INFLUENCE OF SOIL TYPES AND IMPORTANCE FACTORS ON THE SEISMIC RESPONSE OF RC BUILDINGS

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Approval sheet of the Thesis

This is to certify that we have read this thesis entitled "Influence of Soil Types and Importance Factors on the Seismic Response of RC Buildings" and that in our opinion it is fully adequate, in scope and quality, as a thesis for the degree of Master of Science.

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I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

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ABSTRACT

INFLUENCE OF SOIL TYPES AND IMPORTANCE FACTORS ON THE SEISMIC RESPONSE OF RC BUILDINGS

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Experiences from previous earthquakes have shown that level of structural damages depends on soil characteristics where the structure is built on. Also, changing functioning and occupancy of the building after construction increases the scale of these damages. This study aims to investigate the effects of soil types B, C, and D and importance classes II, III and IV, given in the Eurocode 8, on seismic response of reinforced-concrete dual-framed structures evaluated by using linear static analysis. For this purpose, analysis and design of low and mid-rise buildings are considered. The analysis is performed with the equivalent lateral force procedure using Tekla Structural Designer software package. Combinations on analysis and design for different types of soils and different importance factors are done on a 4-storey dual-framed and a 7-storey dual-framed structures, representing low and mid-rise buildings respectively. Results are compared considering the required total amount of reinforcement for each building alternative. It is quite clear that the demand for reinforcement of buildings built on soil type D is much higher than those in soil types C and B. Also the demand for reinforcement is much increased for buildings in importance class IV compared to those in Importance class III and II. The increase in reinforcement demand from a building type having Importance class II with soil type B to a building type having Importance class IV with soil type D is 109.8 % for 4-storeys and 134.96 % for the 7-storeys. Comparisons in cost of construction carried out taking in consideration demands for reinforcement of each alternative buildings, show an increase of 39 % for 4 storeys, and 47 % for 7-storeys, from building designed for II-B to building designed for IV-D.

Keywords: *reinforced-concrete buildings, soil classifications, importance factors, seismic behavior, cost*

ABSTRAKT

NDIKIMI I TIPEVE TE TRUALLIT DHE FAKTOREVE TE RENDESISE NE PERFORMANCEN SIZMIKE TE NDERTESAVE BETON-ARME

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Përvojat nga tërmetet e mëparshme kanë treguar se niveli i dëmeve strukturore varet nga karakteristikat e dherave ku ndërtohet struktura. Gjithashtu, ndryshimi i funksionimit dhe banimit të ndërtesës pas ndërtimit rrit shkallën e këtyre dëmtimeve. Ky studim synon të investigojë efektet e tipeve te truallit B, C dhe D, dhe klasat e rëndësisë II, III dhe IV, të dhëna në Eurokodin 8, në performancen sizmike të strukturave dual-rame të betonit të armuar duke përdorur analizën statike lineare. Për këtë qëllim janë konsideruar analiza dhe projektimi i ndërtesave të ulëta dhe të mesme. Analiza kryhet me procedurën ekuivalente të forcës anësore duke përdorur programin kompjuterik Tekla Struktural Designer. Kombinime në analizën dhe projektimin ne llojet e ndryshme të truallit dhe faktorët e rëndësisë janë bërë në strukturat dual-rame 4-katëshe dhe 7-katëshe, që përfaqësojnë respektivisht ndërtesa të ulëta dhe të mesme. Rezultatet janë konsideruar duke marrë parasysh sasinë e nevojshme totale të armaturës për secilën alternativë të ndërtesës. Është mjaft e qartë se kërkesa për përforcim në armim të ndërtesave të ndërtuara në llojin e truallit D është shumë më e lartë se ato në truallin C dhe B. Gjithashtu kërkesa për armaturë është shumë më e lartë për ndërtesat me rëndësi të klasës IV krahasuar me ato të Rëndësisë së klasës III dhe II . Rritja e kërkesës për përforcim në armim nga një tip ndërtese që ka Klasën e Rëndësisë II me llojin e truallit B në një tip ndërtese që ka Klasën e Rëndësisë IV me llojin e truallit D është 109.8% për ndërtesat 4-katëshe dhe 134.96% për ato 7-katëshe. Krahasimet në koston e ndërtimit të kryera duke marrë në konsideratë kërkesat për përforcimin në armim të secilës ndërtesë, tregojnë një rritje prej 39% për ndërtesat 4-katëshe dhe 47% për ato 7-katëshe, nga ndërtesa te projektuara per II-B në ndërtesa te projektuara për IV-D.

Fjalët kyçe: *beton-arme, tipe të truallit, faktori i rëndësisë, performance sizmike, kosto*

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CHAPTER 1

INTRODUCTION

1.1 General

From the November 2019 earthquake in Albania we have seen that such natural events have a huge impact to human beings in terms of their life safety and costs on properties. The level of damage that happens to reinforced-concrete buildings during an earthquake depends on several factors such as the soil type where the structure sits in, the quality of materials that the structure is made of, the structural system and the structural importance which the structure is composed of, the degree of seismicity in the area where the structure is built in, the mass of the building, non-structural elements, etc. However, during the design phase of the buildings, most of the above factors are not taken in full consideration so that the construction cost can remain to a minimum. But, in the occurrence of earthquakes, the effect of such "savings", is of totally opposite impact for the economy of a country, as it paralizes normal growth.

1.2 Objective

In this thesis, the analysis of the influence of soil types and importance factors in terms of EUROCODE 8 [1] are investigated on the seismic response of a low and mid-rise dual-framed structure. The main objective is to investigate and compare how the reinforcement amount required by the structure varies for different soil types and different importance classes. Also, comparisons between Ductility Class Medium and Ductility Class High structures are done.

The impact of the construction costs on the buildings is estimated by considering the weights of reinforcement, as other materials such as concrete and shuttering remain unchanged for all structure types.

1.3 Scope

To achieve the main objectives, we need to model and design structures with different seismic design alternatives taking into consideration different soil types and importance factors. The software program used to generate the calculations for each building type will be Tekla Structural Program [2]. Two different types of buildings are modeled, based on the height criteria: a 4-storey high building and a 7-storey high one. These heights are considered due to most common found constructed buildings. To the software program are assigned the dead and live loads that act on the structure. After that are determined all the parameters including soil types, importance class, reference peak ground acceleration and behavior factor. The combination of loads for the static and seismic analysis are generated by the program automatically. An analysis and design using equivalent lateral force method is implemented. The amount of reinforcement for each solution is obtained which is used to make a comparative table in the impact of the cost.

1.4 Organization of the thesis

This thesis is divided in 5 chapters. The organization is done as follows:

In Chapter 1, it is described the problem statement, thesis objective and scope of works.

Chapter 2 includes the literature review in the published papers and other researches done relative to this thesis topic.

Chapter 3 consists of the methodology followed in this study. It provides information on the characteristics of the buildings, the software program used for modeling, and the analysis procedure followed to evaluate the data.

Chapter 4 gives a comparison of results, regarding the total displacement and the adopted reinforcement of each model of the buildings. Additionally, a cost analysis is carried out and compared between the models of the buildings.

Chapter 5 contains conclusions extracted from the received results.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

When we build a structure we expect that it will be able to resist the loads for which it is designed, and to be able to do it through its service life with the best possible efficiency.

The structures have to be able to resist their own loads and a variety of external loads with different backgrounds. These loads may be due to the use of the building, non-structural elements, or loads created by the environment, such as the lateral loads of earthquake, snow or wind. Factors that influence the design decisions include the anticipated use of the structure and the type of soil it will be built upon. So, during the design phase, loads and other parameters involved must be taken into account in order to get the best structural design possible. Cost is another important factor when selecting an alternative of the structure to build upon. The designer ought to decrease costs as much as possible but without interfering with the strength of the structure. It is of high interest to know how the different soil types and occupancy of buildings influence in their construction costs.

H. Ince, E. Toy, and M. Tolon (2018) have evaluated the influence of local site effects on the seismic response of buildings in terms of 2018 Turkish Seicmic Design Code provisions and have analyzed their impact on the cost of the construction of buildings. In their study, a two-storey reinforced concrete-framed (residential house) was used as an example. According to their results, the cost of the structure built of soil D is more expensive than the cost of the one built on the soil class A. The cost difference was around 22.57 % between soil classes A and D. [3]

M. Mubarak et al. (2019) investigate the potential cost changes of the reinforced concrete (RC) beam and column elements as an implication of variations in seismic load received by a building constructed in different seismic areas. This study was applied to a prototype of the two-storey building. The structure analysis performed with dynamic analysis by varying seismic design categories based on eight seismic zones in the observed area. The utilization of a building prototype was applied to three indices of seismic importance factor to represent the building occupancy category. The results of the study explaining the increase in the total cost of the two RC elements are 0.68%, 1.70%, and 1.54%, respectively, for the seismic importance factor indices of 1.00, 1.25, and 1.50. The variations of the costs due to the factor of seismic load and building occupancy categories indicate that both factors need to be considered in the cost estimation process of buildings. In their research the Indonesian National Standard (SNI) was used. [4]

M. Z. Ramli, A. Adnan, M. A. A. Kadir, M. N. A Alel (2017) in their study estimated the requirement of reinforcement between non-seismic (Eurocode 2, EC2) and seismic design by using EC8 with different ductility class. Three zones with different Peak Ground Acceleration (PGA) value has been chosen, namely Kedah or Johor (low ductility 0.06g), Penang or Kuala Lumpur (medium ductility 0.08g) and Lahad Datu (medium ductility 0.14g). The results shows that the quantity of reinforcement requirement for beams had increased between 7% to 32.4%, while columns increased between 28% to 420.3% for different ductility class. In addition, the cost of construction is becoming more expensive because the cost of reinforcement requirement is increasing with the increase of ductility class from low to Medium. [5]

B. Yon, M. E. Oncu, and Y. Calayır (2015) in their paper investigated the effect of seismic zones and local soil conditions given in Turkish Seismic Code on the nonlinear response of reinforced concrete buildings, evaluated using the distributed plastic hinge approach. A RC frame building was selected for numerical analysis, and the nonlinear dynamic time history analyses were performed. For the purposes of analyses, selected earthquake records were adjusted to become compatible with the design response spectrum, taking into account seismic zones and local soil conditions. Interstorey drifts, cross-sectional forces at the base of the building, and energy dissipation for selected hinges, were compared. The results showed that the nonlinear response of reinforced concrete buildings is considerably affected by seismic zones and local soil conditions. Consequently, seismic zones should be considered together with local soil conditions when designing new reinforced concrete buildings or evaluating existing buildings. [6]

M. Rakočević, V. Bojović, and I. Mrdak in their paper presented the seismic analysis of a structure of six-storey RC frame, founded on different soil types. The seismic analysis was performed in accordance with European regulations and still valid ex-Yugoslavian code PIOVSP'81. In accordance with the performed analysis it was concluded that seismic performance of the structure founded on the soil types B and C, was similar (for the structure on soil type C seismic forces were 15% higher than for the structure on the soil type B). However, when the structure was founded on the soil type D, seismic forces were 80% higher than for the soil type B. [7]

I. Oz, S. M. Senel, M. Palanci and A. Kalkan (2020) in their study investigate the effects of soil-structure interaction on the seismic performance of buildings. 40 existing buildings from Turkey were selected and nonlinear models were constructed by considering fixed-base and stiff, moderate and soft soil conditions. Buildings designed before and after Turkish Earthquake code of 1998 were grouped as old and new buildings, respectively. Different soil conditions classified according to shear wave velocities were reflected by using substructure method. Inelastic deformation demands were obtained by using nonlinear time history analysis and 20 real acceleration records selected from major earthquakes were used. The results have shown that soil-structure interaction, especially in soft soil cases, significantly affects the seismic response of old buildings. The most significant increase in drift demands occurred in first stories and the results corresponding to fixed-base, stiff and moderate cases are closer to each other with respect to soft soil cases. Distribution of results has indicated that effect of soil structure interaction on the seismic performance of new buildings is limited with respect to old buildings. [8]

Ž. Nikolić, N. Živaljić, and H. Smoljanović (2017) in their paper analysed two RC buildings, one with a wall structural system and the other with a frame system, previously designed for DCM and DCH ductility, by using incremental dynamic analysis in order to study differences in the behaviour of structures between these ductility classes, especially the failure mechanism and ultimate collapse acceleration. Despite the fact that a higher behaviour factor of DCH structures influences lower seismic resistance, in comparison to DCM structures, a strict application of the design and detailing rules of Eurocode 8 in analysed examples caused that the seismic resistance of both frames does not significantly differ. [9]

V. Thiruvengadam and Thangmuansang Guite (2017) in their study are considering twelve to twenty storeyed reinforced concrete buildings with moment resisting frames in combination with shear walls with column grids commonly adopted for office occupancy. All buildings are designed for the design peak ground accelerations of 0.05g to 0.18g applicable for low to high seismic zones as per the Indian seismic code. The study has contributed towards the quantity and cost modelling aspects of reinforced concrete structural systems designed for different levels of seismic effects and quantifies the cost premium for incorporating the seismic safety. It has been brought out that such extra cost implications are not likely to exceed about 10 to 16% for the very severe seismic zone for the building systems studied. [10]

M. Türkmen, H. Tekeli and A. Kuyucular (2016) in their study have investigated cost variations of structural systems of RC apartment buildings in Turkey. 4-8 storey residential buildings are designed. Cost of RC structural system of each design case is calculated due to formal Turkish Unit Prices. Buildings, being regular and irregular in plan, and built on good soil type A through to poor soil type D considering most severe seismic attacks, are all dealt to compare their costs with each other. Quite remarkable extra cost (up to %20) of RC structural system is needed for only irregular and high buildings. [11]

CHAPTER 3

METHODOLOGY

3.1 Material Properties

The structural behavior of reinforced concrete structure depends upon the individual mechanical characteristics of RC constituents. Due to such reason, it is of high importance to determine the individual physical and mechanical parameters of concrete and reinforcing steel.

3.1.1. Concrete

Concrete is an artificial material gained from the mixture of determined quantities of cement, aggregates and water. Cement and water create a paste that surrounds the aggregates, constituting a heterogeneous material. Sometimes, substances called admixtures and additions are added to modify some properties of the concrete. There are many types of concrete available, created by varying the proportions of the main ingredients. In this way or by substitution for the cementitious and aggregate phases, the finished product can be tailored to its application with varying strength, durability, workability, density, or chemical and thermal resistance properties.

Some advantages of concrete are:

- It can be manufactured to the desired strength with relatively low cost.
- The durability is very high.
- It can be cast to any desired shape.
- The maintenance cost is almost negligible.
- Concrete makes a building fire-safe due to its noncombustible nature.

- It can withstand high temperatures.
- It is resistant to wind and water.

Some disadvantages of concrete are:

- Tensile strength is relatively low.
- It is less ductile.
- The weight is high compared to its strength.
- It may contain soluble salts that cause efflorescence.

Mechanical and physical properties of concrete are defined in Eurocode 2 [12] and EN 206 [13].

Figure 1. Concrete

Table 1. Exposure classes for minimum strength of concrete [14]

	Exposure classes																	
	No risk of corrosion or attack	Carbonation-induced corrosion				Chloride-induced corrosion						Freeze/thaw attack				Aggressive chemical environment		
						Sea Water			Chloride other than from sea									
	X0	XC1	XC2	XC3	XC4	XS1	XS2	XS3	XD1	XD2	XD3	XF1	XF2	XF3	XF4	XA1	XA2	XA3
Minimum w/c	-	0,65	0,6	0,55	0,5	0,5	0,45	0,45	0,55	0,55	0,45	0,55	0,55	0,5	0,45	0,55	0,5	0,45
Minimum strength class	C12/15	C20/25	C25/30	C30/37	C30/37	C30/37	C35/45	C35/45	C30/37	C30/37	C35/45	C30/37	C25/30	C30/37	C30/37	C30/37	C30/37	C35/45
Minimum cement content (kg/m3)	-	260	280	280	300	300	320	340	300	300	320	300	300	320	340	300	320	360
Minimum air content (%)	-	-	-	-	-	-	-	-	-	-	-	-	4,0	4,0	4,0	-	-	-
Other requirements													Aggregate in accordance with EN 12620 with sufficient freeze/thaw resistance			Sulphate resisting cement		

Table 2. Stress and deformation characteristics for concrete [12]

	Strength classes for concrete													
f_{ck} (MPa)	12	16	20	25	30	35	40	45	50	55	60	70	80	90
$f_{ck,cube}$ (MPa)	15	20	25	30	37	45	50	55	60	67	75	85	95	105
f_{cm} (MPa)	20	24	28	33	38	43	48	53	58	63	68	78	88	98
f_{ctm} (MPa)	1,6	1,9	2,2	2,6	2,9	3,2	3,5	3,8	4,1	4,2	4,4	4,6	4,8	5,0
$f_{ctk,0,05}$ (MPa)	1,1	1,3	1,5	1,8	2,0	2,2	2,5	2,7	2,9	3,0	3,1	3,2	3,4	3,5
$f_{ctk,0,95}$ (MPa)	2,0	2,5	2,9	3,3	3,8	4,2	4,6	4,9	5,3	5,5	5,7	6,0	6,3	6,6
E_{cm} (GPa)	27	29	30	31	32	34	35	36	37	38	39	41	42	44
ε_{c1} (‰)	1,8	1,9	2,0	2,1	2,2	2,25	2,3	2,4	2,45	2,5	2,6	2,7	2,8	2,8
ε_{cu1} (‰)	3,5									3,2	3,0	2,8	2,8	2,8
ε_{c2} (‰)	2,0									2,2	2,3	2,4	2, 5	2,6
ε_{cu2} (‰)	3,5									3,1	2,9	2,7	2,6	2,6
n	2,0									1,75	1,6	1,45	1,4	1,4
ε_{c3} (‰)	1,75									1,8	1,9	2,0	2,2	2,3
ε_{cu3} (‰)	3,5									3,1	2,9	2,7	2,6	2,6

3.1.2 Steel reinforcing rebar

Steel is an element that provides tensile strength to concrete. According to Eurocode 2 [12], passive reinforcement is achieved by using, mainly, two types of bars: ribbed weldable steel bars and ribbed weldable steel supplied in coils. The most common ribbed bars in the steel market are of nominal diameters of 8, 10, 12, 14, 16, 18, 20, 22, 25 and 32 mm.

Some advantages of steel reinforcing rebar are:

- Steel has high modulus of Elasticity i.e. 200GPa (200 x 10^9 N/m²). This helps the steel to stretch in tension (upto 200GPa) without breaking and regain its shape on removal of load.
- Ductility of steel is high.
- Steel is resistant to rough conditions during transport, storage, and placing on construction site. If minor damage happens, it does not significantly affect its performance.
- It can be recycled.

The types of steel reinforcement are defined in the table below:

Table 3. Steel grades and mechanical properties of steel reinforcement in European Countries

Min. R_e (MPa)	Steel Grade	European country	R_e MPa	R_m MPa	A_{gt} %	A %	R_m/R_e -
500	A 500 NR SD	Portugal	500	≥ 575, ≤ 675	8.0	-	≥ 1.15, <1.35
	B 500 SD	Spain	500	575	9.0	≥ 20	≥ 1.15, <1.35
	B 500 A	Great Britain	500	525	2.5	-	1.05
	B 500 B		500	540	5.0	-	1.08
	B 500 C		500	≥ 575, ≤ 675	7.5	-	≥ 1.15, <1.35
	B 500 A	Germany	500	525	2.5	-	1.05
	B 500 B		500	540	5.0	-	≥ 1.08, <1.35
	B 500 A	Greece	≥ 500	≥ 525	≥ 2.5	-	1.05
	B 500 C		≥ 500	≥ 575, ≤ 675	≥ 7.5	-	≥ 1.15, <1.35
	B 500 A	France	500	≥ 525	2.5	-	1.05
	B 500 B		500	≥ 540	5.0	-	1.08
	B 500 A	Bulgary	500	550	2.5	-	1.05
	B 500 B		500	550	5.0	-	1.08
	B 500 C		500	575	7.5	-	≥ 1.15, <1.35
450	B 450 B	France	450	≥ 486	5.0	-	1.08
	B 450 C		450	≥ 517.5, ≤ 607.5	7.5	-	≥ 1.15, <1.35
	B 450 A	Italy	450	540	≥ 2.5	-	≥ 1.05
	B 450 C		450	540	≥ 7.5	-	≥ 1.15, <1.35
400	A 400 NR SD	Portugal	400	≥ 460, ≤ 540	8.0	-	≥ 1.15, <1.35
	B 400 SD	Spain	400	480	8.0	≥ 16	≥ 1.15, <1.35

The most common used reinforcement rebar in Albania is B 500C type.

3.2 Procedures of design according to EUROCODE 2

3.2.1 Concrete cover and spacing of bars

The concrete cover on the reinforcement bars is put as it is described in EC2 section 4.4.1 [12], taking into consideration safe transmission of bond forces, durability and fire resistance of the elements.

It is very important to be identified ahead the environmental conditions and the corresponding exposure classes as decribed in Table 4.1 of EC2 [12], so that concrete cover is determined correctly.

The spacing of bars is designed according to section 8.2 of Eurocode 2 [12].

3.2.2 Column design

Columns are exposed to axial loads and biaxial bending moment. So, they must be designed to resist these loads. Furthermore, shear forces in the columns have to be taken in consideration as well, as they will be generated due to interaction of different elements.

Bending is analyzed taking into account the rules in section 6.1 of Eurocode 2 [12]. One of the most important point to consider is:

For reinforced concrete cross-sections subjected to a combination of bending moment and compression, it is necessary to assume the minimum eccentricity, eo = h/30 but not less than 20 mm where h is the depth of the section (EC2 6.1 - 4) [12].

As biaxial moment acts in the vertical element, the above rule has to be developed to both axes. Then, section 5.8.9 of Eurocode 2 [12] gets into consideration that behaviour defining the eccentricities from where the design will be done.

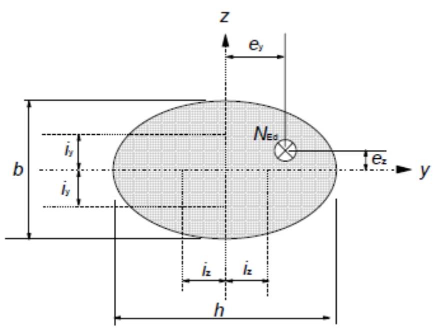


Figure 2. Definition of eccentricities e_y and e_x (European committee for standardization – 2004a)

The design reinforcement to deal bending moments in column is designed according to the rules in section 9.5 of EC2 [12] and they are as follow:
(2) The total amount of longitudinal reinforcement should not be less than $A_{s,min}$.

$$\boldsymbol{A_{s,min} = max\,\langle \frac{0.10\,N_{ed}}{f_{yd}}; 0.002\,A_c \rangle} \qquad \textit{(Equation 1)}$$

(3) The area of longitudinal reinforcement should not exceed $A_{s,max}$.
The recommended value is 0.04·Ac outside lap locations unless it can be shown that the integrity of concrete is not affected and that the full strength is achieved at ULS. This limit should be increased to 0.08·Ac at laps.

Shear reinforcement is present using links, loops or helical spiral as to deal with traversal forces, according to the rules of bent and disposition made in sections 8.3 and 8.7 of EC2. Verification for shear resistance follows procedure as defined in section 6.2.1 of Eurocode 2: $V_{Rd} = V_{Rd.s} + V_{ccd} + V_{td}$ (Equation 2)

Where:
$V_{Rd,c}$ is the design shear resistance of the member without shear reinforcement.
$V_{Rd,s}$ is the design value of the shear force which can be sustained by the yielding shear reinforcement.
$V_{Rd,max}$ is the design value of the maximum shear force which can be sustained by the member, limited by crushing of the compression struts.
V_{ccd} is the design value of the shear component of the force in the compression area, in the case of an inclined compression chord.
V_{td} is the design value of the shear component of the force in the tensile reinforcement, in the case of an inclined tensile chord.
Verifications according to the rules in section 6.2.3 of EC2 [12] have to be done for elements that do not need shear reinforcement. But, minimum shear reinforcement must be provided as ruled in section 9.2.2 of EC2 [12].
For elements requiring shear reinforcement, verifications according to the rules in section 6.2.3 of EC2 [12] have to be done to provide required shear reinforcement.

For this particular case, columns, some additional rules must be accomplished such as bar spacing and minimum diameter. These rules are in the section 9.5.3 of EC2 [12] and are as follows:

(1) The diameter of the transverse reinforcement (links, loops or helical spiral reinforcement) should not be less than 6 mm or one quarter of the maximum diameter of the longitudinal bars, whichever is the greater. The diameter of the wires of welded mesh fabric for transverse reinforcement should not be less than 5 mm.

(2) The transverse reinforcement should be anchored adequately.

(3) The spacing of the transverse reinforcement along the column should not exceed Scl,tmax which can be determined as the least of:

- 20 times the longitudinal reinforcement diameter
- The lesser dimension of the column
- 400 mm

(4) The maximum spacing required in (3) should be reduced by a factor 0.6:

(i) in sections within a distance equal to the larger dimension of the column cross-section above or below a beam or slab;

(ii) near lapped joints, if the maximum diameter of the longitudinal bars is greater than 14 mm. A minimum of 3 bars evenly placed in the lap length is required.

(5) Where the direction of the longitudinal bars changes, (e.g. at changes in column size), the spacing of transverse reinforcement should be calculated, taking account of the lateral forces involved. These effects may be ignored if the change of direction is less than or equal to 1 in 12.

(6) Every longitudinal bar or bundle of bars placed in a corner should be held by transverse reinforcement. No bar within a compression zone should be further than 150 mm from a restrained bar. [12]

3.2.3 Beam design

Beams are exposed to bending moments and shear forces due to their their composition in the building. Also for the beam, the design criterias follow the rules outlined in Eurocode 2 [12].

Bending is analyzed taking into account the rules in section 6.1 of Eurocode 2 [12]. When determing ultimate bending resistance of the beams, the following assumptions are made:

- Plane sections remain plane.

- The strain in bonded reinforcement or bonded prestressing tendons, whether in tension or in compression, is the same as that in the surrounding concrete.

- The tensile strength of the concrete is ignored.

- The stresses in the concrete in compression are derived from the design stress/strain relationship (EC2 3.1.7.) [12]

- The stresses in the reinforcing or prestressing steel are derived from the design curves in EC2 3.2 and 3.3 [12].

- The initial strain in prestressing tendons is taken into account when assessing the stresses in the tendons.

The design is done according to the ultimate limit states (ULS) configuration.

To decide the minimum and maximum longitudinal reinforcement the rules in section 9.2.1.1 of EC2 [12] are followed as below:

The area of longitudinal tension reinforcement should not be taken as less than $A_{s,min}$.

$$\boldsymbol{A_{s,min} = 0.26 \frac{f_{ctn}}{f_{yk}} b_t d} \quad \textit{but not less than} \quad 0.0013\, b_t\, d \qquad \textit{(Equation 3)}$$

Sections containing less reinforcement than As,min should be considered as unreinforced.

The cross-sectional area of tension or compression reinforcement should not exceed As,max outside lap locations. The recommended value is 0,04Ac.

Shear reinforcement rules as for the columns can be done for beams too since links are also used to afford shear stresses. Verification for shear resistance follows procedure as defined in section 6.2.1 of Eurocode 2 [12].

Verifications according to the rules in section 6.2.2 of EC2 [12] have to be done for elements that do not need shear reinforcement. But, minimum shear reinforcement must be provided as ruled out in section 9.2.2 of EC2 [12].

The minimum reinforcement per unit length $A_{sw,}$ can be calculated by enforcing the minimum value of the shear reinforcement ratio, given by expression:

$$\boldsymbol{\rho_w = \frac{A_{sw}}{s\ .\ b_{w\ .\ sin\alpha}}} \qquad \textit{(Equation 4)}$$

$$\boldsymbol{\rho_{w,min} = \frac{0.08\sqrt{f_{ck}}}{f_{yk}}} \qquad \textit{(Equation 5)}$$

Where:

p_w is the shear reinforcement ratio (p_w should not be less than $p_{w,min}$)

A_{sw} is the area of shear reinforcement within length s

s is the spacing of the shear reinforcement measured along the longitudinal axis of the member

b_w is the breadth of the web of the member

α is the angle between shear reinforcement and the longitudinal axis

For elements requiring shear reinforcement, verifications according to the rules in section 6.2.3 of EC2 have to be done to provide required shear reinforcement.

As ruled in section 9.2.2 of Eurocode 2 [12], the maximum space between shear reinforcement ought not exceed $S_{l,max}$

$$S_{l,max} = 0.75d(1+ \cot \alpha) \quad \textit{(Equation 6)}$$

3.2.4 Shearwall design

Shearwalls are structural elements where bending and shear forces occur. To design the walls it is needed to determine their reinforcement, longitudinal (vertical and horizontal) and transversal.

The rules for designing are done as per section 9.6 of Eurocode 2 [12], where the following specification is made:

(1) This clause refers to reinforced concrete walls with a length to thickness ratio of 4 or more and in which the reinforcement is taken into account in the strength analysis. The amount and proper detailing of reinforcement may be derived from a strut-and-tie model. For walls subjected predominantly to out-of-plane bending the rules for slabs apply.

The vertical reinforcement is computed following the rules in section 9.6.2 of EC2:

(1) The area of the vertical reinforcement should lie between $A_{s,vmin}$ and $A_{s,vmax}$.

The recommended values for both parameters are:

$$\boldsymbol{A_{s,min} = 0.002 * A_C} \quad \text{(Equation 7)}$$

$$\boldsymbol{A_{s,max} = 0.04 * A_c} \quad \textit{(Equation 8)}$$

The previous As,vmax value is applicable outside lap locations unless it can be shown that the concrete integrity is not affected and that the full strength is achieved at ULS. This limit may be doubled at laps.

(2) Where the minimum area of reinforcement, As,vmin, controls in design, half of this area should be located at each face.

(3) The distance between two adjacent vertical bars shall not exceed 3 times the wall thickness or 400 mm whichever is the lesser.

The horizontal reinforcement is computed following the rules in section 9.6.3 of EC2 [12]:

(1) Horizontal reinforcement running parallel to the faces of the wall (and to the free edges) should be provided at each surface. It should not be less than As,hmin.

The recommended value is either 25% of the vertical reinforcement or 0,001·Ac, whichever is greater.

(2) The spacing between two adjacent horizontal bars should not be greater than 400 mm.

At the end, the transverse reinforcement is calculated following the rules in section 9.6.4 of EC2 [12]:

(1) In any part of a wall where the total area of the vertical reinforcement in the two faces exceeds 0.02·Ac, transverse reinforcement in the form of links should be provided in accordance with the requirements for columns (EC2 9.5.3). The large dimension referred to in EC2 9.5.3-(4)-(i) [12] need not be taken greater than 4 x thickness of wall.

(2) Where the main reinforcement is placed nearest to the wall faces, transverse reinforcement should also be provided in the form of links with at least of 4 per m2 of wall area.

3.2.5 Solid Slab design

Slabs are exposed to bending moments and shear forces induced by other structural elements. Design rules for solid slabs are explained in section 9.3 of Eurocode 2 [12].

This section applies to one-way and two-way solid slabs for which b and l_{eff} are not less than 5h.

Flexural Reinforcement is covered in section 9.3.1 of EC2 [12].

(1) For the minimum and the maximum steel percentages in the main direction 9.2.1.1 (1) and (3) apply.

(2) Secondary transverse reinforcement of not less than 20% of the principal reinforcement should be provided in one-way slabs. In areas near supports transverse reinforcement to principal top bars is not necessary where there is no transverse bending moment.

(3) The spacing of bars should not exceed $S_{max,slabs}$.

$$S_{max,slabs} = 3\text{h} \leq 400 \text{ mm} \qquad \text{(Equation 9)}$$

Where h is the total depth of the slab.

(4) The rules given in EC2 9.2.1.3 (1) to (3), EC2 9.2.1.4 (1) to (3) and EC2 9.2.1.5 (1) to (2) [2] also apply but with a_l = d. [12]

Shear reinforcement is covered following section 9.3.2 of Eurocode 2 . The thickness of the slab is the most important factor to be considered in this case.

(1) A slab in which shear reinforcement is provided should have a depth of at least 200 mm.

(2) In detailing the shear reinforcement, the minimum value and definition of reinforcement ratio in EC2 9.2.2 apply, unless modified by the following.

In slabs, if $|V_{Ed}| \leq 1/3\ V_{Rd,max}$ (EC2 6.2) [2], the shear reinforcement may consist entirely of bent-up bars or of shear reinforcement assemblies [12].

3.3 Procedures of design according to EUROCODE 8

3.3.1 Response Spectrum

Eurocode 8 [1] is the standard that is used for design of structures for earthquake resistance. So, the elastic response spectrum is determined using Eurocode 8 [1]. Certain input data are required to Eurocode 8 in order to determine the response spectrum. These are:

1. Ground type.
2. Peak ground acceleration
3. Importance factor.
4. Damping correction factor.
5. Spectra type.
6. Behaviour factor (in linear methods of analysis)

3.3.1.1 Ground type

Ground, acting as a filter, changes the spectra of earthquake waves passing through it. The scale of this change depends on ground type. In the Eurocode 8 there are five different typical ground types (A, B, C, D,E) and 2 different special ground types (S1, S2) depending on their mechanical properties.

The sites are classified according to their value of average shear velocity, $v_{s,30}$, when this is available. If not, then the value of N_{SPT} is used. The average shear velocity is calculated according to the equation:

$$v_{s,30} = \frac{30}{\sum_{i=1,N}\frac{h_i}{v_i}} \qquad \textit{(Equation 10)}$$

where *h*i and *v*i denote the thickness (in metres) and shear-wave velocity (at a shear strain level of 10–5 or less) of the *i*-th formation or layer, in a total of *N*, existing in the top 30 m. For sites with ground conditions matching either one of the two special ground types *S*1 or *S*2, special studies for the definition of the seismic action are required. For these types, and particularly for *S*2, the possibility of soil failure under the seismic action shall be taken into account. [1]

Table 4. Ground types and their parameters [1]

Ground type	Description of stratigraphic profile	Parameters		
		$v_{s,30}$ (m/s)	N_{SPT} (blows/30cm)	c_u (kPa)
A	Rock or other rock-like geological formation, including at most 5 m of weaker material at the surface.	> 800	–	–
B	Deposits of very dense sand, gravel, or very stiff clay, at least several tens of metres in thickness, characterised by a gradual increase of mechanical properties with depth.	360 – 800	> 50	> 250
C	Deep deposits of dense or medium-dense sand, gravel or stiff clay with thickness from several tens to many hundreds of metres.	180 – 360	15 - 50	70 - 250
D	Deposits of loose-to-medium cohesionless soil (with or without some soft cohesive layers), or of predominantly soft-to-firm cohesive soil.	< 180	< 15	< 70
E	A soil profile consisting of a surface alluvium layer with v_s values of type C or D and thickness varying between about 5 m and 20 m, underlain by stiffer material with v_s > 800 m/s.			
S_1	Deposits consisting, or containing a layer at least 10 m thick, of soft clays/silts with a high plasticity index (PI > 40) and high water content	< 100 (indicative)	–	10 - 20
S_2	Deposits of liquefiable soils, of sensitive clays, or any other soil profile not included in types A – E or S_1			

3.3.1.2 Peak ground acceleration

The reference peak ground acceleration, chosen by the National Authorities for each seismic zone, corresponds to the reference return period T_{NCR} of the seismic action for the no-collapse requirement (or equivalently the reference probability of exceedance in 50 years, *P*NCR) chosen by the National Authorities.The hazard is described in terms of a single parameter, the value of the reference peak ground acceleration on type A ground, a_{gR}.. These values are available for different hazard zones in the National Annex, usually through a hazard map.

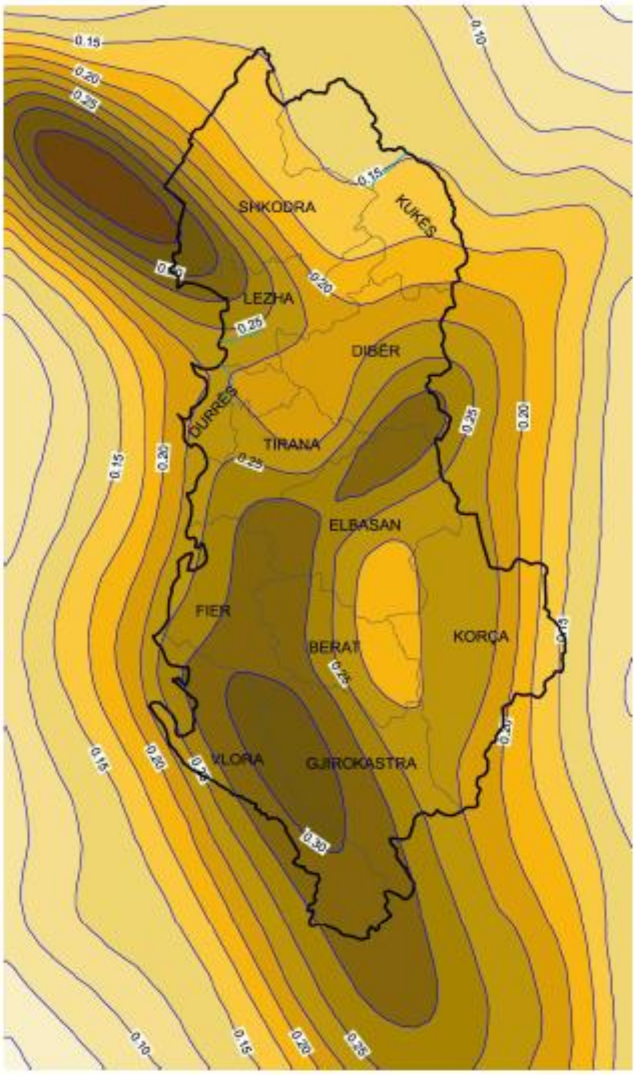


Figure 3. Map of Albania for reference peak ground acceleration on type A gound, a_{gR}, for a return period of T_R=475 years ***[18]***

3.3.1.3 Importance factor.

Buildings are classified in 4 importance classes, depending on the consequences of collapse for human life, on their importance for public safety and civil protection in the immediate post-earthquake period, and on the social and economic consequences of collapse. The importance γ_I is associated with seismic action to decrease or increase its value.

Table 5. Importance classes for buildings [1]

Importance class	Buildings
I	Buildings of minor importance for public safety, e.g. agricultural buildings, etc.
II	Ordinary buildings, not belonging in the other categories.
III	Buildings whose seismic resistance is of importance in view of the consequences associated with a collapse, e.g. schools, assembly halls, cultural institutions etc.
IV	Buildings whose integrity during earthquakes is of vital importance for civil protection, e.g. hospitals, fire stations, power plants, etc.

To take the design ground peak acceleration, the importance factor is multiplied with the previously determined peak ground acceleration.

$$a_g = \gamma_1 * a_{gR} \qquad \text{(Equation 11)}$$

3.3.1.4 Damping correction factor.

Eurocode 8 [1] by default puts a damping ratio of 5%, although the ratio depends on the structural type and materials used. The value of the damping correction factor η may be determined by the $\eta = \sqrt{10/(5+\xi)} \geq 0{,}55$ expression: For a 5% damping ratio, the correction factor is 1.

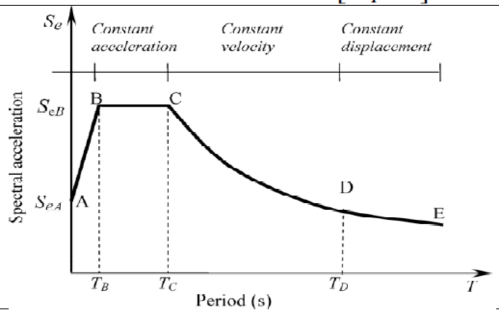
3.3.1.5 Spectra type.

In Eurocode 8 [1], there are considered two types of Spectra: Type 1 refers to the earthquake which has an expected Magnitude M_s bigger than 5.5 and Type 2 refers for a Magnitude $M_s \leq 5.5$.

The values of the periods T_B, T_C and T_D and of the soil factor *S* describing the shape of the elastic response spectrum depend upon the soil type.

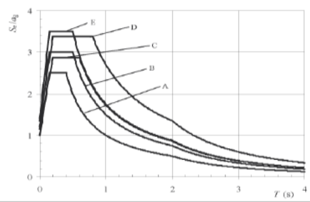
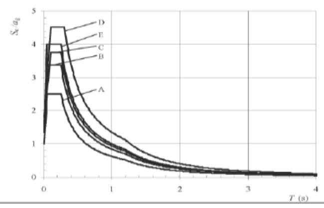
For the horizontal components of the seismic action, the elastic response spectrum *Se*(*T*) is defined by the following expressions:

Table 6. Horizontal Elastic Response Spectrum [1]

Period range	Horizontal elastic response
$0 \leq T \leq T_B$	$S_e(T) = a_g \cdot S \cdot \left[1 + \frac{T}{T_B} \cdot (\eta \cdot 2.5 - 1)\right]$
$T_B \leq T \leq T_C$	$S_e(T) = a_g \cdot S \cdot \eta \cdot 2.5$
$T_C \leq T \leq T_D$	$S_e(T) = a_g \cdot S \cdot \eta \cdot 2.5 \cdot \left[\frac{T_C}{T}\right]$
$T_D \leq T \leq 4s$	$S_e(T) = a_g \cdot S \cdot \eta \cdot 2.5 \cdot \left[\frac{T_C \cdot T_D}{T^2}\right]$
Shape	

All the above values and parameters are summarized for both spectra types as in the table below:

Table 7. Parameters for Horizontal Response [1]

Ground	Type spectra 1				Type spectra 2			
	S	T_B(s)	T_C(s)	T_D(s)	S	T_B(s)	T_C(s)	T_D(s)
A	1.00	0.15	0.40	2.00	1.00	0.05	0.25	1.20
B	1.20	0.15	0.50		1.35	0.05	0.25	
C	1.15	0.20	0.60		1.50	0.10	0.25	
D	1.35	0.20	0.80		1.80	0.10	0.30	
E	1.40	0.15	0.50		1.60	0.05	0.25	
Shape								

3.3.1.6 Behaviour factor.

The behaviour factor q, has to be derived for each direction as follows:

$$q = q_o \, k_w \geq 1{,}5 \qquad \text{(Equation 12)}$$

where

q_o is the basic value of the behaviour factor, dependent on the type of the structural system and on its regularity in elevation ;

k_w is the factor reflecting the prevailing failure mode in structural systems with walls

For buildings that are regular in elevation, the basic values of q_o for the various structural types are given in table below:

Table 8. Basic Value of the behavior factor, q_o, for systems regular in elevation ***[1]***

STRUCTURAL TYPE	DCM	DCH
Frame system, dual system, coupled wall system	$3,0\alpha_u/\alpha_1$	$4,5\alpha_u/\alpha_1$
Uncoupled wall system	3,0	$4,0\alpha_u/\alpha_1$
Torsionally flexible system	2,0	3,0
Inverted pendulum system	1,5	2,0

For buildings which are not regular in elevation, the value of *qo* should be reduced by 20%.

When the multiplication factor $\alpha u/\alpha_1$ has not been evaluated through an explicitcalculation, for buildings which are regular in plan the following approximate values of $\alpha u/\alpha_1$ may be used [3].

a) Frames or frame-equivalent dual systems.

− One-storey buildings: $\alpha u/\alpha 1=1,1$;

− multistorey, one-bay frames: $\alpha u/\alpha 1=1,2$;

− multistorey, multi-bay frames or frame-equivalent dual structures: $\alpha u/\alpha 1=1,3$.

b) Wall- or wall-equivalent dual systems.

− wall systems with only two uncoupled walls per horizontal direction: $\alpha u/\alpha 1=1,0$;

− other uncoupled wall systems: $\alpha u/\alpha 1=1,1$;

− wall-equivalent dual, or coupled wall systems: $\alpha u/\alpha 1=1,2$.

The factor k_w reflecting the prevailing failure mode in structural systems withwalls shall be taken as follows: [1]

$$k_w = \begin{cases} 1{,}00, \text{ for frame and frame} - \text{equivalent dual systems} \\ (1+\alpha_o)/3 \leq 1, \text{but not less than } 0{,}5, \text{ for wall, wall - equivalent and torsionally} \\ \text{flexible systems} \end{cases} \quad \text{(Equation 13)}$$

3.3.2 Methods of analysis

3.3.2.1 Lateral force method of analysis

Eurocode 8 [1] allows the use of lateral force method of analysis when in a building both of the following conditions are fullfiled:

a) they have fundamental periods of vibration T_1 in the two main directions which are smaller than the following values

$$T_1 \leq \begin{cases} 4 \cdot T_C \\ 2{,}0 \text{ s} \end{cases} \quad \text{(Equation 14)}$$

b) they meet the criteria for regularity in elevation.

In this method, the seismic base shear force F_b for each horizontal direction, and is the only earthquake load to be taken in consideration. The following expression is used:

$$F_b = S_d(T_1)\, m\, \lambda \quad \text{(Equation 15)}$$

where

$S_d(T_1)$ is the ordinate of the design spectrum (see **3.2.2.5**) at period $T1$;

T_1 is the fundamental period of vibration of the building for lateral motion in the direction considered;

m is the total mass of the building, above the foundation or above the top of a rigid basement.

λ is the correction factor, the value of which is equal to: λ = 0,85 if $T1 < 2$ TC and the building has more than two storeys, or λ = 1,0.

Also the base shear is split in forces F_I to be applied at each storeys, relative to their mass and height: $\boldsymbol{F_i = F_b \frac{z_i m_i}{\sum_j z_j m_j}}$ (Equation 16)

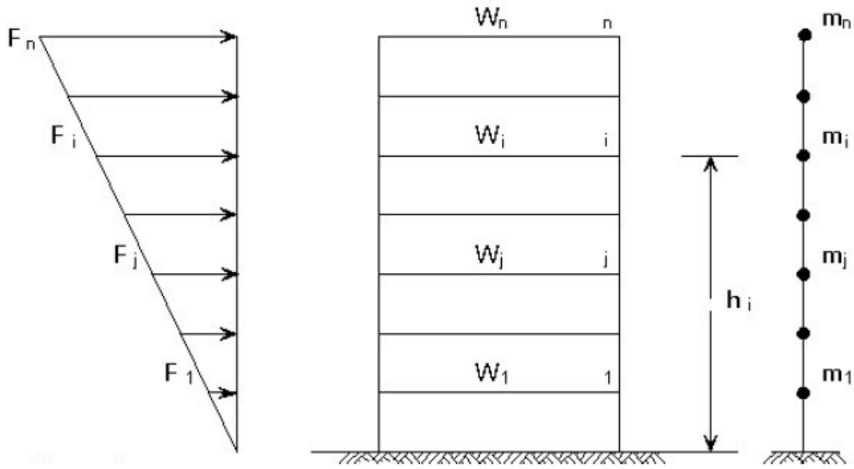


Figure 4. Lateral Force Method Loads Scheme [3]

These forces are static equivalent forces representing the seismic action.

Eurocode 8 [1] gives three different methods for the determination of the fundamental period of vibration T_1:

a) Method of structural dynamic (Rayleigh formula)

$$\boldsymbol{T_1 = 2\pi \sqrt{\frac{\sum m_i \delta_i^2}{\sum F_i \delta_i}}}$$ (Equation 17)

For buildings with heights of up to 40 m the value of T_1, may be approximated by the following formula: $T_1 = C_t \cdot H^{3/4}$ (Equation 18)

Where

Ct is 0,085 for moment resistant space steel frames, 0,075 for moment resistant space concrete frames and for eccentrically braced steel frames and 0,050 for all other structures;

H is the height of the building, in m, from the foundation or from the top of a rigid basement.

A general expression: $\boldsymbol{T_1 = 2 * \sqrt{d}}$ (Equation 19)

Where

d is the lateral elastic displacement of the top of the building, in m, due to the gravity loads applied in the horizontal direction.

In this method, torsional effects have to be taken into account by multiplying the action effects in each load resisting element by a factor δ

$$\boldsymbol{\delta = 1 + 0.6\ \frac{x}{L_e}}$$ (Equation 20)

where

x is the distance of the element under consideration from the centre of mass of the building in plan, measured perpendicularly to the direction of the seismic action considered;

L_e is the distance between the two outermost lateral load resisting elements, measured perpendicularly to the direction of the seismic action considered. [1]

3.3.2.2 Modal response spectrum analysis

In Eurocode 8 [1] following this method of analysis needs the response of all modes of vibration of strucutres contributing significantly to be determined and taken into consideration. These requirements may be deemed satisfied if either of the following can be demonstrated:

– the sum of the effective modal masses for the modes taken into account amounts toat least 90% of the total mass of the structure;

– all modes with effective modal masses greater than 5% of the total mass are taken into account.

For each mode of vibration, the intensity of the seismic action comes from the reference design response spectrum. The spectrum reduced by the behaviour factor q, which takes in consideration the ability of the structure to dissipate energy within the inelastic range. The spectrum reduced by the behaviour factor is used in linear analysis, as a simplified but reliable method of considering the inelastic response of the structure, but still be able to use an elastic model.

Table 9. Horizontal and vertical design spectrum [1]

Period range	Horizontal design response	Vertical design response
$0 \leq T \leq T_B$	$S_d(T) = a_g \cdot S \cdot \left[\frac{2}{3} + \frac{T}{T_B} \cdot \left(\frac{\eta \cdot 2.5}{q} - 1\right)\right]$	$S_{ved}(T) = \frac{S_{ve}(T)}{q}$ q-factor up to 1.5 generally adopted according to EN 1998-1 3.2.2.5(5)
$T_B \leq T \leq T_C$	$S_d(T) = \frac{S_e(T)}{q}$	
$T_C \leq T \leq T_D$	$S_d(T) = \frac{S_e(T)}{q};\ \geq \beta \cdot a_g$	
$T_D \leq T \leq 4s$		

The spectral displacement is calculated from spectral acceleration using: $S_{De}(T) = S_e(T) * (T/2\pi)^2$ (Equation 21)

For each mode of vibration, the design spectral displacement is calculated using design spectrum instead of elastic. Then, it is multiplied by eigenvector of the mode and its participation factor to get a vector with the displacements of all degrees of freedom (nodes) considered in the analysis due to each mode of vibration, as equation below shows:

$$(\boldsymbol{U_n}) = \boldsymbol{S_{Db}}(\boldsymbol{T_n}) * \left(\frac{\boldsymbol{T_n}}{\boldsymbol{2\pi}}\right)^{\boldsymbol{2}} * \boldsymbol{\Gamma_n} * \{\boldsymbol{\phi_n}\} \quad \text{(Equation 22)}$$

$$\boldsymbol{\Gamma_n} = \frac{\sum_l \boldsymbol{\phi_{i,n} m_i}}{\sum_i \boldsymbol{\phi_{i,n}^2 m_i}} \quad \text{(Equation 23)}$$

Where T_n is the period of mode of vibration n; Γ_n is the participation factor of mode n, $\{\phi_n\}$ is the vector containing the shape of mode of vibration n, normalized to mass matrix; $\phi_{l,n}$ is component i of vector $\{\phi_n\}$ and m_i is the mass of degree of freedom i.

From this modal nodal displacements vector, modal effects are computed by using the elastic model of the structure. The results are internal forces, moments, stresses, etc. These modal effects are combined between them. Because of the uncertainty of the combination of each mode's peak response value, Eurocode proposes the use of the SRSS rule (square root of the sum of squares):

$$\boldsymbol{E_E} = \sqrt{\sum_i \boldsymbol{E_{Ei}^2}} \qquad \text{(Equation 24)}$$

where
E_E is the seismic action effect under consideration (force, displacement, etc.);

E_{Ei} is the value of this seismic action effect due to the vibration mode *i*. [1]

3.4 Details of the models

The building models used for this study are one of a four-storey RC dual-framed structure and a seven-storey RC dual-framed structure. The floor plane is same for both of them. Building is in rectangular shape. In the X-direction the distance is 33.3 m, whereas in the Y-direction is 22.75 m. The floor area of a level is 664 m^2. The storey height is constant along the height of the building and it amounts 3.30 m per storey. The total building height of the four-storey building is 13.20 m and the height of seven-storey one is 23.10 m. The dimensions of structural elements are given in the floor plan. For the storey building, foundation is 70 cm thick and for the 7-storey one,foundation is 100 cm.

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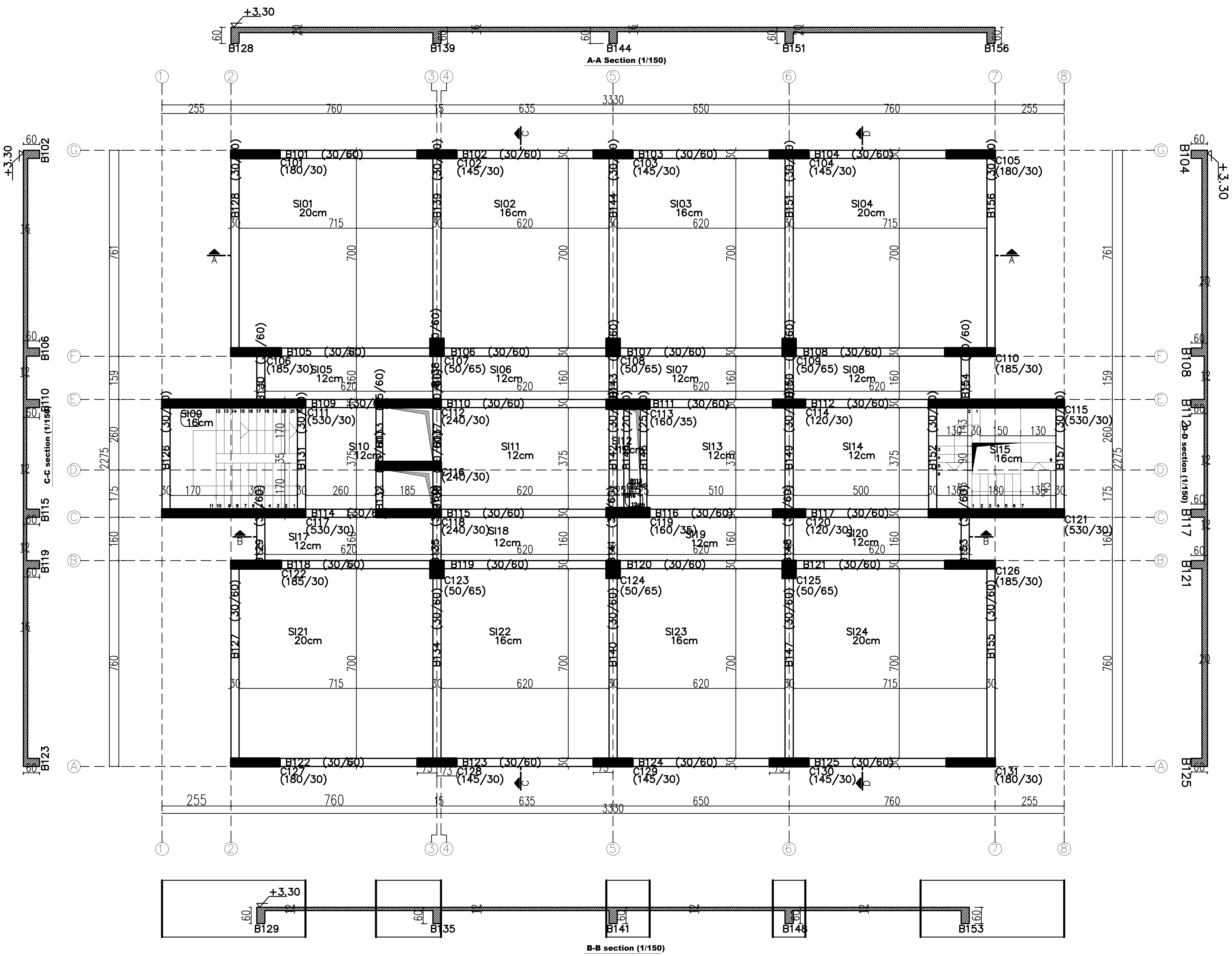


Floor plan (1/150)

Figure 5. Floor Plan

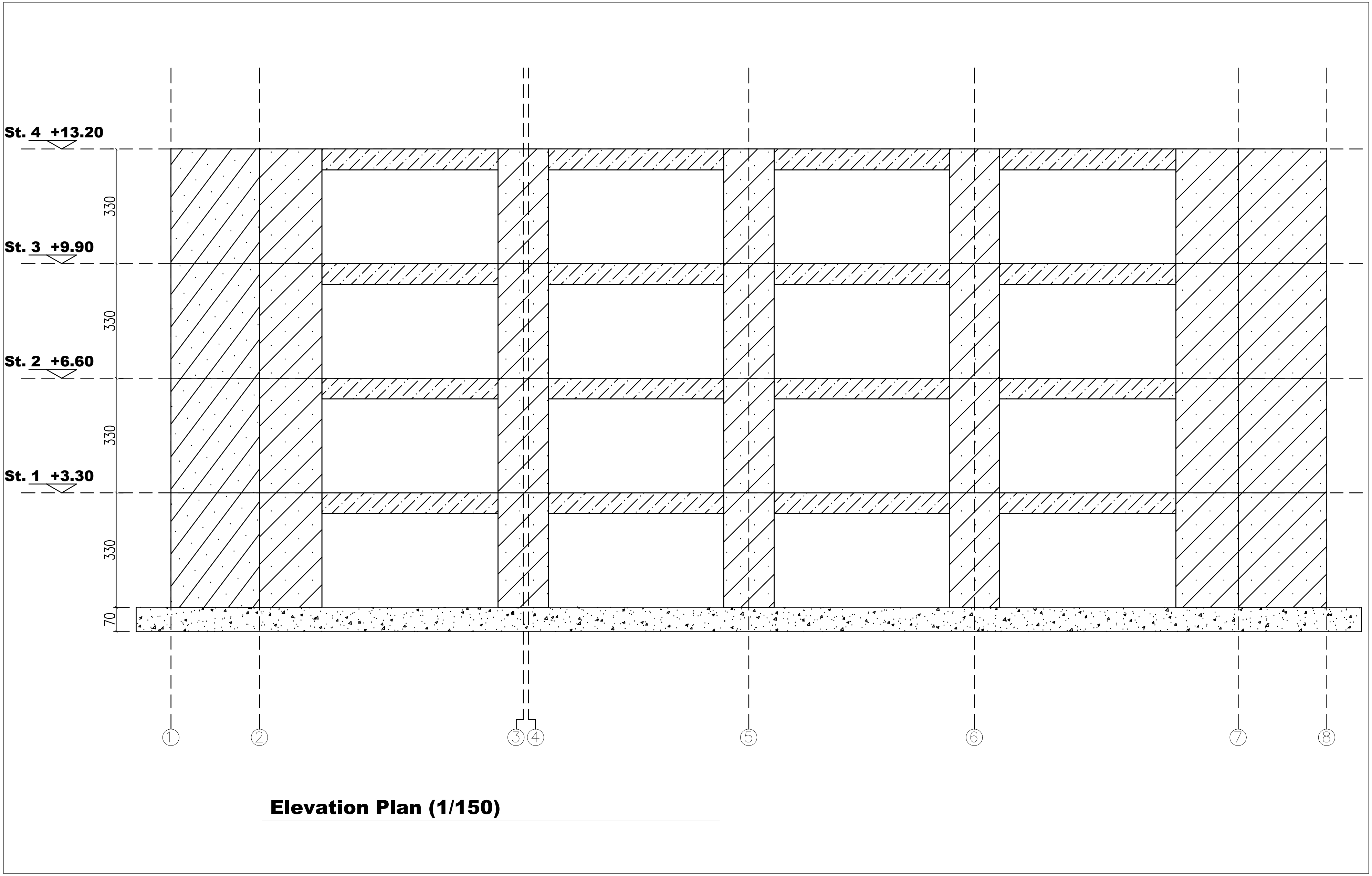


Figure 6. Elevation plan - Storey height of four-storey building.

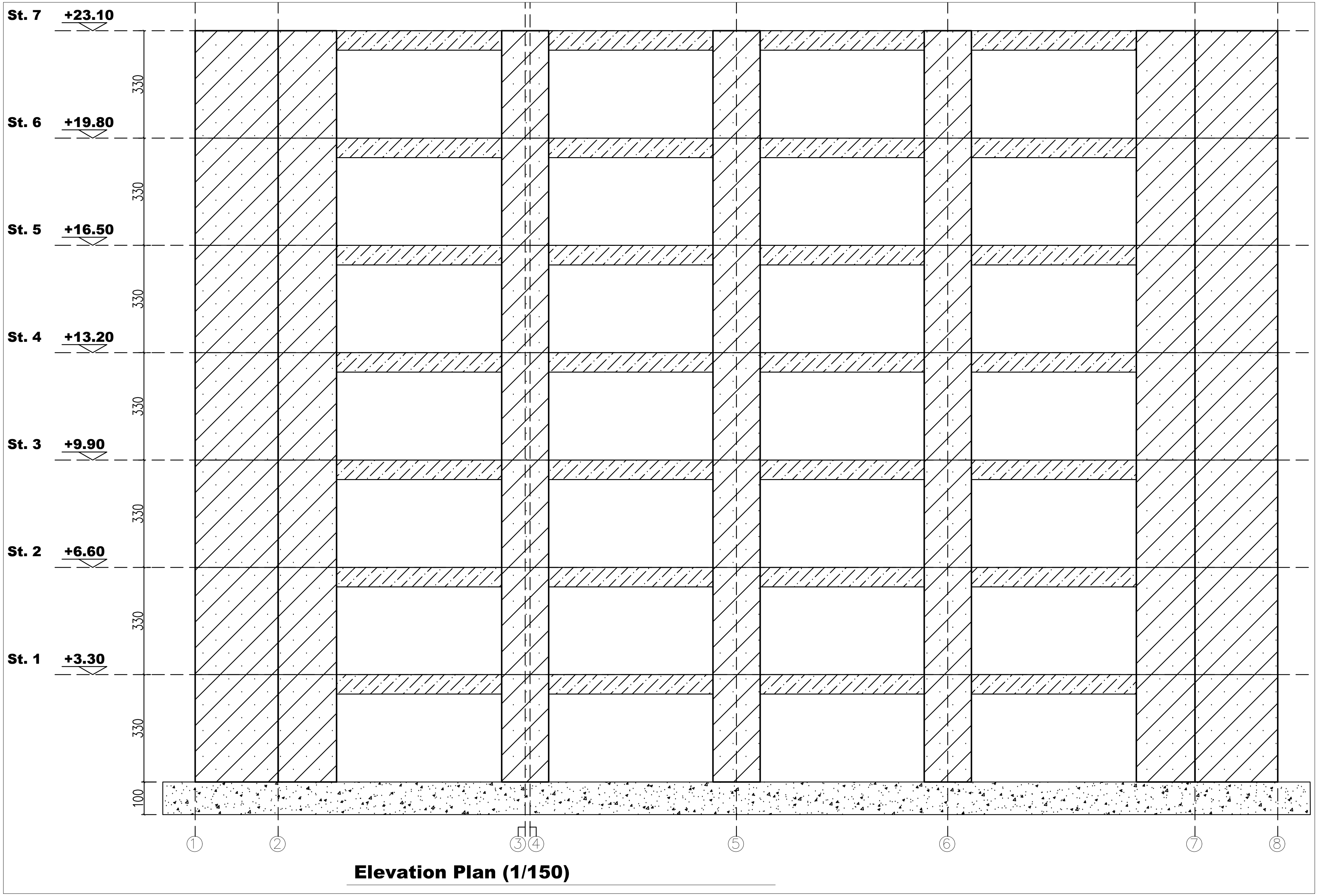


Figure 7. Elevation plan - Storey height of seven-storey building.

As our buildings are reinforced concrete, only two materials are considered when designing the building: concrete and steel rebar. The properties of each materials used are detailed in the following tables.

Table 10. Concrete properties ***[12]***

CONCRETE		
Concrete class	C	30/37
Specific weight	γ_C	2400 kg/m3
Characteristic strength	$f_{ck,cube}$	37 MPa
Elastic modulus	E	32837 MPa
Poisson coefficient	ν	0,2

Table 11. Rebar steel properties ***[12]***

Steel Rebar		
Steel Class	B	500 C
Specific weight	γ_S	7850 kg/m3
Characteristic strength	f_{yk}	500 MPa
Elastic modulus	E	200 GPa
Poisson coefficient	ν	0,3

Permanent dead load amounts to 3 kN/m^2 on the inhabitable floors and uniformly distributed dead load of 6 kN/m on the perimeter beams (façade) of the buildings. For the roof floor a permanent dead load of 2 kN/m2 on the floor and a linearly distributed dead load of 4 kN/m on the perimeter beams are assigned.

For the live load an amount of 2 kN/m2 on the inhabitable floor and a 1.5 kN/m2 on the roof floor are assigned. [15]

Nowadays, computer-aided design programs are common in all areas and especially in the area of structural engineering. These programs are useful tools to get an idea of the behavior that will have a structure in reality when subjected to certain forces. For modeling and computing the structural response of the buildings, the software Tekla Structural Designer 2019 [2] is used. This software includes the elastic response spectra according to Eurocode 8 standard in its database, so that it is not needed to predefine or model it. Only the other parameters are inserted on it in order to do the proper analysis and design. By using this software it is possible to entirely describe the building structure and simulate its behavior under the different considered loads and actions.

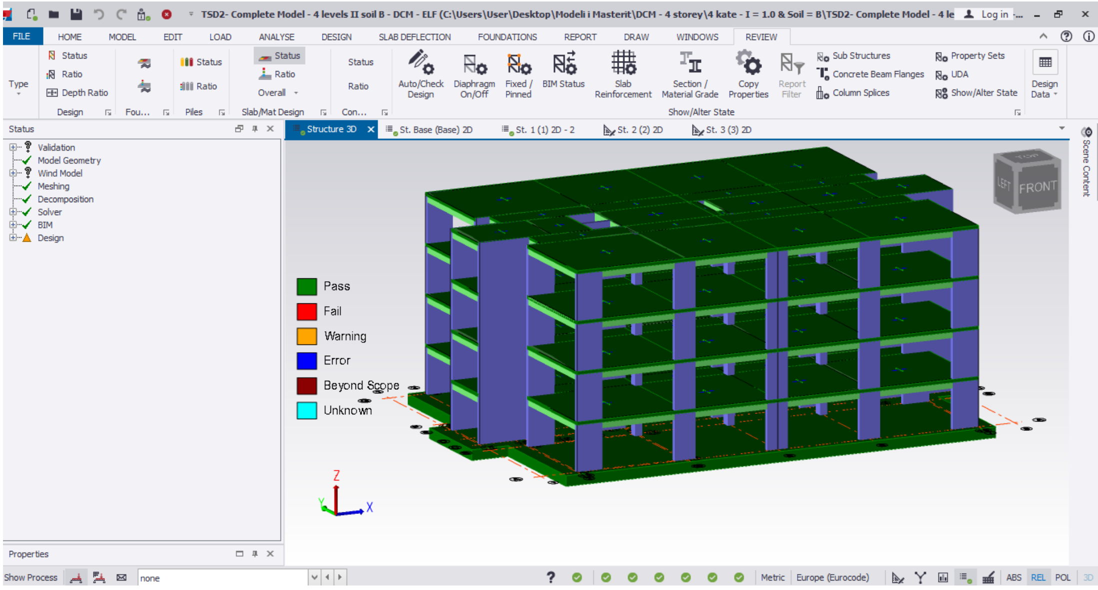
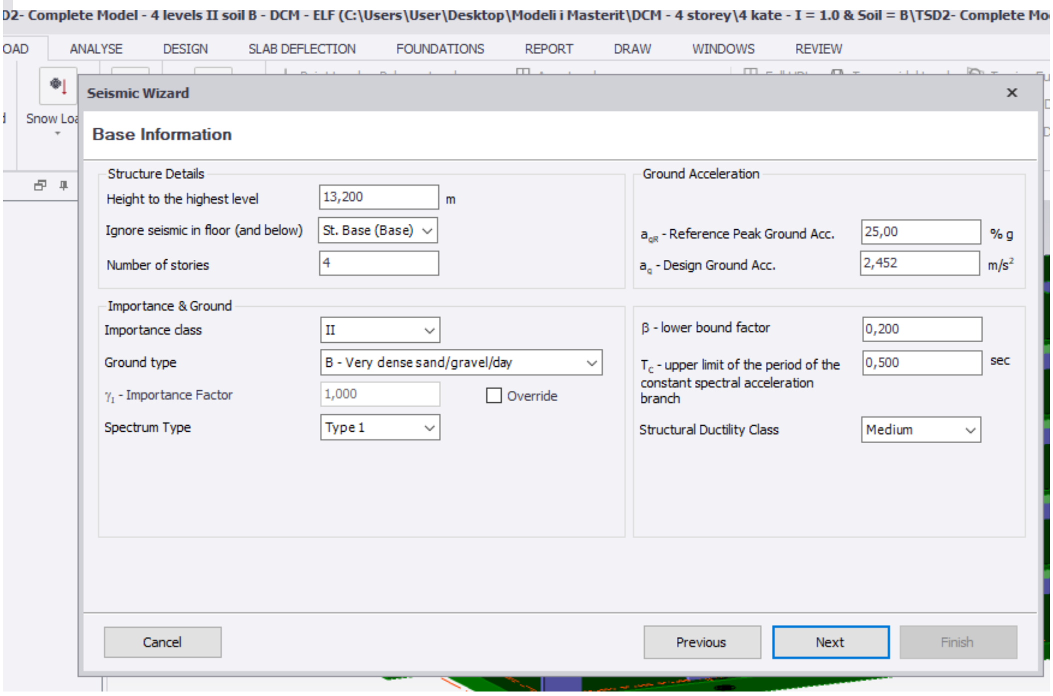


Figure 8. 4-storey building model with TSD 2019 ***[2]***.

Table 12. Seismic Wizard ***[2]***

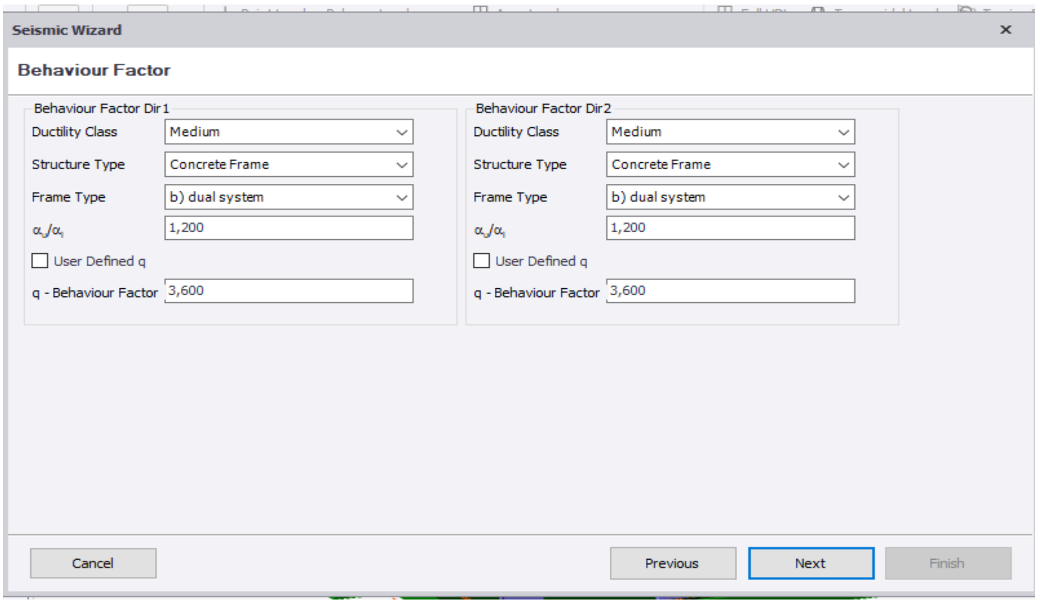


For the seismic action according to Eurocode 8 the parameters are defined as below:

As the buildings are supposed to be located in Tirana, and looking at the map of Albania for reference peak ground acceleration on type A soil, a_{gR}, the design ground acceleration will amount to 0.25g. For the first four-storey model, we will determine an Importance class II with an importance factor $y_I = 1.0$. The soil type will be B, which is a very dense sand, gravel or stiff clay, and with an upper limit period T_c of 0.5 s. Spectrum type will be type 1 as the earthquake is considered to be of a Magnitude Ms > 5.5. [1]

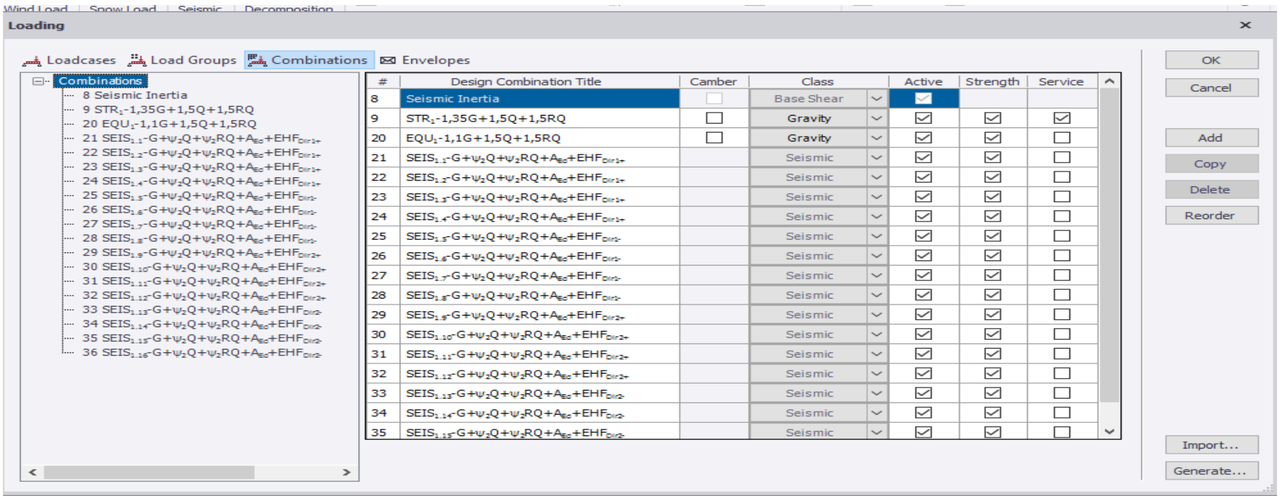
Considering to be a Ductility Class Medium and a frame type of dual system, the behavior factor q will amount to 3.6 for both X and Y directions. When a comparison model is done with a Ductility Class High, the behavior factor q will amount to 5.4 for both X and Y directions.

Table 13. Behavior factor q for DCM. ***[2]***



As we insert these parameters, the software generates the design spectrum and load combinations.

Table 14. Load Combinations ***[2]***



#	Design Combination Title	Camber	Class	Active	Strength	Service
8	Seismic Inertia	☐	Base Shear	☑		
9	STR_1-1,35G+1,5Q+1,5RQ	☐	Gravity	☑	☑	☑
20	EQU_1-1,1G+1,5Q+1,5RQ	☐	Gravity	☑	☑	☐
21	$SEIS_{1.1}\text{-}G+\psi_2Q+\psi_2RQ+A_{Ed}+EHF_{Dir1+}$		Seismic	☑	☑	☐
22	$SEIS_{1.2}\text{-}G+\psi_2Q+\psi_2RQ+A_{Ed}+EHF_{Dir1+}$		Seismic	☑	☑	☐
23	$SEIS_{1.3}\text{-}G+\psi_2Q+\psi_2RQ+A_{Ed}+EHF_{Dir1+}$		Seismic	☑	☑	☐
24	$SEIS_{1.4}\text{-}G+\psi_2Q+\psi_2RQ+A_{Ed}+EHF_{Dir1+}$		Seismic	☑	☑	☐
25	$SEIS_{1.5}\text{-}G+\psi_2Q+\psi_2RQ+A_{Ed}+EHF_{Dir1-}$		Seismic	☑	☑	☐
26	$SEIS_{1.6}\text{-}G+\psi_2Q+\psi_2RQ+A_{Ed}+EHF_{Dir1-}$		Seismic	☑	☑	☐
27	$SEIS_{1.7}\text{-}G+\psi_2Q+\psi_2RQ+A_{Ed}+EHF_{Dir1-}$		Seismic	☑	☑	☐
28	$SEIS_{1.8}\text{-}G+\psi_2Q+\psi_2RQ+A_{Ed}+EHF_{Dir1-}$		Seismic	☑	☑	☐
29	$SEIS_{1.9}\text{-}G+\psi_2Q+\psi_2RQ+A_{Ed}+EHF_{Dir2+}$		Seismic	☑	☑	☐
30	$SEIS_{1.10}\text{-}G+\psi_2Q+\psi_2RQ+A_{Ed}+EHF_{Dir2+}$		Seismic	☑	☑	☐
31	$SEIS_{1.11}\text{-}G+\psi_2Q+\psi_2RQ+A_{Ed}+EHF_{Dir2+}$		Seismic	☑	☑	☐
32	$SEIS_{1.12}\text{-}G+\psi_2Q+\psi_2RQ+A_{Ed}+EHF_{Dir2+}$		Seismic	☑	☑	☐
33	$SEIS_{1.13}\text{-}G+\psi_2Q+\psi_2RQ+A_{Ed}+EHF_{Dir2-}$		Seismic	☑	☑	☐
34	$SEIS_{1.14}\text{-}G+\psi_2Q+\psi_2RQ+A_{Ed}+EHF_{Dir2-}$		Seismic	☑	☑	☐
35	$SEIS_{1.15}\text{-}G+\psi_2Q+\psi_2RQ+A_{Ed}+EHF_{Dir2-}$		Seismic	☑	☑	☐

Table above shows all the load combinations generated and run for analysis of the buildings.

3.5 Method of analysis of the models.

Since buildings are regular in plan and elevation, and symmetrical for both X and Y directions, linear equivalent lateral force method of analysis is used. The criteria is meet as in Eurocode 8 section 4.2.3.3 [1]. The fundamental period of vibration T_1 in the two main directions is smaller than 4xTc or 2.0 s.

Table 15. Analysis procedure used ***[2]***.

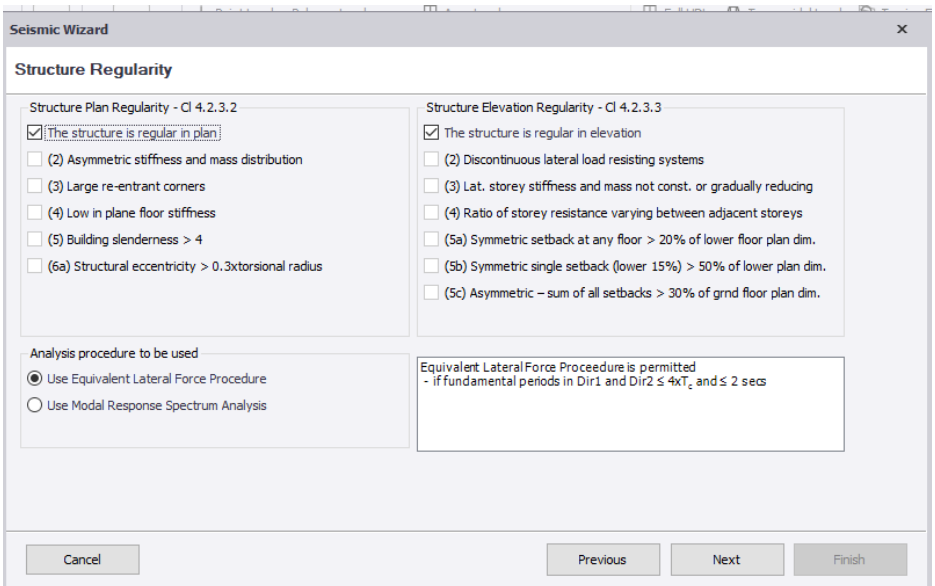


Table 16. Approximate fundamental period of the 4-storey structure ***[2]***

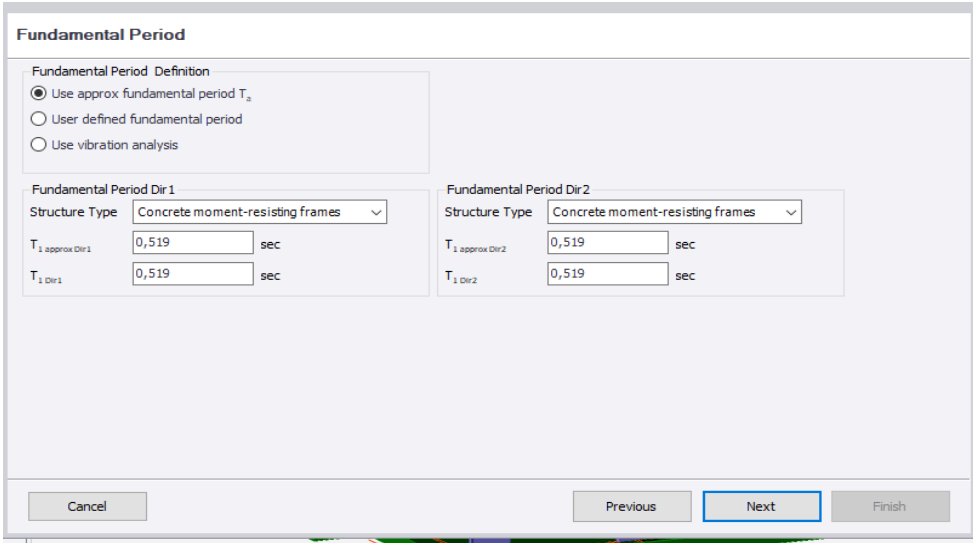


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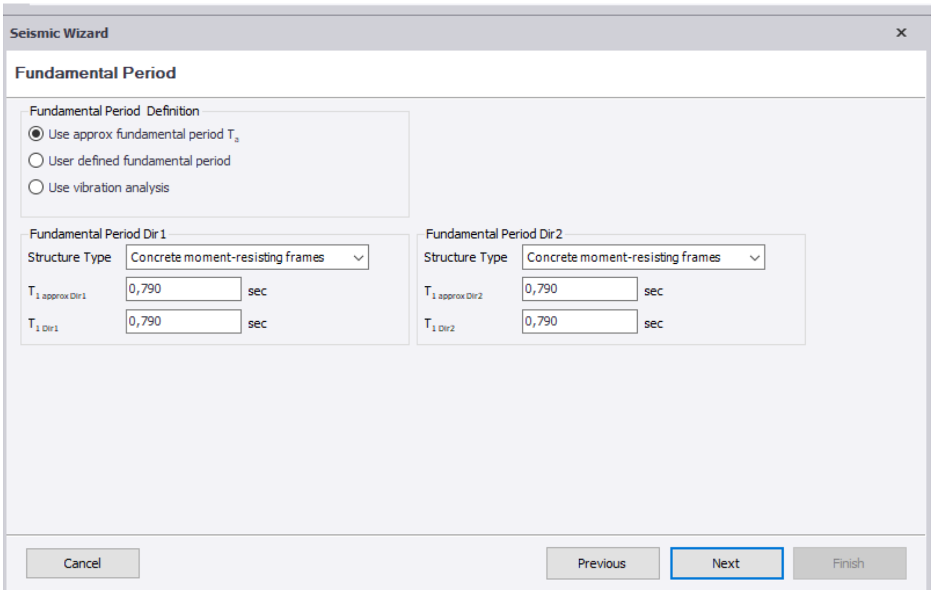
Table 17. Approximate fundamental period of the 7-storey structure ***[2]***



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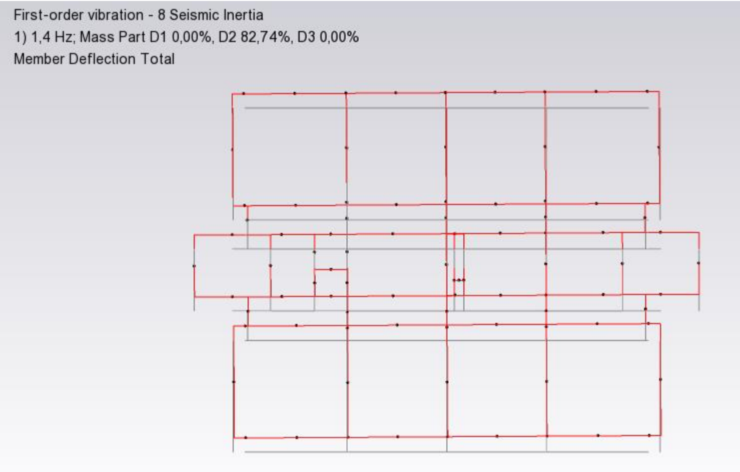
The approximate fundamental periods of vibration, T_a, for the 4-storey buildings is 0.519 sec for each X and Y directions. Whereas for the 7-storey buildings, T_a is 0.790 sec for each X and Y directions.

Modes of vibration have been checked for each building to ensure the validity of the design using 1st order vibration analysis.

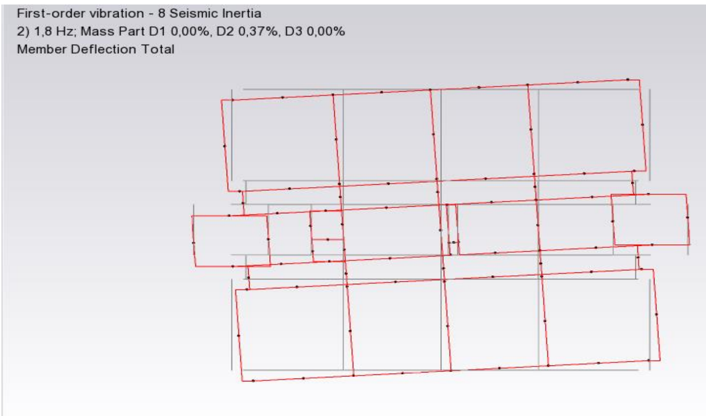
Table 18. The elastic periods (T) and effective Modal masses of the 4-storey building ***[2].***

Mode Number	Period [sec]	Frequency [Hz]	Error [%]	Mass Partic. Trans. Dir 1 [%]	Mass Partic. Trans. Dir 2 [%]	Mass Partic. Trans. Z [%]	Modal Mass Trans. Dir 1 [kN]	Modal Mass Trans. Dir 2 [kN]	Modal Mass Trans. Z [kN]
1	0,718	1,4	0,00	0,00	82,74	0,00	12581,4	12581,4	12581,4
2	0,567	1,8	0,00	0,00	0,37	0,00	5889,1	5889,1	5889,1
3	0,521	1,9	0,00	79,88	0,00	0,00	10880,4	10880,4	10880,4
4	0,201	5,0	0,00	0,00	11,04	0,00	15727,7	15727,7	15727,7
5	0,144	6,9	0,00	0,00	0,05	0,00	7323,1	7323,1	7323,1
6	0,115	8,7	0,00	0,00	3,01	0,00	15709,0	15709,0	15709,0
7	0,082	12,3	0,00	0,00	0,95	0,00	17457,1	17457,1	17457,1
8	0,070	14,2	0,00	14,25	0,00	0,00	7210,7	7210,7	7210,7
9	0,066	15,1	0,00	0,00	0,00	0,00	6991,1	6991,1	6991,1
10	0,040	24,9	0,00	0,00	0,00	0,00	4997,2	4997,2	4997,2

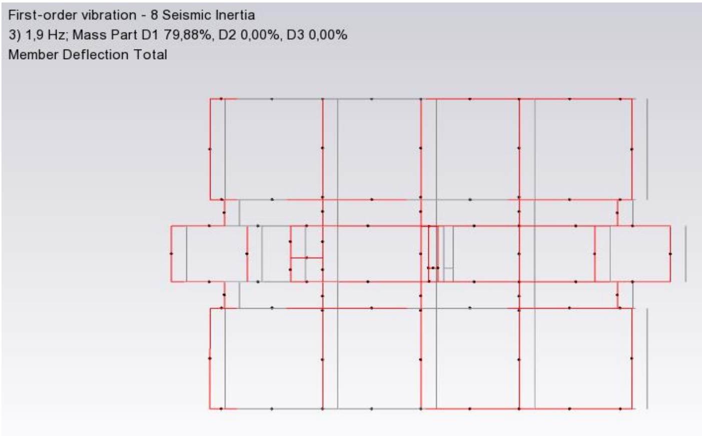
The three fundamental periods of vibration of the 4-storey building are 0.718 s, 0.567 s and 0.521 s. The effective masses show that the first mode is predominantly translational in the Y – direction, the second is torsional and the third is predominantly in the X-direction.



1. mode – Y direction



2.mode - torsional



3.mode – X direction

Figure 9. Three fundamental periods of vibration of 4-Storey building ***[2]***

Table 19. Seismic base shear forces and other information for 4-storey building ***[2]***.

Height of building from foundation or top of rigid basement	13,200	m	
Structural Ductility Class – Low, Medium or High	Medium		
Reference Peak Ground Acceleration, a_{gR}	25,00	% g	PD6698:2009
Ground type	B - Very dense sand/gravel/clay		EN1998-1:2004 Table 3.1
Importance class	II		EN1998-1:2004 Table 4.3
Lower bound factor, β	0,200		
Design ground acceleration, $a_g = (g_{acc} \times a_{gR} \times \gamma_I)$	2,452	m/s²	
Importance factor, γ_I	1,000		
Upper limit of the period of the constant spectral acceleration branch, T_c	0,500	sec	
Effective seismic structure mass, m	3112,88	t	EN1998-1:2004 Cl. 4.3.3.2.2
Structure Type			
Direction Dir1	Concrete moment-resisting frames		
Direction Dir2	Concrete moment-resisting frames		
	Direction Dir1	**Direction Dir2**	
Factor C_t	0,075	0,075	
Approximate fundamental period - $T_{1\,approx}$ [sec]	0,519	0,519	
Fundamental period - T_1 [sec]	0,520	0,718	
α_u/α_l - user defined factor	1,200	1,200	
Behaviour Factor, q	3,600	3,600	
Design Spectrum Ordinate, $S_d(T_1)$ [m/s²]	1,964	1,423	
Correction Factor, λ	0,850	0,850	
Seismic base shear, F_b [kN]	**5196,9**	**3765,1**	

Table 20. Interstorey shear forces for two horizontal directions of 4-storey building**.**

Reference	Level [m]	m_i [t]	Direction Dir1			Direction Dir2		
			Factor	F_i [kN]	Ecc [m]	Factor	F_i [kN]	Ecc [m]
St. 4 (4)	13,200	659,22	0,350	1816,5	1,138	0,350	1316,0	1,665
St. 3 (3)	9,900	817,89	0,325	1690,2	1,138	0,325	1224,6	1,665
St. 2 (2)	6,600	817,89	0,217	1126,8	1,138	0,217	816,4	1,665
St. 1 (1)	3,300	817,89	0,108	563,4	1,138	0,108	408,2	1,665

Table 21. Comulative storey shear forces for both horizontal directions of 4 storey building.

Reference	Level [m]	Σ Shear Major [kN]	Σ Shear Minor [kN]
St. 4 (4)	13,200	-1816,5	0,0
St. 3 (3)	9,900	-3506,7	0,0
St. 2 (2)	6,600	-4633,5	0,0
St. 1 (1)	3,300	-5196,9	0,0
St. Base (Base)	0,000	-5196,9	0,0

Reference	Level [m]	Σ Shear Major [kN]	Σ Shear Minor [kN]
St. 4 (4)	13,200	0,0	-1316,0
St. 3 (3)	9,900	0,0	-2540,6
St. 2 (2)	6,600	0,0	-3356,9
St. 1 (1)	3,300	0,0	-3765,1
St. Base (Base)	0,000	0,0	-3765,1

From the tables above, can be seen that shear forces are higher in X-direction compared to those in Y-direction.

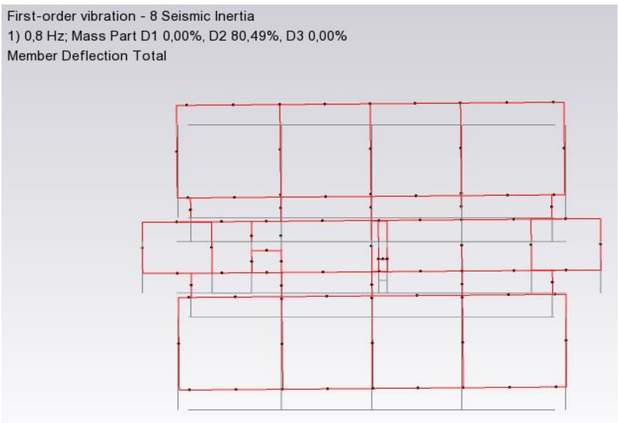
Table 22. Maximum displacement in two directions of the 4-storey building with Importance factor 1.0 and soil type B.

Maximum Displacement for building with Imp. Class II and soil type B		
Direction	Displacement	Load Combination Case
X	40.6 mm	$SEIS_{1.4}$-G+Ψ_2Q+Ψ_2RQ+A_{Ed}+EHF_{Dir1+}
Y	64.0 mm	$SEIS_{1.11}$-G+Ψ_2Q+Ψ_2RQ+A_{Ed}+EHF_{Dir2+}

Table 23. The elastic periods (T) and effective Modal masses of the 7-storey building. ***[2]***

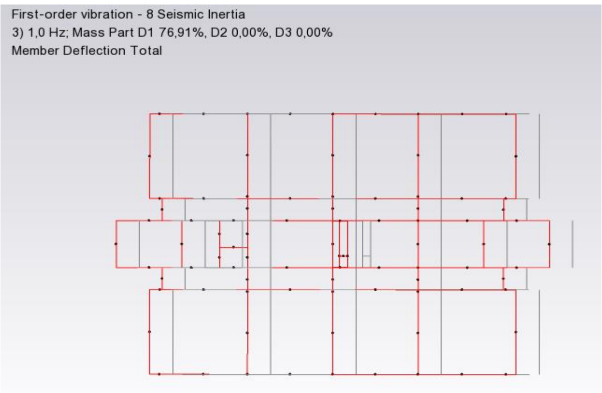
Vibration Frequencies									
Mode Number	Period [sec]	Frequency [Hz]	Error [%]	Mass Partic. Trans. Dir 1 [%]	Mass Partic. Trans. Dir 2 [%]	Mass Partic. Trans. Z [%]	Modal Mass Trans. Dir 1 [kN]	Modal Mass Trans. Dir 2 [kN]	Modal Mass Trans. Z [kN]
1	1,306	0,8	0,00	0,00	80,49	0,00	21080,0	21080,0	21080,0
2	1,013	1,0	0,00	0,00	0,32	0,00	10139,6	10139,6	10139,6
3	0,971	1,0	0,00	76,91	0,00	0,00	19285,1	19285,1	19285,1
4	0,364	2,8	0,00	0,00	11,24	0,00	21463,8	21463,8	21463,8
5	0,285	3,5	0,00	0,00	0,13	0,00	9670,1	9670,1	9670,1
6	0,208	4,8	0,00	0,00	3,30	0,00	26168,7	26168,7	26168,7
7	0,165	6,0	0,00	14,45	0,00	0,00	15171,4	15171,4	15171,4
8	0,143	7,0	0,00	0,00	0,62	0,00	10395,0	10395,0	10395,0
9	0,141	7,1	0,00	0,00	1,26	0,00	12863,5	12863,5	12863,5
10	0,107	9,3	0,00	0,00	0,94	0,00	27938,2	27938,2	27938,2

The three fundamental periods of vibration of the 7-storey building are 1.306 s, 1.013 s and 0.971 s. The effective masses show that the first mode is predominantly translational in the Y – direction, the second is torsional and the third is predominantly in the X-direction.



1.mode – Y direction

2. mode - torsional



3. mode – X direction.

Figure 10. Three fundamental modes of vibration of 7-storey building ***[2]***.

Table 25. Seismic base shear forces and other information for 7-storey building ***[2]***.

Structure details			
Height of building from foundation or top of rigid basement	23,100	m	
Structural Ductility Class – Low, Medium or High	Medium		
Reference Peak Ground Acceleration, a_{gR}	25,00	% g	PD6698:2009
Ground type	B - Very dense sand/gravel/clay		EN1998-1:2004 Table 3.1
Importance class	II		EN1998-1:2004 Table 4.3
Lower bound factor, β	0,200		
Design ground acceleration, $a_g = (g_{acc} \times a_{gR} \times \gamma_I)$	2,452	m/s^2	
Importance factor, γ_I	1,000		
Upper limit of the period of the constant spectral acceleration branch, T_c	0,500	sec	
Effective seismic structure mass, m	5566,53	t	EN1998-1:2004 Cl. 4.3.3.2.2
Structure Type			
Direction Dir1	Concrete moment-resisting frames		
Direction Dir2	Concrete moment-resisting frames		
	Direction Dir1	**Direction Dir2**	
Factor C_t	0,075	0,075	
Approximate fundamental period - $T_{1\,approx}$ [sec]	0,790	0,790	
Fundamental period - T_1 [sec]	0,971	1,306	
α_u/α_i - user defined factor	1,200	1,200	
Behaviour Factor, q	3,600	3,600	
Design Spectrum Ordinate, $S_d(T_1)$ [m/s^2]	1,052	0,782	
Correction Factor, λ	0,850	1,000	
Seismic base shear, F_b [kN]	**4979,1**	**4354,8**	

Table 24. Interstorey shear forces for two horizontal directions of 7-storey building.

Reference	Level [m]	m_i [t]	Direction Dir1			Direction Dir2		
			Factor	F_i [kN]	Ecc [m]	Factor	F_i [kN]	Ecc [m]
St. 7 (7)	23,100	659,22	0,212	1054,4	1,138	0,212	922,2	1,665
St. 6 (6)	19,800	817,89	0,225	1121,3	1,138	0,225	980,7	1,665
St. 5 (5)	16,500	817,89	0,188	934,4	1,138	0,188	817,3	1,665
St. 4 (4)	13,200	817,89	0,150	747,6	1,138	0,150	653,8	1,665
St. 3 (3)	9,900	817,89	0,113	560,7	1,138	0,113	490,4	1,665
St. 2 (2)	6,600	817,89	0,075	373,8	1,138	0,075	326,9	1,665
St. 1 (1)	3,300	817,89	0,038	186,9	1,138	0,038	163,5	1,665

Table 26. Comulative storey shear forces for both horizontal directions of 7-storey building.

Reference	Level [m]	Σ Shear Major [kN]	Σ Shear Minor [kN]
St. 7 (7)	23,100	-1054,4	0,0
St. 6 (6)	19,800	-2175,8	0,0
St. 5 (5)	16,500	-3110,2	0,0
St. 4 (4)	13,200	-3857,8	0,0
St. 3 (3)	9,900	-4418,4	0,0
St. 2 (2)	6,600	-4792,2	0,0
St. 1 (1)	3,300	-4979,1	0,0
St. Base (Base)	0,000	-4979,1	0,0

Reference	Level [m]	Σ Shear Major [kN]	Σ Shear Minor [kN]
St. 7 (7)	23,100	0,0	-922,2
St. 6 (6)	19,800	0,0	-1903,0
St. 5 (5)	16,500	0,0	-2720,2
St. 4 (4)	13,200	0,0	-3374,1
St. 3 (3)	9,900	0,0	-3864,4
St. 2 (2)	6,600	0,0	-4191,3
St. 1 (1)	3,300	0,0	-4354,8
St. Base (Base)	0,000	0,0	-4354,8

From the tables above, can be seen that shear forces are higher in X-direction compared to those in Y-direction.

Table 27. Overall displacement in three directions of the 7-storey building with Importance factor 1.0 and soil type B**.**

Maximum Displacement for building with Imp. Class II and soil type B		
Direction	Displacement	Load Combination Case
X	90.3	$SEIS_{1.4}$-G+Ψ_2Q+Ψ_2RQ+A_{Ed}+EHF_{Dir1+}
Y	149.4	$SEIS_{1.9}$-G+Ψ_2Q+Ψ_2RQ+A_{Ed}+EHF_{Dir1+}

CHAPTER 4

RESULTS AND DISCUSSIONS

Based on the results of structural analysis and on provisions of Eurocode 8, comparisons between buildings with different Importance Classes (II, III, IV), different soil types (B, C, D) and different ductility classes (DCM & DCH) are done in this chapter.

4.1 Comparison of total displacement.

Figure 11 through 14 present the comparison of total displacements for different importance class (II, III, IV) and soil types (B, C, D), for both low and mid-size buildings.

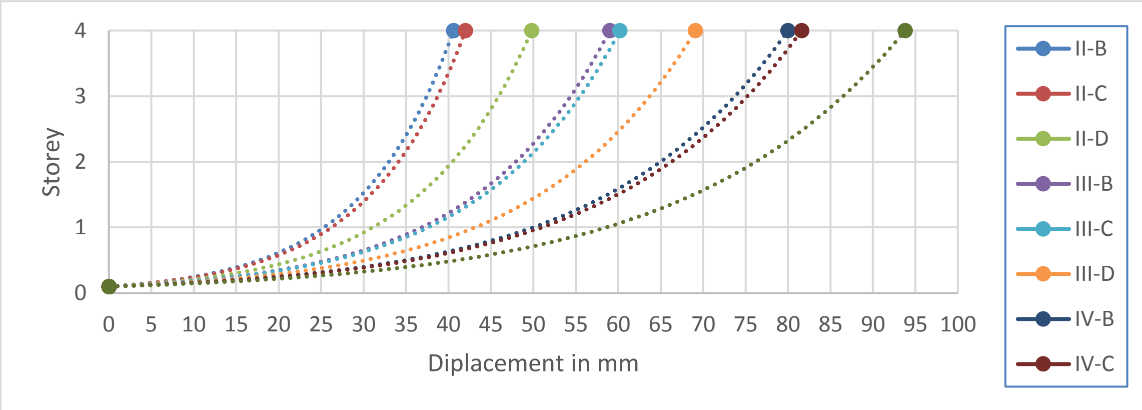


Figure 12. 4 storey building in DCM -X direction displacement

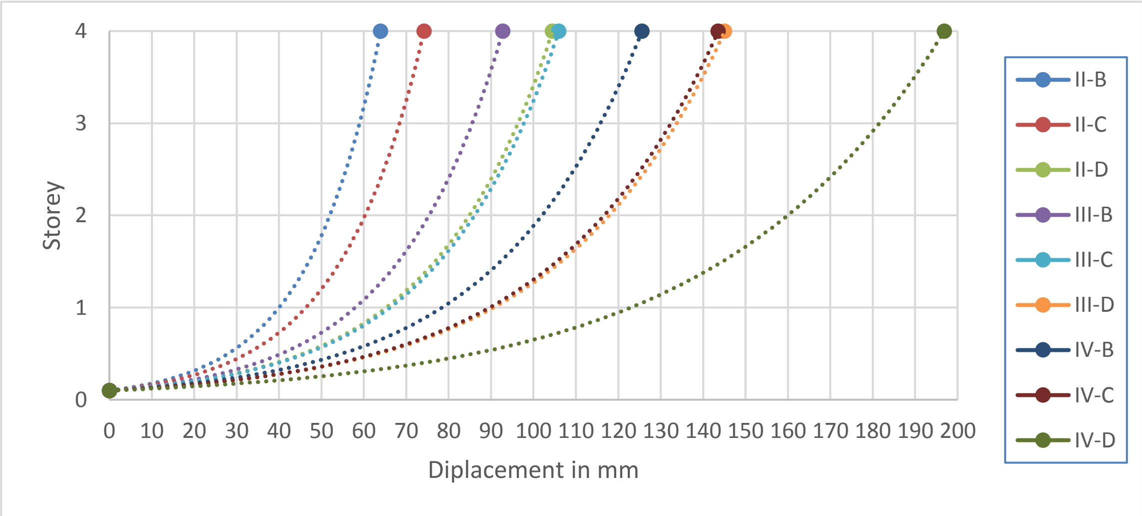


Figure 11. 4 storey building in DCM -Y direction displacement.

Table 28. Comparison of total displacement for 4-storey buildings.

	4 storey building -DCM								
	II			III			IV		
	B	C	D	B	C	D	B	C	D
	Dispplacement in mm								
X - dir.	40,6	42	49,8	59	60,2	69,1	80	81,6	93,8
Y - dir.	64	74,2	104,5	92,8	106	145,1	125,6	143,6	196,9
Comparison x - dir.	0%	3,4%	22,7%	45,3%	48,3%	70,2%	97,0%	101,0%	131,0%
Comparison y - dir.	0%	15,9%	63,3%	45,0%	65,6%	126,7%	96,3%	124,4%	207,7%

As it can be seen at the table above, the displacement in X-direction of the building with Importance class IV and located in soil type D is 131% higher than that of the building with Importance Class II and located in soil type B. For the displacement in Y-direction, the difference is 207.7 %.

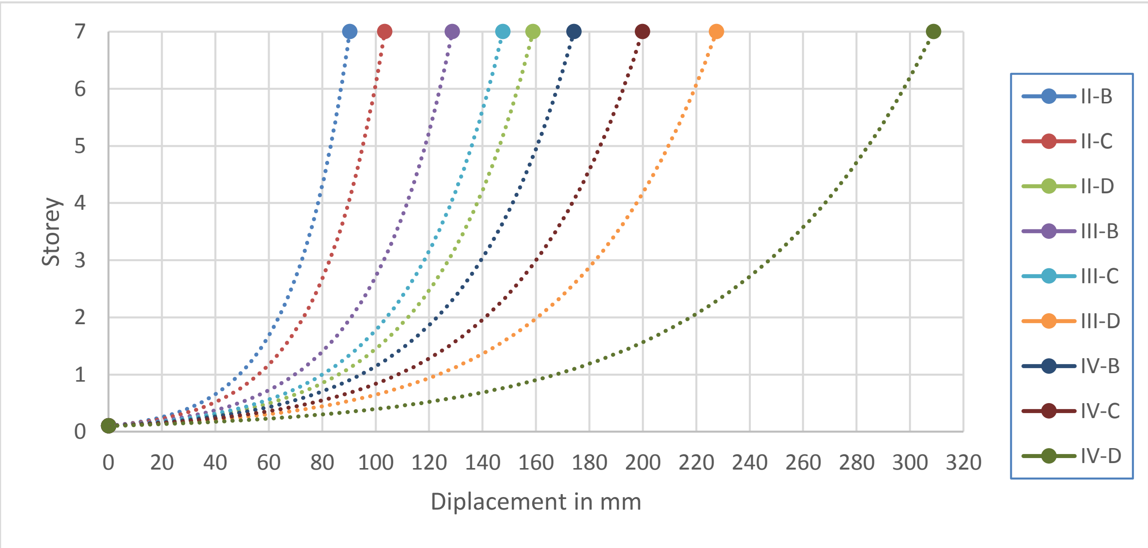


Figure 13. 7 storey building in DCM -X direction displacement

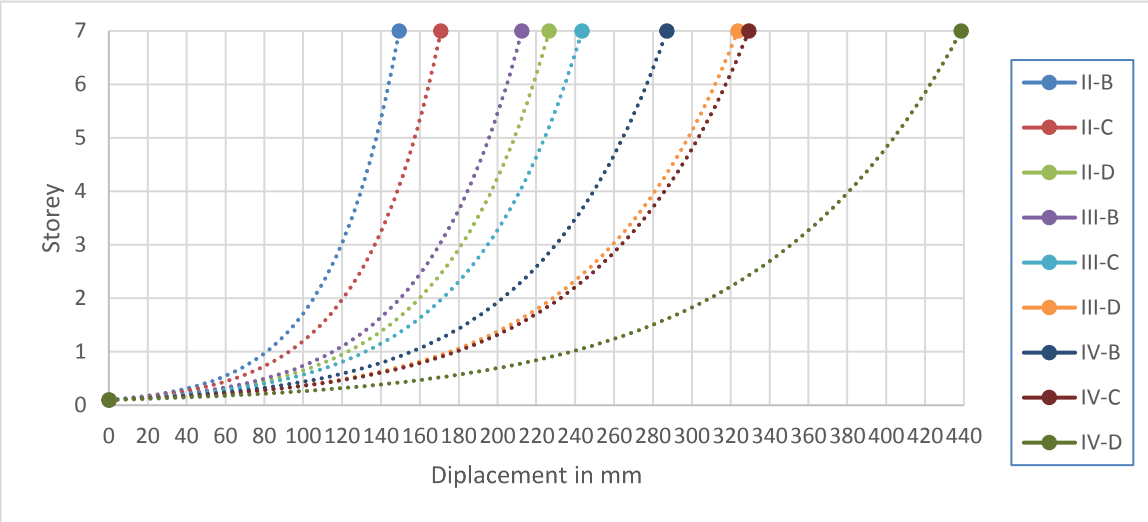


Figure 14. 7 storey building in DCM -Y direction displacement

Table 29. Comparison of total displacement for 7-storey buildings

	7 storey building -DCM								
	II			III			IV		
	B	C	D	B	C	D	B	C	D
	Displacement in mm								
X-dir.	90,3	103,4	158,9	128,7	147,6	227,6	174,2	199,9	308,8
Y-dir.	149,4	170,9	226,6	212,5	243,5	323,7	287,2	329,4	438,6
Comparison x-dir.	0%	14,5%	76,0%	42,5%	63,5%	152,0%	92,9%	121,4%	242,0%
Comparison y-dir.	0%	14,4%	51,7%	42,2%	63,0%	116,7%	92,2%	120,5%	193,6%

As it can be seen at the table above, the displacement in X-direction of the building with Importance class IV and located in soil type D is 242% higher than that of the building with Importance Class II and located in soil type B. For the displacement in Y-direction, the difference is 193.6 %.

4.2 Comparison of adopted reinforcement.

Comparison of adopted longitudinal and shear reinforcement weights for foundation, columns, beams and slabs are shown in the following tables for each typical buildings.

Table 30. Comparison of adopted reinforcement for typical 4-storey buildings.

Number of Stories : 4									
Reference Peak ground acceleration : 0,25g									
Spectrum Type : Type 1									
Structural ductility : Medium									
Analysis procedure to be used : Equivalent Lateral Force Procedure									
Structural Type: Concrete moment-resisting frames; T_1 = 0,718 sec									
Ductility Class: Medium; q-Behaviour factor = 3,60									
Importance Class:	II	II	II	III	III	III	IV	IV	IV
Soil type:	B-very dense sand /gravel/ clay	C-Deposits of dense/medium dense sand	D-Loose to medium soil	B-very dense sand/ gravel /clay	C-Deposits of dense/medium dense sand	D-Loose to medium soil	B-very dense sand/ gravel / clay	C-Deposits of dense/medium dense sand	D-Loose to medium soil
Reinforcement weight (ton)									
Mat Foundation	41.20	43.95	50.83	53.54	53.54	71.11	66.84	69.59	95.53
Columns:	25.77	28.30	35.39	31.87	36.20	52.07	43.56	48.30	80.03
Beams	25.94	28.76	35.30	34.70	38.24	50.23	47.40	52.61	71.89
Slabs	47.83	47.83	47.83	47.83	47.83	47.83	47.83	47.83	47.83
Total Weights	140.74	148.85	169.35	167.94	175.81	221.24	205.63	218.33	295.27
Increment in kg and % relative to Imp.II & Soil type B	0.00	8.11	28.61	27.20	35.07	80.50	64.89	77.59	154.53
	0.00%	5.76%	20.33%	19.32%	24.92%	57.20%	46.11%	55.13%	109.80%
Increment within same Im.class and different ground type	0.00%	5.76%	20.33%	0.00%	4.69%	31.74%	0.00%	6.18%	43.59%
Increment within same grnd type and different Imp. class	0.00%	0.00%	0.00%	19.32%	18.11%	30.64%	46.11%	46.68%	74.36%

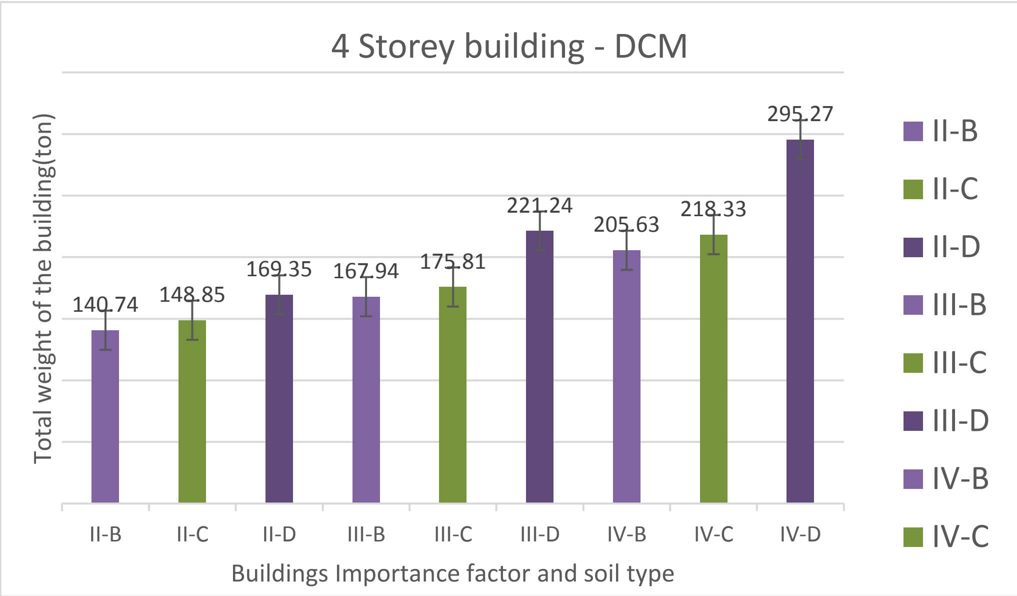


Figure 15. Column chart for reinforcement comparison of 4 Storey buildings with Ductility Class Medium.

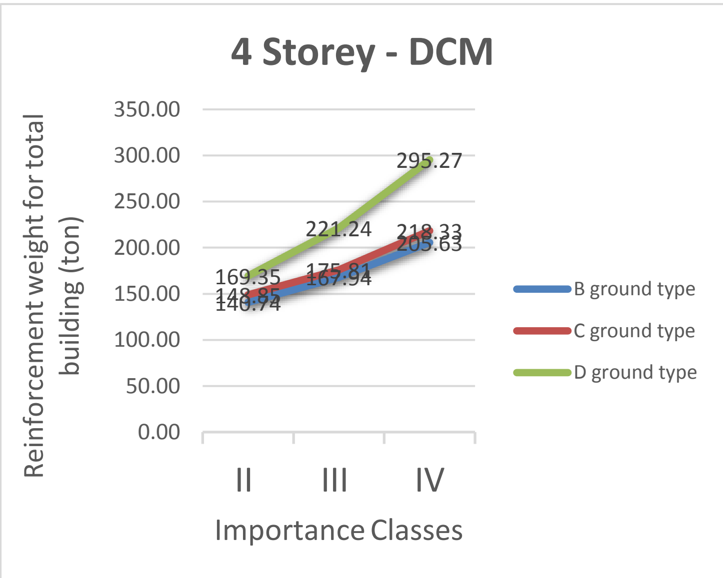


Figure 17. Trend of reinforcement for structures being in same soil types but different Im. Classes.

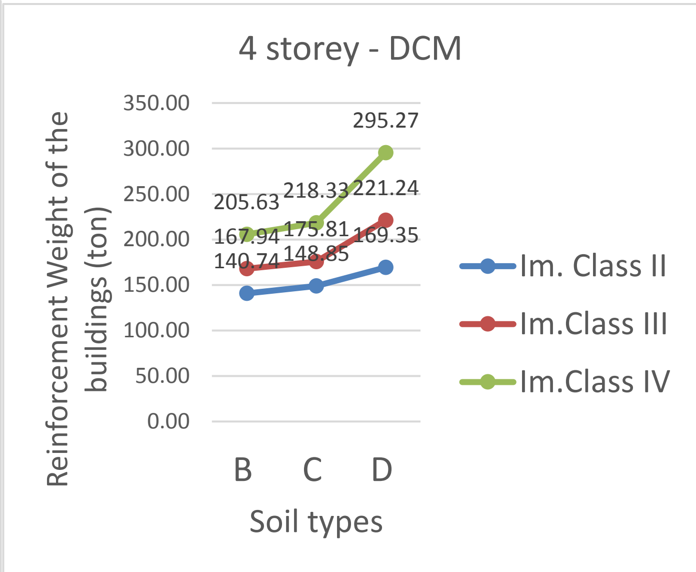


Figure 16. Trend of reinforcement for Structures being in same Importance class but different soil types.

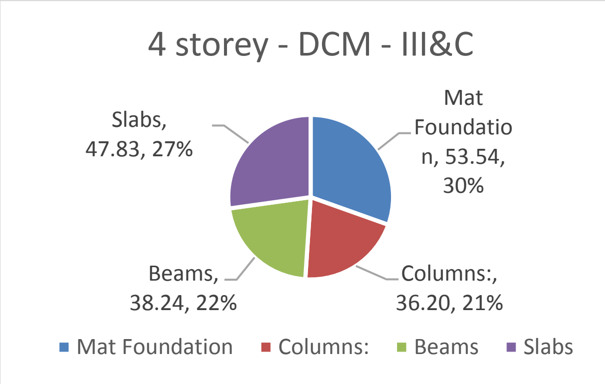


Figure 19. Amount of reinforcement that each type elements occupy in the total reinforcement weight of the 4-storey building with Im.Class III and soil type C

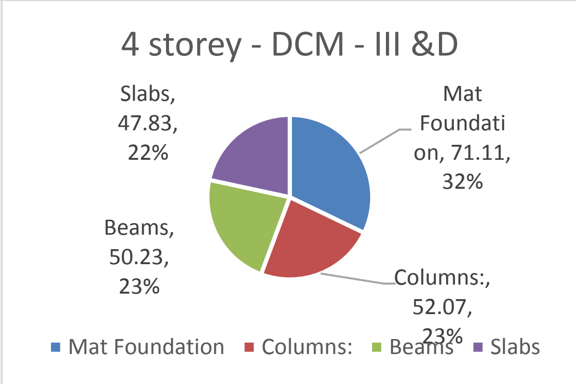


Figure 18. Amount of reinforcement that each type elements occupy in the total reinforcement weight of the 4-storey building with Im.Class III and soil type D.

As we can see from the Table 30, within the same importance class II the demand for reinforcement for 4-storey buildings located in soil type B to soil type C increases with 5.76 %, wheareas from ground type B to D the demand is 20.33 %.

Looking at the 4-storey buildings with Importance class III, the demand for reinforcement from ground type B to ground type C is 4.69 %, and from ground type B to D goes to 31.74 % higher.

To the buildings within Importance class IV, the demand for reinforcement from building located in ground type B to ground type C increases with 6.18 %, and from building in ground type B to D increases with 43.59 %.

Comparing the demand for reinforcement of the buildings when they are located in the same ground types but with different importance classes follows as below:

1. Located on soil type B, from the building with Importance Class II to that with Importance Class III, the demand for reinforcement increases with 19.32 %, and from Importance Class II to IV the increase is 46.11 %.
2. Located on soil type C, from the buildings with importance class II to that with importance class III, the demand for reinforcement increases with 18.11 %, and for the ones from importance class II to IV increase is 46.68 %.
3. Located on soil type D, from the building with Importance Class II to that with Importance Class III, the demand for reinforcement increases with 30.64 %, and from Importance Class II to IV the increase is 74.36 %.

Table 31. Comparison of adopted reinforcement for typical 7-storey buildings.

Number of Stories : 7									
Reference Peak ground acceleration : 0,25g									
Spectrum Type : Type 1									
Structural ductility : Medium									
Analysis procedure to be used : Equivalent Lateral Force Procedure									
Structural Type: Concrete moment-resisting frames; T_1 = 1.306 sec									
Ductility Class: Medium; q-Behaviour factor = 3,6									
Importance Class:	II-B	II-C	II-D	III-B	III-C	III-D	IV-B	IV-C	IV-D
Soil type:	B-very dense sand/ gravel/ clay	C-Deposits of dense/medium dense sand	D-Loose to medium soil	B-very dense sand/ gravel / clay	C-Deposits of dense/medium dense sand	D-Loose to medium soil	B-very dense sand/ gravel / clay	C-Deposits of dense/medium dense sand	D-Loose to medium soil
Reinforcement weight (ton)									
Mat Foundation	52.67	52.67	74.15	63.31	66.84	103.56	82.78	94.27	139.75
Columns:	42.28	44.67	61.52	52.05	59.26	93.26	72.96	84.33	137.29
Beams	50.36	53.39	79.02	64.39	75.29	123.75	90.17	99.39	180.79
Slabs	86.27	86.27	86.27	86.27	86.27	86.27	86.27	86.27	86.27
Total Weights	231.57	236.99	300.96	266.01	287.65	406.83	332.17	364.26	544.10
Increment in kg and % relative to Imp.II & Soil type B	0	5.42	69.384	34.437	56.074	175.258	100.597	132.686	312.527
	0.00%	2.34%	29.96%	14.87%	24.21%	75.68%	43.44%	57.30%	134.96%
Increment within same Im.class and different ground type	0.00%	2.34%	29.96%	0.00%	8.13%	52.94%	0.00%	9.66%	63.80%
Increment within same grnd type and different Imp. class	0.00%	0.00%	0.00%	14.87%	21.37%	35.18%	43.44%	53.70%	80.79%

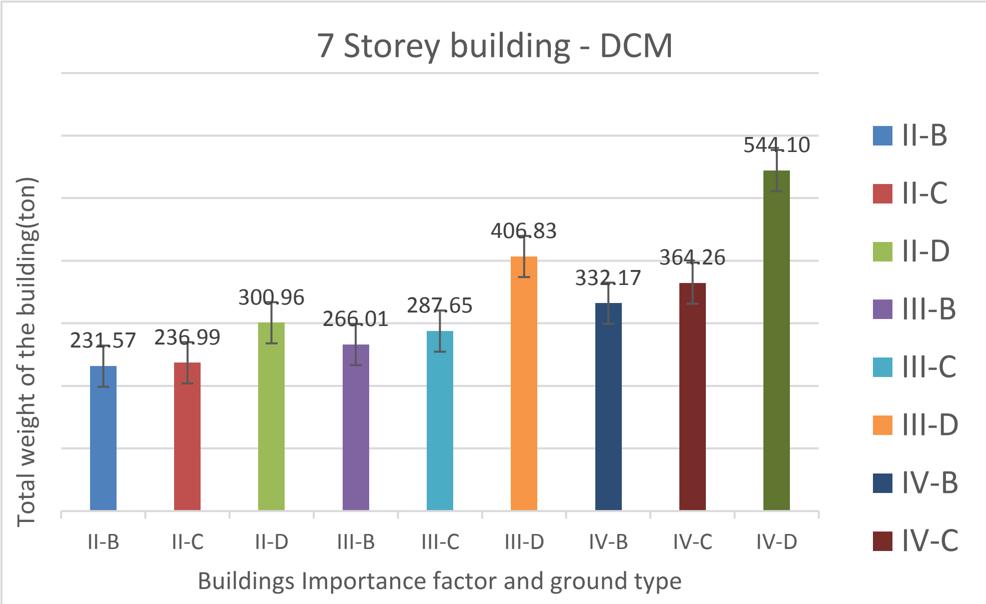
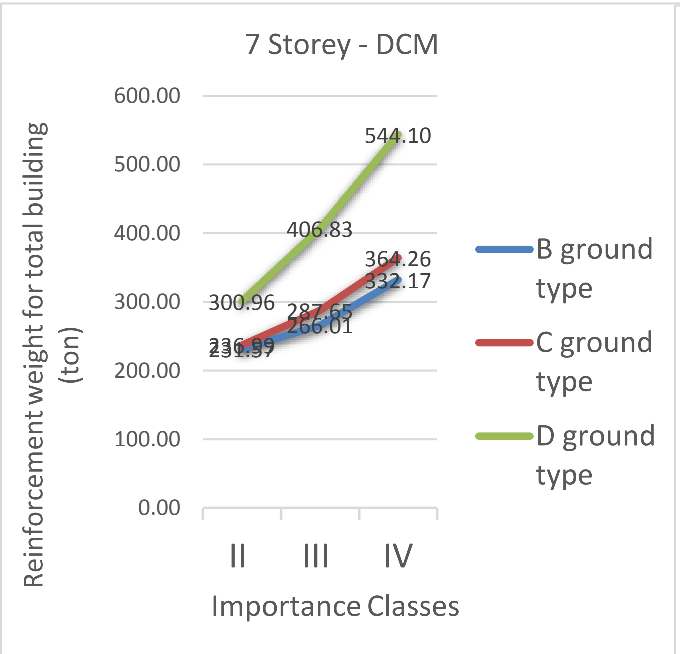


Figure 20. Column chart for reinforcement comparison of 7-Storey buildings with Ductility Class Medium



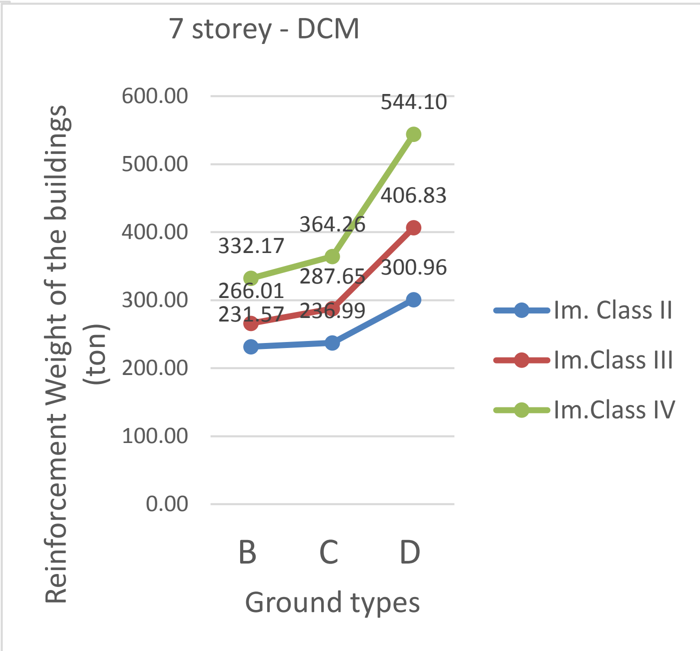


Figure 22. Trend of reinforcement for strucures being in same soil types but different Im. Classes.

Figure 21. Trend of reinforcement for Structures being in same Importance class but different soil types.

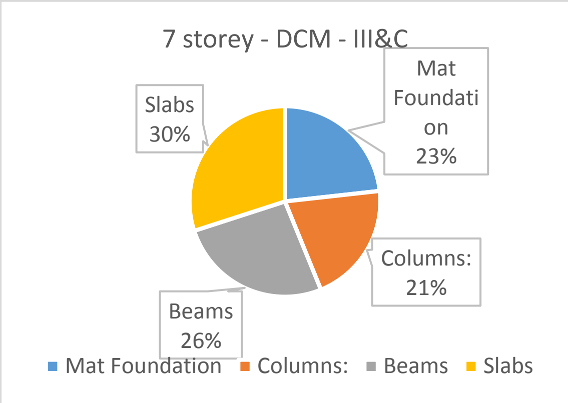


Figure 23. Amount of reinforcement that each type elements occupy in the total reinforcement weight of the 7-storey building with Imp, Class III and soil type D.

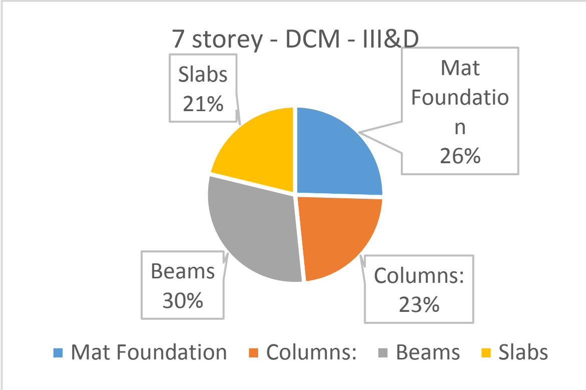


Figure 24. Amount of reinforcement that each type elements occupy in the total reinforcement weight of the 7-storey building with Im.Class III and soil type C.

As we can see from the Table 31, within the same importance class II the demand for reinforcement for 7-storey buildings located in soil type B to soil type C increases with 2.34 %, whearеas from soil type B to D the demand is 29.96 %.

Looking at the 7-storey buildings with Importance class III, the demand for reinforcement from soil type B to soil type C is 8.13 %, and from soil type B to D goes to 52.94 % higher.

To the buildings within the same Importance class IV, the demand for reinforcement from building located in soil type B to soil type C increases with 9.66 %, and from building in soil type B to D increases with 63.80 %.

Comparing the demand for reinforcement of the buildings when they are located in the same soil types but with different importance classes follows as below:

1. Located in soil type B, from the building with Importance Class II to that with Importance Class III, the demand for reinforcement increases with 14.87 %, and from Importance Class II to IV the increase is 43.44 %.
2. Located in soil type C, from the buildings with importance class II to that with importance class III, the demand for reinforcement increases with 21.37 %, and for the ones from importance class II to IV increase is 53.70 %.
3. Located in soil type D, from the building with Importance Class II to that with Importance Class III, the demand for reinforcement increases with 35.18 %, and from Importance Class II to IV the increase is 80.79 %.

Below we are continuing with comparison in the adopted reinforcement when buildings are designed for different ductility classes.

Table 32. Comparison of adopted reinforcement for different ductility classes of typical 4-storey buildings

Number of Stories : 4				
Reference Peak ground acceleration : 0,25g				
Spectrum Type : Type 1				
Structural ductility : Medium and High				
Analysis procedure to be used : Equivalent lateral force Procedure				
Structural Type: Concrete moment-resisting frames; T_1 = 0,718 sec				
Ductility Class: Medium & High; q-Behaviour factor = 3,6 for DCM and 5,4 for DCH				
Importance Class:	II	II	IV	IV
Ductility Class	DCM	DCH	DCM	DCH
Soil type:	B-very dense sand / gravel / clay	B-very dense sand / gravel / clay	D-Loose to medium soil	D-Loose to medium soil
Reinforcement weight (ton)				
Mat Foundation	41.20	37.01	95.53	66.06
Columns:	25.77	23.13	80.03	43.42
Beams	25.94	22.10	71.89	46.32
Slabs	47.83	48.35	47.83	48.35
Total Weights	140.74	130.59	295.27	204.15
Difference in reinforcement weight	10.15		91.12	
	0.00%	-7.21%	0.00%	-30.86%

As we can read from the table above, there is a decrease in the demand for reinforcement when the building is designed in Ductility Class High compared to Ductility Class Medium. For the building located in soil type B and Importance Class II, the decrease in reinforcement is 7.21 %. Whereas, for the building located in soil type D and Importance Class IV, the decrease in reinforcement is 30.86 %.

In DCH, the behavior factor q, which takes into consideration the capacity of the structure to dissipate energy within the elastic range, is higher. Thus, it will make the buildings require less reinforcements. When other factors are involved that indicate the design response spectrum, this difference in reinforcement between DCM and DCH becomes higher.

Table 33. Comparison of adopted reinforcement for different ductility classes of typical 7-storey buildings.

Number of Stories : 7				
Reference Peak ground acceleration : 0,25g				
Spectrum Type : Type 1				
Structural ductility : Medium & High				
Analysis procedure to be used : Equivalent Lateral Force Procedure				
Structural Type: Concrete moment-resisting frames; T_1 = 1.306 sec				
Ductility Class: Medium&High; q-Behaviour factor = 3,6 for DCM and 5,40 for DCH				
Importance Class:	II	II	IV	IV
Ductility Class	DCM	DCH	DCM	DCH
Ground type:	B-very dense sand / gravel / clay	B-very dense sand / gravel / clay	D-Loose to medium soil	D-Loose to medium soil
Reinforcement weight (ton)				
Mat Foundation	52.67	46.38	139.75	98.83
Columns:	42.28	39.84	137.29	84.99
Beams	50.36	39.62	180.79	101.90
Slabs	86.27	86.51	86.27	86.51
Total Weights	231.57	212.35	544.10	372.24
Difference in reinforcement weight	19.23		171.87	
	0.00%	-8.30%	0.00%	-31.59%

As we can read from the table above, there is a decrease in the demand for reinforcement when the building is designed in Ductility Class High compared to Ductility Class Medium. For the 7-storey building located in soil type B and Importance Class II, the decrease in reinforcement is 8.30 %. Whereas, for the building located in soil type D and Importance Class IV, the decrease in reinforcement is 31.59 %.

4.3 Cost comparison.

This estimation of cost comparison is calculated taking in consideration the quantity of reinforcement, concrete and shuttering for all typical buildings. The most up-to-date marketplace prices have been taken in consideration regarding the reinforcement, concrete and shuttering. A cost unit of €/m^2 is calculated for each building model. The cost regarding labor force and equipment are included within each respective activity work.

Table 34. Estimation of quantity and cost for different 4 storey buildings.

Number of Stories : 4										
Reference Peak ground acceleration : 0,25g										
Spectrum Type : Type 1										
Structural ductility : Medium										
Analysis procedure to be used : Equivalent Lateral Force Procedure										
Structural Type: Concrete moment-resisting frames; $T_{1\ approx}$ = 0,519 sec										
Ductility Class: Medium; q-Behaviour factor = 3,60										
Importance Class:	**unit**	II	II	II	III	III	III	IV	IV	IV
Ground type:		B-very dense sand / gravel / cl	C-Deposits of dense/medium dense sand	D-Loose to medium soil	B-very dense sand / gravel / cl	C-Deposits of dense/medium dense sand	D-Loose to medium soil	B-very dense sand / gravel /cl	C-Deposits of dense/medium dense sand	D-Loose to medium soil
Total Reinforcement Weights	**Kg**	140738	148850	169348	167935	175805	221242	205628	218327	295271
Price of reinforcement	€/kg	0,75	0,75	0,75	0,75	0,75	0,75	0,75	0,75	0,75
Total cost **A**	€	105553,5	111637,5	127011	125951,25	131853,75	165931,5	154221	163745,25	221453,25
Amount of concrete C30/37	m3	1300	1300	1300	1300	1300	1300	1300	1300	1300
Price of concrete C30/37	€/m3	70	70	70	70	70	70	70	70	70
Total cost **B**	€	91000	91000	91000	91000	91000	91000	91000	91000	91000
Total area of shuttering	m2	6963	6963	6963	6963	6963	6963	6963	6963	6963
Price for m2 of shuttering	€/m2	14	14	14	14	14	14	14	14	14
Total Cost **C**	€	97482	97482	97482	97482	97482	97482	97482	97482	97482
Cost A + B + C	€	294035,5	300119,5	315493	314433,25	320335,75	354413,5	342703	352227,25	409935,25
Building's Total area	m2	2656	2656	2656	2656	2656	2656	2656	2656	2656
Price per square meter	€/m2	110,71	113,00	118,79	118,39	120,61	133,44	129,03	132,62	154,34
Increase in cost	**%**	**0%**	**2%**	**7%**	**7%**	**9%**	**21%**	**17%**	**20%**	**39%**

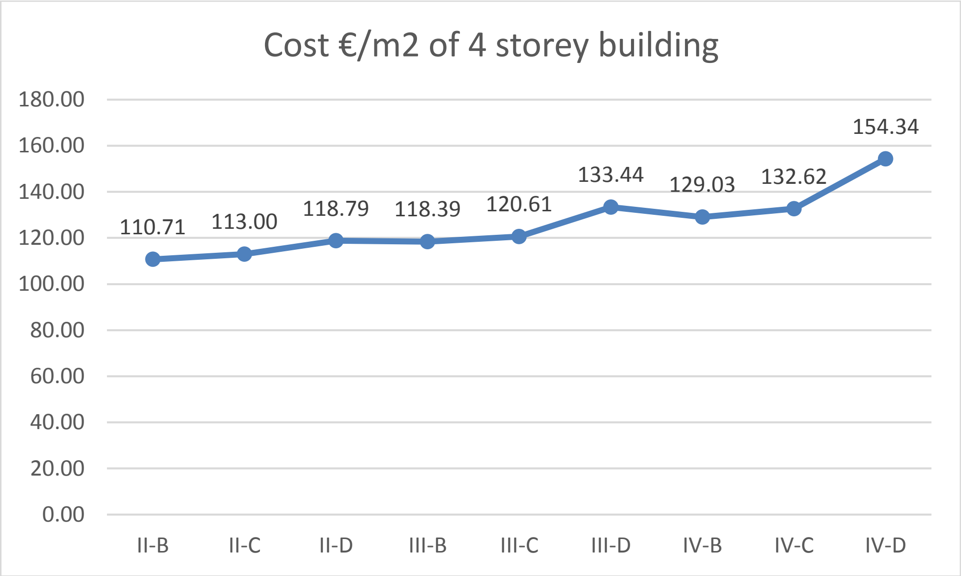


Figure 25. Construction cost graph for different 4 storey buildings.

As a result of the work done, it has been observed for the 4-storey buildings, that there is an increase in construction cost of 39 % from building designed with soil type B and Importance class II to building designed with soil type D and Importance class IV.

Table 35. Estimation of quantity and cost for different 7 storey buildings.

Number of Stories : 7										
Reference Peak ground acceleration : 0,25g										
Spectrum Type : Type 1										
Structural ductility : Medium										
Analysis procedure to be used : Equivalent Lateral Force Procedure										
Structural Type: Concrete moment-resisting frames; $T_{1\ approx}$ = 0,790 sec										
Ductility Class: Medium; q-Behaviour factor = 3,60										
Importance Class:	**unit**	II	II	II	III	III	III	IV	IV	IV
Ground type:		B-very dense sand / gravel / cl	C-Deposits of dense/medium dense sand	D-Loose to medium soil	B-very dense sand / gravel / cl	C-Deposits of dense/medium dense sand	D-Loose to medium soil	B-very dense sand / gravel / cl	C-Deposits of dense/medium dense sand	D-Loose to medium soil
Total Reinforcement Weights	**Kg**	231573	236993	300957	266010	287647	406831	332170	364259	544100
Price of reinforcement	€/kg	0,75	0,75	0,75	0,75	0,75	0,75	0,75	0,75	0,75
Total cost **A**	€	173679,75	177744,75	225717,75	199507,5	215735,25	305123,25	249127,5	273194,25	408075
Amount of concrete C30/37	m3	2320	2320	2320	2320	2320	2320	2320	2320	2320
Price of concrete C30/37	€/m3	70	70	70	70	70	70	70	70	70
Total cost **B**	€	162400	162400	162400	162400	162400	162400	162400	162400	162400
Total area of shuttering	m2	11624	11624	11624	11624	11624	11624	11624	11624	11624
Price for m2 of shuttering	€/m2	14	14	14	14	14	14	14	14	14
Total Cost **C**	€	162736	162736	162736	162736	162736	162736	162736	162736	162736
Cost A + B + C	€	498815,75	502880,75	550853,75	524643,5	540871,25	630259,25	574263,5	598330,25	733211
Building's Total area	m2	4648	4648	4648	4648	4648	4648	4648	4648	4648
Price per square meter	€/m2	107,32	108,19	118,51	112,88	116,37	135,60	123,55	128,73	157,75
Increase in cost	**%**	**0%**	**1%**	**10%**	**5%**	**8%**	**26%**	**15%**	**20%**	**47%**

As a result of the work done, it has been observed for the 7-storey buildings, that there is an increase in construction cost of 47 % from building designed with soil type B and Importance class II to building designed with soil type D and Importance class IV.

Also, can be observed that, as buildings are higher and have more storeys, the increase in construction cost becomes bigger too, from building designed with soil type B and Importance class II to building designed with soil type D and Importance class IV,

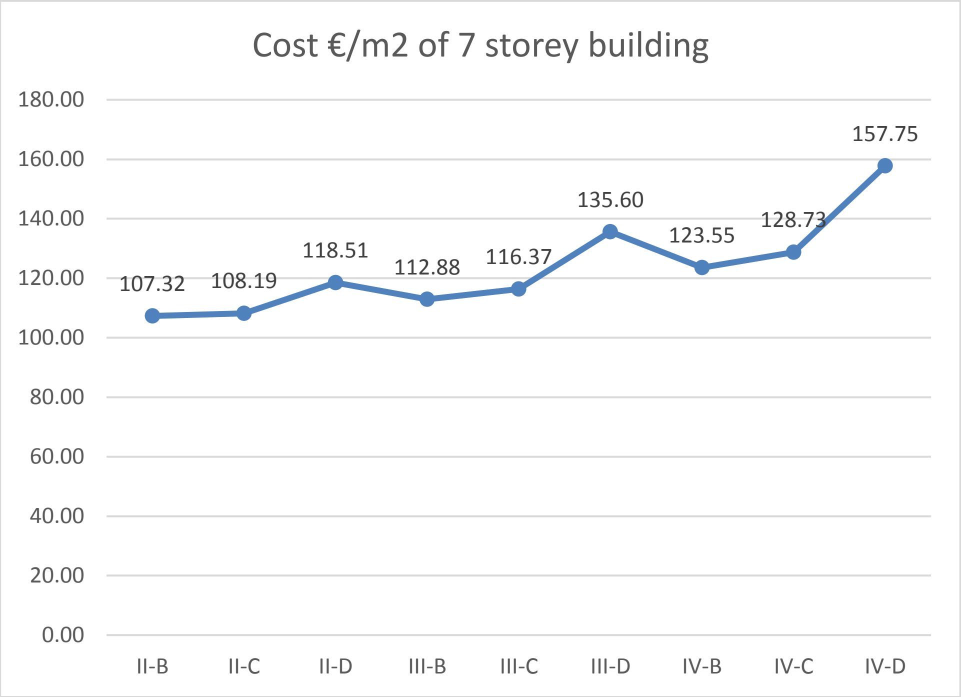


Figure 26. Construction cost graph for different 7 storey buildings

CHAPTER 5

CONCLUSIONS

5.1 Conclusions

In this thesis, using the Eurocode standards it was evaluated the effect of Importance Classes and soil types on seismic behavior of buildings. Three importance classes II, III and IV were used for investigation. Regarding the soil types, soil of category B, C and D were used for investigation in respective to each Importance class. The results related with reinforcement required for each structural element were used for comparison. Finally, an analysis of building cost was examined and used for comparison between the structures.

In accordance with the performed analysis, it can be concluded that a change in soil types from B to D and a change in occupancy of the building from II to IV, significantly affects the sesismic performance of the strucuture. The demand for reinforcement of structural elements tends to increase with 5.76 % from 4-storey building designed for II-B to 4- storey building designed for II-C and 20.33 %% from 4-storey building designed for II-C to 4-storey building designed for II-D. The maximum reinforcement demand for 4-storey building was required for building designed for IV-D with an increase of 109.8% from that of II-B.

The demand for reinforcement of structural elements tends to increase with 2.34 % from 7-storey building designed for II-B to 7-storey building designed for II-C and 29.96 % from 7-storey building designed for II-C to 7-storey building designed for II-D. The maximum reinforcement demand for 7-storey building was required for building designed for IV-D with an increase of 134.96 % from that of II-B.

Clearly, the study indicated that soil types and Importance classes are very important factors that must be considered in the cost estimation. The cost estimation process has to be done by considering aspects of the soil conditions where it will be built, and the occupancy that building will have. These considerations are required to make sure that the building is designed safely from the aspects of structural resistance to earthquakes and gravity loads, as well as being efficient in terms of its economic aspect.

Furthermore, the total cost required will increase in direct proportion with softer soil conditions and building occupancy categories. Both these conditions show a significant impact on the on the overall increase of the total building cost.

5.2 Recommendations for future research

This study can be possibly extended in the future as follows:

- Although a low and mid-rise buildings were used in this analysis as this types are more built in Albania, from recent investments and maybe even more so in the future we see that there is a rapid increase in trend of constructing high-rise buildings. Modeling, analysis and design of high-rise buildings can be done to investigate and compare in terms of seismic response and cost of construction.
- In this study, building model being symmetric in plan and regular in elevation was used. However, studies can be enhanced for buildings being asymmetric, and irregular in plan and elevation. Asymmetric buildings are more commonly encountered because of land positions to build, and irregular in elevation, as the first two floors usually be higher because of their designation for commercial use.
- In this study, equivalent linear static analysis of lateral force method has been used. It is used behavior factor q in design spectrum to take into account the inelastic response of the structure. However, for even closer realistic results a nonlinear static pushover analysis can be carry out, considering geometrical and material nonlinearities of the structure.

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