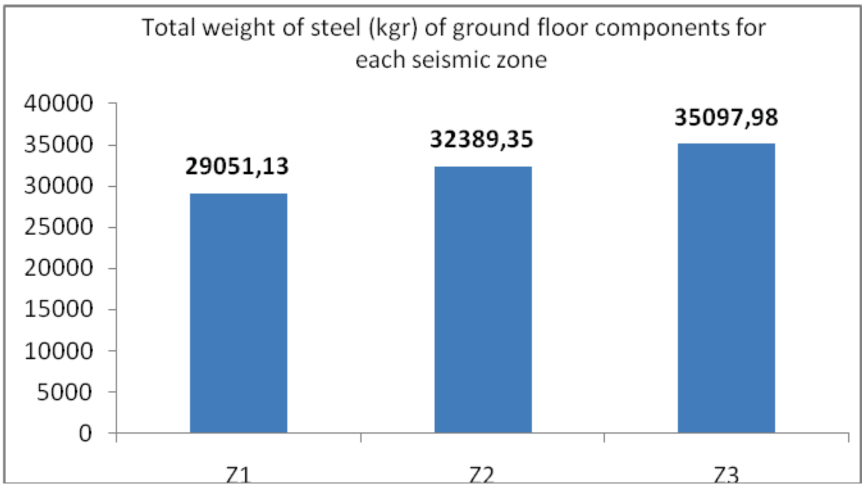

Figure 4: Total weight of steel of ground floor components for each seismic zone.

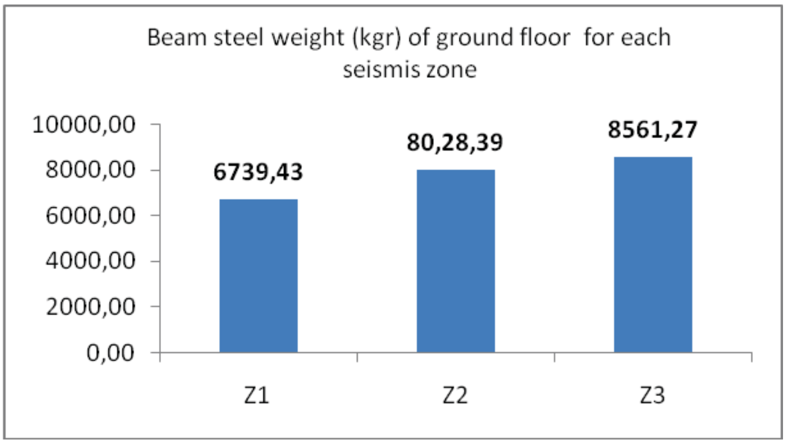

Figure 5: Beam steel weight of ground floor for each seismic zone.

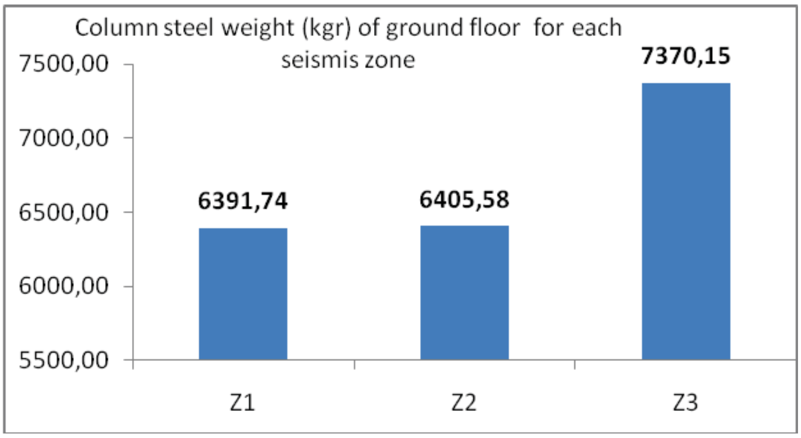

Figure 6: Column steel weight of ground floor for each seismic zone.

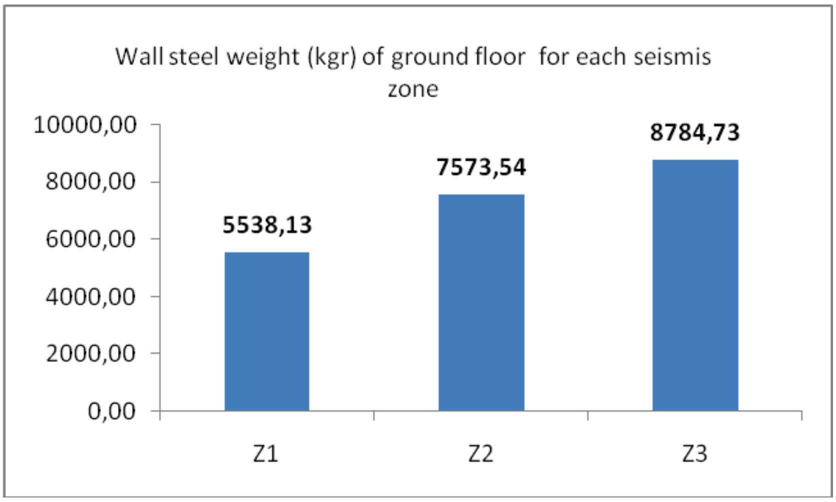

Figure 7: Wall steel weight of ground floor for each seismic zone.

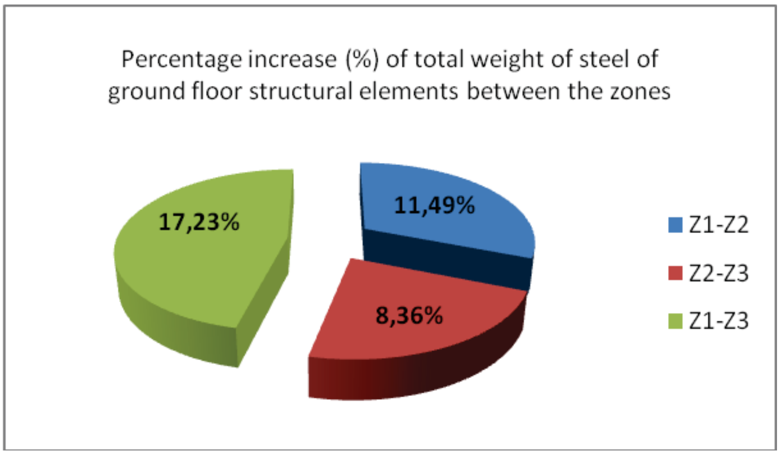

Figure 8: Percentage increase of total weight of steel of ground floor structural elements per zone.

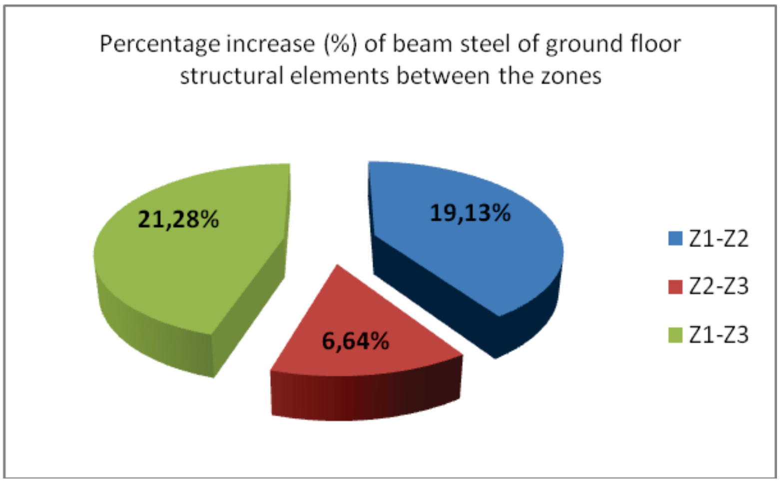

Figure 9: Percentage increase of beam steel of ground floor structural elements per zone.

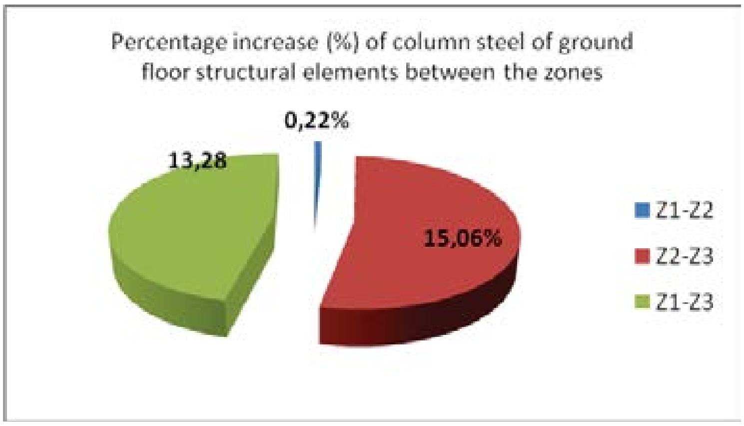

Figure 10: Percentage increase of column steel of ground floor structural elements per zone.

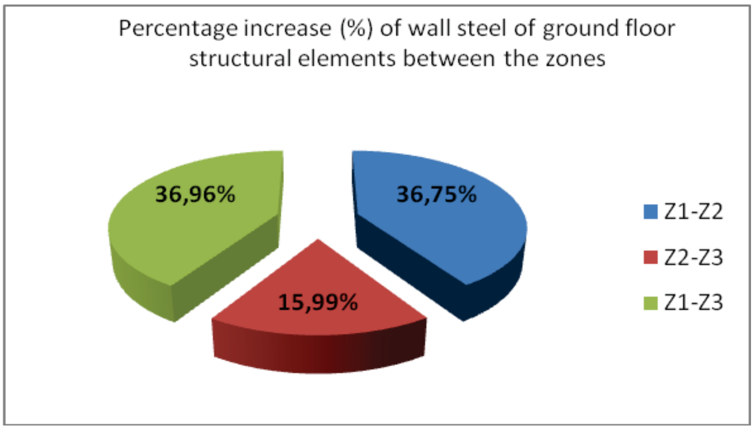

Figure 11: Percentage increase of wall steel of ground floor structural elements per zone.

The analysis of the above diagrams shows the following:

- **Transition from ZI seismic acceleration 0.16g, to ZII seismic acceleration 0.24g**
  - Increase of 11.49% of the total weight of steel of all structural elements
  - Increase of 19.13% in the steel weight of the beams
  - Increase of 0.22% in the steel weight of the columns
  - Increase of 36.75% of the steel weight of the walls

- **Transition from ZII seismic acceleration 0.24g, to ZIII seismic acceleration 0.36g**
  - Increase of 8.36% of the total weight of steel of all structural elements
  - Increase of 6.64% in the steel weight of the beams
  - Increase of 15.06% in the steel weight of the columns
  - Increase of 15.99% of the steel weight of the walls

- **Transition from ZI seismic acceleration 0.16g, to ZIII seismic acceleration 0.36g**
  - Increase of 17.23% of the total weight of steel of all structural elements
  - Increase of 21.28% in the steel weight of the beams
  - Increase of 13.28% in the steel weight of the columns
  - Increase of 21.28% of the steel weight of the walls

- **Increase in seismic acceleration**
  - Zone I to Zone II (0.24-0.16)/0.16 = 50%
  - Zone II to Zone III (0.36-0.24)/0.24 = 50%
  - Zone I to Zone III (0.24-0.16)/0.16 = 125%

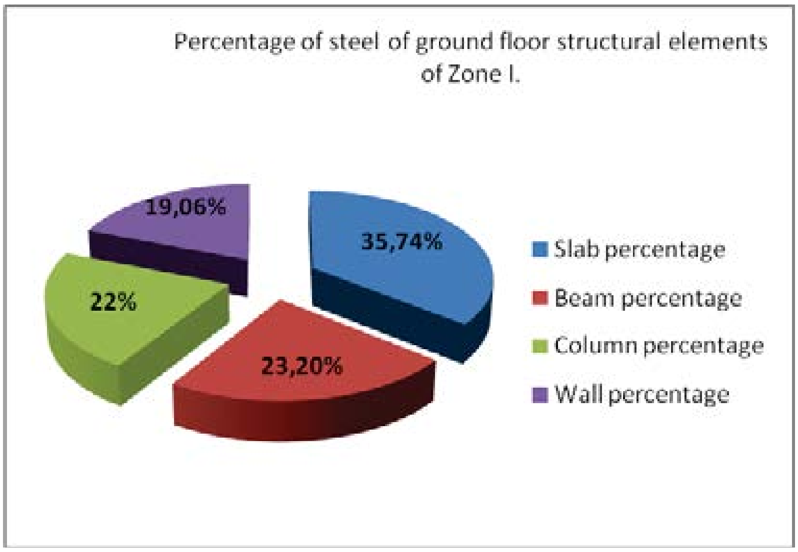

Figure 12: Percentage of steel of ground floor structural elements of Zone I.

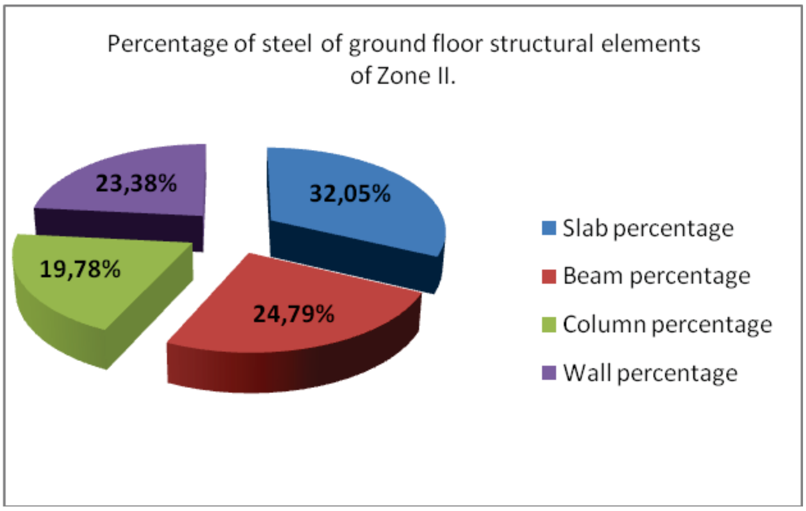

Figure 13: Percentage of steel of ground floor structural elements of Zone II.

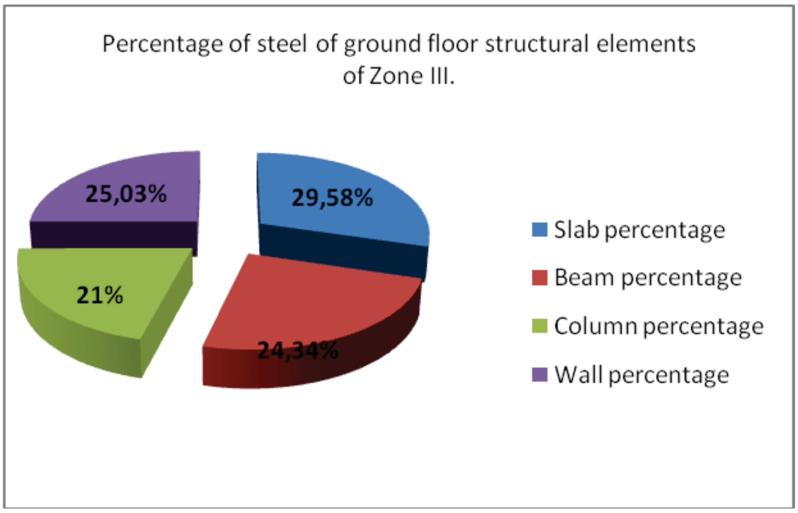

Figure 14: Percentage of steel of ground floor structural elements of Zone III.

From the Figures 12-14, it is concluded that:

- Slabs occupy their largest percentage in steel in ZI 35.74%, then in ZII 32.05% and finally in ZII 29.58%.
- Beams occupy their largest percentage in steel in ZII 24.79%, then in ZIII 24.34% and finally in ZI 23.20%.
- Columns occupy their largest percentage in steel in ZI 22%, then XIII 21% and finally in ZII 19.78%.
- Structural walls occupy their largest percentage in steel in ZII 25.03%, then in ZII 23.38% and finally in ZI 19.06%.

7 CONCLUSIONS

In the present work, a ten-storey reinforced concrete building, without a basement, of rectangular conventional floor plan, was analyzed and detailed in the three seismic zones ZI, ZII, ZIII. The following conclusions emerged:

1. As the seismic hazard in the building increases, the largest percentage increase in steel occurs in the seismic walls. Specifically:
   - ZI (α_g = 0.16g) → ZII (α_g = 0.24g) percentage increase 36.75%
   - ZII (α_g = 0.16g) → ZII (α_g = 0.36g) percentage increase 15.99%
   - ZI (α_g = 0.16g) → ZII (α_g = 0.36g) percentage increase 36.96%

2. The increase in seismic acceleration:
   - From ZI to ZII is a percentage of 50%, while respectively the increase in the total amount of steel is 11.49%, significantly smaller.
   - From ZII to ZIII is a percentage of 50%, while respectively the increase in the total amount of steel is 8.36%, an even greater difference compared to the previous transition.
   - From ZI to ZIII is a percentage by 125%, while respectively the increase in the total amount of steel is only 17.23%.

3. In a reinforced concrete building designed in accordance with the Eurocodes, seismicity affects the construction cost of the building but certainly the increase in construction costs

is significantly smaller compared to the increase in seismic risk. The increase in the total cost of materials is much smaller than the increase in seismic accelerations.

4. A building may be detailed for a seismic hazard zone greater than that provided for in the respective code, taking into account that there is a difference in construction costs.

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