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ANALYTICAL INVESTIGATION OF THE INFLUENCE OF SEISMICITY ON THE CONSTRUCTION COST OF THE R/C LOAD-BEARING STRUCTURE OF A 5-STOREY BUILDING WITH SPRING SUPPORTS

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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 5-storey building with a standard floor plan per floor was used. The supports in this building were simulated using springs to take into account the influence of the soil. 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 with spring supports.

Keywords: Cost estimation, construction costs, seismicity, non-rigid foundation foot, spring support simulation

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1 INTRODUCTION

Over the years the evolution of construction was an inevitable and welcome consequence of the time, as the massive increase in population and its concentration in large urban centers brought to the forefront the construction of complex and multi-storey buildings which were called to meet the primary need of housing. Through the evolution of the constructions, the specialization of the materials came according to the needs of each one [1]–[4]. The needs of each construction are distinguished depending on the use of the construction, the area in which it is located, the soil and weather conditions, the studies required and the cost [5]–[13].

The Greek Seismic Code [14] divides Greece into the three seismic danger zones we know today. Designing a structure for the right seismic zone is another challenge for the engineer. Planning for the minimum zone of an area is sometimes a borderline situation. If one wants to make his construction safer and plan for a higher seismic zone, then one should consider the cost increase that comes with this option [8], [9], [15], [16].

Usually, the seismic hazard in a place is expressed quantitatively either by the probability of seismic acceleration or intensity greater than a certain value within a certain time, or by the value of acceleration or intensity for which the probability of exceeding its value for a certain period of time is below a certain limit.

Thus, from the aforementioned, it is understood that the manifested intensity of an earthquake or its maximum acceleration weakens as the distance from the epicenter increases [17]–[22]. From the statistical evaluation of a large number of earthquakes, empirical laws of attenuation have emerged which connect the intensity (I) with the magnitude of the earthquake (M) and the focal length (Δ).

According to those factors, the earthquake resistant regulations have been evolved worldwide [14], [23], [24], facing with great effectiveness the safety of human life. In the seismic design of reinforced concrete structures, a key parameter is the seismic design actions, based on which the structures in each area are designed (Table 1). With the help of the aforementioned, it became possible to calculate the statistical distribution of a parameter of seismic motion in a certain place, since the individual epicenter distances Δ and the statistical distribution of time of magnitude M in each epicenter are known. Based on the statistical distributions of A and I, seismic hazard maps are compiled (Figure 1).

Zone of seismic risk	Ground acceleration values (g)
Z1	0,16
Z2	0,24
Z3	0,36

Table 1: Ground acceleration values [14].

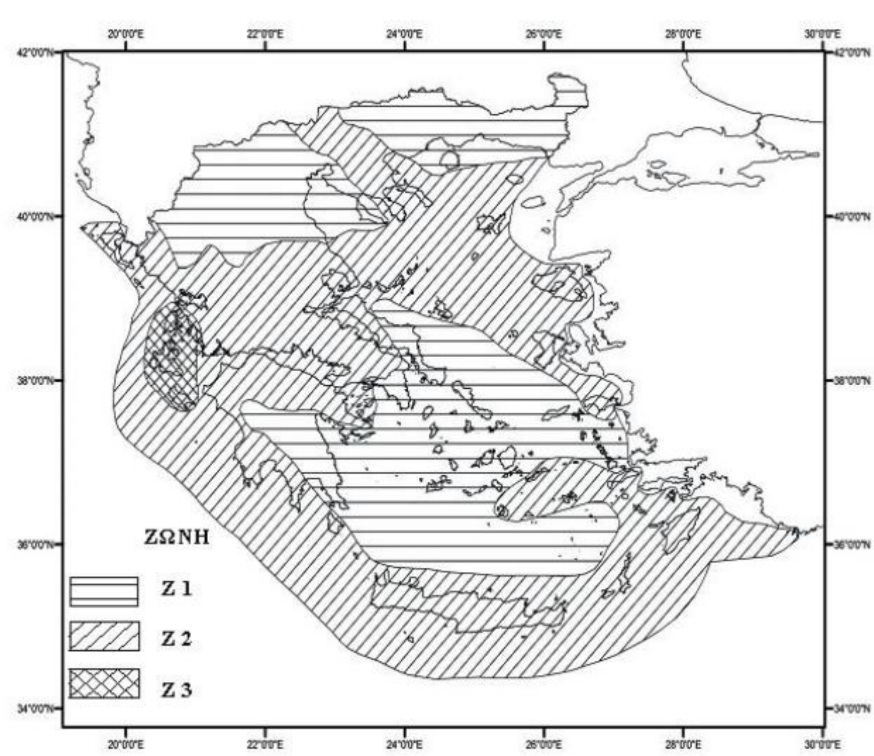


Figure 1: Seismic hazard map of Greece [14].

The following simulation will be analyzed in zone I with maximum seismic horizontal ground acceleration a_g = 0.16g, in zone II with a_g = 0.24g and in zone III with a_g = 0.36g (where g is the acceleration of gravity and is equal to with 9.81 m/sec^2). So, the growth rate from seismic zone I to zone II is equal to 50%, from I to III 125% and from II to III 50%. These percentages should be compared mainly with the percentages of increase in the weight of steel, in order to prove if the construction cost of the building is within reasonable limits.

2 ANALYTICAL RESEARCH

2.1 Building data

The present study presents the simulation and dimensioning, as realistically as possible and based on modern regulations, of three buildings which have the same standard floor plan, the same number of floors (5 floors), but are located in different seismic zones.

The floor plan of the 5-storey building (Figure 2) has dimensions 25×25 m, therefore the total floor plan is equal to E = 625.00 (m^2). The height of the floors is h = 3.00 m, except for the height of the first floor (ground floor) which is h = 4.50 m. Therefore, the total height of the building is h_{sum} = 16.5 m. The influence of the soil is taken into account and spring connections are used for the building's supports [5].

All the beams have the same dimensions 0.25×0.70 m, the walls have a thickness of 0.25 m, while for the columns, those on the 1st and 2nd floor are 0.50x0.50 m while those on 3rd, 4th and 5th floor are 0.45×0.45, 0.40×0.40 and 0.35×0.35 m respectively.

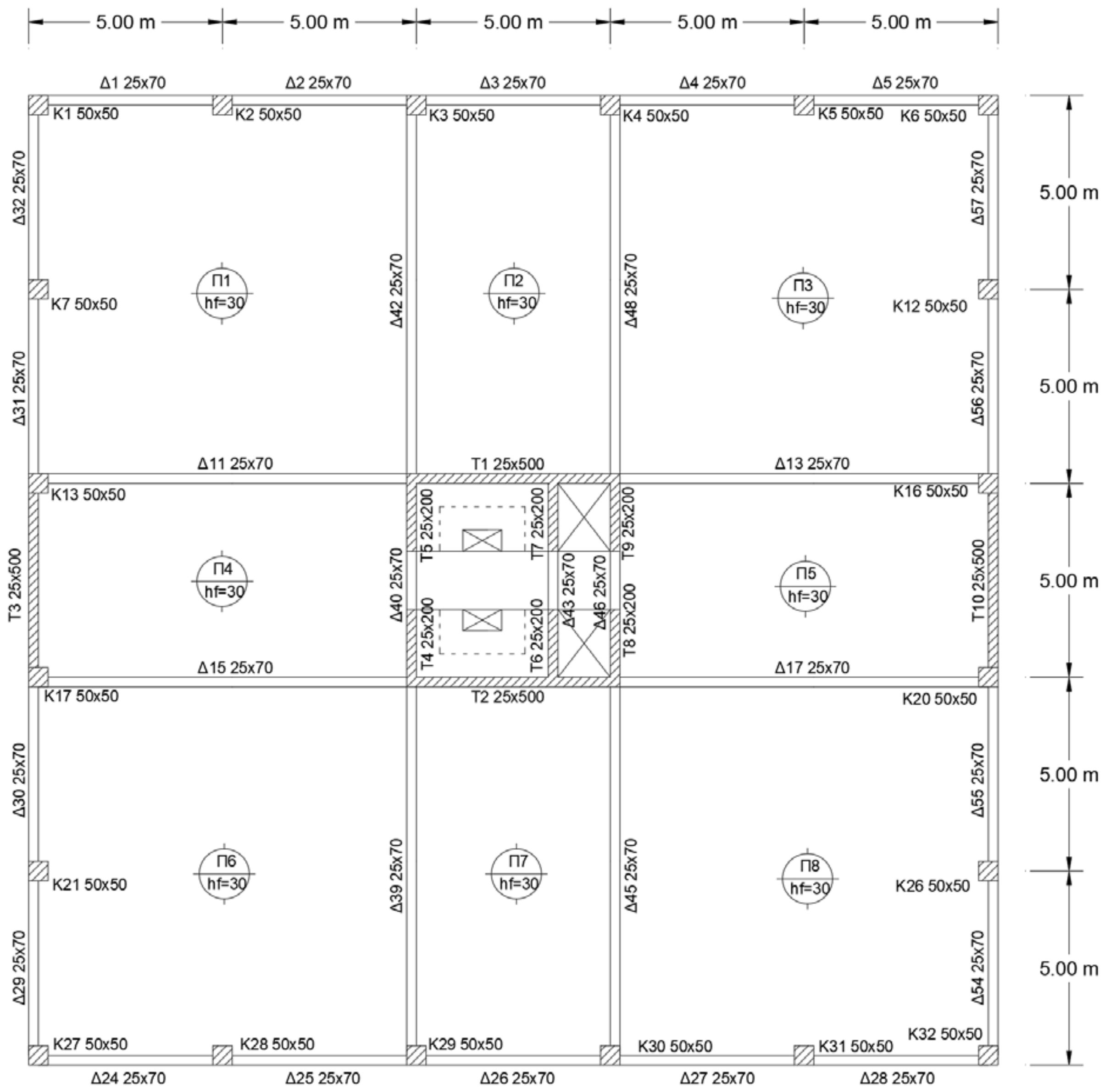


Figure 2: Typical floor plan.

Floor	Height (m)	Beam dimensions (cm)		Wall thickness (cm)	Column dimensions (cm)
		Perimetric	Internal		
1st (Ground floor)	4.50	25×70	25×70	25	50×50
2	3.00	25×70	25×70	25	50×50
3	3.00	25×70	25×70	25	45×45
4	3.00	25×70	25×70	25	40×40
5	3.00	25×70	25×70	25	35×35

Table 2: Dimensions of the structural elements.

2.2 Construction

The building, as a typical construction, is stressed by gravity loads which are the permanent loads (self-weight, etc.), the live loads (human load, etc.) and the seismic loads. For the building in question, the loads are shown in Table 3.

PERMANENT LOADS		
N/A	**Type**	**Value**
1	Flooring	1.40 kN/m^2
2	Partition brick structures	1.00 kN/m^2
3	Perimeter brick structures	8.00 kN/m
4	Roofing	3.50 kN/m^2
5	Parapet roof load	3.60 kN/m^2
LIVE LOADS		
N/A	**Type**	**Value**
1	Ground floor	2.00 kN/m^2
2	Typical floors	2.00 kN/m^2
3	Roof	2.00 kN/m^2
SPECTRUM DATA EC8		
N/A	**Type**	**Data**
1	Spectrum type	Horizontal design spectrum type 1
2	Soil category	B
3	Factor β	0.20
4	Seismic acceleration factor α	For the three categories: α =0.16, 0.24, 0.36
5	Gravity acceleration g	9.81 m/sec^2
6	Coefficient behavior q	Calculation based on EC8

Table 3: Building loads.

2.3 3D Modelling

The modeling of the load-bearing structure of the building will be performed with the finite element software SAP2000. The individual structural elements that were modeled are the beams, the columns and the seismic walls of the building. Also, it is essential to simulate the diaphragm function of the slabs on each floor. The dynamic spectral method analysis according to the EC8 [24] will be applied for the seismic actions of the building.

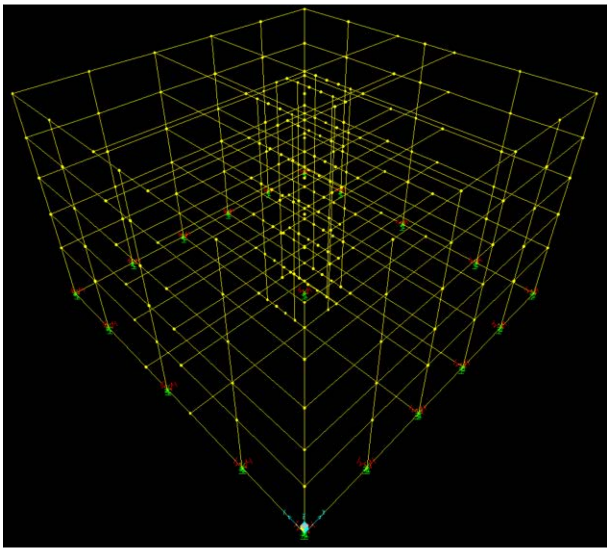
In conclusion, through the simulation some results will be extracted according to which the building will be dimensioned for the three seismic hazard zones and these are the design moments of the beams, the values for N, M_{33}, M_{22} of the vertical elements. Figure 3 presents the 3D model of the building.

Some assumptions were made when designing the simulation of the 5-storey building. Stiffness for cracked sections were considered equal to 0.5. Resistant to torsion was considered equal to 0.1. In beams as well as in vertical elements, the mass is considered zero. On the other hand, the self-weight factor on the beams remains zero, while on the vertical elements it is equal to one. To calculate the masses of each floor, half the masses of the vertical structural elements of the underlying floor and half the masses of the vertical structural elements of the upper floor were considered. In this case, the evenly distributed loads of the slab, as well as, its self-weight were transferred to the beams as an equivalent uniform load to facilitate the introduction of loads into the model.

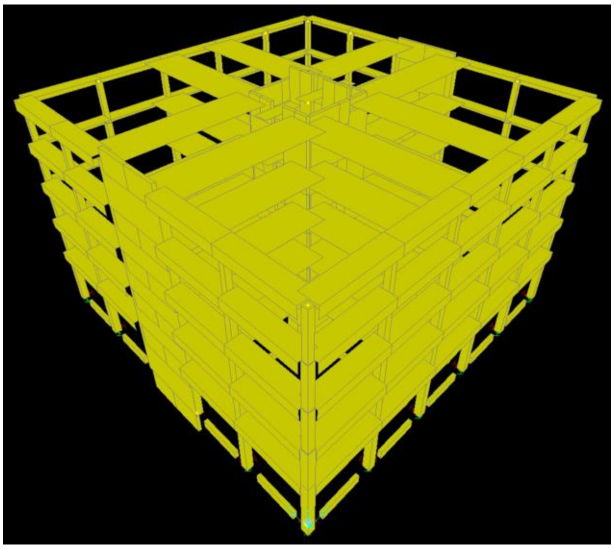
The foundation of the vertical elements of a building has been done in such a way and in soil conditions that cannot be considered as completely rigid. Except in special cases of foundation in rocky soils or with the use of rigid devices, the foundation is expected to show some movement and/or turn, due to the compressibility of the soil on which it is based [25].

For this reason, the simplified Winkler model is usually adopted, which includes the theory of springs at the points of contact of the structural elements with the ground [6]. The use of spring constants for the simulation of supports has been shown to give satisfactory results, compared with more complex simulations with surface finite elements, both in terms of results of stresses and changes in the construction period.

The movement possibilities of the node that simulates the support of a vertical element are a total of 6, three transportational and three rotational (Figure 3). Of the six soil deformation possibilities, those that are practically related to the behavior of building foundations and are usually taken into account are three: the possibility of vertical movement (vertical spring K_z) and the two rotational around the two horizontal axes (rotational springs K_{rx} and K_{ry}). The deformations in the remaining three movement possibilities are negligible and can be considered as completely rigid in their direction.



(a)



(b)

Figure 3: Views of the 3D building model: (a) Linear finite elements (b) Sections.

2.4 Material properties

For all the load-bearing structural elements of the construction, C30/37 quality concrete and B500C quality steel were used for the reinforcement bars. According to Eurocode 2 [26], concrete has a characteristic strength f_{ctm} = 2.9 MPa. Also, for concrete quality C30/37, the measure of elasticity is given equal to E_{cm} = 32 GPa. The Poisson ratio is considered equal to zero (ν = 0) for cracked concrete. Steel of quality B500C has a characteristic strength f_{yk} = 500 MPa.

2.5 Measurements of building materials

The dimensioning and pre-measurement has taken place only for the level of the ground floor, both for reasons of simplicity and for the fact that it is the most vulnerable floor and, based on this, the results were simply multiplied by the number of floors of the building, so that the total measurement of building materials is resulted. Thus, the large process of dimensioning the building has taken place first, where the slabs were checked for bending, while the beams, columns and walls were checked for bending and shear, for each seismic zone. Thus, it was calculated the required reinforcement for each structural element.

This was followed by the measurement of materials, where it was considered a necessary procedure to estimate the construction cost. The volume of concrete and the weight of reinforcement for each seismic zone were calculated (Table 4). Table 4 displays the measurements for the concrete material, which remain the same for all three seismic zones. Similar calculations have taken place for the measurement of the steel material used for the concrete reinforcements.

CONCRETE MEASUREMENT					
STOREY	**SLABS (m^3)**	**BEAMS (m^3)**	**COLUMNS (m^3)**	**WALLS (m^3)**	**TOTAL (STOREY) (m^3)**
1	180	30.28	22.50	36.00	268.78
2	180	30.28	15.00	24.00	249.28
3	180	30.28	12.15	24.00	246.43
4	180	30.28	9.60	24.00	243.88
5	180	30.28	7.35	24.00	241.63
				TOTAL	**1249.98**

Table 4: Concrete measurement.

3 RESULTS ANALYSIS

3.1 Beams

Referring to the beams, it is observed that the cross sections remain the same throughout the building and their reinforcement for the entire construction has been calculated approximately according to the reinforcement of the ground floor, so there is no change in both the steel/concrete ratio and the percentage increase in steel weight steel.

As shown in Figure 4 there is an increase in the weight of the reinforcement of 4.32% from seismic zone I to II and 9.81% from seismic zone II to III. This increase is very small compared to the increase of seismic acceleration (from seismic zone I to II is 11.5 times smaller and from II to III 5 times smaller).

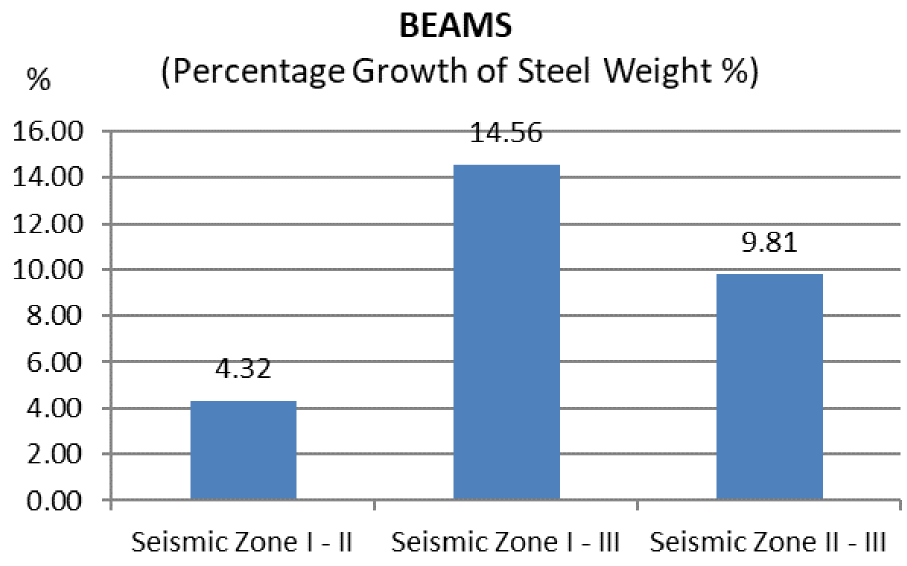


Figure 4: Percentage growth of beams' steel weight between all seismic zones.

3.2 Walls

Through the diagram (Figure 5), it is observed that the percentage increase of the steel of the walls between the seismic zones is almost the same whether we are talking about the walls of the ground floor specifically or we are talking about the walls of the building as a whole. Moving from seismic zone I to II the percentage increase of steel is 36.47%. From seismic zone I to III the percentage increase of steel is 61.92% while from seismic zone II to III the percentage increase of steel is 18.65%.

The walls are also the vertical elements of the construction that are relatively less affected by the earthquake. The increase in the weight of steel from seismic zone I to II is of the order of 36.37%, from I to III 61.75% and from II to III 18.61%. It is observed that in seismic zone II the reinforcement increases considerably. This zone mostly affects the construction. The rate of increase in weight of steel is about 1.4 times less than the rate of increase of seismic acceleration in the first case, 2 times lower in the second and 2.7 times lower in the third.

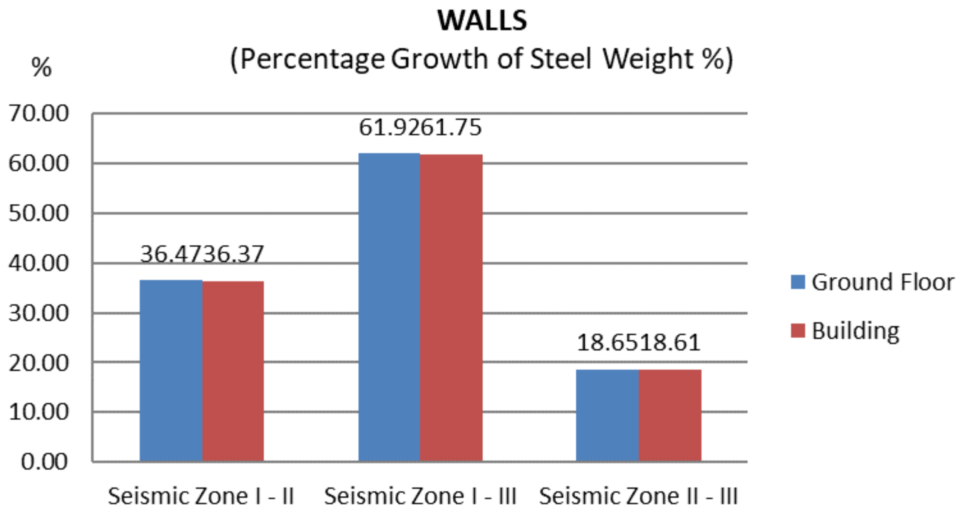


Figure 5: Percentage growth of walls' steel weight for the ground floor (blue) and the whole building (red).

3.3 Columns

The columns are the vertical structural elements of the present construction, which are more stressed by the earthquake [27], [28][29]–[34]. It is observed that in all seismic zones the weight of column reinforcement is always greater than that of the walls (Figure 6). In Figure 7 the increase in the weight of steel for the whole building from seismic zone I to II is of the order of 22.10%, from I to III 42.03% and from II to III 16.32%. It is observed that in seismic zone II the reinforcement increases considerably. This zone mostly affects the construction. The rate of increase in weight of steel is about 2.3 times smaller than the rate of increase of seismic acceleration in the first case, 1.2 times lower in the second and 3 times lower in the third.

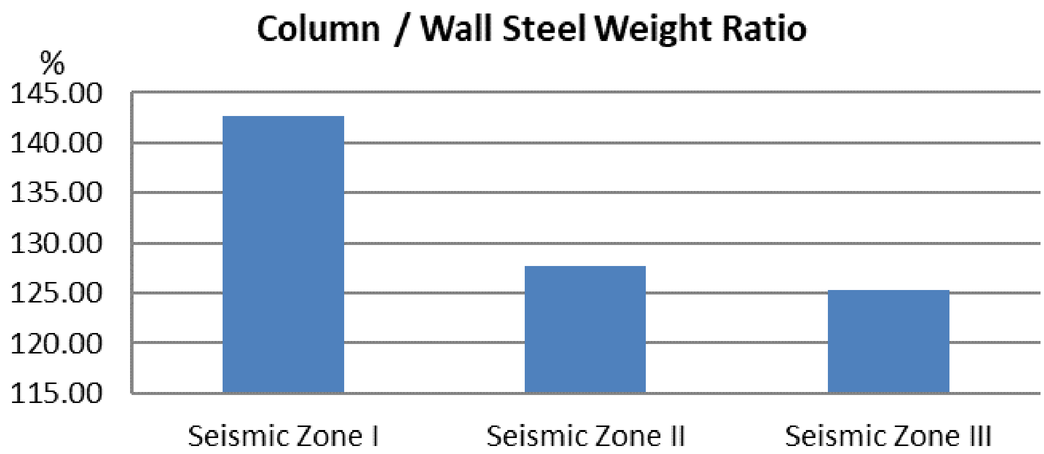


Figure 6: Column/wall steel weight ratio.

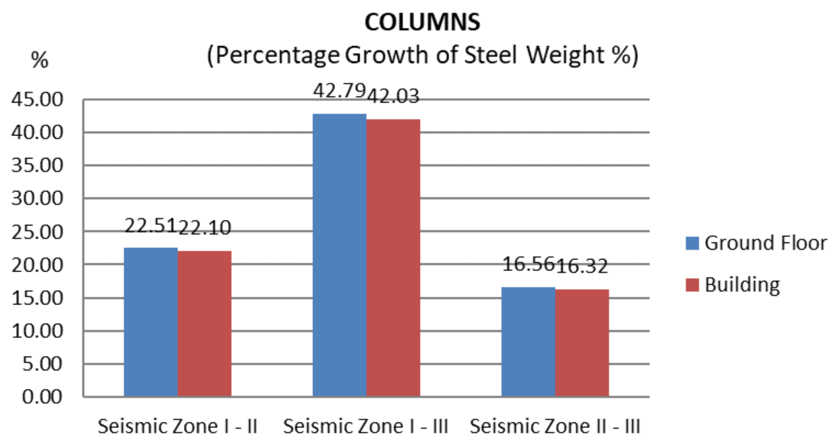


Figure 7: Percentage growth of columns' steel weight for the ground floor (blue) and the whole building (red).

3.4 Whole Building

In conclusion, in terms of reinforcement weight, there is an increase of 9.67% from seismic zone I to zone II and 20.80% from zone I to zone III. There is also an increase from zone II to zone III of the order of 10.15%. The above increases refer to the total weight of the reinforcement on the ground floor. However, the same increases apply to the entire building.

As for the whole construction, let's say that as it is logical, as the weight of the reinforcement increases, separately for each structural element, moving from one seismic zone to another, the same increases are displayed for the whole construction. This change plays a very important role, while with the increase of the weight of the reinforcement, there is a corresponding increase of the cost of the construction. However, the total increase in the quantity of materials and consequently the construction costs from seismic zone I to II is only of the order of 8.28%, i.e. 6 times less than the increase in seismic acceleration in the respective zones. Also, the increase in the amount of materials from seismic zone I to III is of the order of 18.81%, i.e. 2.6 times smaller than the increase in seismic acceleration in these zones. Finally, the increase in the amount of materials from seismic zone II to III is of the order of 9.72%, i.e. 5 times less than the increase in seismic acceleration in the respective zones.

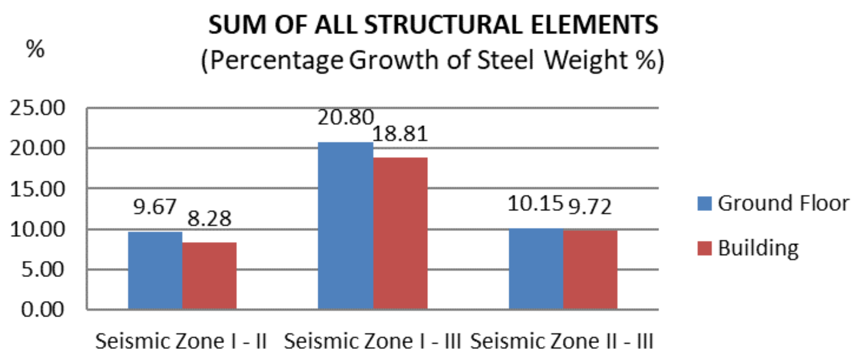


Figure 8: Percentage growth of all structural elements' steel weight for the ground floor (blue) and the whole building (red).

4 CONCLUSIONS

The structure studied in the present research is a five-storey reinforced concrete building without a basement with rectangular conventional floor plan and with spring supports. It has been designed for all three seismic hazard zones Zone I, Zone II and Zone III. The resulting conclusions can be summarized as follows:

1. In conclusion, observing the results obtained for all the structural elements in the three seismic zones, it can be said that the rate of increase of construction costs from one zone to another is quite small compared to the rate of increase of seismic acceleration in the respective zones.
2. Thus, if an engineer wishes, for reasons of greater safety, to design his construction, using the immediately larger seismic zone than the one in which the construction is actually located, he can do so without significantly increasing the cost of materials.
3. The rate of increase in the cost of materials is less than the safety thus ensured by the engineer for its construction.
4. Thus, it is concluded that for a five-storey reinforced concrete building, with a strong core wall arrangement and spring supports, the influence of seismic hazard on the construction cost of the load-bearing system should not be significant because the percentage increase of materials required is much smaller than the large percentage increases of the respective seismic accelerations.

REFERENCES

[1] D. S. Vijayan, A. Mohan, J. Revathy, D. Parthiban, and R. Varatharajan, "Evaluation of the impact of thermal performance on various building bricks and blocks: A review," *Environmental Technology and Innovation*, vol. 23, p. 101577, 2021, doi: 10.1016/j.eti.2021.101577.

[2] D. S. Vijayan, P. Devarajan, and A. Sivasuriyan, "A review on eminent application and performance of nano based silica and silica fume in the cement concrete," *Sustainable Energy Technologies and Assessments*, vol. 56, no. February, p. 103105, 2023, doi: 10.1016/j.seta.2023.103105.

[3] A. Algburi, M. Sheikh, and M. Hadi, "Analytical investigation on the behavior of circular and square RC columns strengthened with RPC and wrapped with FRP under uniaxial compression," *Journal of Building Engineering*, vol. 25, pp. 1–8, 2019, doi: 10.1016/j.jobe.2019.100833.

[4] H. P. Hong, H. Yuan, L. Deng, and Y. Bai, "Axial capacity of steel tube-reinforced concrete stub columns," *Engineering Structures*, vol. 183, no. December 2018, pp. 523–532, 2019, doi: 10.1016/j.engstruct.2019.01.044.

[5] N. Alamanis, "Influence of random soil strength properties on the earthquake vulnerability of slopes with embedded oil and natural gas pipelines," *Energy Systems*, 2020, doi: 10.1007/s12667-020-00394-9.

[6] N. Alamanis and P. Dakoulas, "Effect of spatial variability of soil properties on the stability and permanent seismic displacements of highway slopes," 2019.

[7] N. Alamanis and P. Dakoulas, "Effects of spatial variability of soil properties and ground motion characteristics on permanent displacements of slopes," *Soil Dynamics and Earthquake Engineering*, vol. 161, no. June, p. 107386, 2022, doi:

10.1016/j.soildyn.2022.107386.

[8] T. Chrysanidis, V. Panoskaltsis, and I. Tegos, "Parametrical cost analysis of an ultra high-rise building: Detailed design," *International Journal of Applied Engineering Research*, vol. 11, no. 18, pp. 9644–9650, 2016.

[9] T. Chrysanidis and I. Tegos, "Cost Comparison and Parametrical Investigation of the R/C Shear Wall Core of a Tall Building," *International Journal of Engineering Research and Technology*, vol. 5, no. 09, pp. 592–595, 2016.

[10] T. Chrysanidis and M. Stergiou, "Cost study of construction of a 10-storey building in different seismic zones according to modern seismic codes," in *Lecture Notes in Civil Engineering (2022), Proceedings of the 4th International Conference on Civil Engineering and Architecture (ICCEA 2021)*, 2021, pp. 85–94. doi: https://doi.org/10.1007/978-981-16-6932-3_8.

[11] T.-E. Makris and T. Chrysanidis, "Does the seismicity of the area have an impact on the construction cost of the load-bearing structure of R/C buildings?," in *Proceedings of the 8th ECCOMAS Thematic Conference on Computational Methods in Structural Dynamics and Earthquake Engineering (COMPDYN 2021)*, 2021, pp. 4535–4546. doi: https://doi.org/10.7712/120121.8805.19134.

[12] D. Parthiban *et al.*, "Role of industrial based precursors in the stabilization of weak soils with geopolymer – A review," *Case Studies in Construction Materials*, vol. 16, no. January, p. e00886, 2022, doi: 10.1016/j.cscm.2022.e00886.

[13] D. S. Vijayan and D. Parthiban, "Effect of Solid waste based stabilizing material for strengthening of Expansive soil- A review," *Environmental Technology and Innovation*, vol. 20, p. 101108, 2020, doi: 10.1016/j.eti.2020.101108.

[14] Ministry of Environment Planning and Public Works, "Greek Earthquake Resistant Design Code," Athens, Greece, 2003, p. . (In Greek).

[15] T. Chrysanidis, "Degree of Elongation of Maximum Code-Prescribed Reinforced Walls: Modes of Failure and Displacements of Lateral Buckling Phenomenon," *International Journal of Trend in Research and Development*, vol. 3, no. 4, pp. 435–440, 2016.

[16] P. Tselempi and T. Chrysanidis, "Differentiation of the construction cost of a fifteen-storey R/C building depending on the seismic hazard zone," in *Proceedings of the 8th ECCOMAS Thematic Conference on Computational Methods in Structural Dynamics and Earthquake Engineering (COMPDYN 2021)*, 2021, pp. 4520–4534. doi: https://doi.org/10.7712/120121.8804.19133.

[17] T. Chrysanidis, I. Tegos, and N. Alamanis, "Experimental Research on Improvement of the Ductility of R/C Seismic Walls Through Slip Prevention With the Use of Steel Rhs," *Ingegneria Sismica*, vol. 39, no. 1, pp. 1–29, 2022.

[18] T. Chrysanidis, D. Mousama, E. Tzatzo, N. Alamanis, and D. Zachos, "Study of the Effect of a Seismic Zone to the Construction Cost of a Five-Story Reinforced Concrete Building," *Sustainability (Switzerland)*, vol. 14, no. 16, 2022, doi: 10.3390/su141610076.

[19] T. Chrysanidis, "The effect of longitudinal reinforcement ratio on the lateral buckling behavior of R/C walls modelled using prism elements," *Journal of Building Engineering*, vol. 42, no. 102456, 2021, doi: 10.1016/j.jobe.2021.102456.

[20] T. Chrysanidis, “A Case of Lateral Buckling Under Seismic Action Using a Prism Column Specimen,” *Structural Engineering International*, 2021, doi: 10.1080/10168664.2021.2003741.

[21] T. Chrysanidis and I. Tegos, “Axial and transverse strengthening of R/C circular columns: Conventional and new type of steel and hybrid jackets using high-strength mortar,” *Journal of Building Engineering*, vol. 30, no. January, p. 101236, 2020, doi: 10.1016/j.jobe.2020.101236.

[22] T. Chrysanidis, “Evaluation of Out-of-Plane Response of R/C Structural Wall Boundary Edges Detailed with Maximum Code-Prescribed Longitudinal Reinforcement Ratio,” *International Journal of Concrete Structures and Materials*, vol. 14, no. 1. 2020. doi: 10.1186/s40069-019-0378-4.

[23] International Conference of Building Officials, “Uniform Building Code – Volume 2: Structural Engineering Design Provisions,” Whittier, California, USA, 1997.

[24] European Committee for Standardization, “EN 1998-1:2004, Eurocode 8: Design of structures for earthquake resistance - Part 1: General rules, seismic actions and rules for buildings,” Brussels, Belgium, 2004.

[25] C. Anagnostopoulos, T. Chrysanidis, and M. Anagnostopoulou, “Experimental data of cement grouting in coarse soils with different superplasticisers,” *Data in Brief*, vol. 30, p. 105612, 2020, doi: 10.1016/j.dib.2020.105612.

[26] European Committee for Standardization, “EN 1992-1-1:2004, Eurocode 2: Design of concrete structures - Part 1-1: General rules and rules for buildings,” Brussels, Belgium, 2004.

[27] T. Chrysanidis and I. Tegos, “Size of seismic tensile strain and its influence on the displacements due to transverse buckling of ultra-highly reinforced structural walls,” *ARPN Journal of Engineering and Applied Sciences*, vol. 11, no. 23, pp. 13884–13890, 2016.

[28] T. Chrysanidis and V. Panoskaltsis, “Experimental investigation on cracking behavior of reinforced concrete tension ties,” *Case Studies in Construction Materials*, vol. 16, no. June 2022, p. e00810, 2022, doi: 10.1016/j.cscm.2021.e00810.

[29] T. Chrysanidis and V. Panoskaltsis, “Analytical investigation of the tensile experiments to prisms with varying longitudinal ratio for studying the lateral buckling of R/C walls,” in *Proceedings of the 8th ECCOMAS Thematic Conference on Computational Methods in Structural Dynamics and Earthquake Engineering (COMPDYN 2021)*, 2021, pp. 2730–2743. doi: https://doi.org/10.7712/120121.8670.18669.

[30] T. Chrysanidis and V. Panoskaltsis, “Numerical study of the tensile experiments modelling the elongation degree of highly-reinforced extreme edges of seismic walls for studying the transverse buckling phenomenon,” in *Lecture Notes in Civil Engineering (2022), Proceedings of the 4th International Conference on Civil Engineering and Architecture (ICCEA 2021)*, 2021, pp. 119–130. doi: https://doi.org/10.1007/978-981-16-6932-3_11.

[31] T. Chrysanidis and V. Panoskaltsis, “Analytical investigation of the tensile experiments modeling the elongation degree of R/C walls for studying the lateral buckling phenomenon,” in *Proceedings of the 8th ECCOMAS Thematic Conference on Computational Methods in Structural Dynamics and Earthquake Engineering*

(COMPDYN 2021), 2021, pp. 2718–2729. doi: https://doi.org/10.7712/120121.8669.18668.

[32] T. Chrysanidis and V. Panoskaltsis, "Does the degree of tensile strain have an impact on the cracking behavior of vertical structural elements?," in *IOP Conference Series: Materials Science and Engineering, 2020 5th International Conference on Civil Engineering and Materials Science (ICCEMS 2020)*, 2020, vol. 897. doi: 10.1088/1757-899X/897/1/012004.

[33] T. Chrysanidis and V. Panoskaltsis, "Experimental investigation of the influence of tensile strain on the cracking of R/C vertical structural elements," in *Proceedings of the XI International Conference on Structural Dynamics (EURODYN 2020)*, 2020, pp. 3174–3185. doi: 10.47964/1120.9259.18582.

[34] T. Chrysanidis and V. Panoskaltsis, "Analytical study on the effect of extreme seismic strains on the transverse buckling of ultra- reinforced seismic walls and their environmental design," in *IOP Conference Series: Earth and Environmental Science, 2nd International Conference on Environmental Design (ICED 2021)*, 2021, p. 899. doi: 10.1088/1755-1315/899/1/012033.