Effect of location of thickened concrete slabs and type of material on the seismic behavior of structure buildings

دراسة تأثيرمكان وسمك البلاطات الخرسانية ونوع الخرسانة المستخدمة علي السلوك الزلزالي للمباني الخرسانية

by

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Abstract

The design against lateral force (wind load and seismic load) is mandatory for high rise buildings. There are many factors that should be considered while estimating the seismic force that shall be applied to a building as well as certain checks to ensure building safety against that seismic force.

Many structural engineers attempt to keep the seismic drift within the allowable value given by code of practice. The common problem is the seismic drift exceed the allowable values. Different solution is used to overcome this issue such as increasing in shear wall size, use larger size of beams, use thickened slab, use bracing, use advanced mass damper etc..

Practically, the idea of use thickened slab appears to author while design building with transfer slab. The more thickened transfer slab, the less seismic drift is obtained. This idea may not studied before from this point of view.

Thus, this research focuses on the estimation of seismic behavior of concrete structures by performing many structure models with different heights at moderate seismic zones. The seismic force in this research is based on UBC97 code of practice. All the structural models have been analyzed and compared in similar circumstances.

The research also attempts to find a practical solution which doesn't need advanced technology by increasing the slab thickness in certain floors to reduce the seismic drift.

The increase in slab thickness causes a complete change in all structural analysis results of a building (the total displacement and the total base shear). This research covers the results of increasing the slab thicknesses to obtain a good comparison between all models.

Results show that the thickened slabs is good solution for seismic drift. The thickened slab should be located at certain floors to get the optimum reduction in seismic drift as well as the seismic drift shape of the structure.

On the other hand, another approach using Ultra High Performance Concrete (UHPC) is used in certain floors without changing the slab thicknesses to observe the effect of using UHPC on the seismic behavior of structural building.

Results of second approach show using of UHPC has a minor effect on the seismic behavior compared to results using the thickened slabs.

الملخص

يعتبرالتصميم ضد القوي الجانبية (الرياح والزلازل) من أساسيات التصميم الإنشائي للمباني العالية. وهناك عوامل عديدة لإستنتاج قوي الزلازل المؤثرة علي المبني قيد الدراسة للتحقق من كفاءة المنشأ عند تعرضه لمثل هذه الهزات.

يسعى العديد من مهندسي التصميم الإنشائي الي تحقيق قيمة الإنزياح الزلزالي ضمن القيم المسموح بها في الأكواد الهندسية ويوجد حلول شائعة لتقليل قيم الإنزياح الزلزالي مثل (زيادة أبعاد حوائط القص - زيادة أبعاد الجسور الخرسانية المستخدمة - زيادة سمك الأسقف الخرسانية المستخدمة - إستخدام عناصر متقاطعة بشكل قطري تربط بين الأعمدة وحوائط القص - إستخدام تقنيات متقدمة مثل المخمدات الكتلية - ويوجد أيضا حلول اخري).

عمليا ، فإن الفكرة في إستخدام البلاطات ذات السماكات الأكبر ظهرت لدي الباحث عندما قام بتصميم أحد المباني ذات نظام البلاطات السمكية الناقلة للاحمال عند وجود أعمدة مزروعة. لقد وجد أنه كلما زاد سمك تلك البلاطات السميكة فإنه يقل بالتبعية قيم الإنزياح الزلزالي . هذه الفكرة ربما لم يتم تغطيتها في أبحاث سابقة بهذا الخصوص.

وعليه ، فإن هذا البحث يركز علي إستنباط سلوك المباني الخرسانية عند تعرضها لقوي جانبية وذلك عن طريق نمذجة العديد من المباني ثلاثية الابعاد وذات إرتفاعات مختلفة ويطبق عليها لشدة زلزالية متوسطة .

تم إستخدام الكود الأمريكي UBC97 في أعمال التحليل وإستنتاج القوي الزلزالية في هذا البحث .

يهدف أيضا البحث الي إيجاد حل عملي ولا يحتاج إلي أي تكنولوجيا متقدمة لتقليل قيم الإنزياح الزلزالي عن طريق إستخدام بلاطات خرسانية ذات سمك اكبر علي إرتفاعات محددة حيث يتم التحقق من المكان الأمثل لتحقيق أقل قيمة من قيم الإنزياح الزلزالي.

و حيث أن زيادة سمك الاسقف الخرسانية يتبعه تغيير في كامل نتائج التحليل الإنشائي للعناصر الرأسية والأفقية (الإزاحة الكلية للمبني و مقدار قوي القص القاعدي المؤثر عن سطح الارض) ، فقد قام البحث بتغطية نتائج زيادة السمك الخرساني في بعض الاسقف ليكون هناك مقارنة واضحة بين حالات الدراسة.

وقد أظهرت النتائج ان استخدام بلاطات ذات سمك أكبر يعتبر حل جيد وفعال لتقليل قيم الازاحة الجانبية للمباني . كما وجد أن المكان المستخدم للبلاطات ذات السمك الاكبر يجب ان تقع في الربع الثاني من المبني لتحقيق أقل إنزياح زلزالي . وتبين أيضا أن قيم وشكل الازاحة الجانبية للمباني تعتمد وبشكل رئيسي علي مكان البلاطات ذات السمك الأكبر.

من ناحية اخري ، تم دراسة مقترح ثاني يعتمد على تثبيت نفس سمك المقطع الخرساني ولكن بإستخدام خرسانة فائقة الاداء عند بعض البلاطات للوقوف علي مدي تأثير نوع الخرسانة المستخدمة علي السلوك الزلزالي للمباني العالية.

وبخصوص تأثير استخدام الخرسانة فائقة الاداء فان النتائج اظهرت ان لها تأثير بسيط علي السلوك الزلازلي وذلك بالمقارنة بالنتائج الواردة عند إستخدام بلاطات ذات سمك أكبر.

Acknowledgments

It was a significant challenge to prepare this dissertation. I would like to express my sincere gratitude to all people supporting and encourage me to complete high graduate study.

I would like to express my sincere appreciation and gratitude to my dissertation supervisors, Dr. Gul Ahmed Jokhio and Prof. Abid Abu-Tair for their continuous support, detailed review of my dissertation, rapid feedbacks during this period which has improved the work and quality of the dissertation.

I dedicate this work to my wife who supported me to accomplish this work and for her encouragement to achieve my goals.

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Chapter 1 Introduction

1.1 General

Number of high rise building is increasing due to human needs and lack of open land in crowded cities. Population growth in Dubai one of the fastest rates all over the world. The total population increased from 200 thousand in 1975 to more than 2.3 million persons at 2015. Annual growth rate around 8% which is one of highest rate all over the world(Elessawy, 2017), the total built up area of Dubai city increased from 40 km^2 at 1971 to 109 km^2 at 1985 to 977 km^2 at 2015. The demand of high rise buildings in UAE are increasing annually.

Material used in high rise building is reinforced concrete could be reinforced concrete, steel structure, precast concrete, Etc. with different structural systems, the selection of an appropriate system depends on many variables such as availability of material, environmental parameter, sustainability requirements, serviceability requirements.

The goal of seismic design is basically to safeguard against major structural failure and losses of life, not to limit the damage or to maintain function (UBC97, 1997). Safety against collapse is the most important objective on seismic design of building , all building should have an enough margin to avoid collapse while subjected to an earthquake.(Shi *et al.*, 2011)

Structural design of high rise buildings mainly aims to reduce the horizontal movement of the building in case if any lateral force is applied on the building. This research introduces a simple way that could be used to decrease the lateral movement of stories in high rise buildings by using thickened slab on specific locations to eliminate the seismic the horizontal movement of the building.

Reducing the lateral movement of a building will lead to reducing internal stresses in all the vertical members which in turn results in attaining smaller sections compared to others with large lateral movements. Consequently, this process will reduce the total cost of the building and give the ability to architectural engineers to use more spaces to get more benefits from the building.

Estimation of seismic forces relies on many factors (ductility of the system, time period of the structure, seismic zone, seismic profile type, importance factor and the total weight of the structure). These factors will be explained in details in the following paragraphs.

1.2 Codes of practice

Many international and local codes of practice could be used to estimate the seismic force such as UBC 97, ASCE07, IS, EGP, Mexico codes, etc. Many studies have been done to compare between UBC97 and other codes to identify the differences between codes. A study done on 1999 compared between UBC97 and Mexico code in terms of seismic requirements and the author concluded that the design of any structure according to the provisions of UBC97 would satisfy the requirement of the Mexican code (Tena-Colunga, 1999). Another paper studied the similarities and differences between Saudi Building Code (SBC) and UBC97 and they stated that the both are similar in recognizing that all areas in same zone doesn’t have the same ground peak acceleration since SBC introduce S_1& S_s coefficients while UBC based on seismic zone factor (Z). They stated also selection of structure analysis procedure (estimation of base shear, seismic drift, acceptance criteria of drift, etc.) are different between the two codes .In UBC based on seismic zone while SBC based on seismic design category (SDC).(Ismaeil, Nazar and Ismaeil, 1997).

1.3 Seismic zone and ground motion

UBC 97 classifies each site to a seismic zone in accordance with the seismic maps. Every site is assigned to seismic zone factor (Z).

Seismic zone factor (Z) is the expected acceleration that could be subjected to a building (a percentage of ground acceleration). UBC shows the seismic zone and the corresponding peak ground acceleration. The high seismicity zones are zone 4 while the lowest zone is zone 0 as shown Table 1.3.1

The (Z) factor is the effective zero period ground acceleration on soft rock that has probability of 10% on exceeding in 50 years.(Bachman and Bonneville, 2000)

Since no local code of practice is announced, a very important research carried out to estimate seismic hazard assessment of the United Arab Emirates and its surrounding areas based on a probabilistic approach. They stated that the UAE has law to moderate seismic hazard levels, however high seismic activity was noted in northern part of the UAE. The Peak Ground Acceleration (PGA) on bed rock ranges between 0.22g for a return value of 475 years to 0.38*g for a return value of 1900 years. This magnitude of PGA can cause structural damage to key structure and lifeline systems. Therefore, they highly recommend that any major structure in this region shall be designed against earthquake effect. (Abdalla and Al-Homoud, 2004)

Seismic zone	Seismic activity	Acceleration
1	Low seismic zone	0.075 * g
2	Moderate seismic zone	(0.15 : 0.20)*g
3	High seismic zone	0.30* g
4	Very high seismic zone	0.40*g

Table 1.3.1 Seismic zone and corresponding ground acceleration

1.4 Soil profile types

Soil type has a great effect on the estimation of seismic force that the soil transfer the kinetic energy generated on bedrock. A study on three types of midrise moment resisting building frames including 5, 10, and 15 stories with three types of soil carried out to study the effects of the type of soil on the superstructure using FLAC 2D software(Tabatabaiefar and Fatahi, 2014). The Authors stated that dynamic soil-structure interaction in terms of seismic design of the structure has a significant effect on its seismic response.

Soil classification (S_A, S_B , S_C , S_D , S_E and S_F) is selected based on the shear wave velocity , standard penetration test (for cohesion less soil layers) , undrained shear strength for the top

30.48 m of soil profile (UBC97, 1997)which could classified as **Error! Reference source not found.** as below

Soil profile type	Soil profile name/generic description	Average soil properties for top 100 feet (30480mm) of soil profile		
		Shear wave velocity (m/s)	Standard penetration test (SPT) (blows/foot)	Undrained shear strength, (kpa)
S_A	Hard rock	>1500	---	---
S_B	Rock	760 : 1500	---	---
S_C	Very dense soil and soft rock	360 : 760	>50	>100
S_D	Stiff soil profile	180 : 360	15 : 50	50 : 100
S_E	Soft soil profile	<180	<15	<50
S_F	Soil vulnerable to potential failure or collapse or Peats / organic clay with top 30480 mm or very high plasticity clays.			

Table 1.4.1 soil profile types (UBC97, 1997)

1.4.1 Shear wave velocity

Shear wave could transferred through soil profile, the velocity of the wave is higher for hard soil and lowest for loose soil. One of advantage of this test that it measures behavior of subsurface better than data collected by point location but it is high cost and need experience. Shear wave velocity could determine using the following formula:

$$vs = \frac{\sum_{i=1}^{n} d}{\sum_{i=1}^{n} (\frac{d}{v})} \qquad \text{Equation 1.4-1}$$

Where

v_s : shear wave velocity in soil profile in (m/s)

d_i: thickness of the layer in (m)

v: shear wave velocity in the layer in (m/s)

1.4.2 Standard penetration test (SPT)

SPT is common test used to explore all soils and rock layers, SPT test is field test and is carried out by using a hammer falls free fall from certain height, certain settlement is determined before test and number of blows are counted versus in order to reach this settlement value. The more dense soil profile the higher number of blows. The advantage of SPT is the ease of the test and low cost of it but on the other hand it is limited to explore all the soil profile.

1.4.3 Undrained shear strength

This test carried out for cohesive soil (silt and clay). The test based on applying effective normal stress to the specimen to get the shear stress of the soil using Mohr circle.

1.5 Seismic performance evaluation:

There are few method for evaluation of seismic forces:

- Response spectrum analysis (RSA).
- Time history analysis (THA).

Response spectrum analysis is a linear dynamic statistical method that could measure the contribution from each natural mode of vibration to indicate the most likely maximum response of an elastic structure.

Time history analysis (THA) is a more accurate method that based on applying a record of historical earthquake. This record is the relation between ground acceleration shaking force and the time. This method evaluates the response of the structure at each step of the load application and then all steps are combined by certain method as will be discussed in next chapter. Unfortunately historical records are available for few cities but it is not possible to get this records for every city. Furthermore, THA dynamic load has a peak value occurs on a certain time it is not recommended to estimate the behavior of any structure using this peak value since the response shall be based on the full record of earthquake load. For example, if two structure building are constructed on same seismic zone, the seismic behavior of both could be different that because of different configuration of building and building structural system.

1.6 Seismic parameter Ca & Cv

Since motion occurs on the bed rock, this force is transferred through the soil to reach the surface. Seismic parameters to be adopted to model the acceleration transferred to subsurface, we could name it as acceleration (Ca). (Ca) value based on two variable (the seismic zone, the soil profile type).

Furthermore, there is another parameter based on both two previous parameter but it consider the velocity of waves that will transferred to surface from the origin of motion on bedrock. This parameter is Cv

For seismic zone 4, Ca & Cv parameter are not only based on seismic zone and soil profile but also based on the distance between the location of the desired building and the near source of earthquake.

1.7 Time period

Time period is the elastic fundamental period of vibration of a structure. There are many ways to estimation time period (T) such as :

- Simulate the building using prototype technique and investigate all desired data needed for design proposes.
- Use historical data observed from existing building at same city of the desired building.
- Use formulas mentioned on codes.

UBC states two ways to investigate the fundamental period as follows

1.7.1 method (A) - Empirical method

UBC states an empirical equation to estimate the time period as follows

$$T = Ct * H^{\frac{3}{4}} \qquad \textit{Equation 1.7-1}$$

While :

Ct: empirical factor based on structure system

= 0.0853 for steel moment-resisting frame.

= 0.0731 for concrete moment-resisting frame

= 0.0488 for other buildings

H: height of the building in meters

A Study done to investigate the accuracy of this empirical equation in Taiwan, the researchers observed 21 building structure with different heights and different plan layout and they found that the height of the building plays very important role compare to the ratio between horizontal dimensions on predicting the fundamental period of structure. (Hong and Hwang, 2000)

1.7.2 Method B

A more realistic method could be used to estimate the fundamental period of the structure since it is based on the dynamic properties of the structure, deformation characteristics and applied lateral forces. Major of design engineer relies on the empirical equation since it is simple and give reasonable values.

1.8 Ductility of reinforced structure:

Ductility of a reinforced concrete structure (R) is defined as the ability of the structure to resist the large deformation caused by lateral load using the capacity of the section to absorb energy by hysteretic behavior.(Bungale S. Taranath, 2010)

Consider a concrete frame beam as a part of the lateral load resisting system. One end of this beam will try to shake upward (due to upward movement) and down ward (due to down ward movement) and this movement will occur alternately due to the cyclic nature of the load. As a result of this lateral deflection, the beam will be divided to (virtually) many segments held together by reinforcement and concrete cage. Figure 1.8.1

If the beam cracks due to this movement, all shear force will be transferred by longitudinal and transverse reinforcement until crushing of concrete section (depends on rapture modulus of concrete). After crushing, the section could still resist and absorb more energy due to the confinement of stirrups with the longitudinal reinforcement.

This phenomenon could be summarized in that the ductility is the nonlinear behavior of the reinforced concrete material that could be used to absorb the hysteretic seismic cyclic load

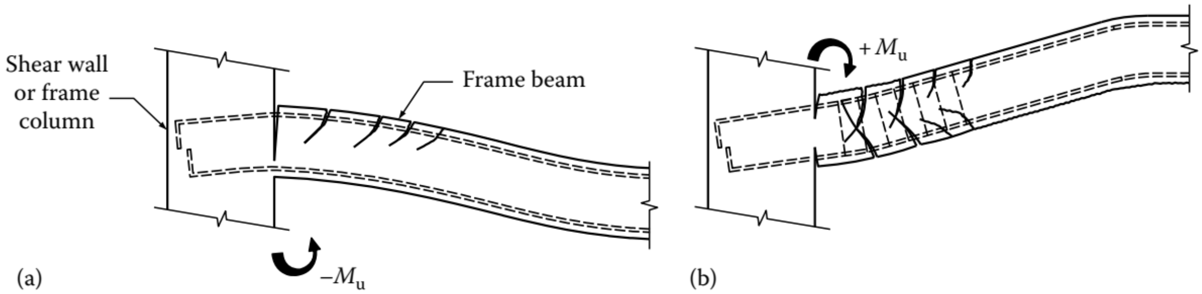


Figure 1.8.1 frame beam subjected to cyclic load(Bungale S. Taranath, 2010)

Consider observing the deflection of the previous beam subjected to cyclic load, the behavior of the beam could be plotted as Figure 1.8.2.

The beam section will start to elongate until reaching yield point (Δ_y) and beam still subjected to the load, the beam reach the maximum point of deflection (Δ_m) and then the ultimate point before rapture (Δ_u). This margin between start of loading until ultimate point could be defined as ductility of the beam. Furthermore, the design limit is yielding point divided by factor of safety.

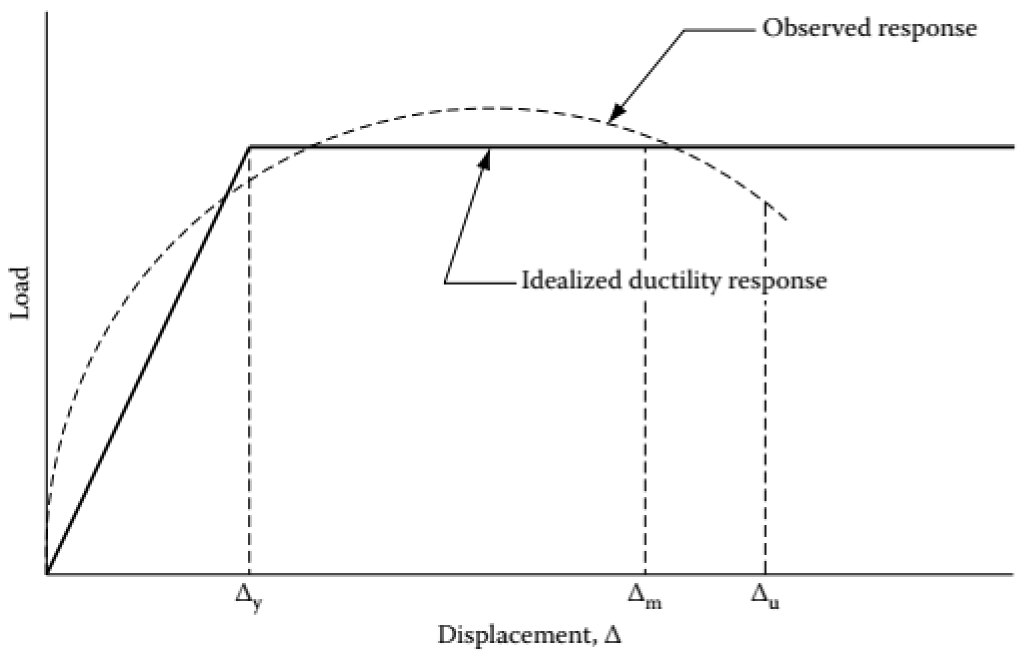


Figure 1.8.2 Ductility model (Bungale S. Taranath, 2010)

1.9 Minimum design lateral load

The design base shear is the maximum expected lateral force on the base of the structure due to seismic activity. The design base shear based on many variable stated on V = $\frac{Cv*I}{R*T}*w$ Equation 1.9-1.

The importance of calculation of design base shear that designer should ensure that the strength level of the structure shall be more maximum design base shear.V max =$\frac{2.5*Ca*I}{R}*w$ Equation 1.9-2

The total design base shear in could be determined from the response spectrum curve shown on Figure 1.9.1 and the curve could be represented on equations as follows:

$V = \frac{Cv*I}{R*T}*w$ *Equation 1.9-1*

$V\,max = \frac{2.5*Ca*I}{R}*w$ *Equation 1.9-2*

$V\,min = 0.11*Ca*I*w$ *Equation 1.9-3*

While:

V: design base shear (KN)

I: importance factor

R: ducility factor

T: fundamental time period

Cv & Ca : seismic factor related to seismic zone and soil profile type

W : seismic weight (total permanent dead load + 0.25% of Live load)

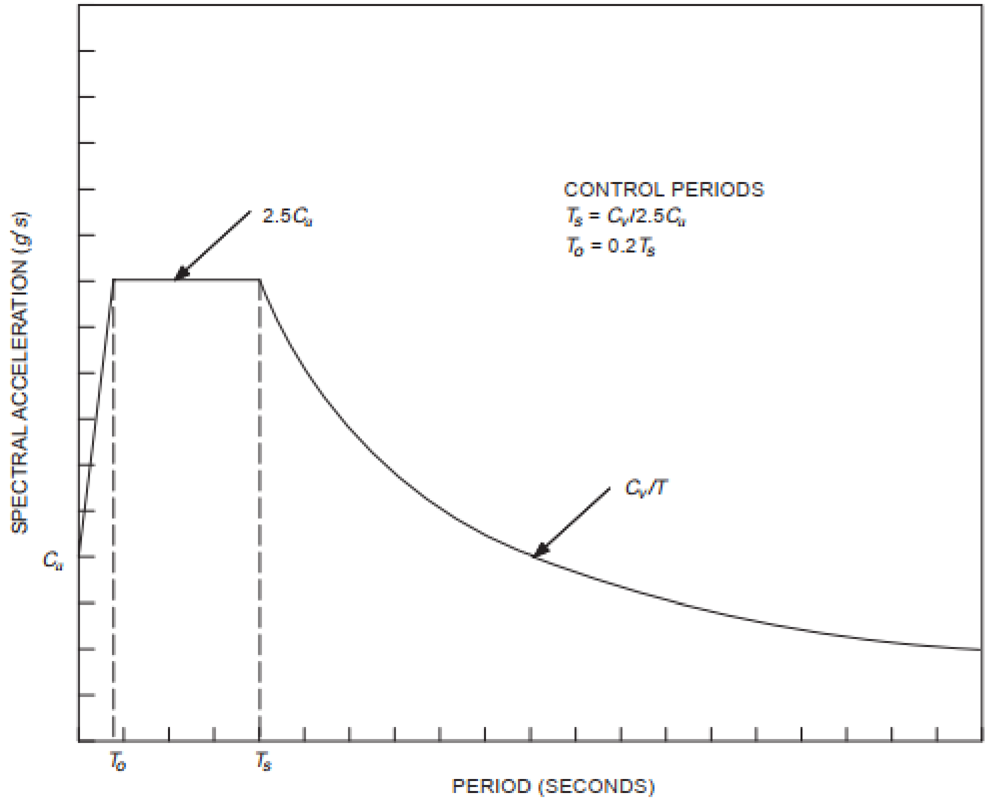


Figure 1.9.1 response spectrum curve

1.10 Research significance:

The seismic behavior of a building depends on may factors such as soil profile , seismic zone that where a building will be located, importance of building , lateral load resisting system type , time period of structural , distribution of shear wall and column along the building , own weight of structural and applied live loads.

Seismic behavior defined as the response of structure to seismic drift, shear force applied, p-delta effects, combination of modes.

This research focus the on the effect of use thickened slab and usage of ultra-high performance concrete on the seismic behavior. Many designer face problem of lateral drift that exceed the allowed value, this research tries to find a simple way to reduce the seismic drift of a structure.

1.11 Research scope:

The challenge in this research is to create 3D models without any type of irregularities with the same plan layout and the same vertical element distribution and apply the same lateral loads on each model to estimate the predicted behavior of the structure without any torsional effects.

The typical main slab thickness is 20 cm, the thickened slab is (40cm) for two times the slab thickness and (60cm) for three times the slab thickness … etc.

The difference between models is only the location of the thickened slabs. The study is based on grouping the structure into 4 quarters or lumped mass into one slab located on 1/3 or 2/3 of total building height on separated model and then extract the results from each model to compare between all models and show the conclusion.

1.12 Research objective:

Majority of structural engineers use Post-tensioned slabs for high rise building as it allows the use of thinner sections compared with traditionally reinforced slabs disregarding its role in reducing the seismic drift. To reduce seismic drift, slabs could be mixed between traditionally reinforced concrete and post-tensioned slabs, which is the main objective of this research.

As long as slabs are used as horizontal elements carried on vertical elements, slabs also act as a diaphragm which will transfer and distribute the horizontal force to all vertical elements. Basically, if this diaphragm is rigid, it will tend to absorb the energy caused by earthquake and reduce the seismic drift of buildings.

Majority of research is focused on estimating and comparing between two different structural systems such as (the study on the behavior of flat slab and solid slab against seismic load) but there is a research gap in the use the same structural system with different configuration such as slab thickness or usage of larger beam sizes. Thus, this research aims to study the performance of the same structural system with different configurations and to estimate the structural behavior in all cases and then conclude the optimum location of rigid diaphragm to get the minimum drift.

The subsequent chapters display comprehensive summary of dynamic analysis concepts, the previous researches conducted for lateral displacement and story drift of different structural systems in different seismic zone and results of this research.

Chapter 2 Literature review

2.1 *Introduction*

Literature review is focusing on brief on three main topics:

1. Introducing of some information about lateral force resisting system as stated on codes and some recent studies related to the structure system used in this research.
2. Studies on dynamic analysis in codes and some related studies to this research topic.
3. Recent studies on comparative between different systems to show there is no recent studies focus on this research topic.

2.2 Structural systems types*:*

Lateral force resisting systems is the system used to resist the any lateral load subjected to a structure. UBC 97 distinguishes between six-types of structural system (UBC97, 1997).

1. Bearing wall system.
2. Building frame system.
3. Moment resisting frame system.
4. Dual system.
5. Cantilever column building frame system.
6. Shear wall frame interaction system.

There are many differences between this system such as type of vertical elements (core wall or columns) and some conditions related to ductility requirement shall be applied to selected system. For simplification, selection of the structure system based on the expected behavior of the lateral force resisting system and the expected ductility that any system could reach. Since the system used on this research is Moment resisting frame system, the research will discuss this system is details on the following paragraphs.

2.3 Moment resisting frame system.

Moment resisting frame systems could be defined as a full space frames consisting from shearwall and beams / slabs providedto resist the lateral loads . Space frame shall be used to resist both garvity and lateral load as shown onFigure 2.3.1. A moment resisting frame could be classiffied into three catagories :

1. Ordinary moment resisting frame (OMRF).
2. Intermediate moment resisting frame (IMRF).
3. Special moment resisting frame (SMRF).

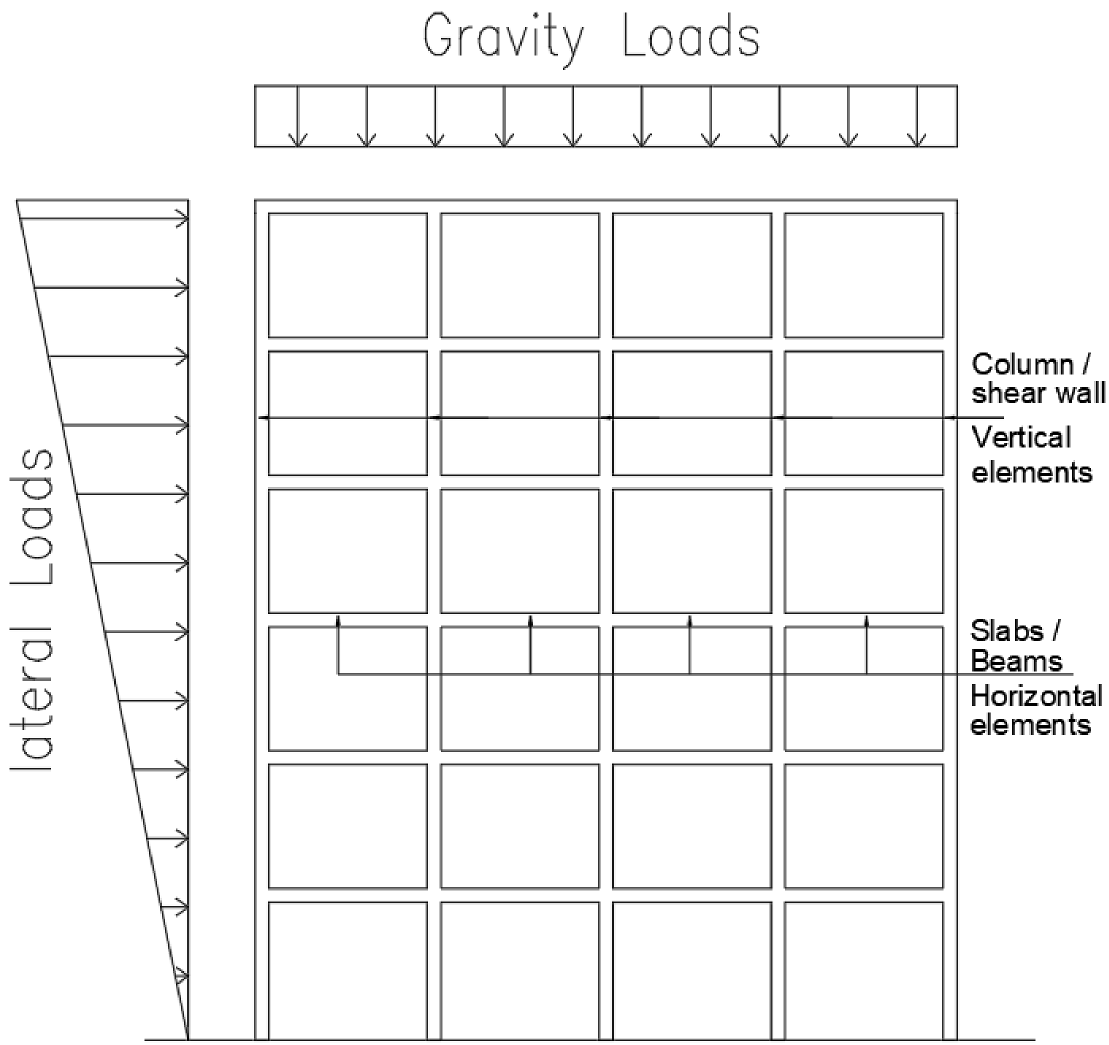


Figure 2.3.1 Moment resisting frame

Furthermore, Each sytem has many limitation and requirements of structural deatialing of reinforecement, ductilty details for intermediate moment resisting frames are shown on the follwing figures to state and obsever the meaning of ductlity details. coulmn details as shown in Figure 2.3.2 , beam details as shown in Figure 2.3.3 and slab details as shown in Figure 2.3.4. These details to achieve the ductlity requirment of the lateral forces resisting system and it is importnant to mention that the ductility details for ordinate and specia; moment reisiting frame are different. Addittionally, without applying those structure details, system will not acheive the desired ductility. therefore, each system has its own value of ductiliy factor (R) .

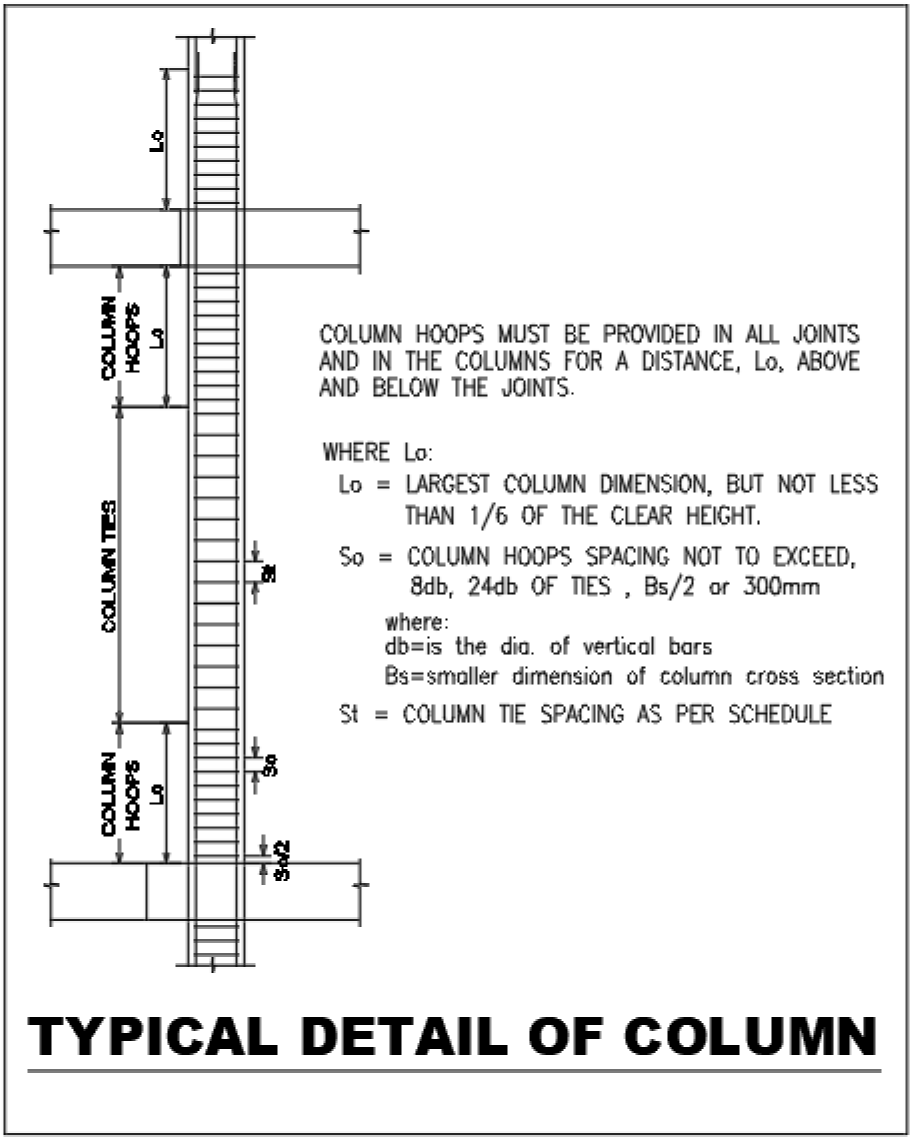


Figure 2.3.2 typical reinforcement detail of column in MRF system

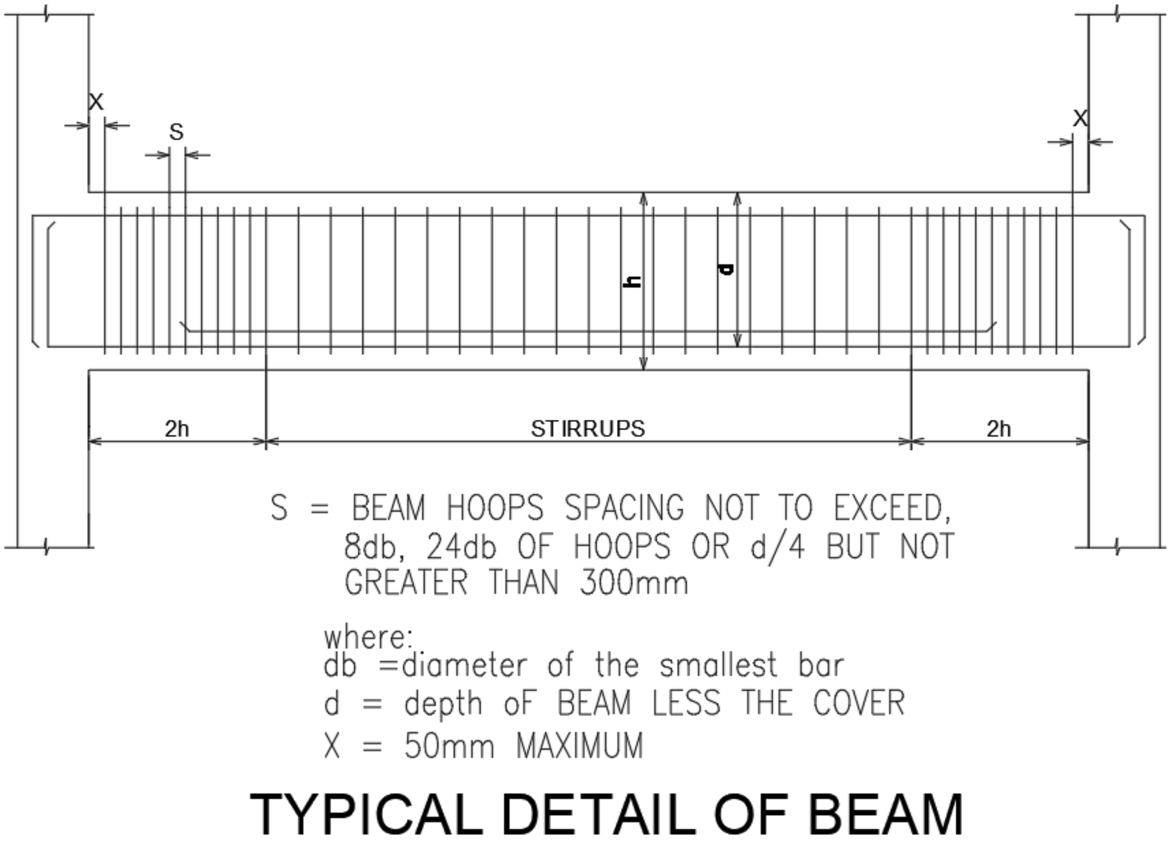


Figure 2.3.3 typical reinforcement detail of beam in MRF system

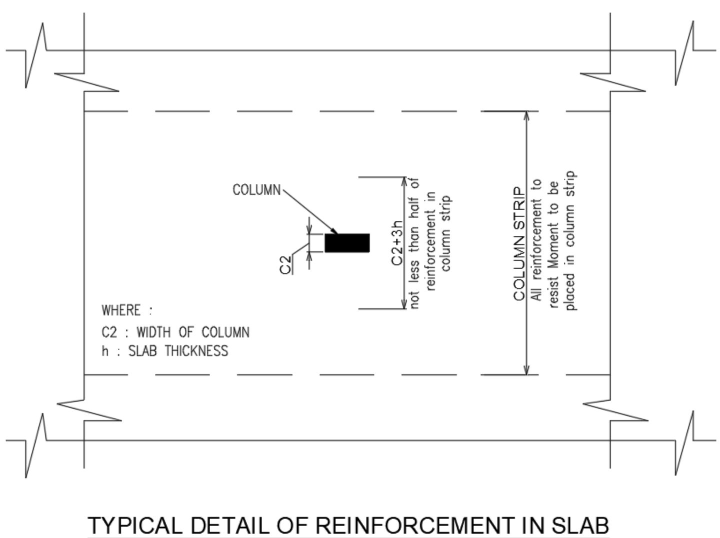


Figure 2.3.4 typical reinforcement detail of slab in MRF system

A study on assessment ot moment resisting frame infilled with masonary work done in tyurkey to verfiy the performance of the MRF and by observing three building had been damaged by recent earthquake, the researchers developed new method to predict and assess the exiting building that designed before the adopdation of seismic codes. (Erduran and Yakut, 2007) however, major of building recently designed does't consider the in fill material (block wall / partition wall) as a structure element could be a part of lateral load resisting system because of arch opening but the resreach and actual behaviour of the exising stsructure show that designer could use the in fill block work as a part of resisting system.

Selection of which type of this three is based on the seismic zone (ACI Committee 318, 2014) where is the structure locate. This could be summorized as follows

Ordinary moment resisting frame (OMRF) is limited to zone 0, 1

Intermediate moment resisting frame (IMRF) is limited to zone 2A, 2B

Special moment resisting frame (SMRF) is limited to high seismic zone 3, 4

A study on effect of ground motion acceleration on the residual inter story drift in moment resisting concrete frame building. The study covered 6, 9 and 12 story building in three different seismic zones. All Structure model considered geometric and material non-linear behavior of the structure using Ruaumoko 3D software. The research conclude that there are some structure parameter such as number of story, ductility level of the MRF system and post yielding stiffness ratio have effect on the residual inter story drift of concrete frame building(Valenzuela-Beltrán *et al.*, 2020). They found that the magnitude of residual inter story drift calculated in this study is 1% close to the collapse limit. Therefore, they stated that those buildings are suffering large permanent deformation post to earthquake which in sequence lead to high repair cost.

2.4 *Dynamics of structure*

This paragraph consists of two main topics

1. Basic background concept of structure dynamics.
2. Literature review on the structure dynamics in codes.

Using structure dynamics analysis in the study is the key to predict the behavior of the structural building due to lateral load. The design base shear calculated through V = $\frac{Cv*I}{R*T}*w$ Equation 1.9-1 shows that the design base shear is proportional with the weight of structure and is inversely proportional with the time period of structure. This is the static procedure of calculation the base shear and in sequence the displacement and inter story drift of the structure but when using dynamic analysis, the more weight in slab is considered is adding more stiffening force to the structure to resist the applied lateral load.

The sub-sequence paragraphs will illustrate the equation of motion for single / multi degree of freedom and the factors affecting on it.

2.4.1 Single degree of freedom system

This system consists of a single degree of freedom subjected to external force$\boldsymbol{p}(\boldsymbol{t})$. The force acts on the lumped mass which is mainly located on the slab while mass of the column is disregarded. The system has a damper to absorb the energy

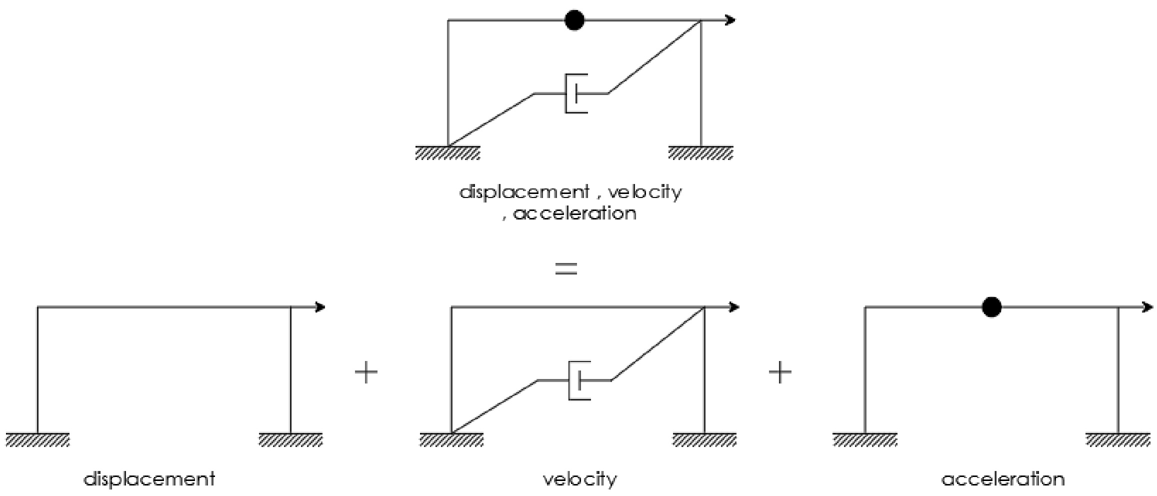


Figure 2.4.1 After applying the force, the system tends to vibrate with a certain acceleration and velocity and to produce certain displacement(Chopra, 2012).

The general equation could be expressed as follows:

$$\boldsymbol{m\ddot{v}} + \boldsymbol{c\dot{v}} + \boldsymbol{kv}^{\cdot} = \boldsymbol{p}(\boldsymbol{t}) \qquad \textit{Equation 2.4-1}$$

Where

$\boldsymbol{m}$: Mass of system

$\boldsymbol{\ddot{v}}$: Acceleration of system

$\boldsymbol{c}$: damping ratio of system

$\boldsymbol{\dot{v}}$: Velocity of system force

$\boldsymbol{k}$: Stiffness of system

$\boldsymbol{v}$: Displacement of system

$\boldsymbol{p}(\boldsymbol{t})$: External applied force

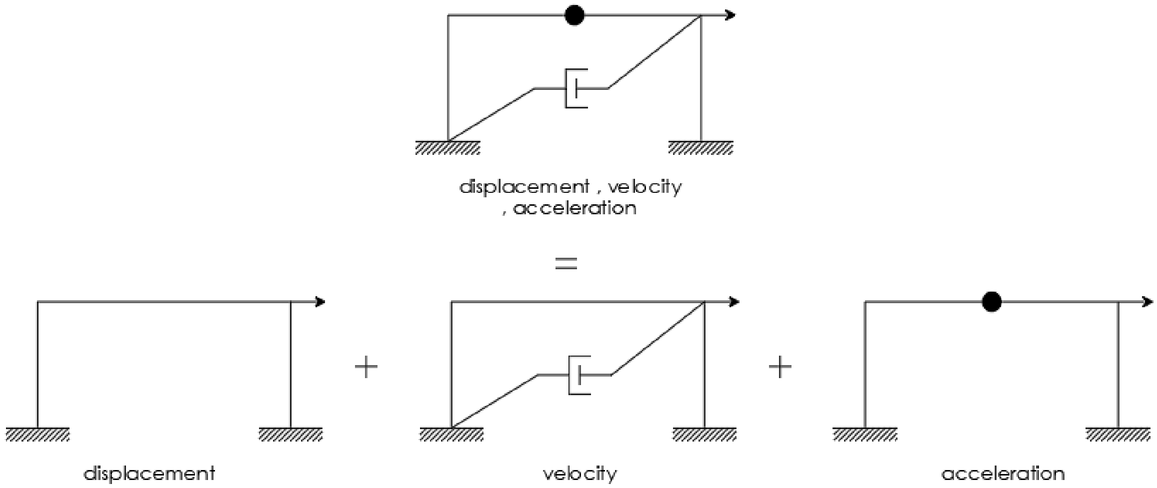


Figure 2.4.1 equation of motion component

The system shown on

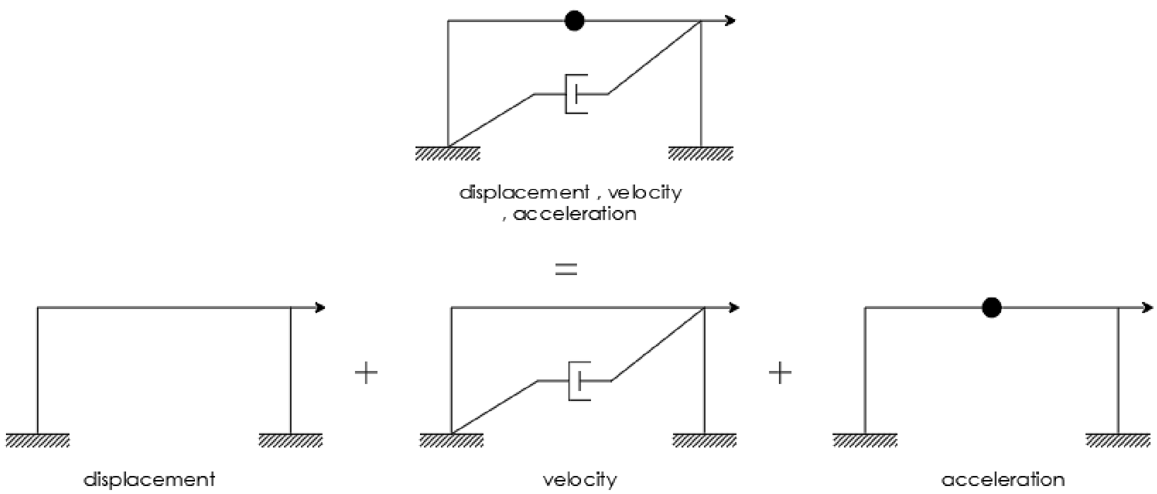
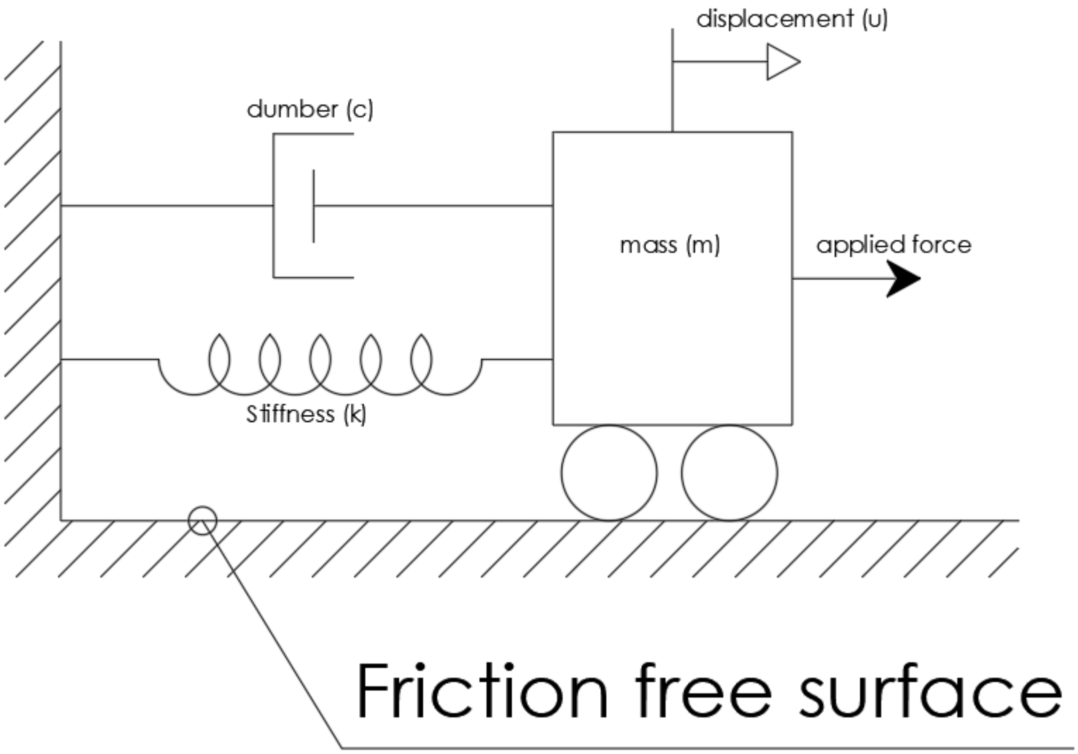


Figure 2.4.1 is used to analyze and predict the behavior of few structure such as silo, one story building, Etc.

Another explanation of equation $\boldsymbol{m\ddot{v} + c\dot{v} + kv^{\cdot} = p(t)}$ Equation 2.4-1 could be expressed on free body diagram of single degree of freedom as shown on Figure 2.4.2



Figure

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2.4.2 Simple system (two story shear building)

System consist of two story shear building Figure 2.4.3 the equation of motion could be applied to this system with format of matrices as below

$$\boldsymbol{m_j \ddot{v}_j + c_j \dot{v}_j + k_j v_j = p_j(t)} \qquad \textit{Equation 2.4-2}$$

Where

$\boldsymbol{m_j}$: Mass of system at story (j)

R
E
F

$\boldsymbol{\ddot{v}_j}$: Acceleration of system at story (j)

$\boldsymbol{c_j}$: damping ratio of system at story (j)

$\boldsymbol{\dot{v}_j}$: Velocity of system force at story (j)

R
e
f
8
5
1

k_j : Stiffness of system at story (j)

v_j : Displacement of system at story (j)

$p_j(t)$: External applied force at story (j)

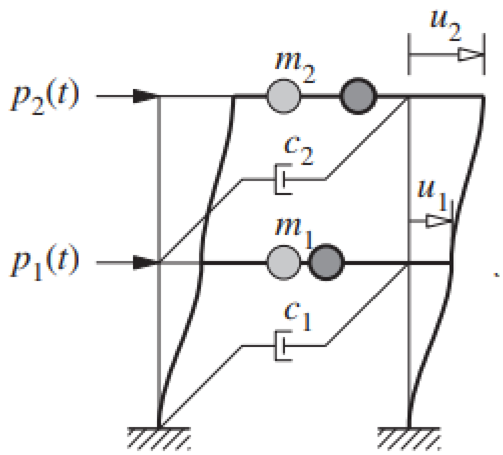

Figure 2.4.3 two story shear building configuration

This equation can also be formulated in the matrix form as below

$$\begin{bmatrix} m_1 & 0 \\ 0 & m_2 \end{bmatrix} \begin{bmatrix} \ddot{v}_1 \\ \ddot{u}_2 \end{bmatrix} + \begin{bmatrix} c_1 + c_2 & -c_2 \\ -c_2 & c_2 \end{bmatrix} \begin{bmatrix} \dot{v}_1 \\ \dot{u}_2 \end{bmatrix} + \begin{bmatrix} k_1 + k_2 & -k_2 \\ -k_2 & k_2 \end{bmatrix} \begin{bmatrix} v_1 \\ v_2 \end{bmatrix} = \begin{bmatrix} p_{1\,(t)} \\ p_{2\,(t)} \end{bmatrix} \qquad \text{Equation 2.4-3}$$

Where

m_1 : Mass of story 1

m_2 : Mass of story 2

$\ddot{v}_1$: Acceleration of story 1

$\ddot{v}_2$: Acceleration of story 2

c_1 : damping ratio of story 1

c_2 : damping ratio of story 2

k_1 : Stiffness of story 1

$\boldsymbol{k_2}$: Stiffness of story 2

$\boldsymbol{p_1(t)}$: External applied force at story 1

$\boldsymbol{p_2(t)}$: External applied force at story 2

This approach is simple but it assumes that the story is rigid and all the lateral displacement is constant at each floor. On the other hand, a story may consist of many nodes while each node may have 3 degrees of freedom. Considering a two story building consisting of 3 nodes per story means 18 degree of freedom as shown on Figure 2.4.4. Consider axial deformation is neglected since the building is low rise (i.e. deformation of columns could be neglected), the degrees of freedom could be reduced to 8 only as shown on Figure 2.4.5

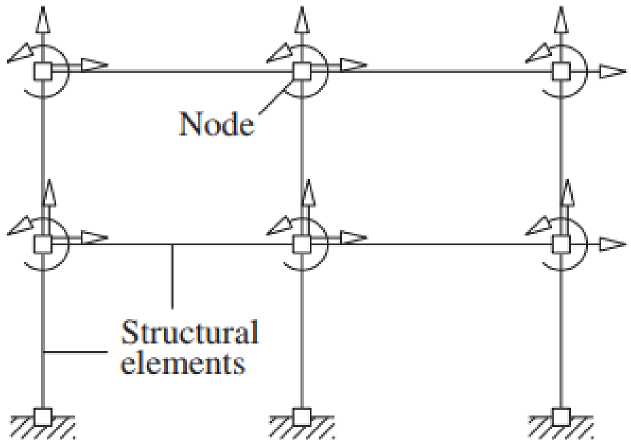

Figure 2.4.4 Degrees of freedom (axial deformation included)

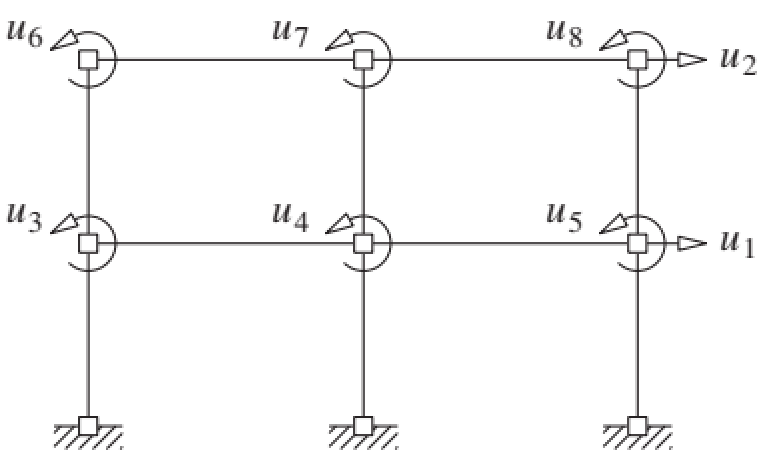

Figure 2.4.5 Degrees of freedom (axial deformation neglected)

2.5 Explanation of equation of motion component

To obtain the dynamic equation of motion, it could be divided into many parts as explained in the next section.

2.5.1 Elastic force:

For linear systems, an elastic force could be developed using the concept of superposition and stiffness influence coefficient (Figure 2.5.1, Figure 2.5.2 and Figure 2.5.3)

The concept of stiffness influence coefficient could be defined as applying a unit displacement at a specified joint. As an example. Consider using a unit displacement ($U_1 = 1.0$) is applied at joint 5 to solve the equation as shown in Figure 2.5.2 . Stiffness matrix could be obtained based on this assumption.

To proceed with the other degrees of freedom, a unit rotation is applied on joint 4 as shown on Figure 2.5.3. The same procedure is to be repeated to get stiffness matrix corresponding to this unit rotational displacement.

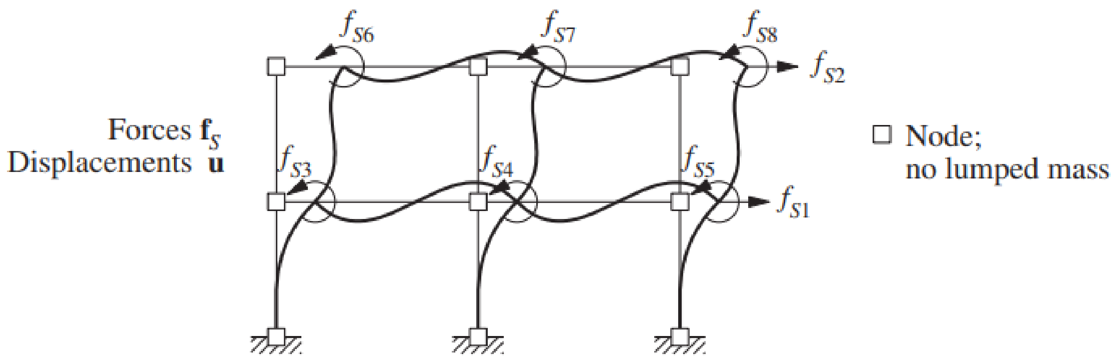

Figure 2.5.1 stiffness component of frame

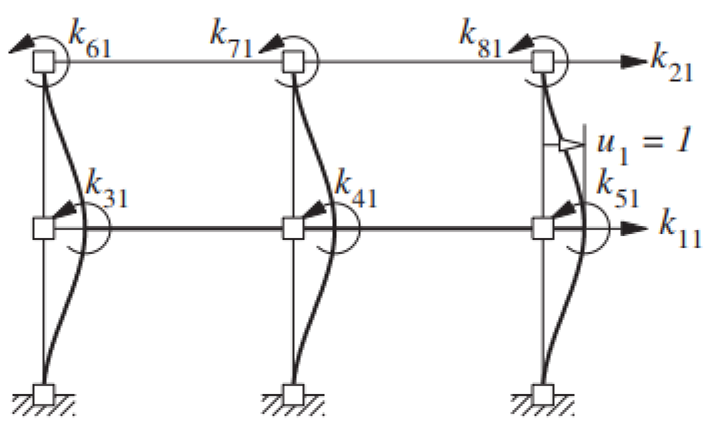

Figure 2.5.2 stiffness influence of frame @ U1 = 1.0

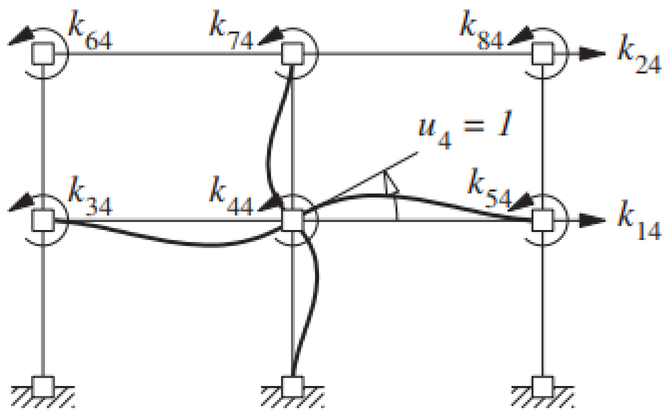

Figure 2.5.3 stiffness influence of frame @ U4 = 1.0

By applying this procedure to all joints we could obtain the general form of elastic force.

$$f_s = K\,\upsilon \qquad \textit{Equation 2.5-1}$$

Where :

f_s : Elastic force

K : Stiffness value

υ : Displacement (transition or rotational)

This equation could be formed for multi degree of freedom as follows

$$\begin{bmatrix} f_{s1} \\ f_{s2} \\ \vdots \\ f_{sn} \end{bmatrix} = \begin{bmatrix} k_{11} & k_{12} & \dots & k_{1j} & \dots & k_{1n} \\ k_{21} & k_{22} & \dots & k_{2j} & \dots & k_{2n} \\ \dots & \dots & \dots & \dots & \dots & \dots \\ k_{n1} & k_{n2} & \dots & k_{nj} & \dots & k_{nn} \end{bmatrix} \begin{bmatrix} \upsilon_1 \\ \upsilon_2 \\ \vdots \\ \upsilon_n \end{bmatrix} \qquad \textit{Equation 2.5-2}$$

2.5.2 **Damping force**

Damping force is illustrated as the force absorbed eternally by the system by various mechanism depend on the system material and environmental surrounded condition. As example, in the real building structure, most of energy dissipates through the friction effect between material molecules and friction between structural and non-structure elements such as between bricks and partition walls. Furthermore, friction between the building structure and the wind outside the building may also affect the damping coefficient of the structure.

Using a smart idea, many structural designers try to put a viscous damper inside the structure to absorb the external force which leads to reducing the amount of vibration displacement.

For the two story shear building shown on Figure 2.5.4. The component of damping force could be expressed as flowing formula:

$$f_d = c\,\dot{\upsilon} \qquad \textit{Equation 2.5-3}$$

Where

f_d : damping force

c: damping ratio

$\dot{\upsilon}$: Velocity of system

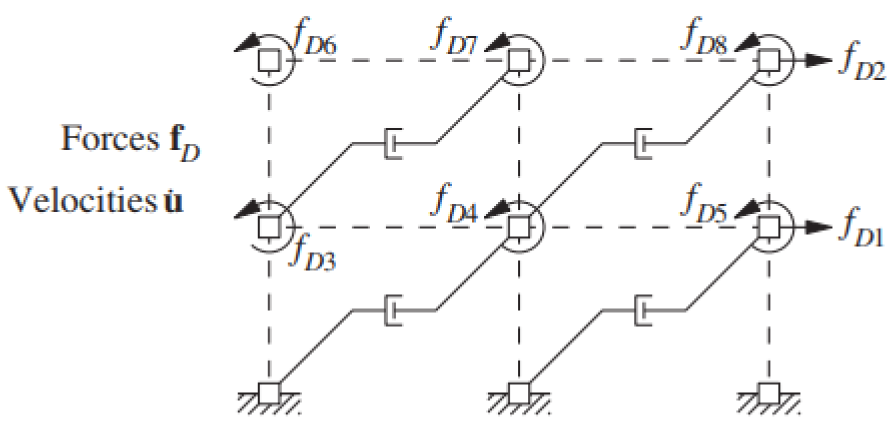

Figure 2.5.4 damping component of frame

For multi degree of freedom system, damping force could be expressed in a matrix form as below

$$\begin{bmatrix} f_{d1} \\ f_{d2} \\ \vdots \\ f_{dn} \end{bmatrix} = \begin{bmatrix} c_{11} & c_{12} & \cdots & c_{1j} & \cdots & c_{1n} \\ c_{21} & c_{22} & \cdots & c_{2j} & \cdots & c_{2n} \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ c_{n1} & c_{n2} & \cdots & c_{nj} & \cdots & c_{nn} \end{bmatrix} \begin{bmatrix} \dot{\upsilon}_1 \\ \dot{\upsilon}_2 \\ \vdots \\ \dot{\upsilon}_n \end{bmatrix} \qquad \textit{Equation 2.5-4}$$

2.5.3 **Inertia force**

The mass of the structure is lumped at a story, the external force acts on the mass with the acceleration ($\ddot{v}$).

Using the same procedure mentioned earlier, a unit acceleration is applied at a specified joints, the same joint as selected previously as shown on Figure 2.5.5, Figure 2.5.6, Figure 2.5.7 . By applying the concept of superposition, we could obtain the general form of inertia force.

$$f_I = m\,\ddot{v} \quad \textit{Equation 2.5-5}$$

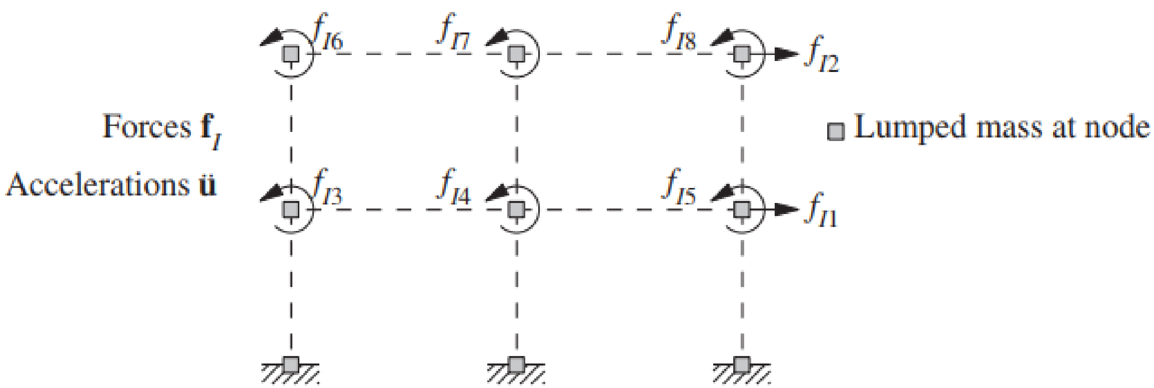

Figure 2.5.5 mass component of frame

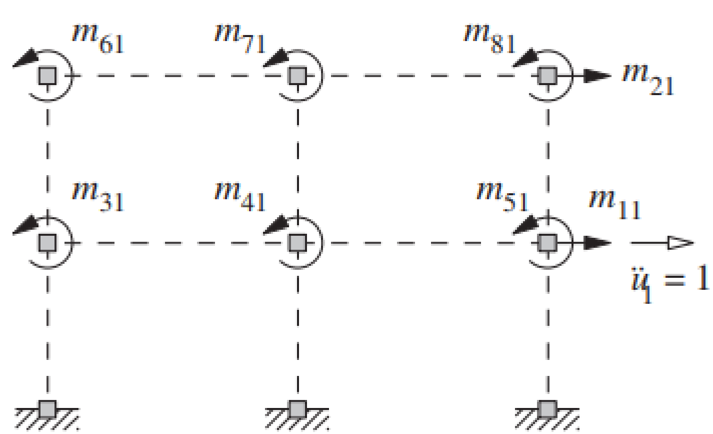

Figure 2.5.6 mass influence coefficient for Ü1 = 1.0

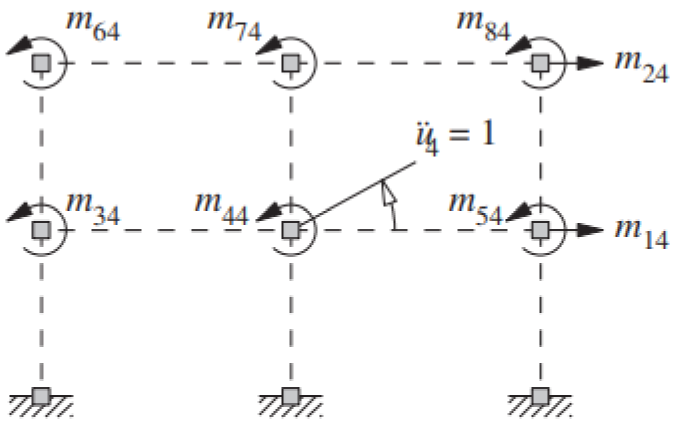

Figure 2.5.7 mass influence coefficient for Ü4 = 1.0

These procedures could be followed for multi degree of freedom, the matrix form could be obtained as follows

$$\begin{bmatrix} f_{I1} \\ f_{I2} \\ \vdots \\ f_{In} \end{bmatrix} = \begin{bmatrix} m_{11} & m_{12} & \dots & m_{1j} & \dots & m_{1n} \\ m_{21} & m_{22} & \dots & m_{2j} & \dots & m_{2n} \\ \dots & \dots & \dots & \dots & \dots & \dots \\ m_{n1} & m_{n2} & \dots & m_{nj} & \dots & m_{nn} \end{bmatrix} \begin{bmatrix} \ddot{v}_1 \\ \ddot{v}_2 \\ \vdots \\ \ddot{v}_n \end{bmatrix} \quad \textit{Equation 2.5-6}$$

Consider horizontal slab rested on many column is analyzed as shown on Figure 2.5.8. Using the concept of tributary areas, the slab is divided into parts and mass is lumped at nodes. The more nodes we got , the more complex of solving equation.

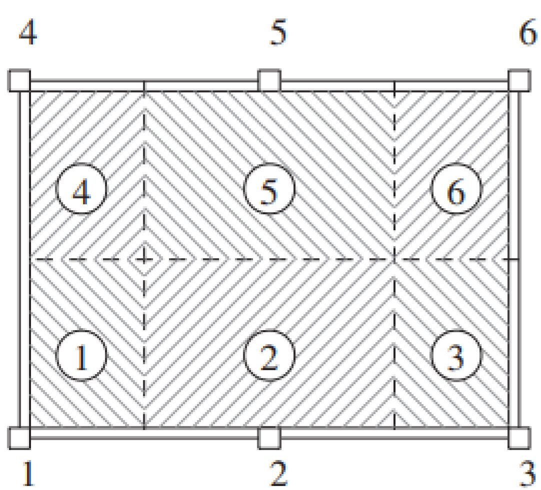

Figure 2.5.8 Tributary areas for distributing diaphragm mass to nodes.

The more degrees of freedom , The system has the more complex is the solution of matrices, this could lead to the use of finite element method and the structure can be analyzed only using advanced computer software such as ETABS

2.6 *Structural dynamics in building codes.*

2.6.1 **Equivalent lateral force (ELF).**

Most of building codes allow the use equivalent lateral force (ELF) procedure for many regular buildings with low time period. Equivalent lateral force method is based on estimating the base shear force which depends on the zone factor and soil profile log, and it does not consider the structural system of the building.(Chopra, 2012) . Also, equivalent lateral force method is based on the assumption of gradually varying distribution of mass and stiffness along with the height of the building structure (Loads and Structures, 2007). Nevertheless many buildings have irregularities in their masses and stiffness along their height. Thus, dynamic analysis is required to be performed.

2.6.2 **Modal response spectrum analysis**

Modal response spectrum analysis is a dynamic analysis method where the structure is decomposed into a numbers of single degree of freedom systems and each system has its mode shape, fundamental vibration mode and time period may be obtained.

(López and Cruz1996) (López and Cruz, 1996) state that UBC building code allow modal response analysis of structures and recommend it for all kinds of buildings since it is based on the combination of all failure modes of the structure and it shall apply to Irregular buildings as well. López and Cruz's study presents the effects of the number of modes required for design of buildings, by modeling three ideal buildings which represent real buildings since they are approximately regular in plan. They found that the dynamic parameters of structures are independent of the contribution of higher modes, the fundamental period or the number of bays, rather, they mainly depend on the number of stories.

The displacement in each mode is obtained from the corresponding spectral acceleration, modal participation and mode shape. By combining the modal response statistically, reasonably accurate estimation of displacements and internal forces.

2.6.3 *Methods of modal combination*

Consider a building is analyzed using modal response spectrum analysis, the results of the structure is represented by the mode of failures. There are many ways to combine the results of modes and to produce the structure final results such as absolute sum (ABS), Square Root of the Sum of the Squares (SRSS), Complete Quadratic Combination (CQC) and more other methods.

Number of modes shall be contributed and combined to get the desired displacement is varies according to soil classification, number of floors, structural system, Etc. A study published in 1996 to get optimum number of modes by (Lopez and Cruz). They conclude that for five percent tolerance, any 20 story building resting on a very soft soil would require only three mode shape but if resting on stiff soil it may require six mode shapes (López and Cruz, 1996) . For a more common approach ASCE07 states that number of modes required is the number that could have at least 90% of the modal mass participate in the total response.

The most conservative method is the absolute sum (ABS) of the modal response values since this approach assume that the maximum modal response for all modes occurs at the same time and at the same location. This assumption gives very conservative values of dynamic properties of the structure.

Another approach is to combine the modal response values using square root of the sum of the Squares (SRSS) to get the corresponding displacement and forces. SRSS method assumes that the maximum modal values are statically independent and since large structures contain large number of frequencies and mode shape. Therefore, SRSS method could not be the best approach to combine the values (Williams, 2005)

Another approach is Complete Quadratic Combination CQC method that can be used for modal combination. This method was firstly developed in 1981 and gave more realistic values than the SRSS method. (Williams 2005) carried out a comparison between all the three methods (absolute method, SRSS method, CQC method) while he applied time history seismic load (Taft 1952 earthquake) to a symmetric four story building (Williams, 2005) . The study proves that SRSS give base shear 30 % less than accurate time history shear force while absolute values method gives base shear 10 % more accurate time history shear force. On the other hand, values obtained from CQC gives a more accurate values compared to time history values as shown on Figure *2.6.1*

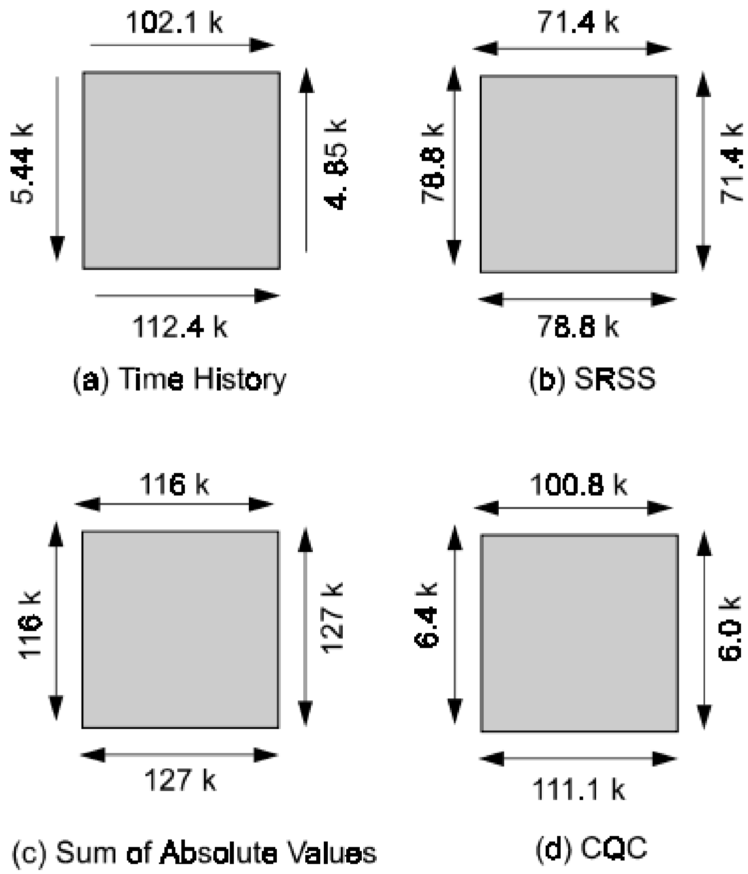

Figure 2.6.1 comparison of modal combination methods

2.7 Scaling of design values

With combing of mode shape results, dynamic base shear could be obtained but this value should be scaled with the ELF base shear for many reasons such as:

- The base shear obtained from (ELF) method based on 100% of mass participation is done during the first mode shape, which is practically does not happen.
- Usually the fundamental period (T) for modal response spectrum analysis is higher than fundamental period (T) for ELF method and since practically codes require a certain value of the period used, which shall not be more than a constant value times the ELF period. This means (T) used in base shear is usually less than (T) for dynamic analysis.
- Response of whole structural shall be obtained by multi modes not only single mode.

UBC 97 , ASCE 7 and many international Codes allow both response spectrum analysis (RSA) and response history analysis (RHA) procedure for dynamic analysis of structures (Chopra, 2012)

2.8 *Recent studies*

Review of recent studies shows much research has been done on the seismic performance of different structural systems and different materials (concrete and steel). Some of these studies are presented below.

2.8.1 Comparative studies

Ravi Kumar (V, K and J, 2018) and Uttamasha Gupta (2012) (Gupta, Ratnaparkhe and Gome, 2012) studied and compared between flat slab and grid slab systems by performing the analysis of multistory RCC building frame using the dynamic analysis (Response spectrum analysis). Ravi Kumar (V, K and J, 2018) preform models consisted of 12 stories with the parameters including the plan and columns layout, applied loads, and material specifications were kept constant. The only variable considered was the type of flat and different oil profiles (hard soil, medium soil, soft soil) i.e. either flat slab or grid slab. A total of 15 number of modes were considered for each model.

While Uttamasha Gupta (2012) (Gupta, Ratnaparkhe and Gome, 2012) perform two cases, the first was a flat slab with drop panels while the second was a two way grid slab. They investigated four cases (7 story, 9 story, 11 story, 13 story).This research used different sizes of plan to check the effects of plan and column configuration on the behavior. The authors implemented their study using STAAD software and they conclude the result as below:

- The most important conclusion was that, the researcher observed that the maximum shear force occurs in the columns of story 3 while the building height is 12 m. This means maximum shear force happened at ¼ of the total height. Furthermore, base shear of flat slab is less than grid slab.
- For all models, drift values followed parabolic curve along the height, the maximum value lies somewhere at middle stories but it still varies based on the seismic configuration and seismic force applied, building drift in grid slab is less than drift in flat slab system.
- Use of flat slab with drop panel did not have a great effect on the seismic drift since values of drift after applying drop panels changed within 0.50 mm only.
- The system of flat slab with drop panels required larger amount of reinforcement in columns compared with the system with flat slab resting on beams.

These conclusions are reasonable although the structural system of grid slab has low thickness of slab, which means lower value of seismic weight and seismic base shear. Hence, the fundamental time period of building with only edge beam and low thickness of slab is less than the fundamental time period of such a rigid flat slab and drop panel above columns.

Also, dropped beams of the grid slab system tie the columns against side sway which means grid slab gives lower value of seismic drift.

Another comparative study was done by RaviKant Singh (‘RESEARCH PAPERS SEISMIC ANALYSIS OF MULTISTOREY’, 2019) to compare between structural analysis methods.

The research performed analysis of 5 story buildings. Analysis performed using ETABS software. The different methods of analysis was a) Linear static analysis or equivalent static analysis (ELF) b) Non-linear static analysis or Pushover analysis c) Linear dynamic analysis or response spectrum analysis (RSA) d) Non-linear dynamic analysis or time history analysis (THA).

The researcher obtained the value of base shear using (ELF method) and (RSA analysis) as 742 and 242 KN respectively and he concluded that equivalent static analysis is not reliable comparing to response spectrum and time history analyses. Time history analysis is the most realistic method for seismic analysis that provides a better check for the safety of the structure.

But, the observation of this research values is the values and conclusion seems to be not scaled up since base shear of dynamic analysis shall be scaled for many reason that stated on 2.7

A study on the seismic behavior of structural systems was done by Pradip S., Aniket B. (2015) (Pradip S. Lande1, 2015) to evaluate the seismic performance of the structural systems shown below for two different story heights located in zone 4 models to get and predict the seismic response of different systems a) Flat slab building b) Flat slab with marginal beams c) Flat slab with shear walls d)Flat slab with drop panel e) Conventional building (solid slab system) f) Flat slab resting on shear walls systems

Two different models with the heights of (G+6) stories & (G+12) stories located in zone 4. The model was analyzed by using ETABS with Linear dynamic analysis (response spectrum analysis)

The researchers concluded that

- Maximum story displacement was found for the flat slab system for both the models.
- Minimum story displacement was for the building with shear wall, which indicates that shear wall is a lateral force resisting system.
- For all the systems, the seismic drift values follow a parabolic path along the height with maximum value lying somewhere near the middle stories for the model of (G+6) building for the model of (G+12) building.
- It could be observed that the maximum drift of (G+6) model occurs at the second floor level which means 1/3 of the overall height while the same for (G+12) model occurs at the fourth floor level, which is still 1/3 of overall height.
- Another observation can be made, which is that since flat slab resulted in higher values of seismic displacement and shear wall resulted in the lowest values, it is recommended to

use a combination of systems to get the best performance and to allow architectural spaces.

A study done by Wei Wang and others in 2016 (Wang *et al.*, 2016) aimed to get uniform inter story drift using tension only braced steel beams. The researchers wanted to get a direct relation between the bracing systems and stiffness of main frames for three heights of building (2 story – 4 story – 6 story). Since the braces behave as energy absorbers, damping ratio is important to obtain the relation. The analysis was done using three different methods. A) Modal analysis method (RSA method) b) pushover analysis method c) nonlinear time history analysis method (THA method).

The study stated that the stiffness ratio between bracing system and frames has the main impact on seismic performance of the structural. A value of 2:3 stiffness of bracing members to vertical column for low rise structural building could result in getting uniform inter-story drift. On the other hand, no single constant value could be obtained for ratio for middle rise building.

The paper also stated that uniform inter story drift could be archived when the braces yield for the first time in both method of analysis (pushover analysis, time history analysis).

In respect to using high technology in concrete, the recent studies shows there is enhancement in concrete properties. A study on the behavior of ultra-high performance concrete (UHPC) was done in 2019 to check the flexural, shear and torsion behavior of UHPC(Matrose *et al.*, 2019). The researcher showed that UHPC improves serviceability, ductility, strength and energy dissipation capacity in case if the structure is subjected to cyclic seismic loads, the study was based on 142 laboratory tests done on UHPC. The tests included different types of structural elements such as columns, beams and beam-column connections and shear walls. The paper concluded that flexural and shear strength can be increase by 50% if steel fibres are added to concrete mix, using UHPC in columns can reduce the lateral drift by 60% compared to columns with conventional concrete, using UHPC in beam column connections leads to enhancing the ability to avoid shear failure modes without adding transverse reinforcement, by adding 2% steel fibres to the design mix of walls can increase the drift capacity up to 200 %.

UHPC failure mode is not brittle failure (concrete crushing), the failure mode is presented as fracture of longitudinal bars due to low cycle fatigue phenomena.

Chapter 3 Methodology

3.1 *Introduction*

This chapter illustrates the research approach, methodology and strategy established to show and present the results, the aim of this research is obtaining the effect of using thickened slab at different location on the seismic performance of a structure building and the effect of using UHPC in a certain locations at constant slab thicknesses. Since the reduction of seismic drift is a useful objective, it may cause increase in the total base shear and it is affect the total displacement of the structural building. For that purpose three cases studies for both approaches is carried out with three different heights. The chosen height is 12, 16 and 20 floors since the system used as lateral force resisting system is the optimum for such heights. For the higher structure, another solution could be studied like outrigger system or mass dampers etc.…

This chapter illustrates the structural models considered in this research and describes the models, models constraints and data required to present the results.

3.2 Research design

The researchers have used common software for analysis and comparison ETABS

Most of the research papers concerning between comparing between two systems more the simulation a structural models for one systems and produce the optimum solution for specific system. This research attempts to find such comparison between the same structure system which is easier to be done using a software, the data are more accurate and it saves time, which makes the simulation methodology the best route for such comparisons.

The main objective of this research is exploring a practical solution that could be used to reduce the seismic drift since it is an important check of building safety while structure exposed to seismic force. Generally, using thickened slab in certain floor causes in reduction of seismic drift. This research attempts to find the optimum thickness and location of thickened slab. Also, a second approach is used to check the effect of UHPC on the seismic behavior of structure.

To achieve this objective, analytical research consists of many structural models are performed for three different height of building twelve, sixteen and twenty stories are analyzed using E-tabs software, each model have a plan unique configuration. The research covers 41 structural models (26 models for first approach and 15 models for second approach).

Building are symmetrical on both direction to get the seismic behavior without any torsional effect. Study is based on buildings located in Dubai, UAE which is considered as moderate seismic zone (2B) with seismic acceleration of 0.2g

Equivalent lateral force analysis (static analysis) and modal Response spectrum analysis is performed also (dynamic analysis).

Base shear is scaled up for each case individually and minimum number of modes is checked for 90% participation mass ratio.

After finalizing the model and comparing the seismic provisions between the structural models, This comparison is based on the data obtained from structural models for seismic drift, total displacement and base shear for each building are plotted using Excel spreadsheets.

The curved is analyzed accurately and precisely to observe and obtain the optimum location of thickened slab.

3.3 *Research approach*

The literature review presented in the previous chapter sketched the outline of the principle of dynamics of structure and focused especially on the equation of motion since it's the basis of analysis of high rise structure and predicting the behavior of structure against any certain seismic loads applied. It also provide the basic information of structural dynamics in codes, method of modal combination and scaling up of design value.

The present research approach will focus on the behavior of structure under a dynamic load (earthquake load) and the methods to element seismic drift by conventional solutions not using any advanced nonlinear material such as dampers or base isolation.

For the ease of understanding the results, the structural models used here are imaginary structure rather than real and the models have been created with symmetric plans in both the directions as shown on Figure 3.4.1, putting the central core in the exact middle of structure to get the pure behavior of vibration without any torsional effects.

The floor to floor height and the size of structural shear walls have been constant in all the models.

Two approaches are in this study, one approach is to use thickened slab at different locations and the second approach is to use higher concrete strength (using high performance concrete) at certain floors to study the relevant effects on the seismic behavior.

3.4 *Research strategy*

3.4.1 **First approach (Stiffness approach)**

The main objective of this study is to investigate the behavior of seismic drift using thickened slab positioned on different locations of the building height. Figure 3.4.1 show the typical plan of structure building considered in this study

This study covers three building heights (12 story, 16 story, 20 story)

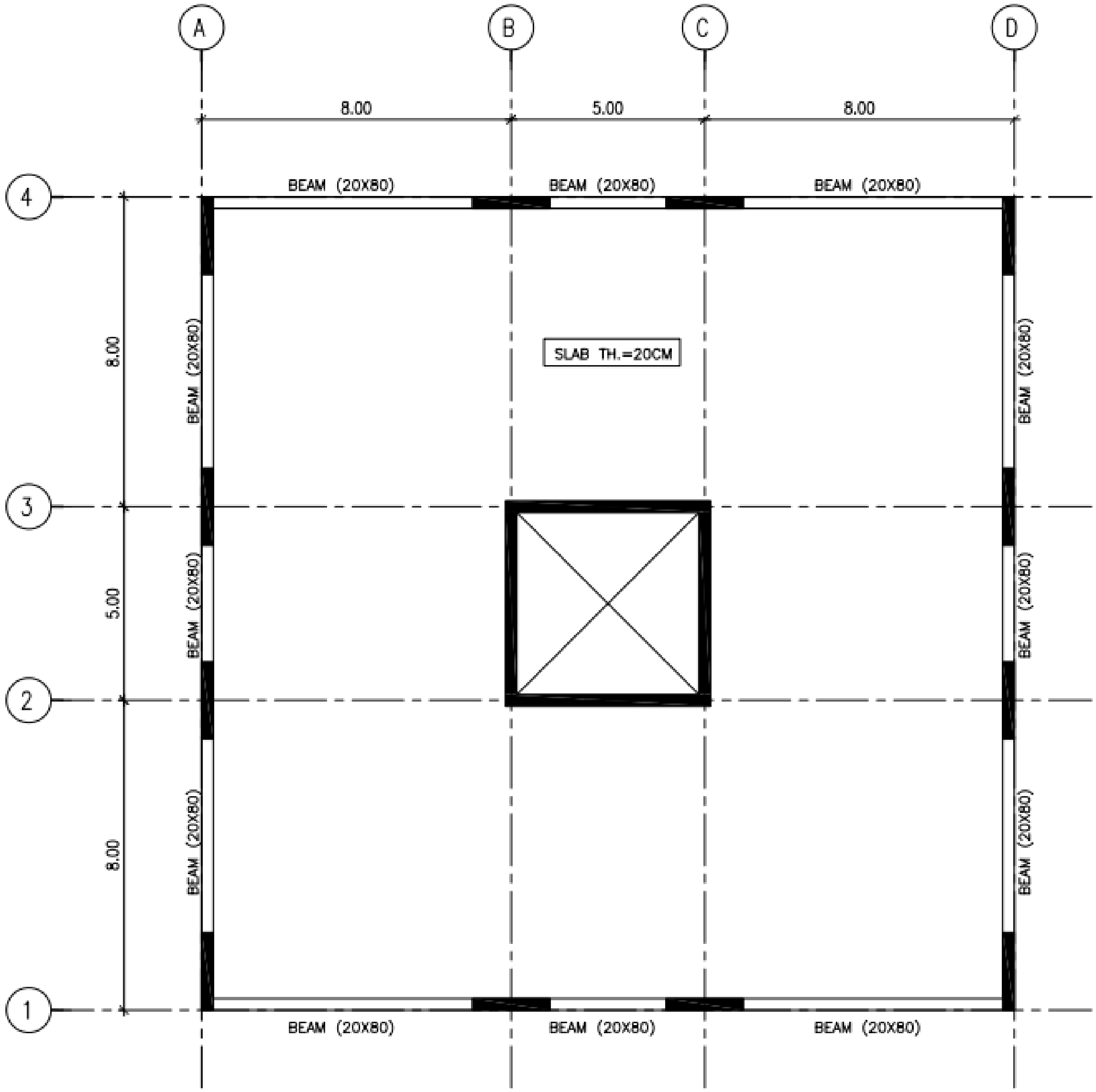

Figure 3.4.1 typical plan of the study

3.4.1 Second approach (Material approach)

Models have been created to discover the seismic behavior of different types of structures while using a mix of compressive strength along the height (conventional RCC and UHPC with higher elastic modulus) for the certain locations on the models with constant slab thickness.

Around six structural buildings with total 41 structure model (26 model for first approach and 15 models for second approach) have been analyzed to explore the proposed relationship between the seismic behavior of the building and the location of the thickened slab. Each type was modeled separately to obtain the results (seismic story drift, seismic displacement and story shear force) and then results were compared and conclusion were obtained.

Models done using advanced CSI software (E-tabs version 17) Output will be extracted form E-tabs software and to plotted using excel spreadsheet programmed by researcher

3.5 Seismic parameter for all structural models

All structure buildings in this study are subjected to a seismic load based on UBC 97 code, with moderate seismic zone (2B), seismic ground acceleration is 0.2g , Seismic importance factor is 1.0 , soil type classification is stiff soil (S_c) and Seismic ductility factor is 5.50 (intermediate moment resisting frame)

3.6 Common data for all models:

Plan size is 21.00 x 21.00 m, core wall is tube section with size of 5.00 x 5.00 and thickness of 20 cm, periphery shear walls size are 0.20 x 2.00 m, periphery beams size are 20 x 80, ground floor height is 5.00 m and typical Floor to floor height is 3.60 m, Grade of steel is 460 MPA and concrete grade is 40MPA for conventional concrete used in first approach while concrete grade of 150MPA for UHPC for second approach.

Dead load applied and live load is shown as:

Dead load on slabs	Own weight	By software
	Finish floor load	2.0 KN/m^2
	Partition equivalent load	4.0 KN/m^2
Live load	3 KN/m^2	

3.7 Analysis approach:

This study consists of main three structural building with same structure system and plan layout and study has two approach of analysis. Each approach has three structural models as follows

3.7.1 Stiffness approach

Three structural models 12, 16 and 20 stories with different configuration on location of thickened slab as will illustrated on preceding paragraphs.

3.7.2 Material approach

The same procedure more three structural models 12, 16 and 20 stories with different configuration of using UHPC on different location on the elevation of the structural buildings as will illustrated on preceding paragraphs.

It is important to mention that material approach has lower models than stiffness approach the effect of using more thick concrete section has a more efficiency on the seismic behavior than using the same section sizes with another type of concrete. Also, there is another practical reason that consider the strength of concrete reduced with time because of bad curing after casting or bad workability of the slab or any other reason related to construction stage. Because of that, relying on concrete compressive strength instead of using more thick section is considered more risky option.

3.8 Structural model 1 – 12 story (stiffness approach)

3.8.1 Introduction

The building consists of 12 stories, the 3d model presented on Figure 3.8.1. Each type has specified configuration of elevation. The total types in structural models is eight types since there is three ways of thickening the slab, first way is without using any thickened slab as shown on Figure 3.8.2, actually this case used to get the basic value that will be compared with other results as will show later. Second way is based on thicken the one quarter of the whole structure as shown on Figure 3.8.3, Figure 3.8.4 and Figure 3.8.5, and the third way is thicken the slabs located on 1/3 & 2/3 the over aver height of the structure as shown on Figure 3.8.6 , Figure 3.8.7 and Figure 3.8.8

3.8.2 Models configuration

Data used for this case is presented in Table 3.8.1

1	Total number of stories	12 story	
2	Total height of building	44.60 m	
3	Main Slab thickness	20 cm	
4	Thickened slab thickness	40 cm & 60 cm	
5	Location of thickened slab	Type 1	No thickened slab
		Type 2	1st & 2nd & 3rd (first quarter)
		Type 3	4th & 5th &6th (second quarter)
		Type 4	7th & 8th &9th (third quarter)
		Type 5	10th & 11th &12th (last quarter)
		Type 6	4th &8th (1/3 & 2/3 height) With slab thickness = 40 cm
		Type 7	4th &8th (1/3 & 2/3 height) With slab thickness = 50 cm
		Type 8	4th &8th (1/3 & 2/3 height) With slab thickness = 60 cm

Table 3.8.1 Structure model 1

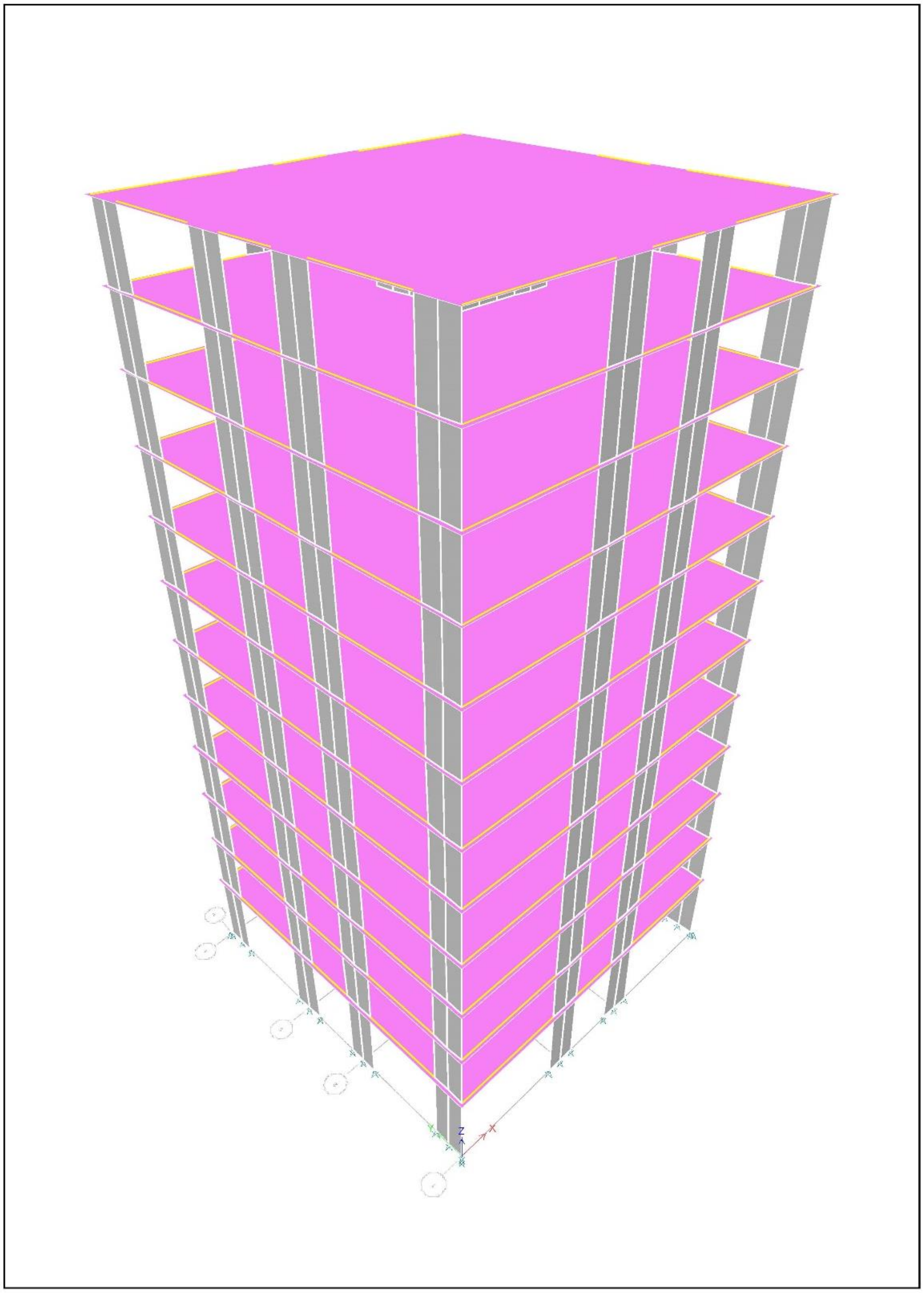

Figure 3.8.1 Structure model 1 - 3D model (12) story structure building

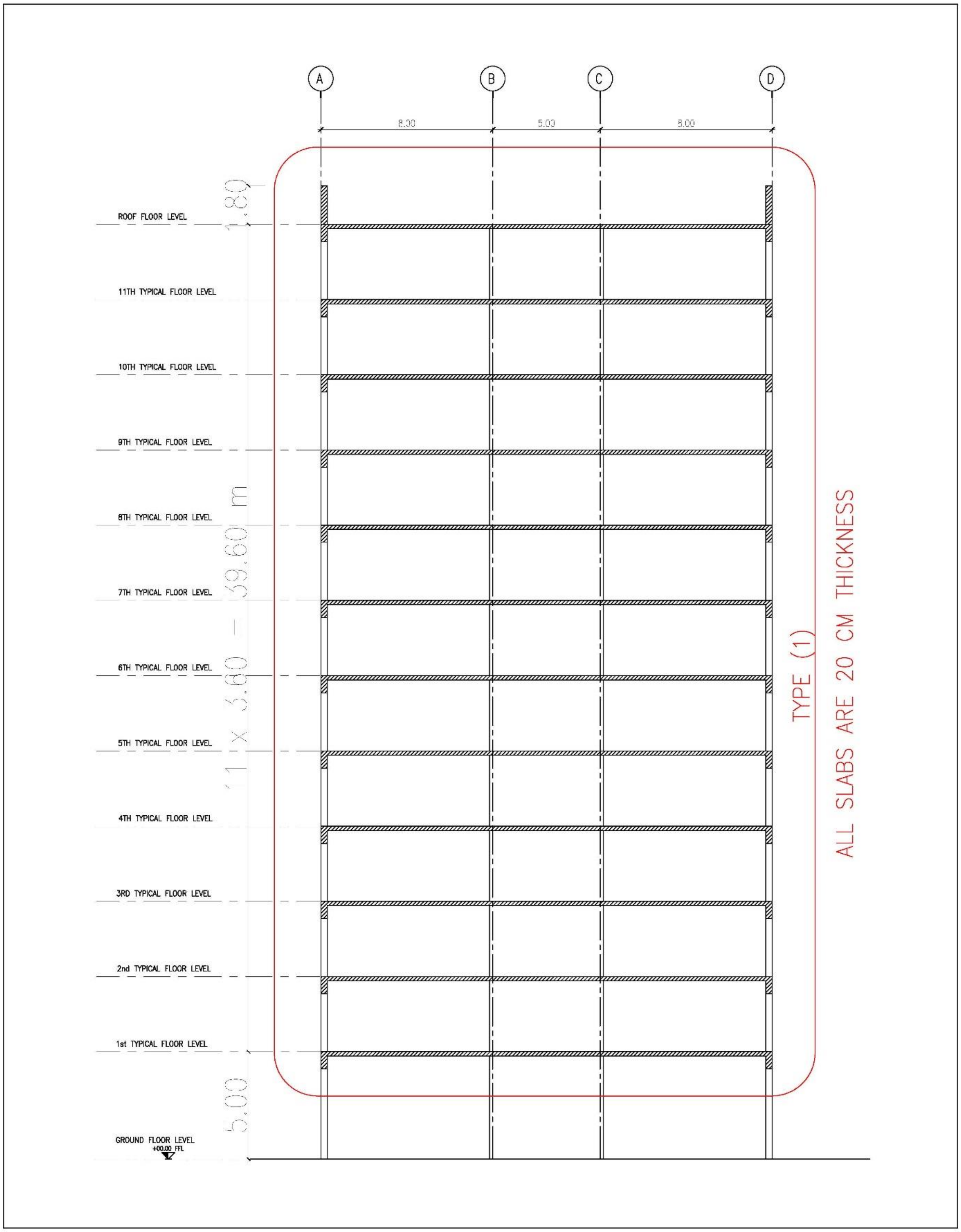

Figure 3.8.2 Structure model 1 – Type (1), without thickened slab

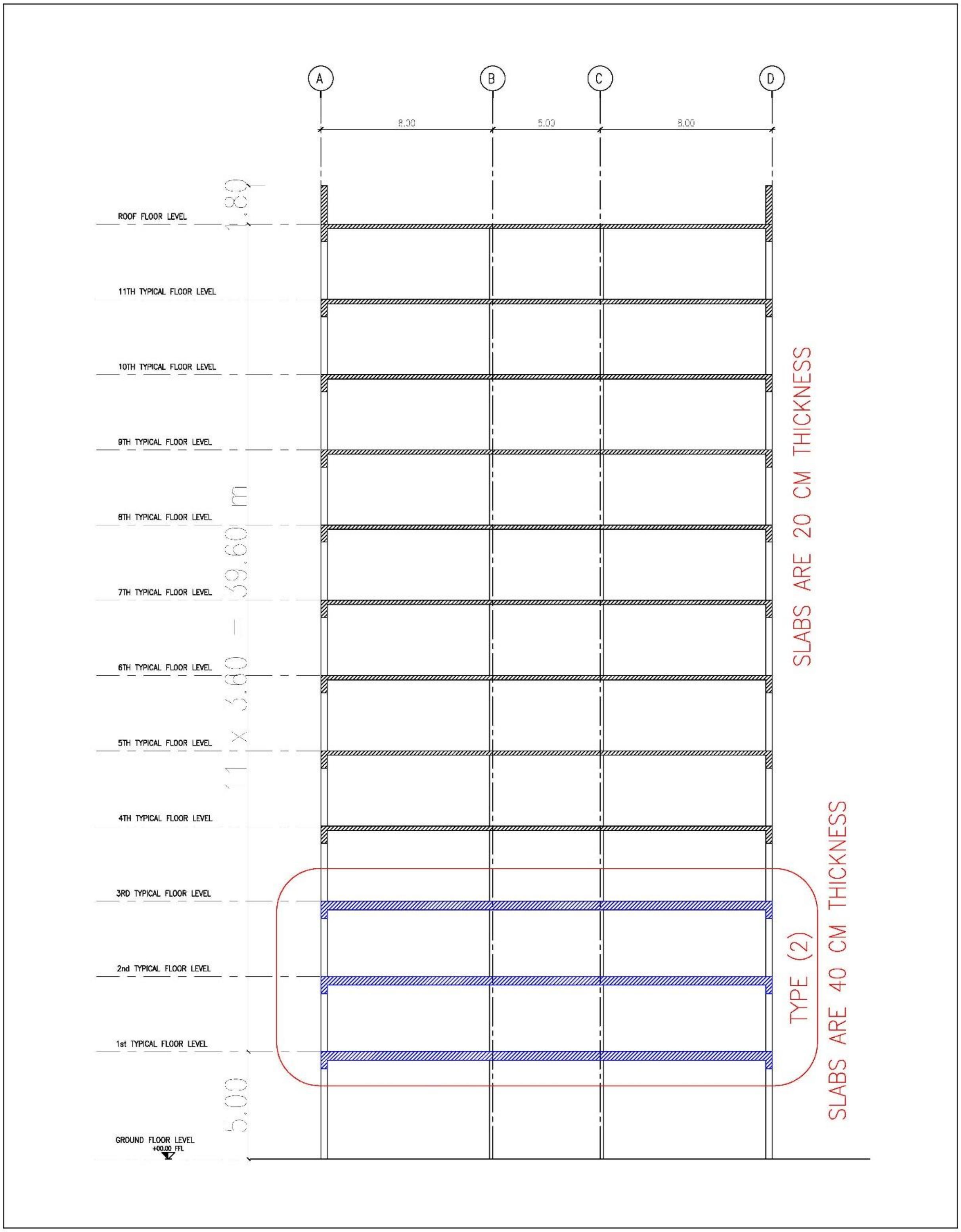

Figure 3.8.3 Structure model 1 – Type (2), with thickened slab at 1st quarter

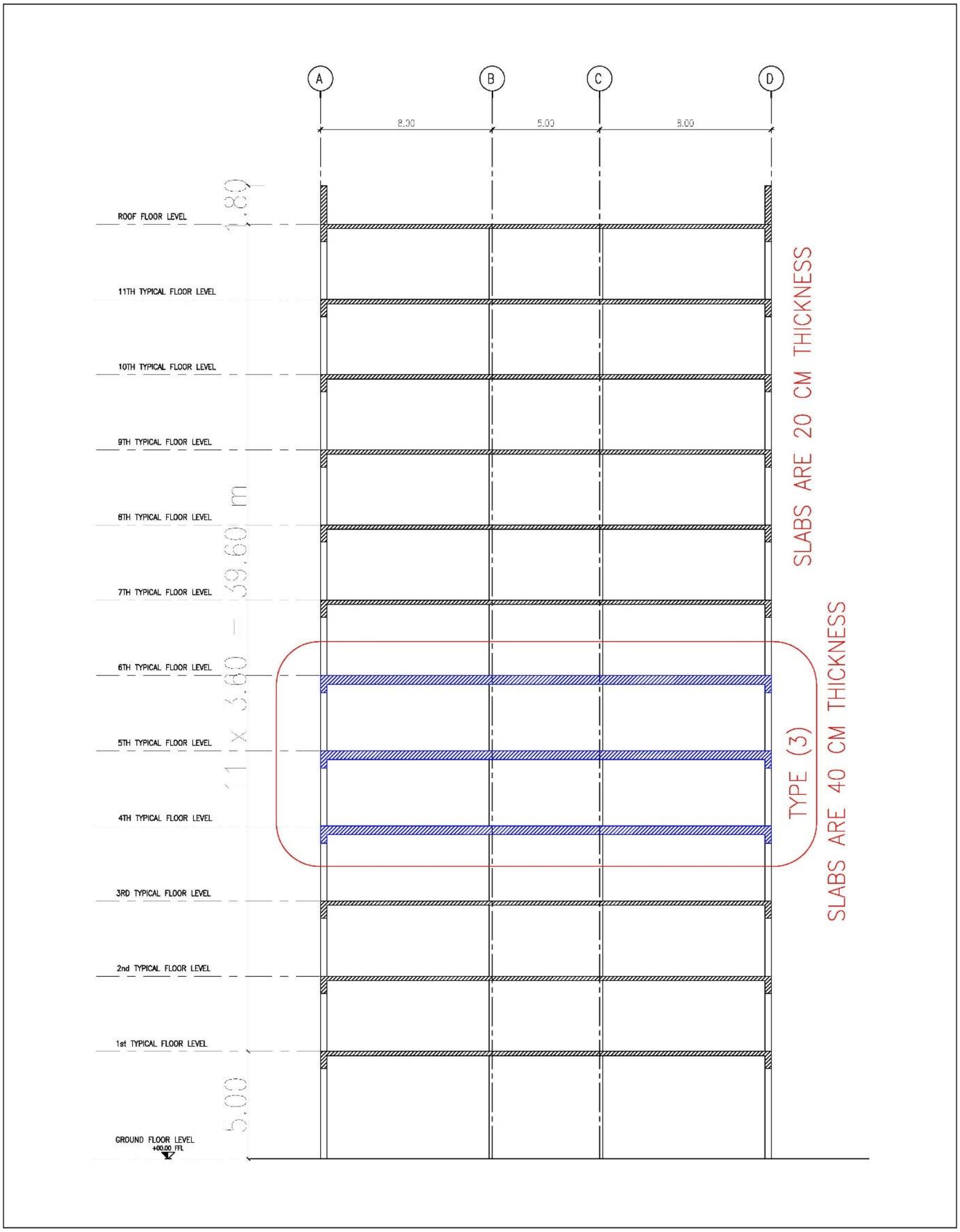

Figure 3.8.4 Structure model 1 – Type (3), with thickened slab at 2nd quarter

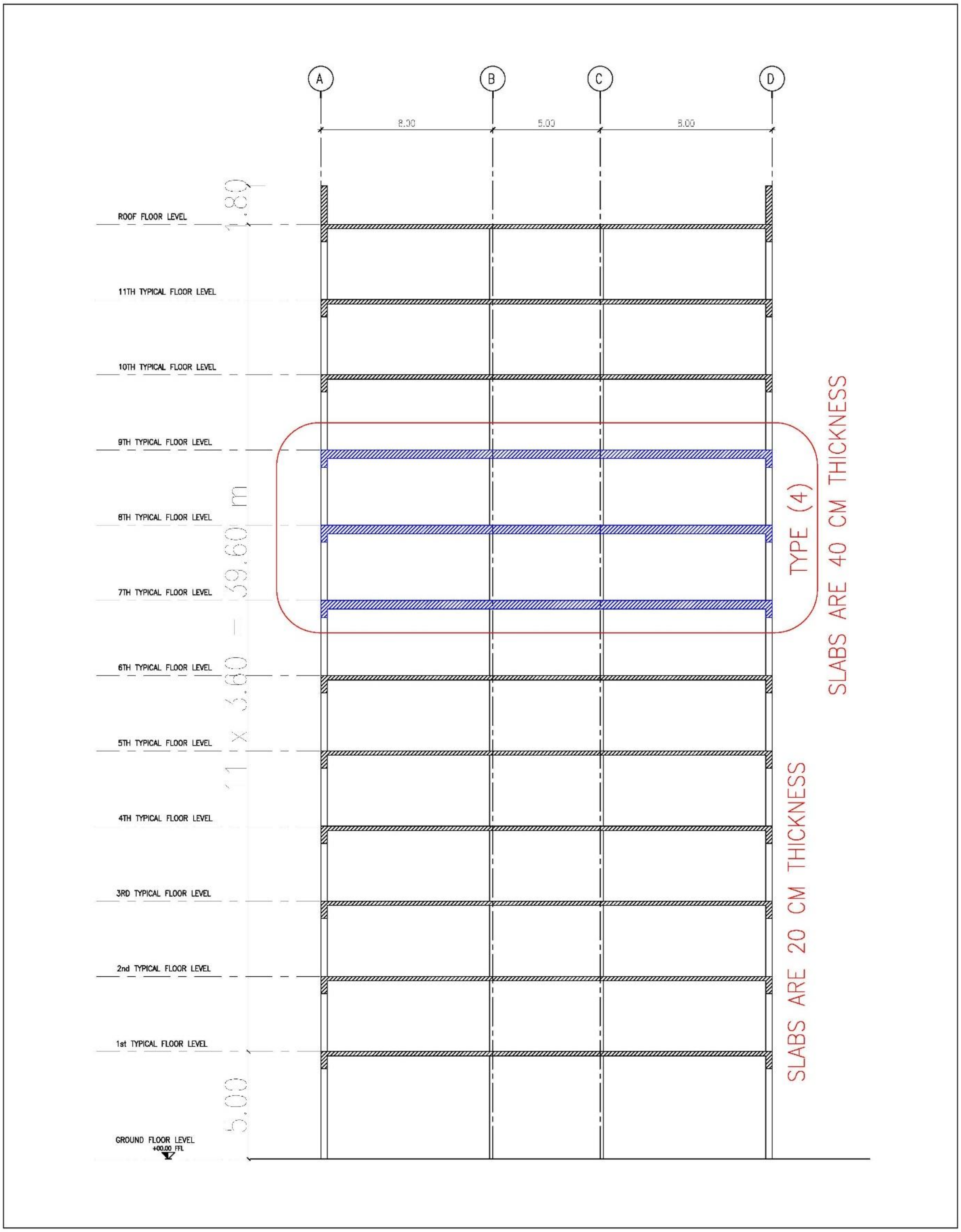

Figure 3.8.5 Structure model 1 – Type (4), with thickened slab at 3rd quarter

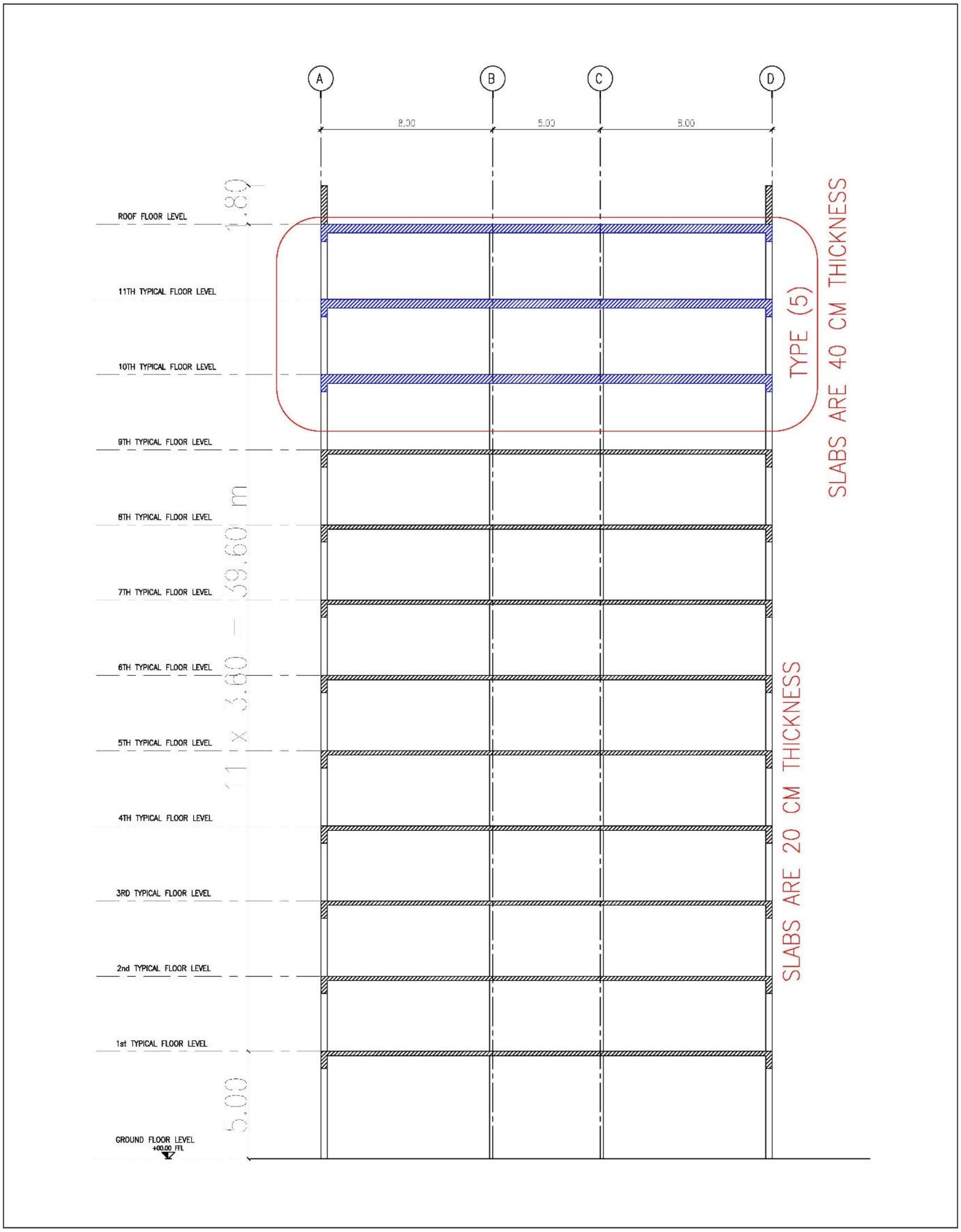

Figure 3.8.6 Structure model 1 – Type (5), with thickened slab at last quarter

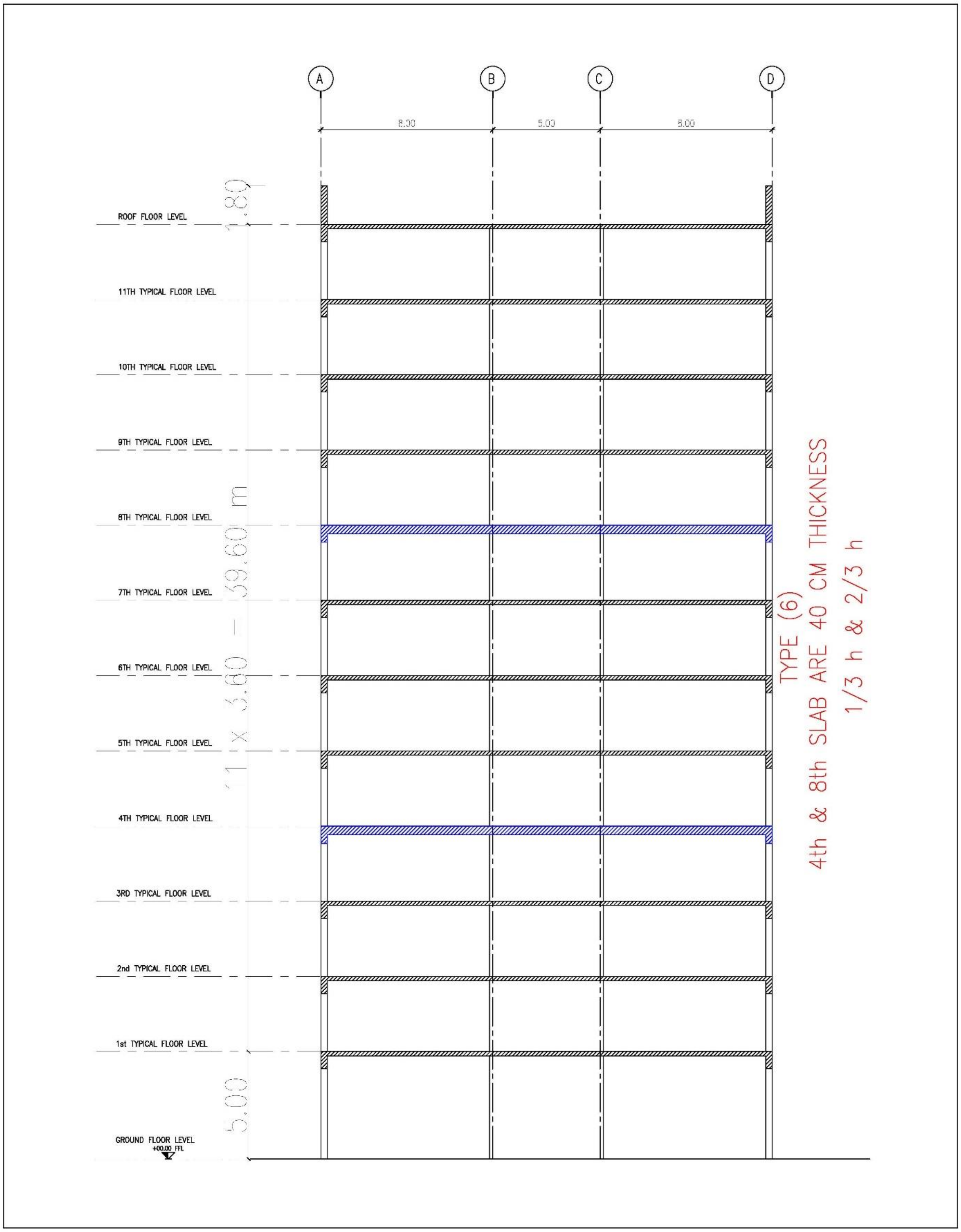

Figure 3.8.7 Structure model 1 – Type (6), with 2 times thickened slab at 1/3 & 2/3 height

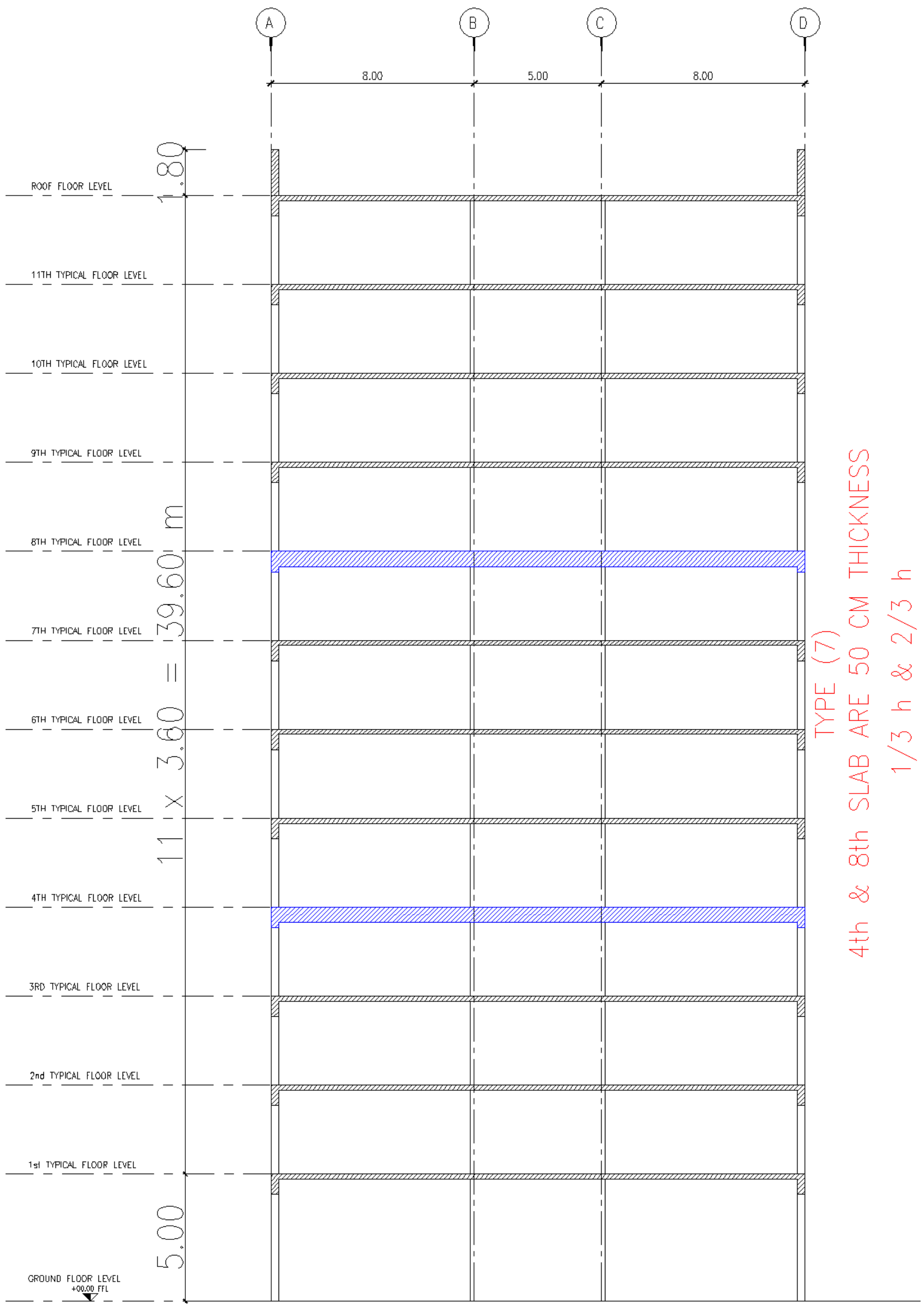

Figure 3.8.8 Structure model 1 - Type (7), with 2.5 times thickened slab at 1/3 & 2/3 height

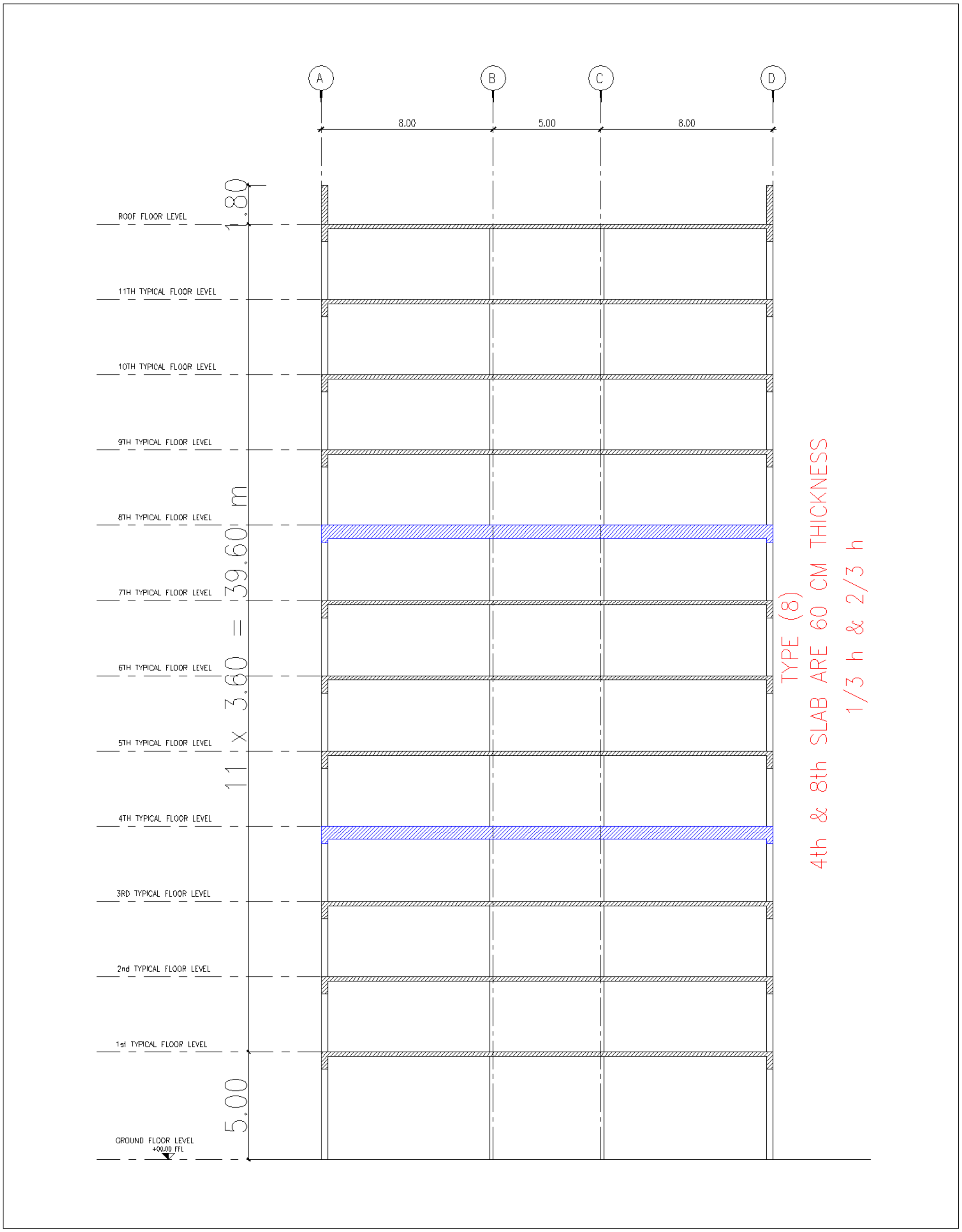

Figure 3.8.9 Structure model 1 - Type (8), with 3 times thickened slab at 1/3 & 2/3 height

3.9 Structure model 2 – 16 story (stiffness approach)

3.9.1 Introduction

The building consists of 16 stories, the 3d model presented on Figure 3.9.1. As described before in structure model 1, structure model 2 also has types that each type based on the configuration of elevation. The total types models in structure model 2 is eight types same Structure model 1. The first type is without using any thickened slab as shown on Figure 3.9.2. Second way is based on thicken the one quarter of the whole structure as shown on Figure 3.9.3, Figure 3.9.4, Figure 3.9.5 and Figure 3.9.6, and the third way is thicken the slabs located on 1/3 & 2/3 the over aver height of the structure as shown on Figure 3.9.7, Figure 3.9.8 and Figure 3.9.9

3.9.2 Models configuration

Data for 16 story flat slab building in

Table 3.9.1

1	Total number of stories	16 story	
2	Total height of building	59.00 m	
3	Main Slab thickness	20 cm	
4	Thickened slab thickness	40 cm & 80 cm	
5	Location of thickened slab	Type 1	No thickened slab
		Type 2	1^{st} & 2^{nd} & 3^{rd} &4^{th} (first quarter)
		Type 3	5^{th} & 6^{th} &7^{th} & 8^{th} (second quarter)
		Type 4	9^{th} & 10^{th} &11^{th} & 12^{th} (third quarter)
		Type 5	13^{th} & 14^{th} &15^{th} &16^{th} (last quarter)
		Type 6	5^{th} &11^{th} (1/3 & 2/3 height) With slab thickness = 40 cm
		Type 7	5^{th} &11^{th} (1/3 & 2/3 height) With slab thickness = 60 cm
		Type 8	5^{th} &11^{th} (1/3 & 2/3 height) With slab thickness = 80 cm

Table 3.9.1 Structure model 2

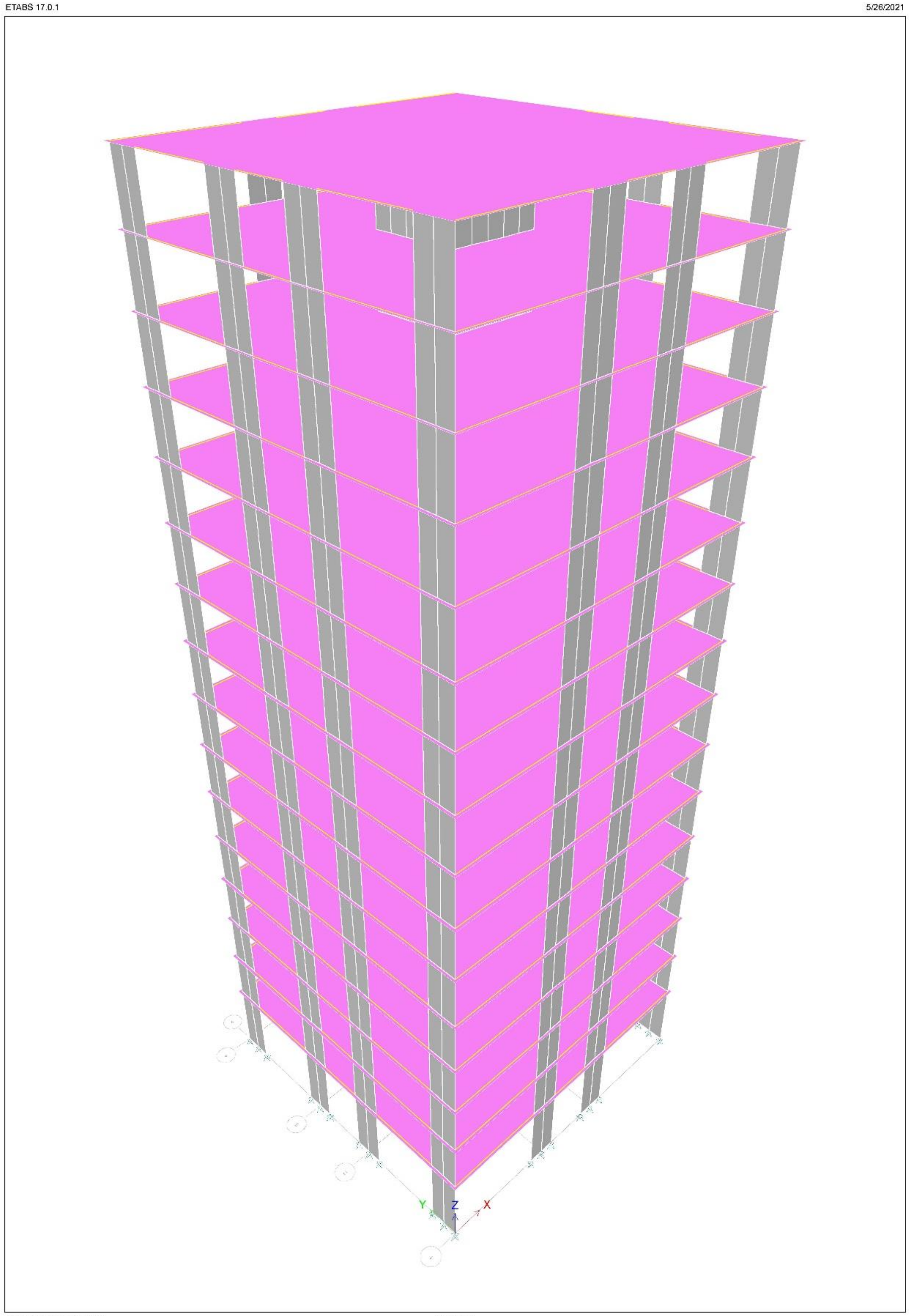

Figure 3.9.1 Structure model (2) - 3D model layout (16) story structural building

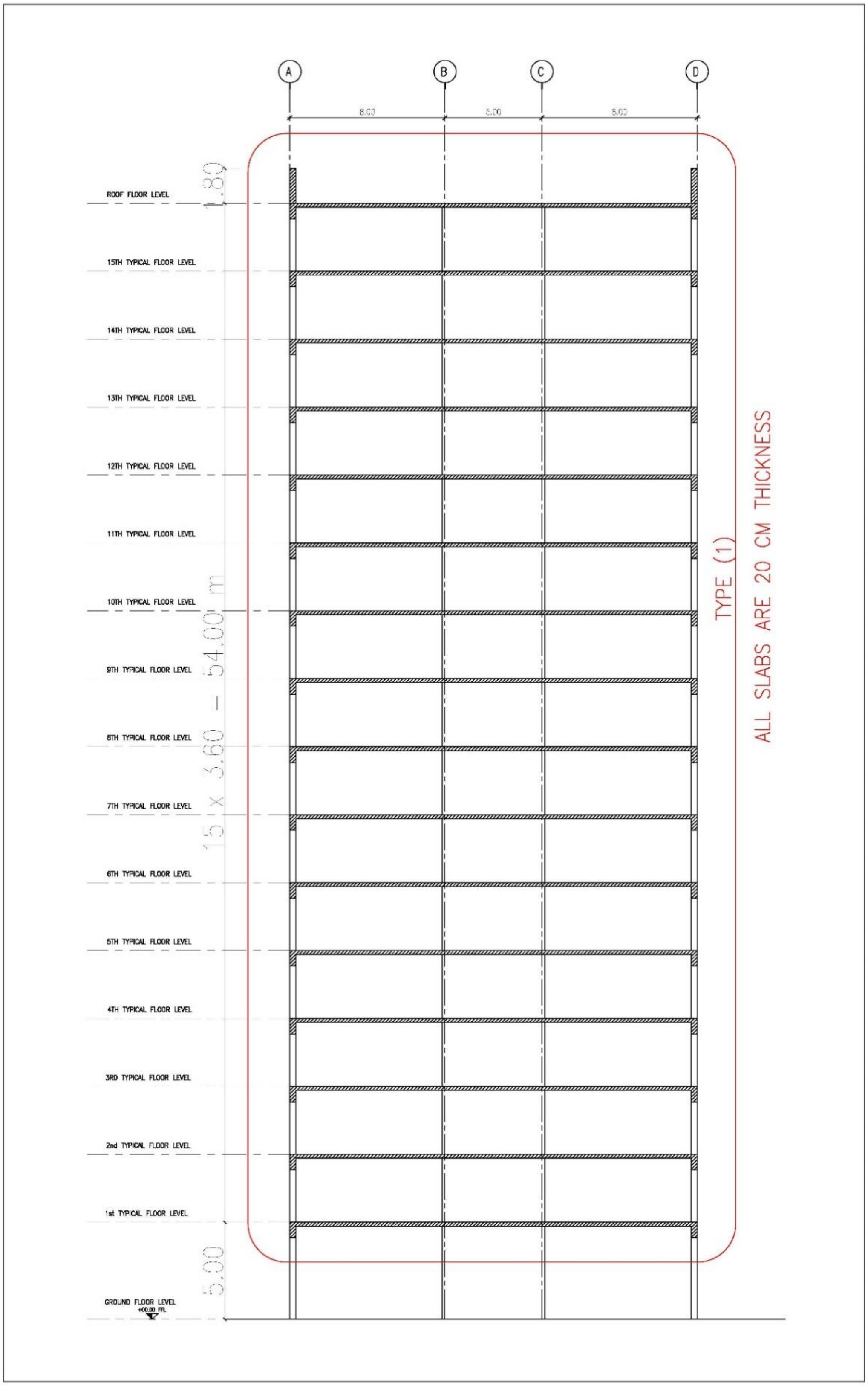

Figure 3.9.2 Structure model 2– Type (1), without thickened slab

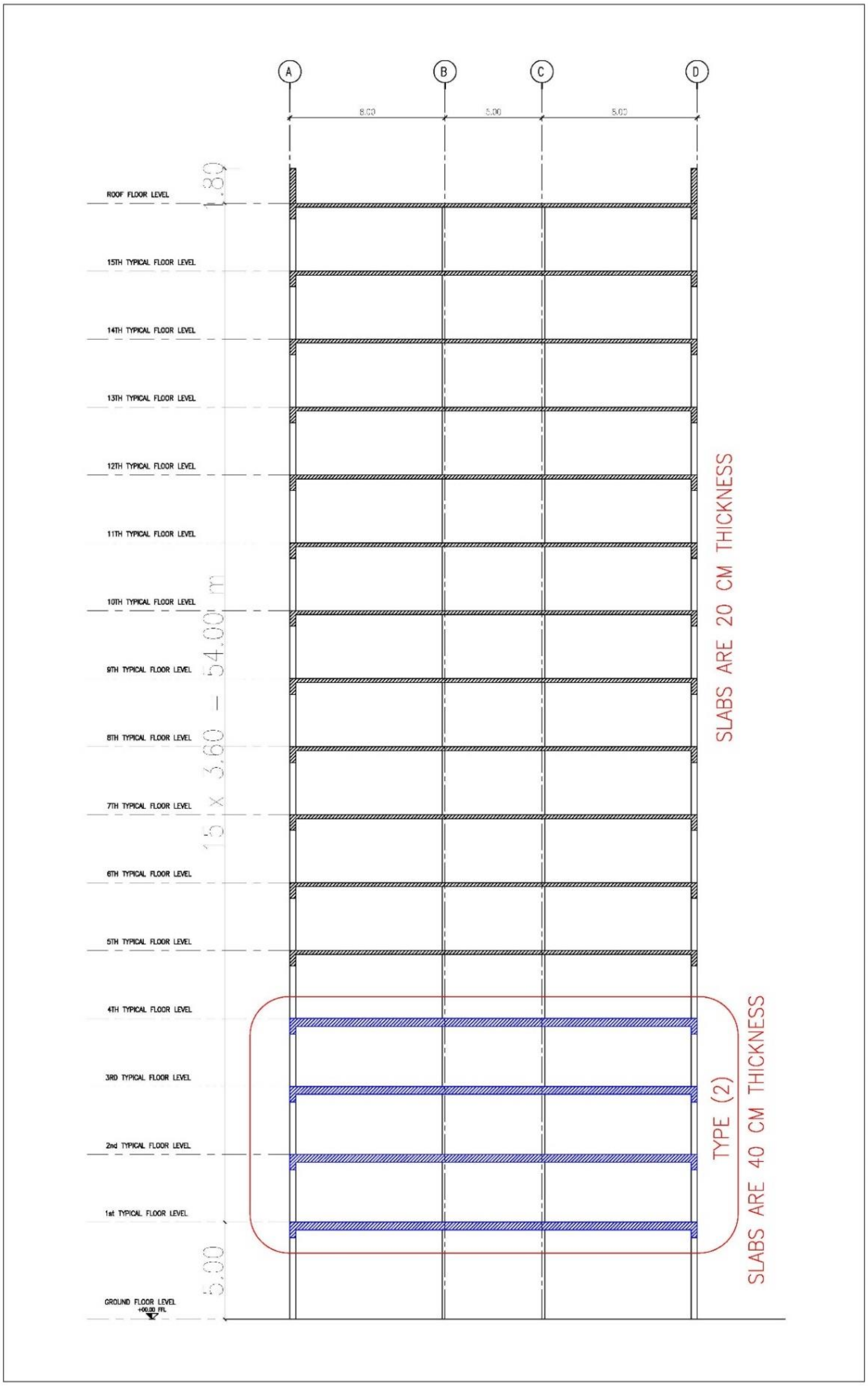

Figure 3.9.3 Structure model 2 – Type (2), with thickened slab at 1st quarter

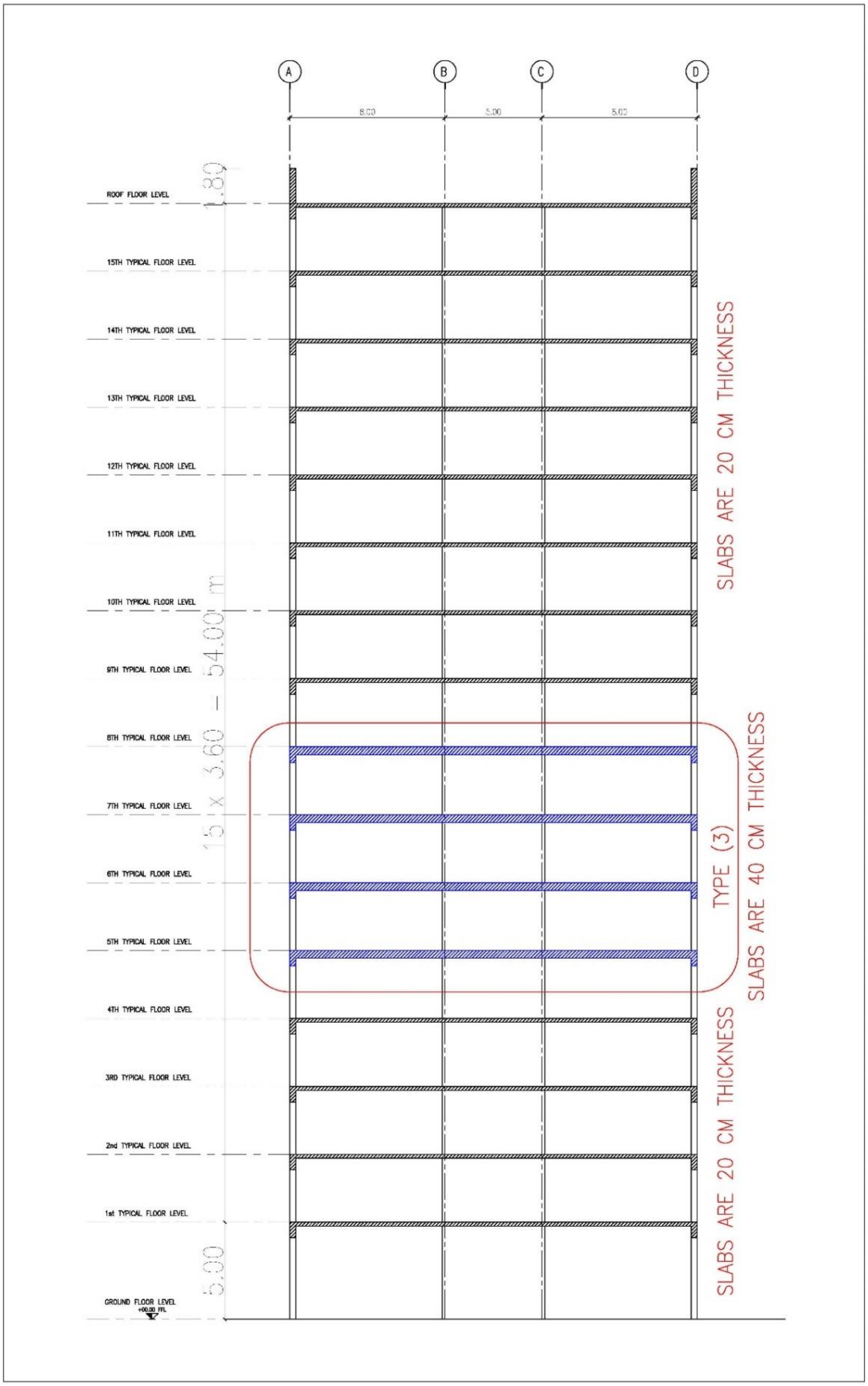

Figure 3.9.4 Structure model 2 – Type (3), with thickened slab at 2nd quarter

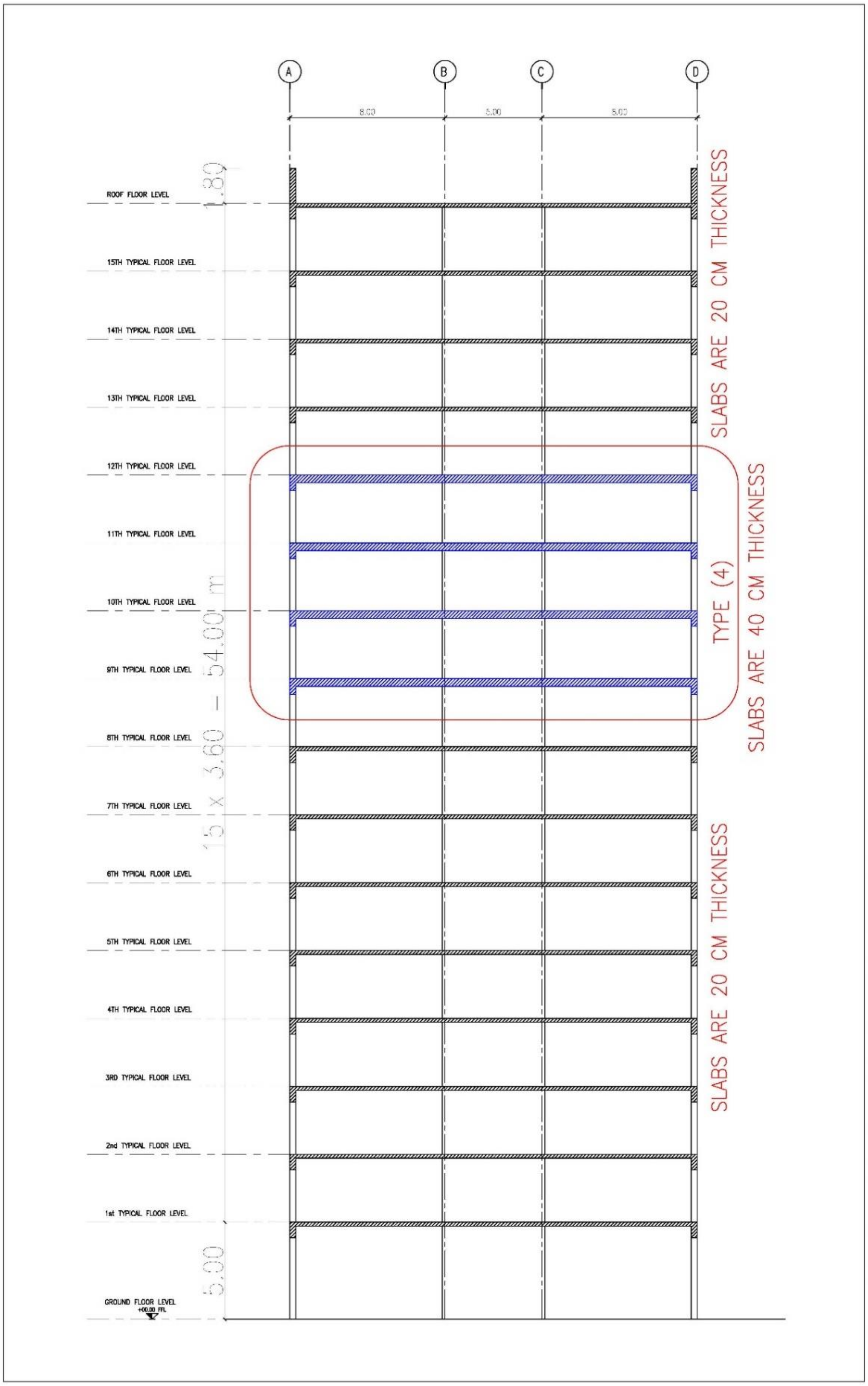

Figure 3.9.5 Structure model 2 – Type (4), with thickened slab at 3rd quarter

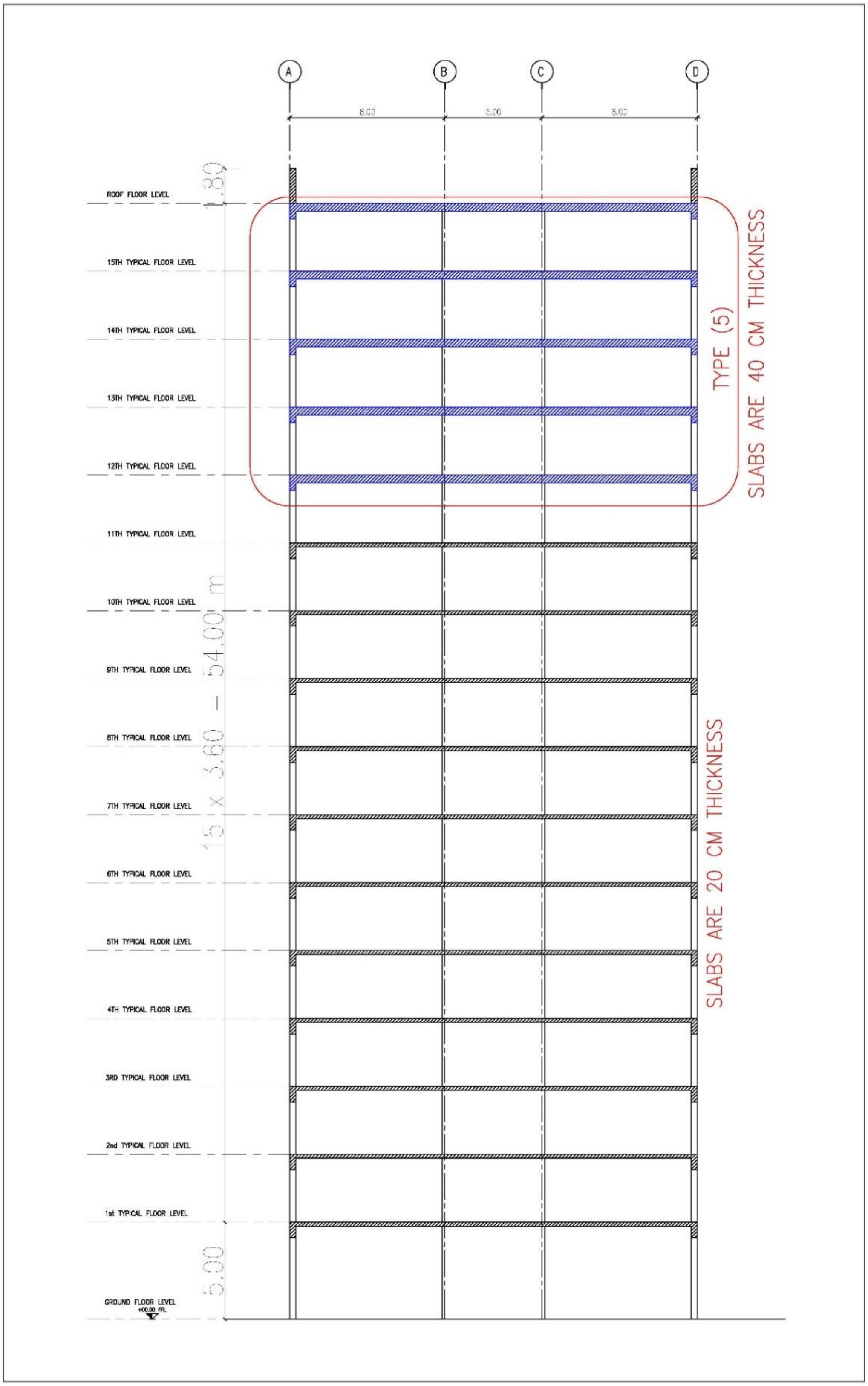

Figure 3.9.6 Structure model 2 – Type (5), with thickened slab at last quarter

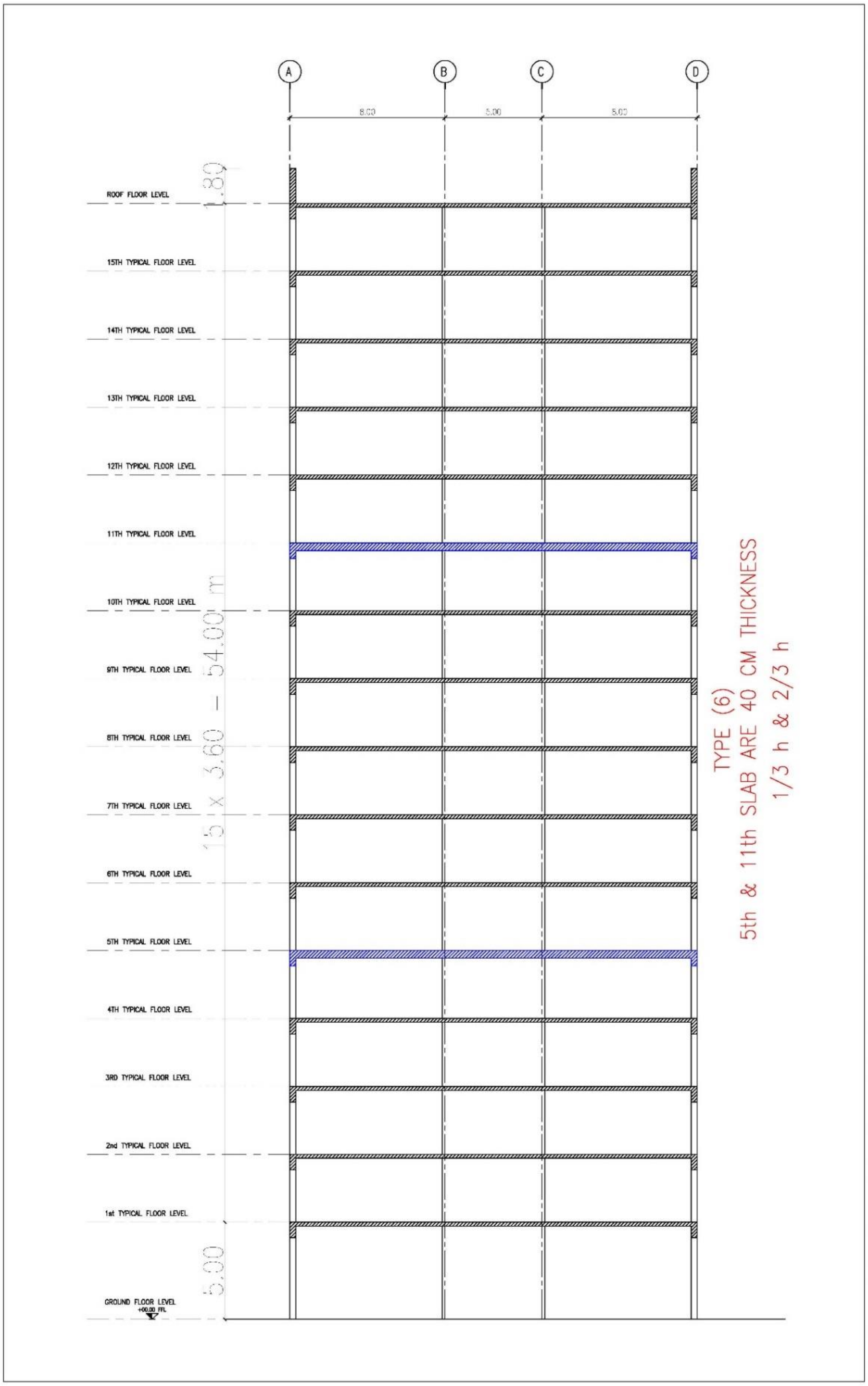

Figure 3.9.7 Structure model 2 – Type (6), with 2 times thickened slab at 1/3 & 2/3 height

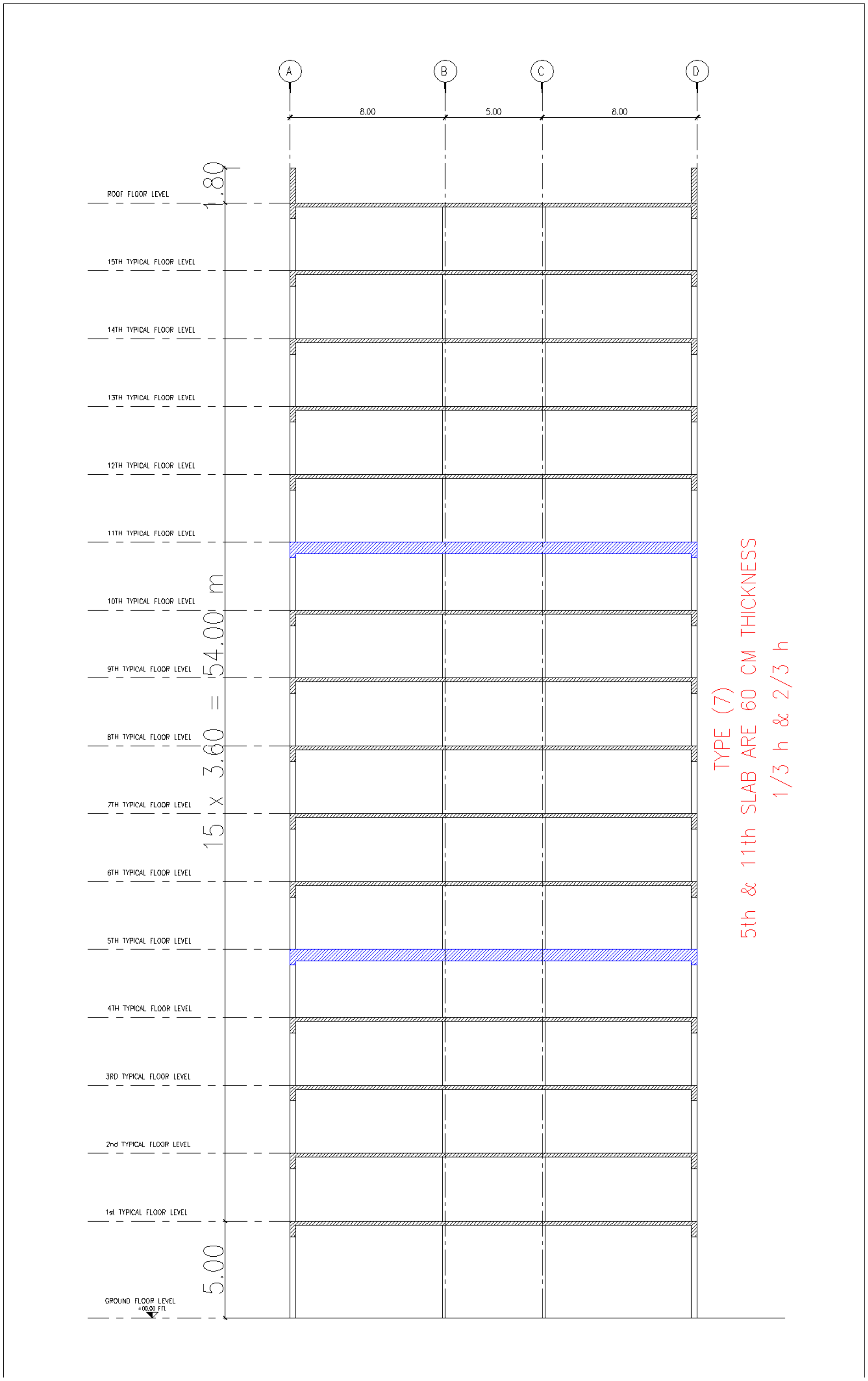

Figure 3.9.8 Structure model 2 – Type (7), with 3 times thickened slab at 1/3 & 2/3 height

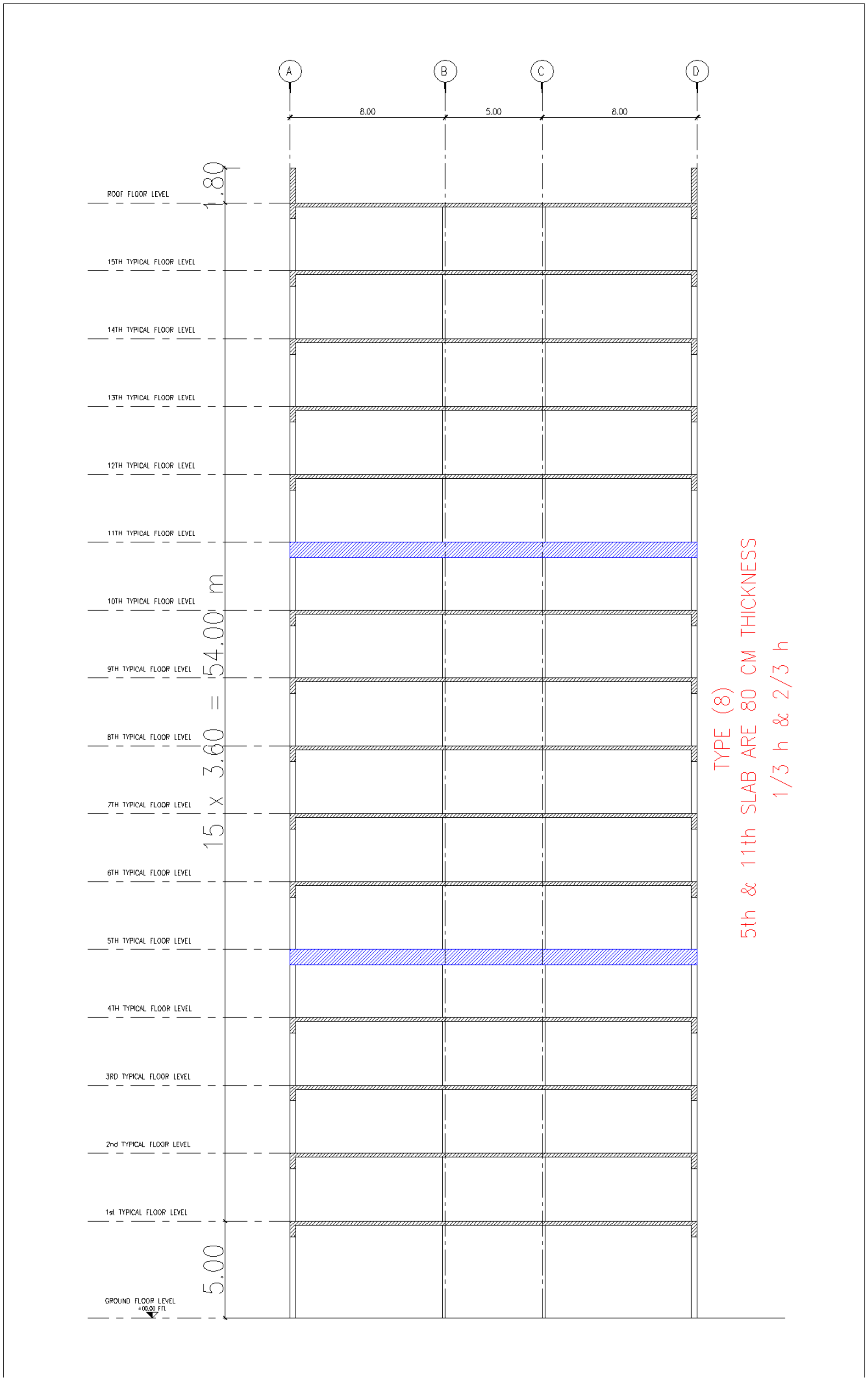

Figure 3.9.9 Structure model 2 – Type (8), with 4 times thickened slab at 1/3 & 2/3 height

3.10 Structure model 3 – 20 story (stiffness approach)

3.10.1 Introduction

The building consists of 20 stories, the 3d model presented on Figure 3.10.1. As described in structure model 1, 2 before. Structure model 3 also has types that each type based on the configuration of elevation. The total types models in structure model 3 is ten types which is more than other recent two cases with two types and the reason for that is the more higher of the structure, the more complex the behavior of the building to observe and the more probable solutions could be found out to get the optimum solution. The first type is without using any thickened slab as shown on Figure 3.10.2 Figure 3.9.2. Second way is based on thicken the one quarter of the whole structure as shown on Figure 3.10.3,Figure 3.10.4 ,Figure 3.10.5 and Figure 3.10.6, and the third way is thicken the slabs located on 1/3 & 2/3 the over aver height of the structure as shown on Figure 3.10.7, Figure 3.10.8 and Figure 3.10.9 while the added two models is thicken one slab on the mid of the total height as shown on Figure 3.10.10 and the third as shown on Figure 3.10.11by 5 times the main slab thickness. The reason of using the five times that consider the first way of thickening the quarters, in that case we thicken 5 slabs of all 20 slabs, for that all thickened parts to be lumped at one slab to observe the difference.

Data for 16 story flat slab building in Table 3.10.1

1	Total number of stories	20 story	
2	Total height of building	73.40 m	
3	Slab thickness	20 cm	
4	Thickened slab thickness	40 cm, 70 cm and 100 cm	
5	Location of thickened slab	Type 1	No thickened slab
		Type 2	1^{st} & 2^{nd} & 3^{rd} &4^{th} &5^{th} (first quarter)
		Type 3	6^{th} &7^{th} & 8^{th} &9^{th} & 10^{th} (second quarter)
		Type 4	11^{th} & 12^{th} &13^{th} &14^{th} &15^{th} (third quarter)
		Type 5	16^{th} &17^{th} &18^{th} &19^{th} &20^{th} (last quarter)
		Type 6	7^{th} &14^{th} (1/3 & 2/3 height) With slab thickness = 40 cm
		Type 7	7^{th} &14^{th} (1/3 & 2/3 height) With slab thickness = 70 cm
		Type 8	7^{th} &14^{th} (1/3 & 2/3 height) With slab thickness = 100 cm
		Type 9	10^{th} (mid height) With slab thickness = 100 cm
		Type 10	7^{th} (1/3 height) With slab thickness = 100 cm

Table 3.10.1 Structure model 3

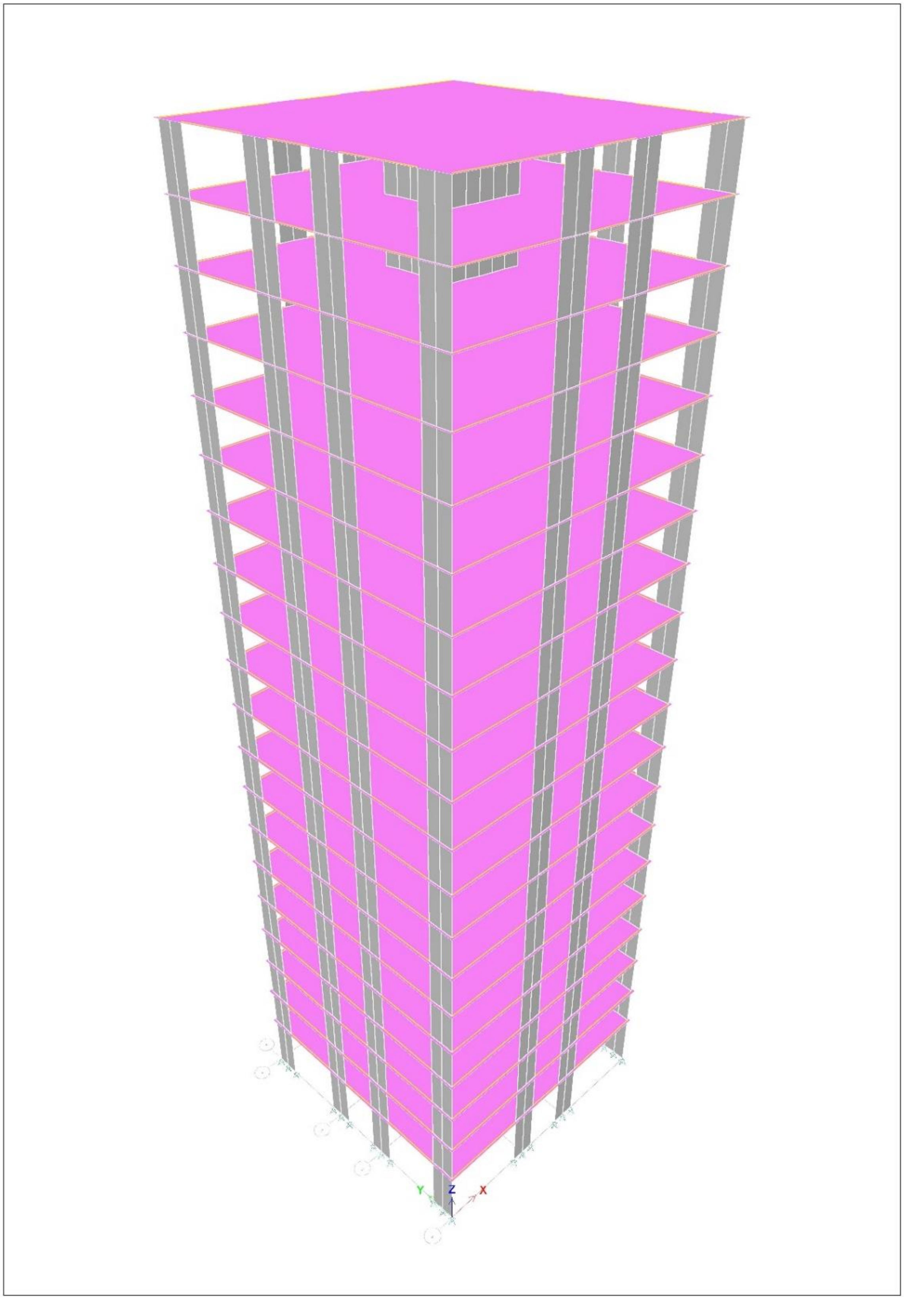

Figure 3.10.1 Structure model (3) - 3D model layout (20) story structural building

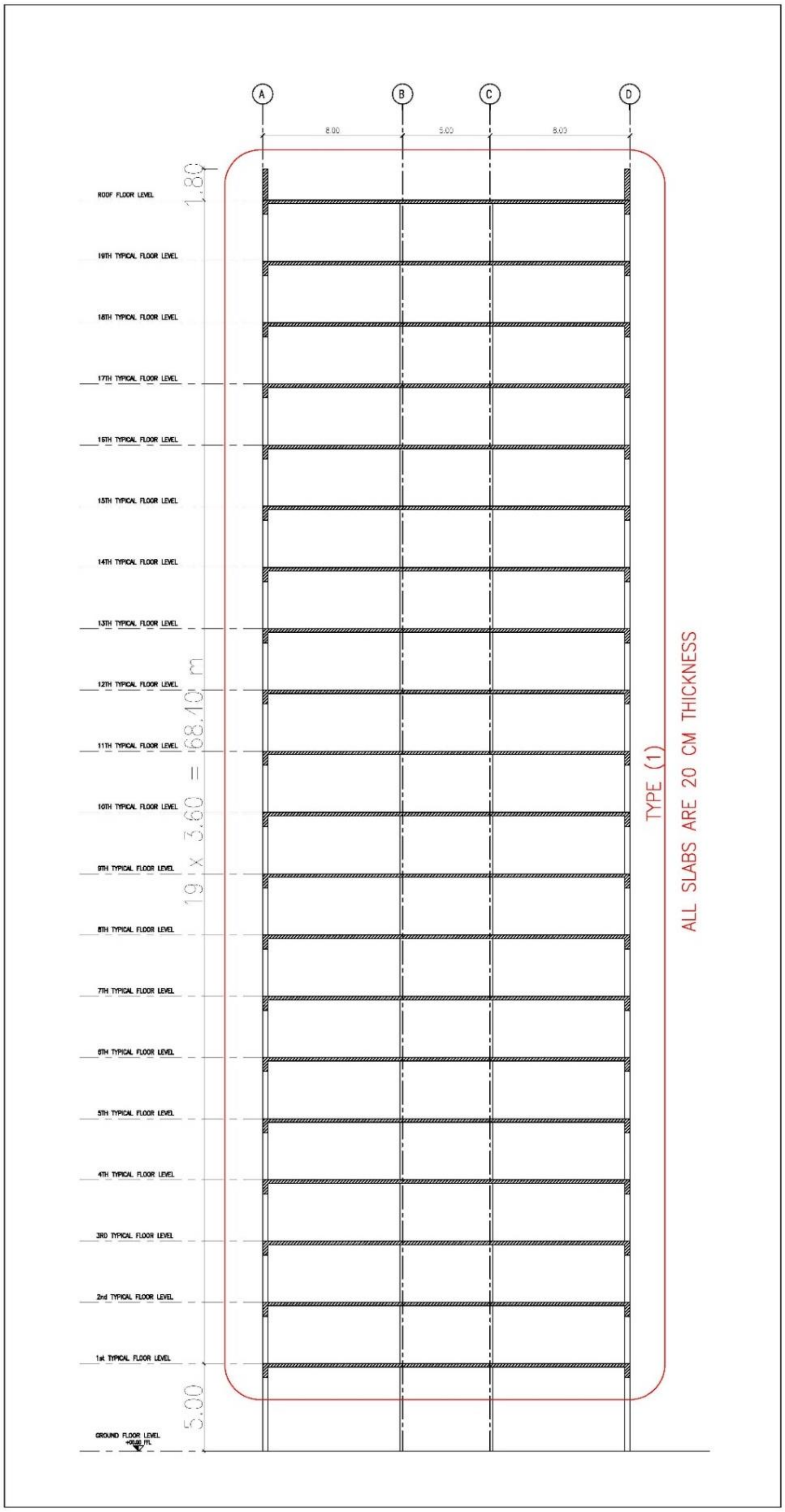

Figure 3.10.2 Case study 3 – Type (1), without thickened slab

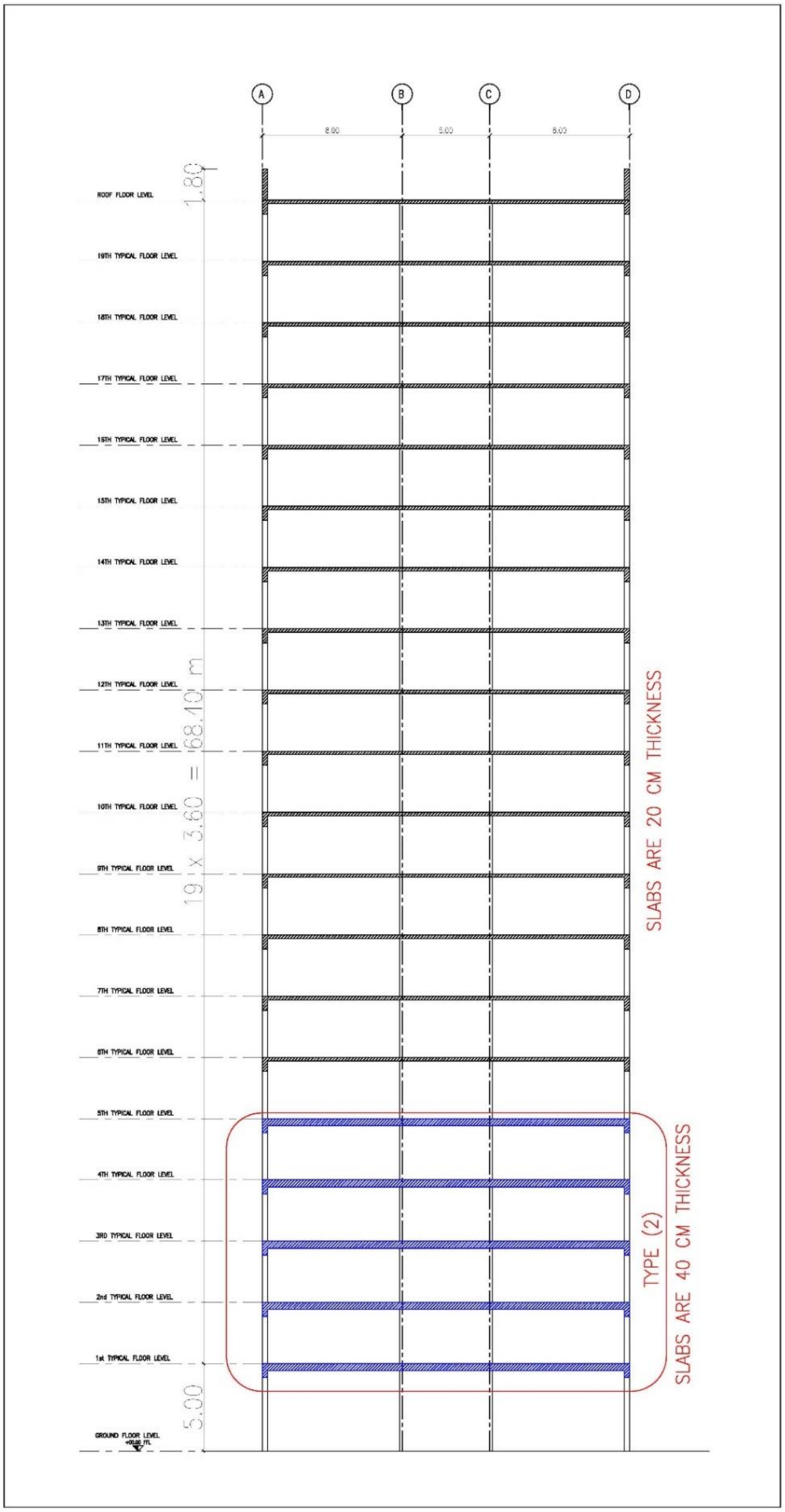

Figure 3.10.3 Structure model 3 – Type (2), with thickened slab at 1st quarter

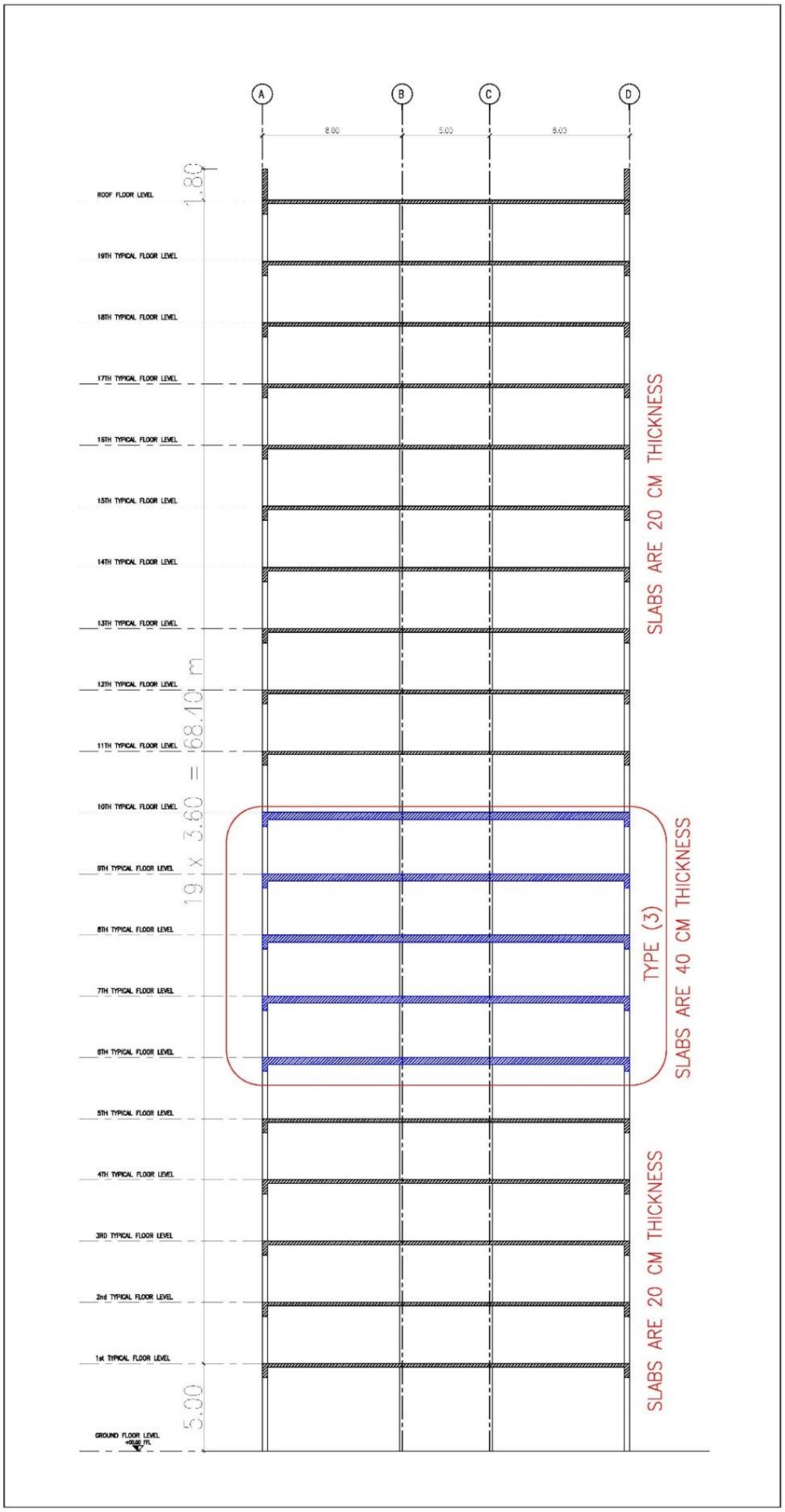

Figure 3.10.4 Structure model 3 – Type (3), with thickened slab at 2nd quarter

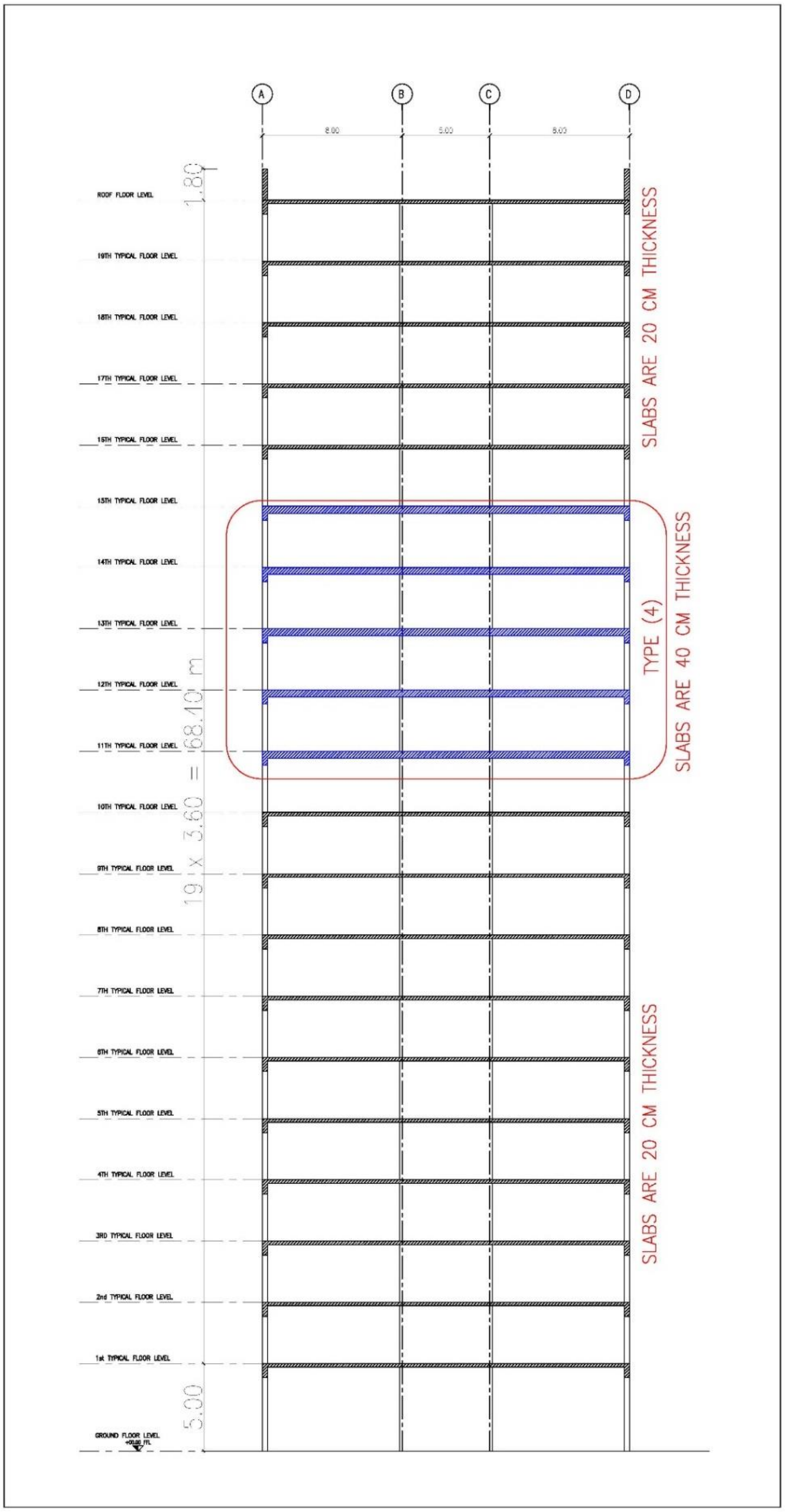

Figure 3.10.5 Structure model 3 – Type (4), with thickened slab at 3rd quarter

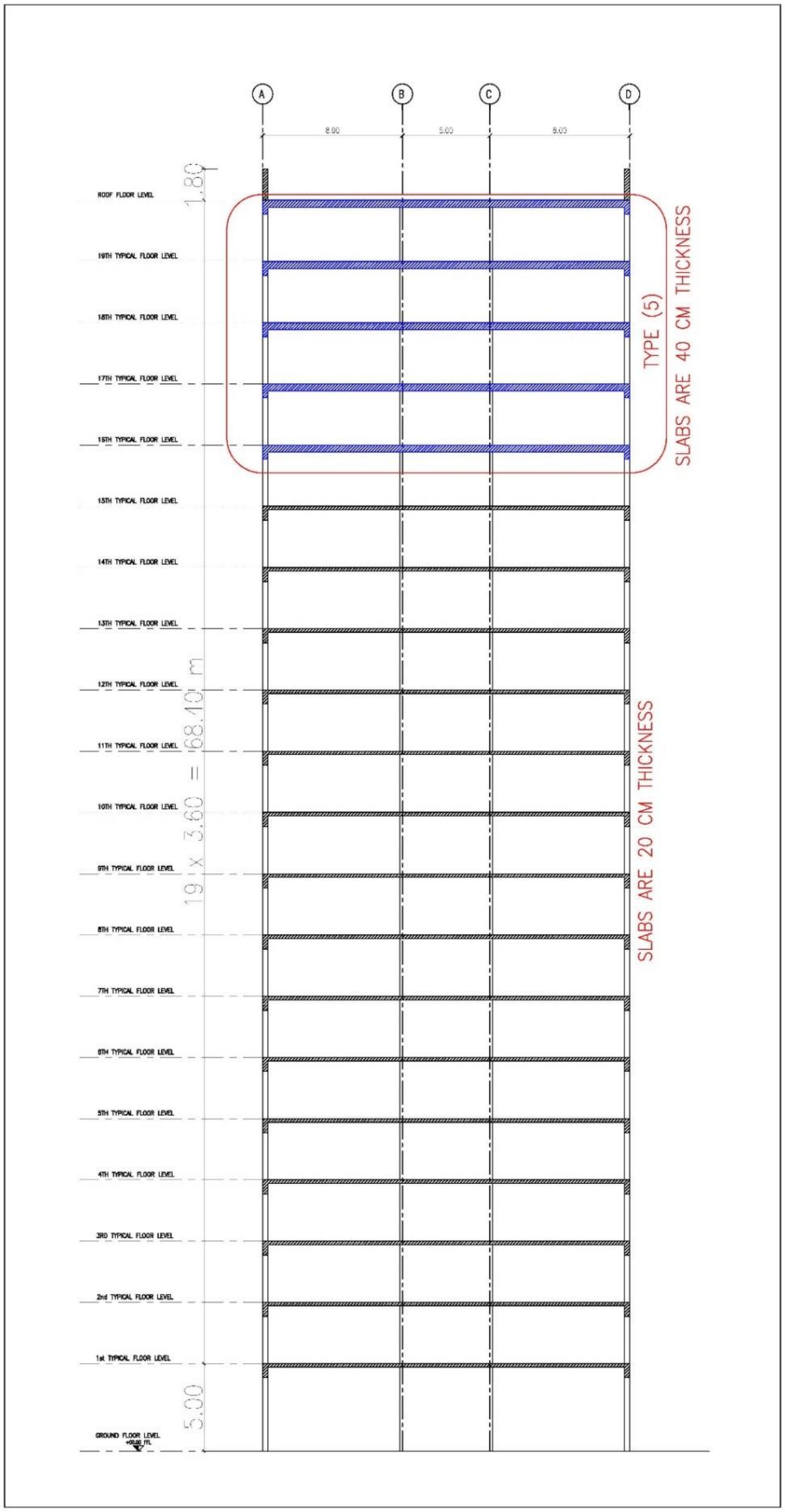

Figure 3.10.6 Structure model 3 – Type (5), with thickened slab at last quarter

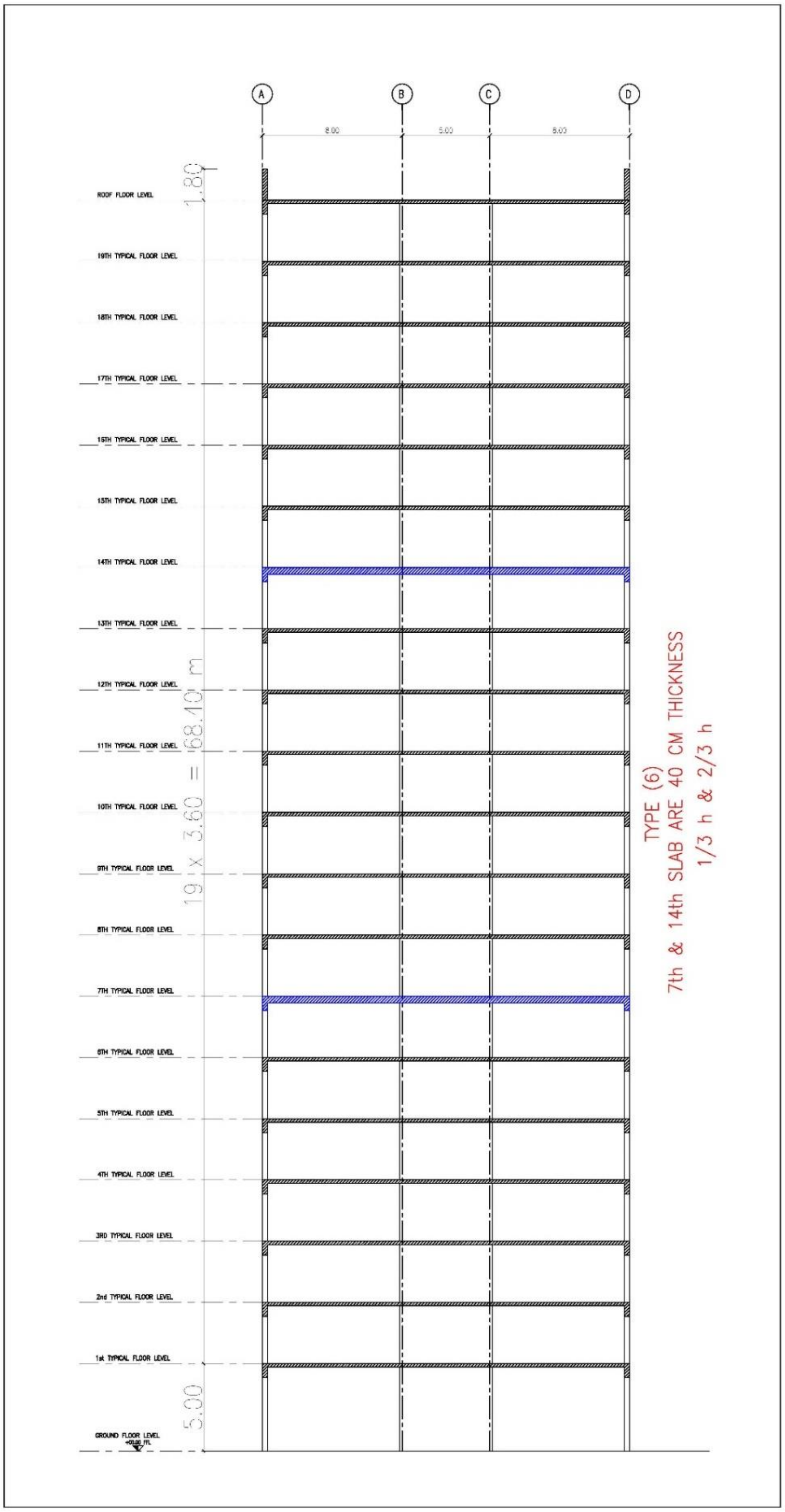

Figure 3.10.7 Structure model 3 – Type (6), with 2 time's thickened slab at 1/3 & 2/3 height

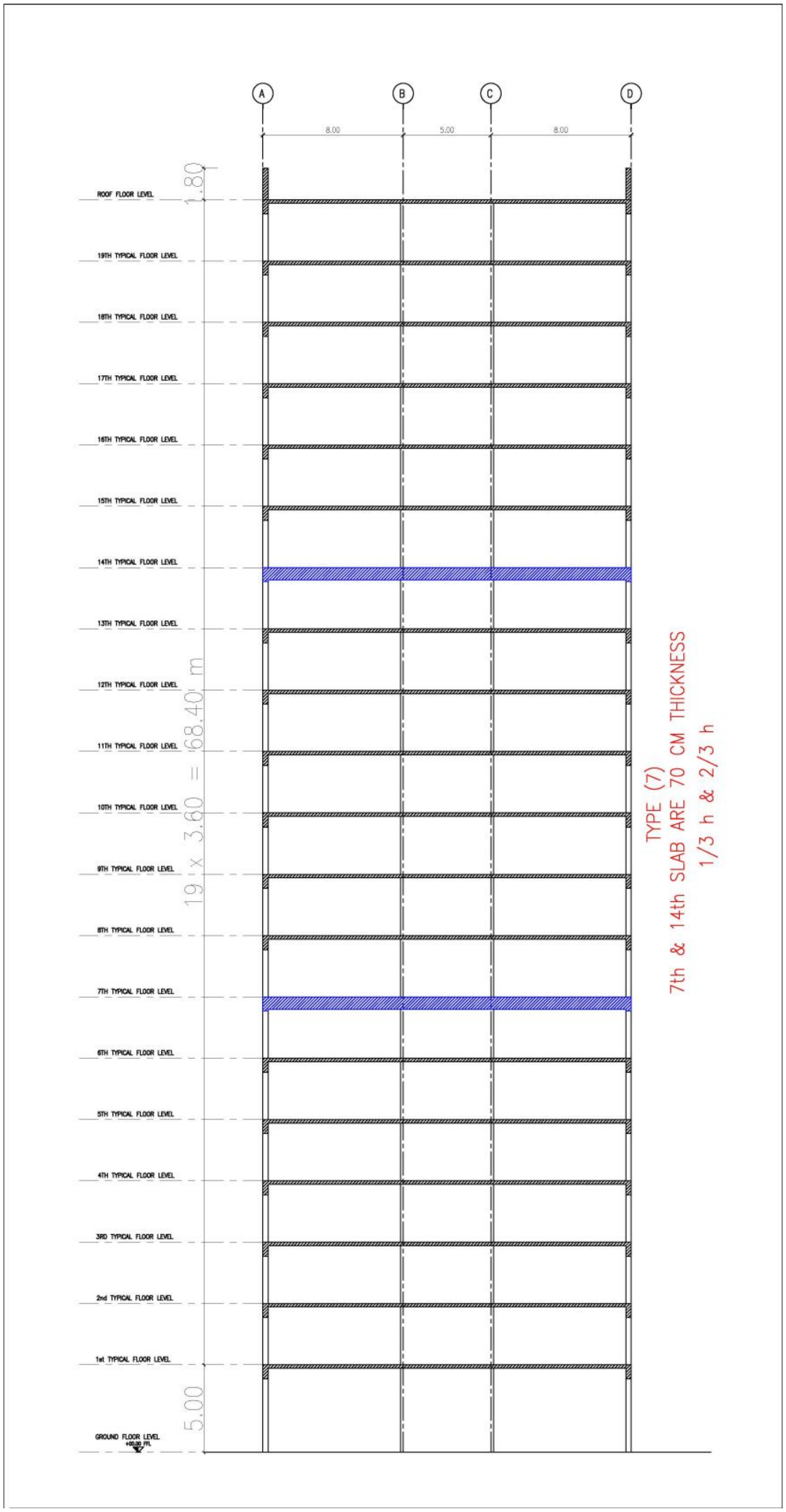

Figure 3.10.8 Structure model 3 – Type (7), with 3.5 times thickened slab at 1/3 & 2/3 height

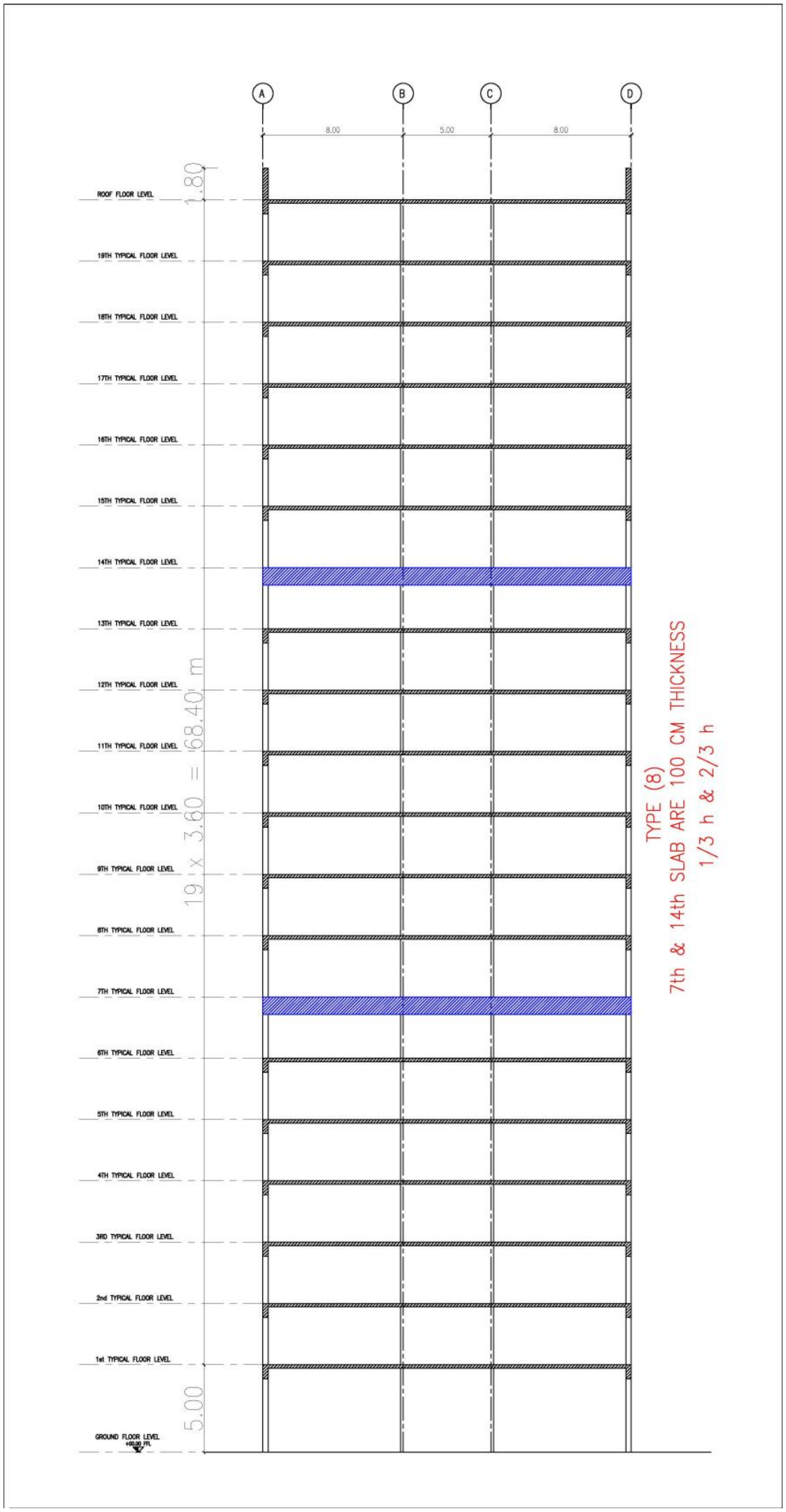

Figure 3.10.9 Structure model 3 – Type (8), with 5 time's thickened slab at 1/3 & 2/3 height

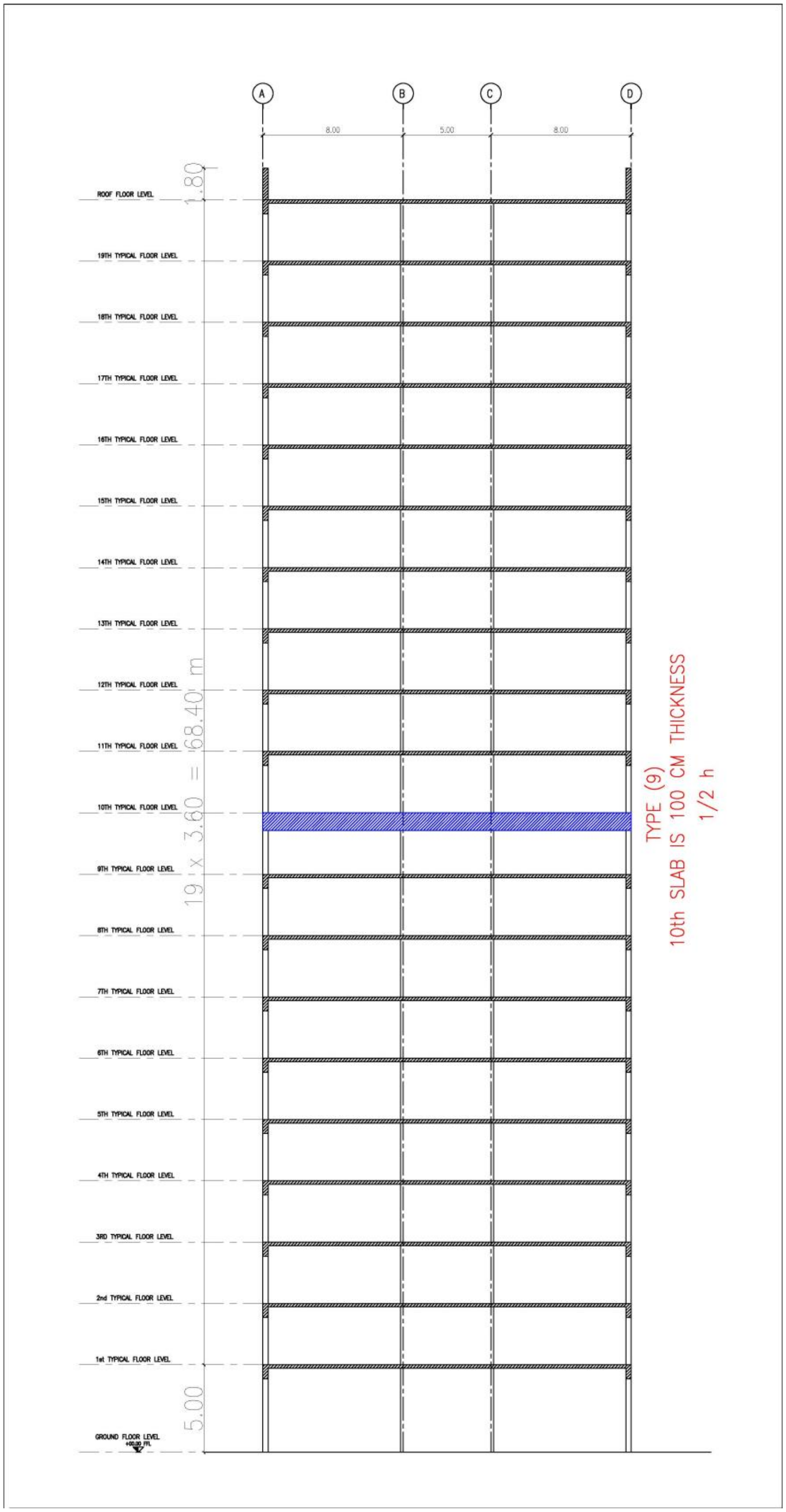

Figure 3.10.10 Structure model 3 – Type (9), with 5 time's thickened slab at mid height

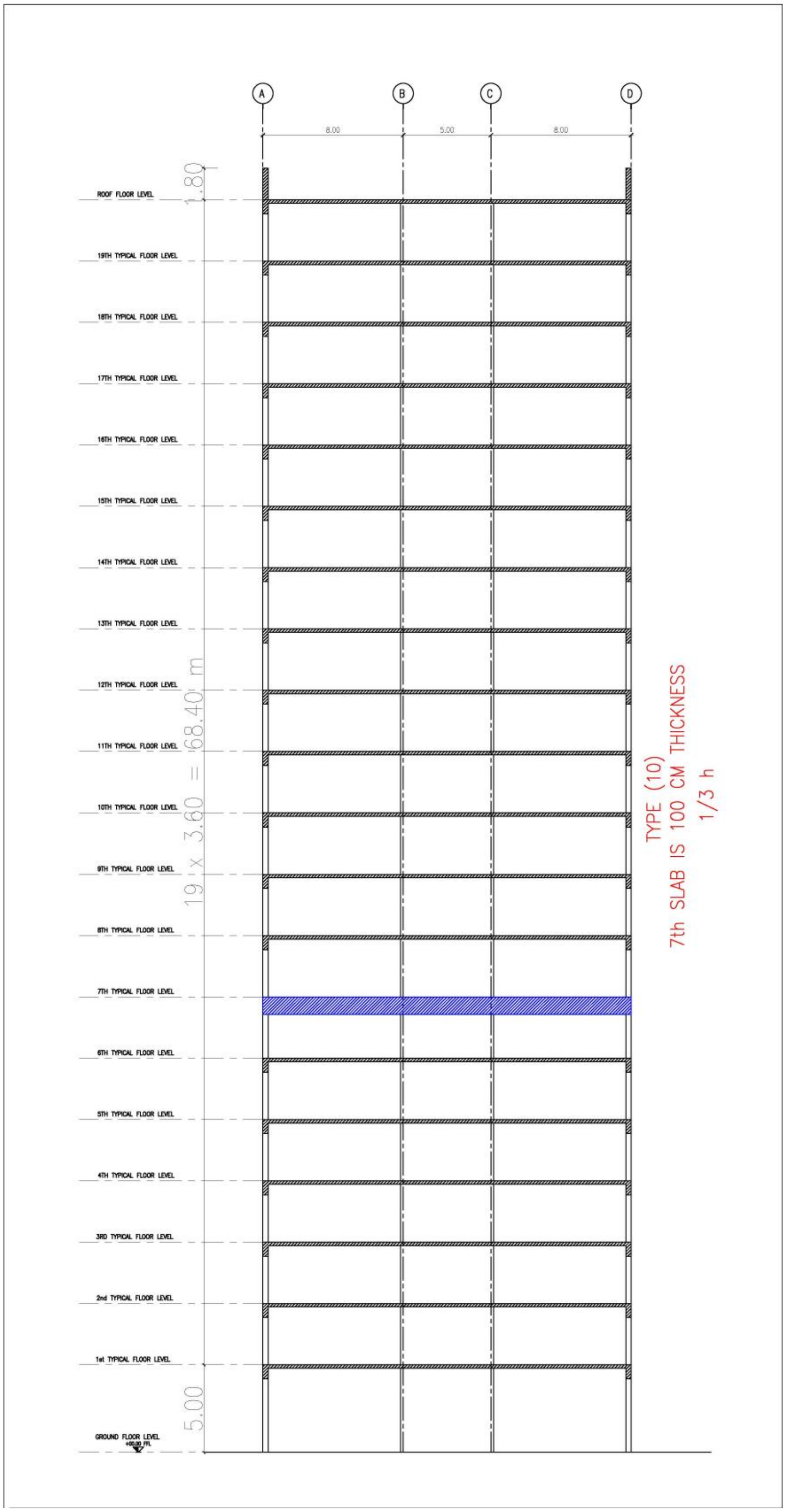

Figure 3.10.11Structure model 3 – Type (10), with 5 times thickened slab at 1/3 height

3.11 Structure model 4 – 12 story (material approach)

The building consists of 12 stories, the 3d model presented on Figure 3.11.1. The total number of models in all second approach are same for each structure model. The number of models in each cases study is five types. There are two ways of using UHPC approach in slabs, the first way is without using any UHPC in all structure as shown on Figure 3.11.2, actually this case used to get the basic value that will be compared with other results as will show later. Second way is based on use of UHPC on the quarters of the whole structure as shown on Figure 3.11.3, Figure 3.11.4, Figure 3.11.5 and Figure 3.11.6.

Input data

Data for 12 story flat slab building in Table 3.11.1

1	Total number of stories	12 story	
2	Total height of building	44.60 m	
3	Slab thickness	20 cm	
4	Grade of concrete	C40	
5	Location of slab with UHPC	Type 1	No UHPC
		Type 2	1^{st} & 2^{nd} & 3^{rd} (first quarter)
		Type 3	4^{th} & 5^{th} &6^{th} (second quarter)
		Type 4	7^{th} & 8^{th} &9^{th} (third quarter)
		Type 5	10^{th} & 11^{th} &12^{th} (last quarter)
6	Grade of Ultra High Performance Concrete	C150	

Table 3.11.1 Structure model 4

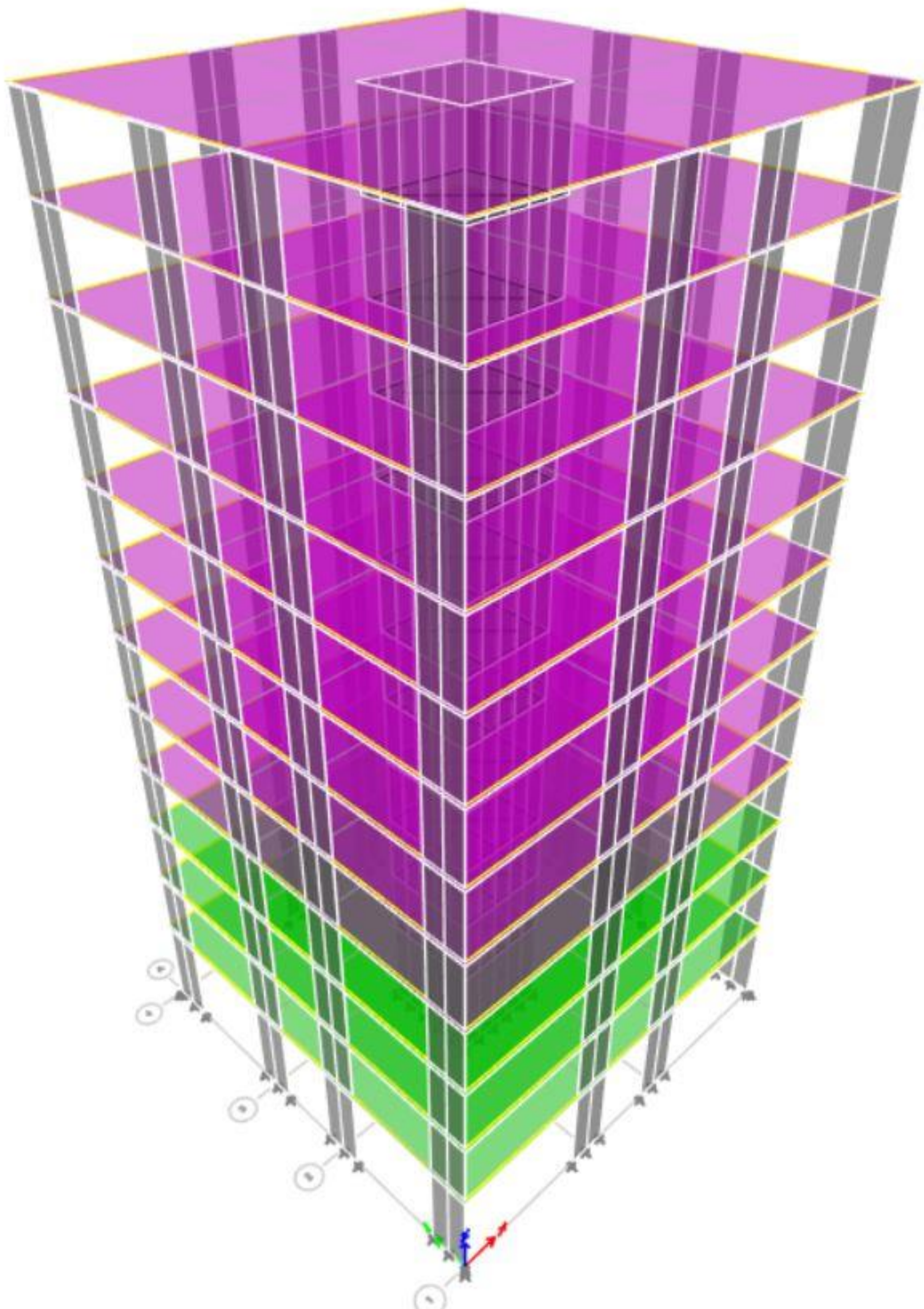

Figure 3.11.1 Structure model (4) - 3D model layout (12) story structural building

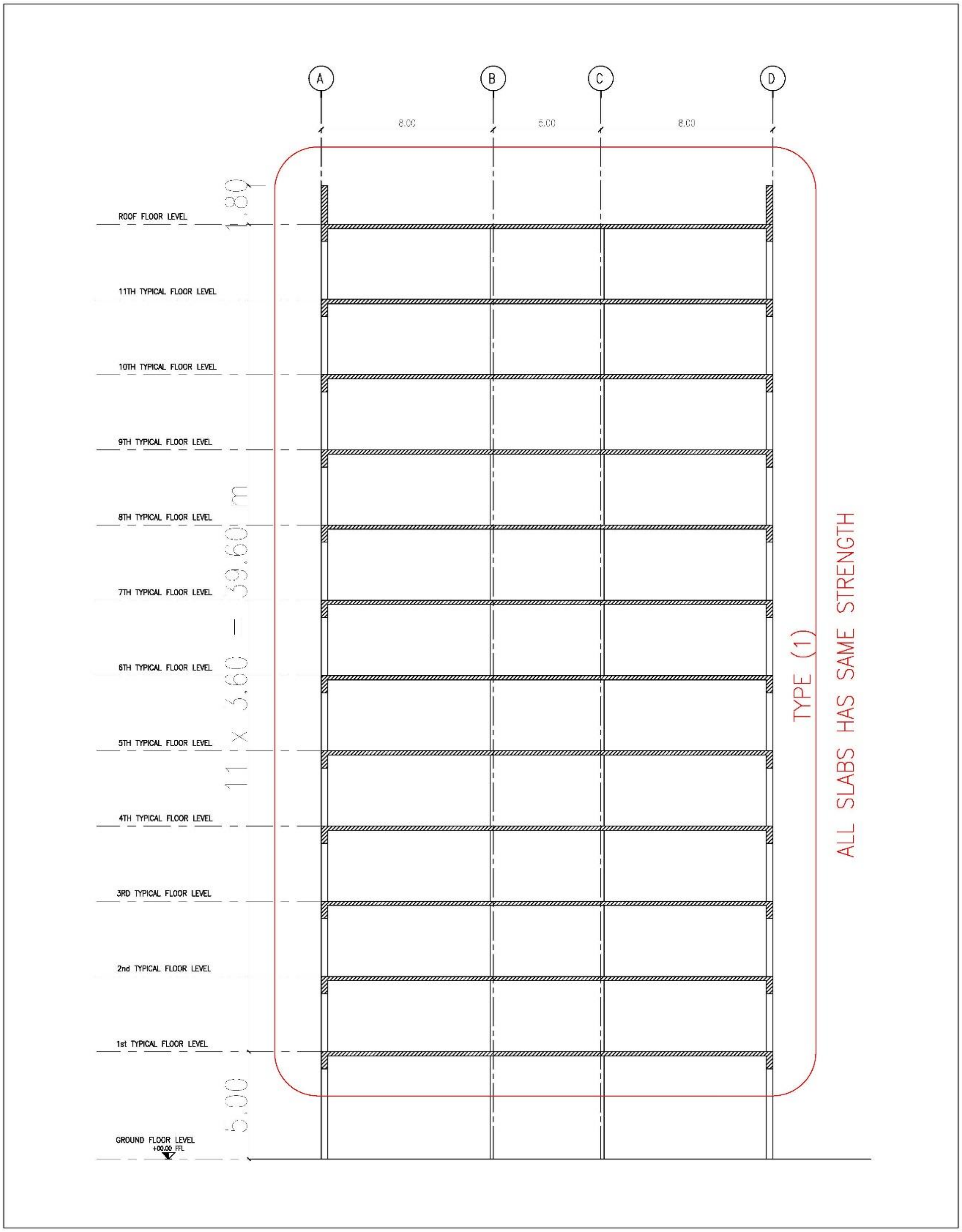

Figure 3.11.2 Structure model 4 – Type (1), without UHPC

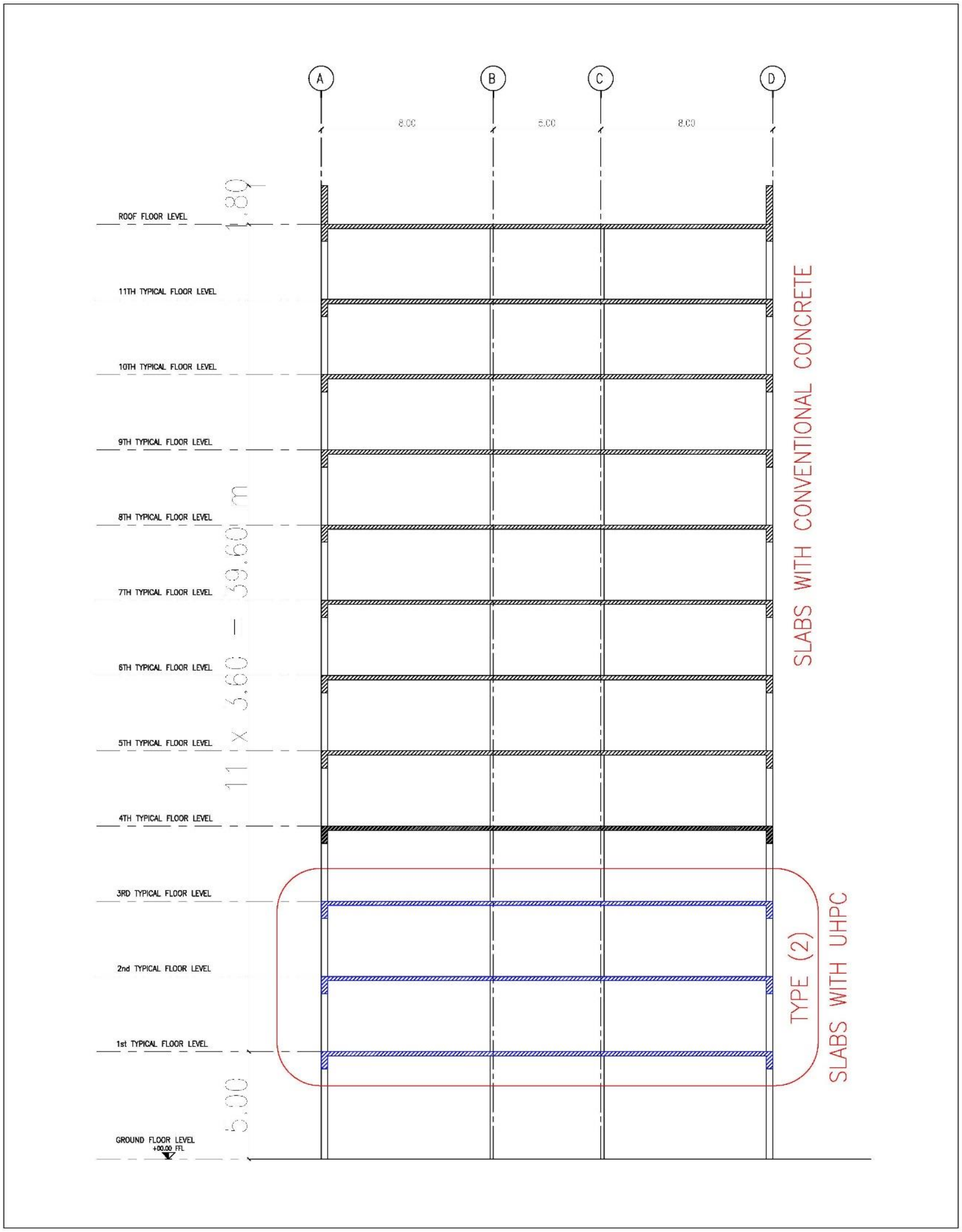

Figure 3.11.3 Structure model 4 – Type (2), with UHPC in 1st quarter

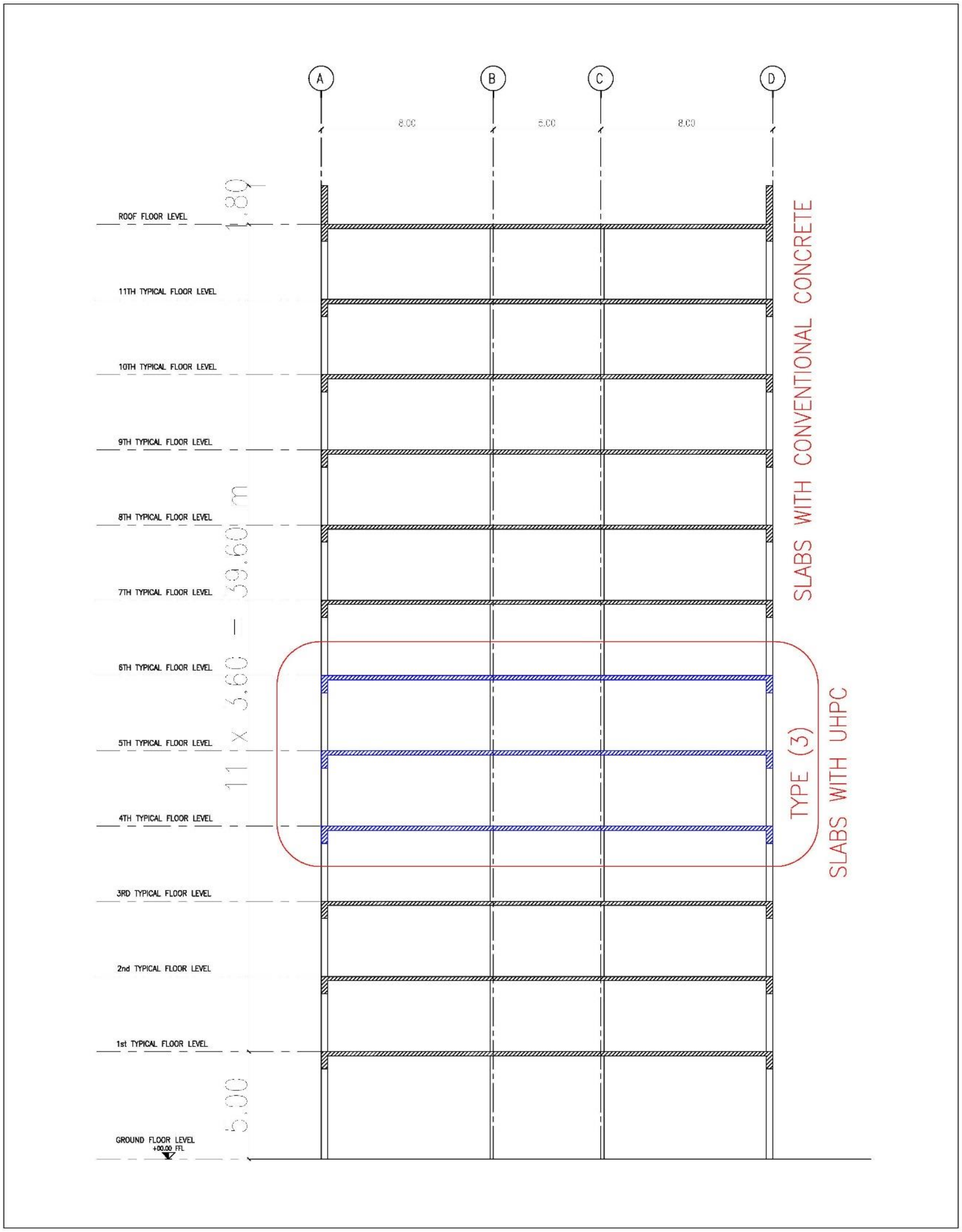

Figure 3.11.4 Structure model 4 – Type (3), with UHPC in 2nd quarter

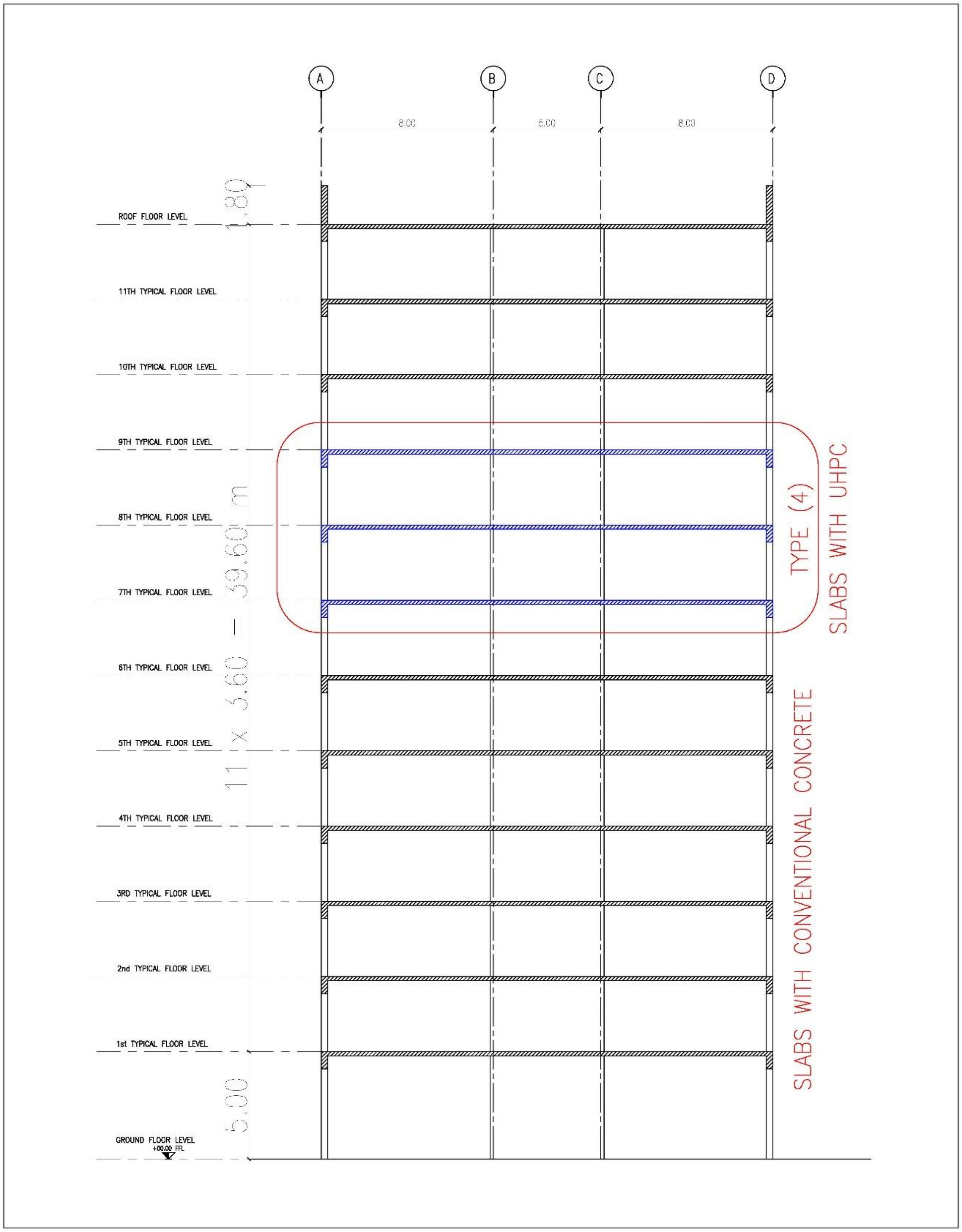

Figure 3.11.5 Structure model 4 – Type (4), with UHPC in 3rd quarter

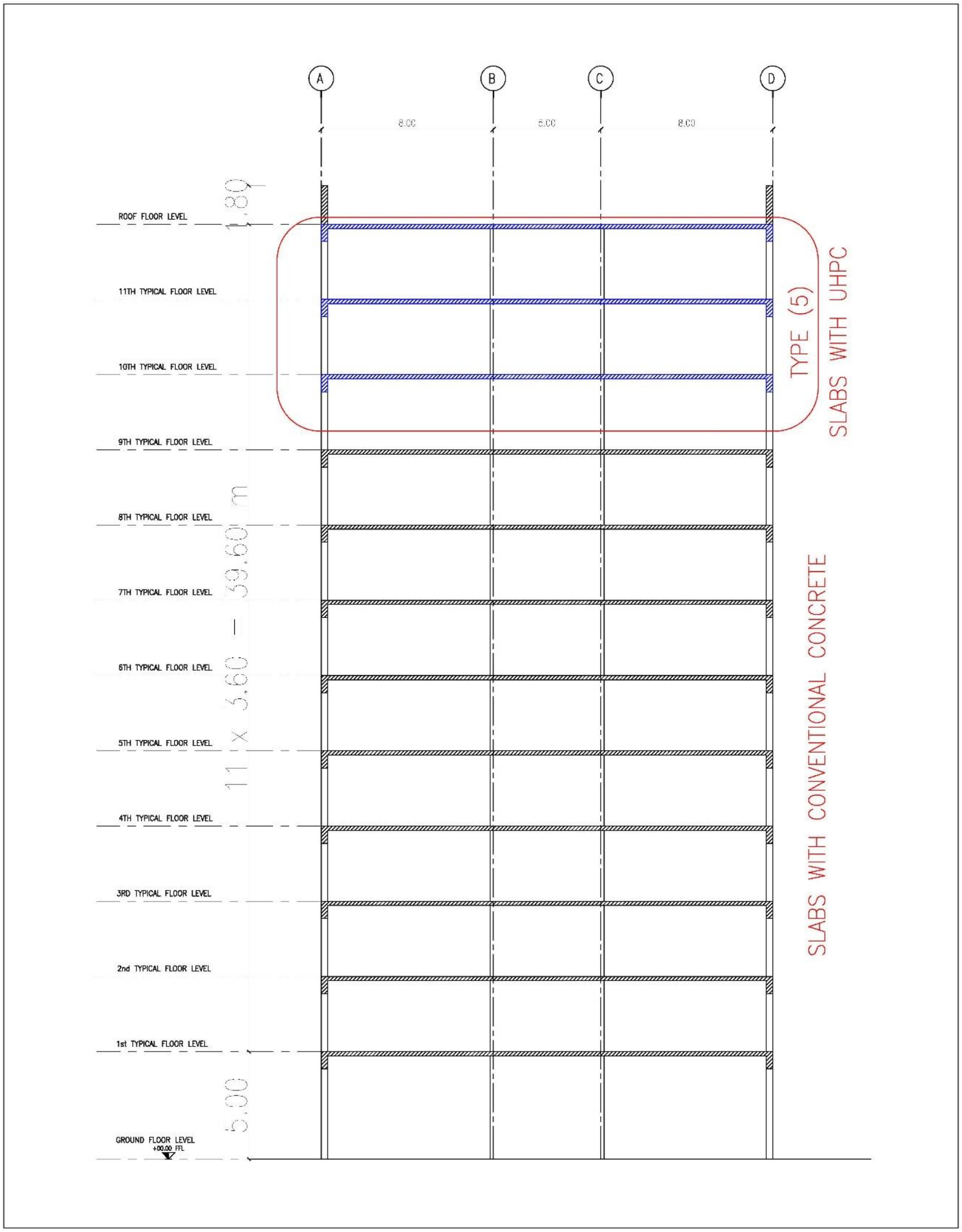

Figure 3.11.6 Structure model 4 – Type (5), with UHPC in last quarter

3.12 Structure model 5 – 16 story (material approach)

The building consists of 16 stories, the 3d model presented on Figure 3.12.1Figure 3.11.1. The same procedures is occur in this structure model. The number of models in each structure model is five types and there are two ways of using UHPC approach in slabs as described before, the first way is without using any UHPC in all structure as shown on Figure 3.12.2Figure 3.11.2. Second way is based on use of UHPC on the quarters of the whole structure as shown on Figure 3.12.3, Figure 3.12.4, Figure 3.12.5and Figure 3.12.6Figure 3.11.6.

Data for 16 story flat slab building in Table 3.12.1

1	Total number of stories	16 story	
2	Total height of building	59.00 m	
3	Slab thickness	20 cm	
4	Grade of concrete	C40	
5	Location of slab with UHPC	Type 1	No thickened slab
		Type 2	1^{st} & 2^{nd} & 3^{rd} &4^{th} (first quarter)
		Type 3	5^{th} & 6^{th} &7^{th} & 8^{th} (second quarter)
		Type 4	9^{th} & 10^{th} &11^{th} & 12^{th} (third quarter)
		Type 5	13^{th} & 14^{th} &15^{th} &16^{th} (last quarter)
6	Grade of Ultra High Performance Concrete	C150	

Table 3.12.1Structure model 5

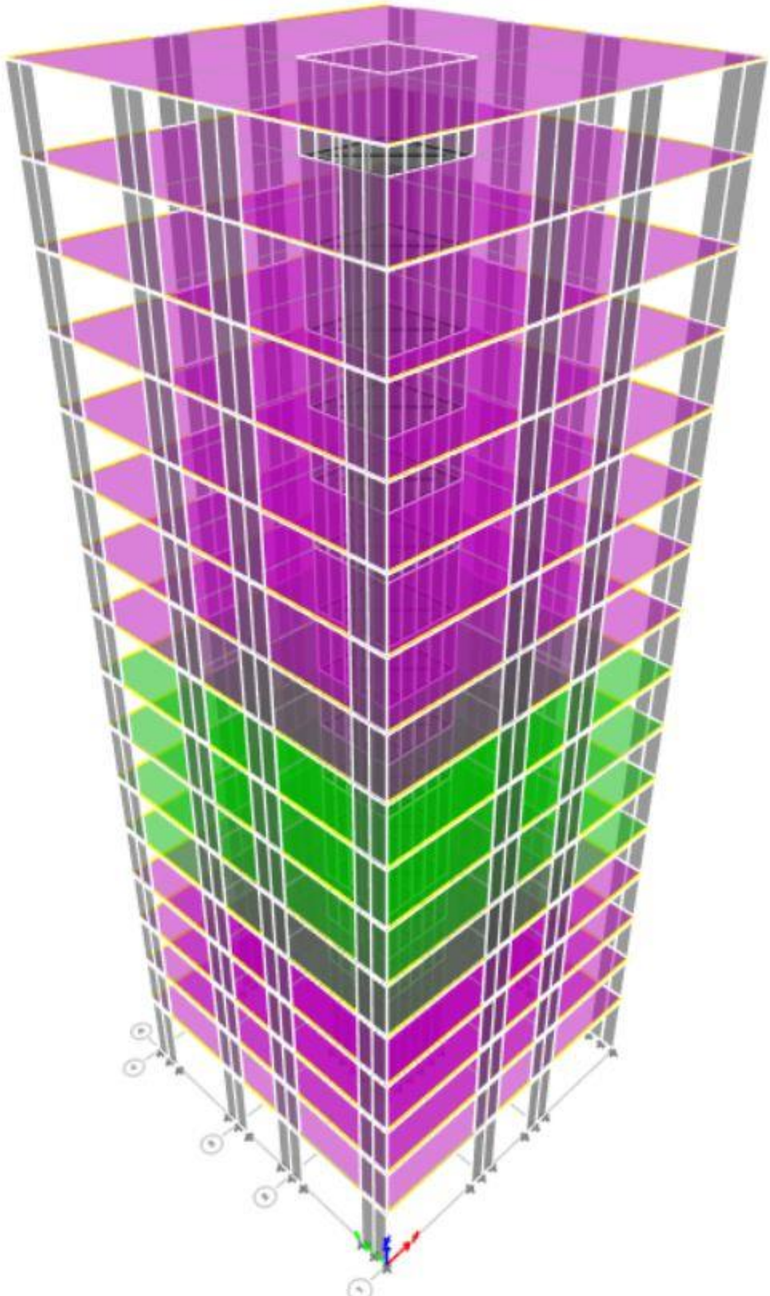

Figure 3.12.1 Structure model (5) - 3D model layout (16) story structural building

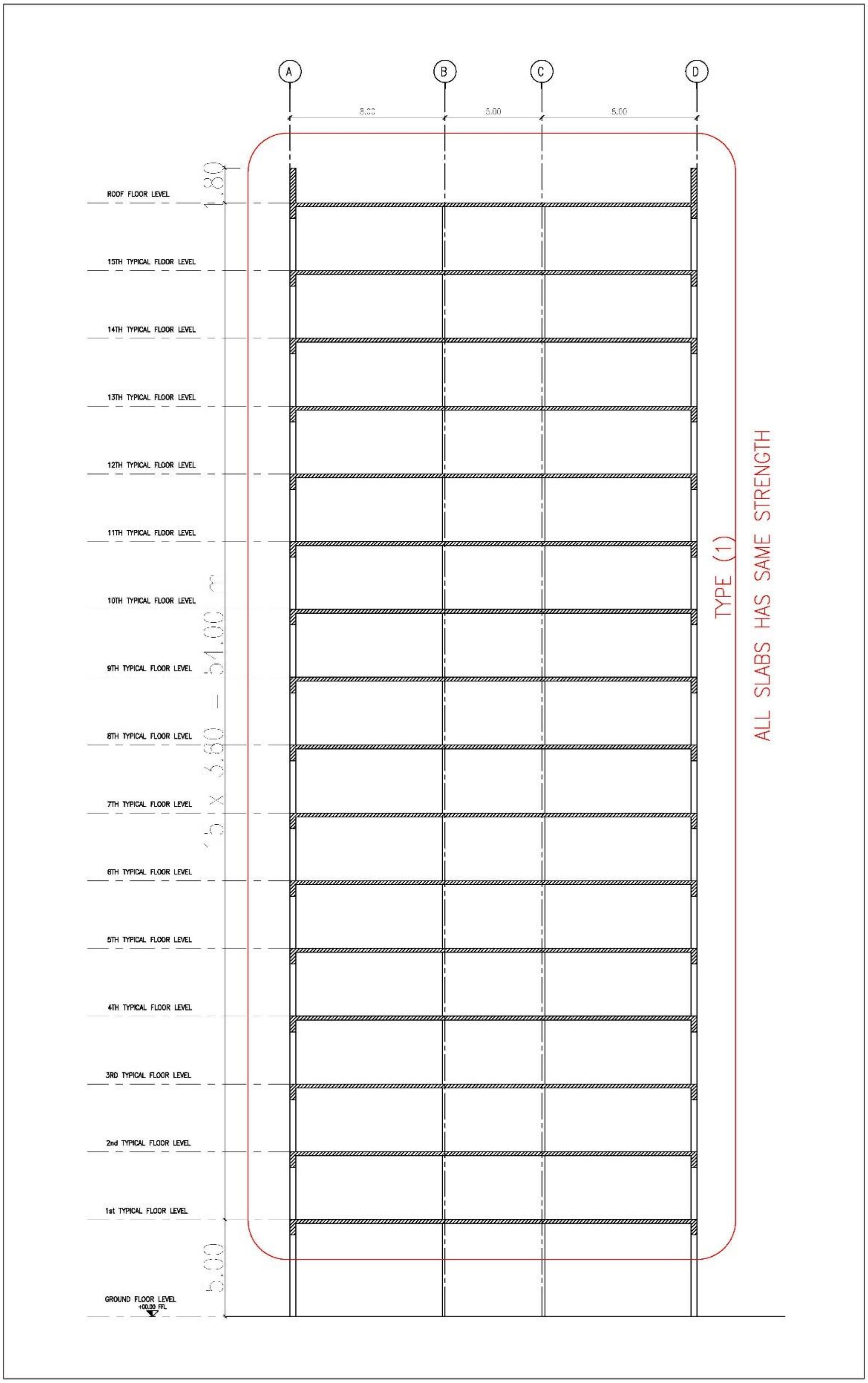

Figure 3.12.2 Structure model 5 – Type (1), without UHPC

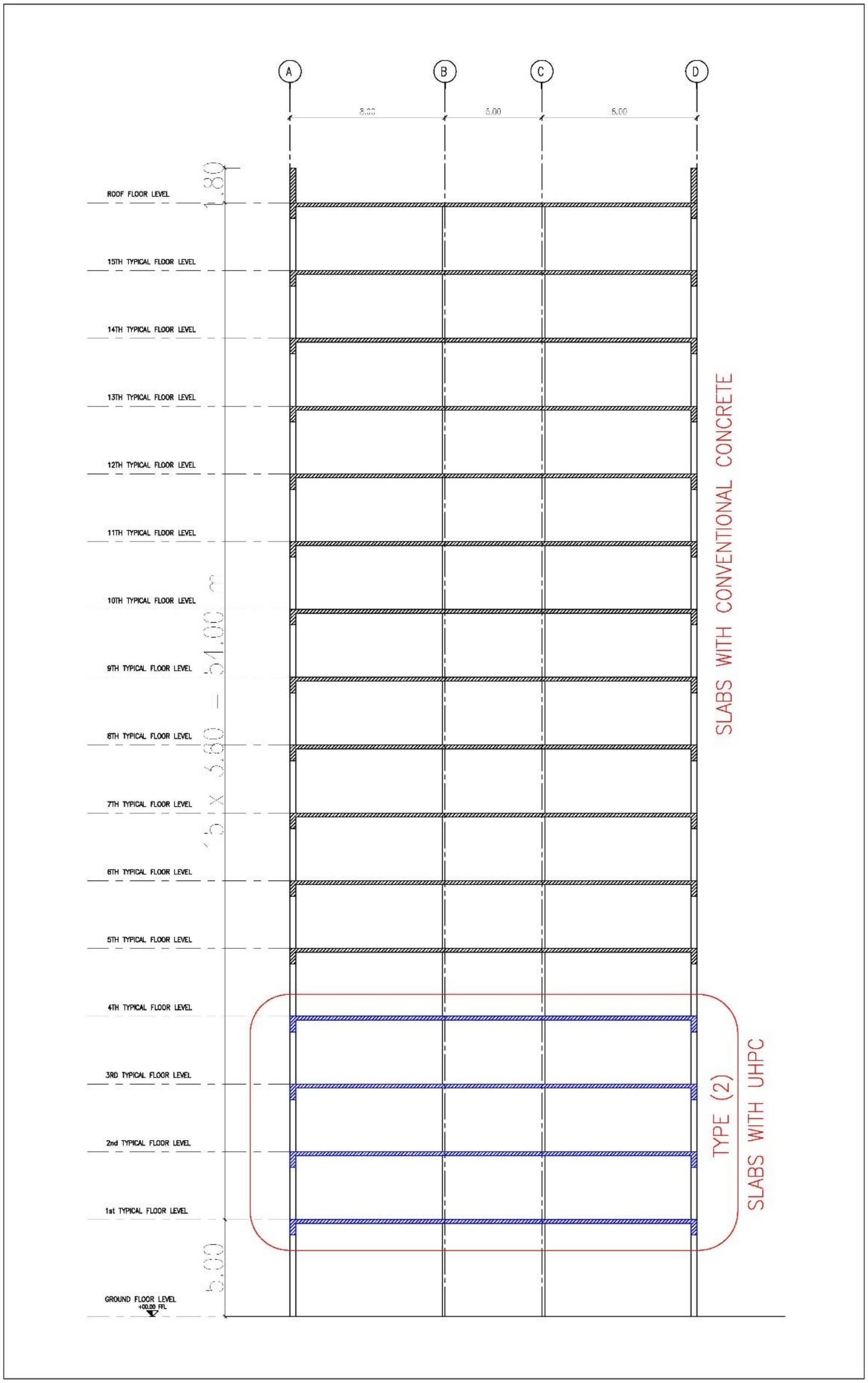

Figure 3.12.3 Structure model 5 – Type (2), with UHPC in 1st quarter

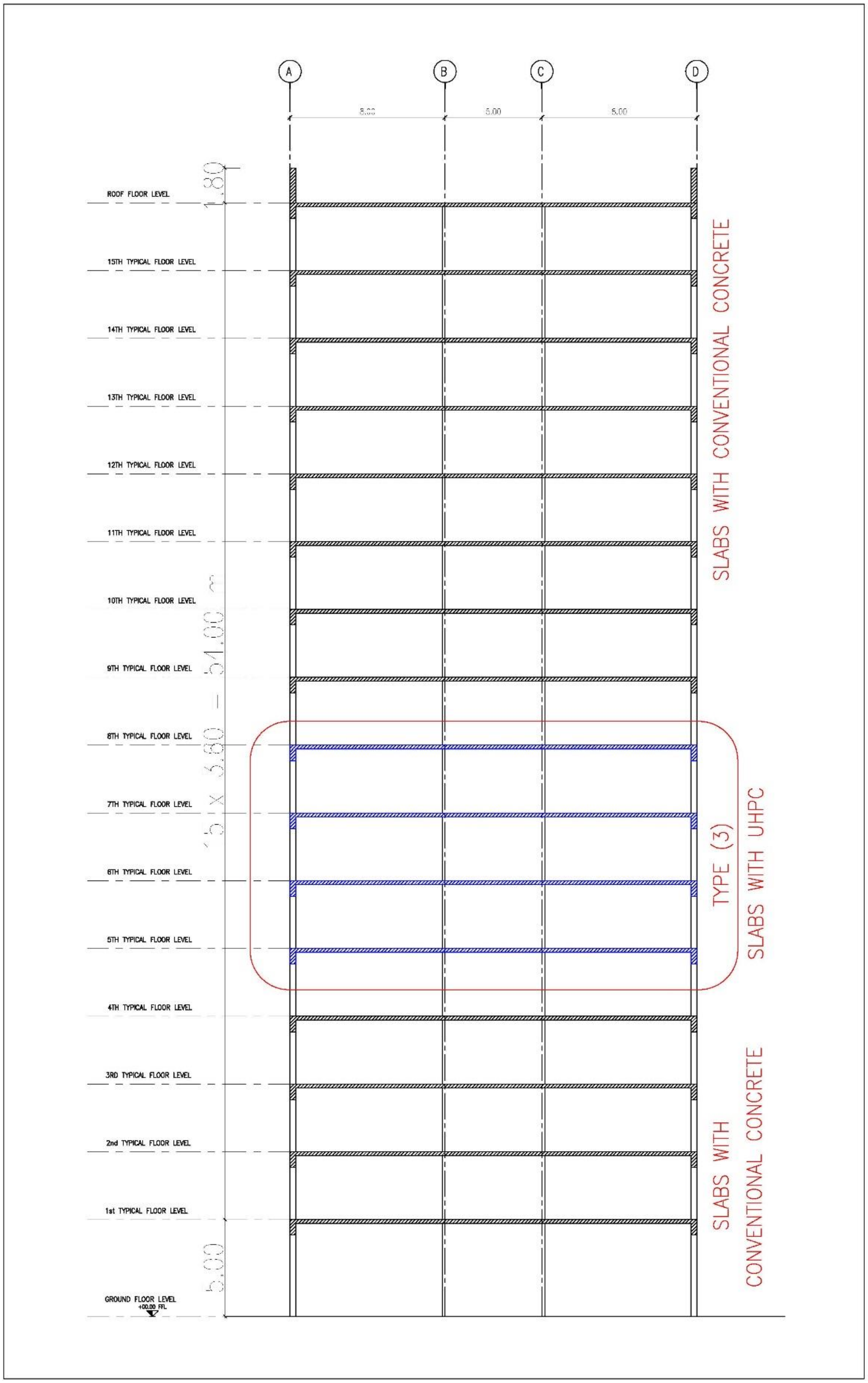

Figure 3.12.4 Structure model 5 – Type (3), with UHPC in 2nd quarter

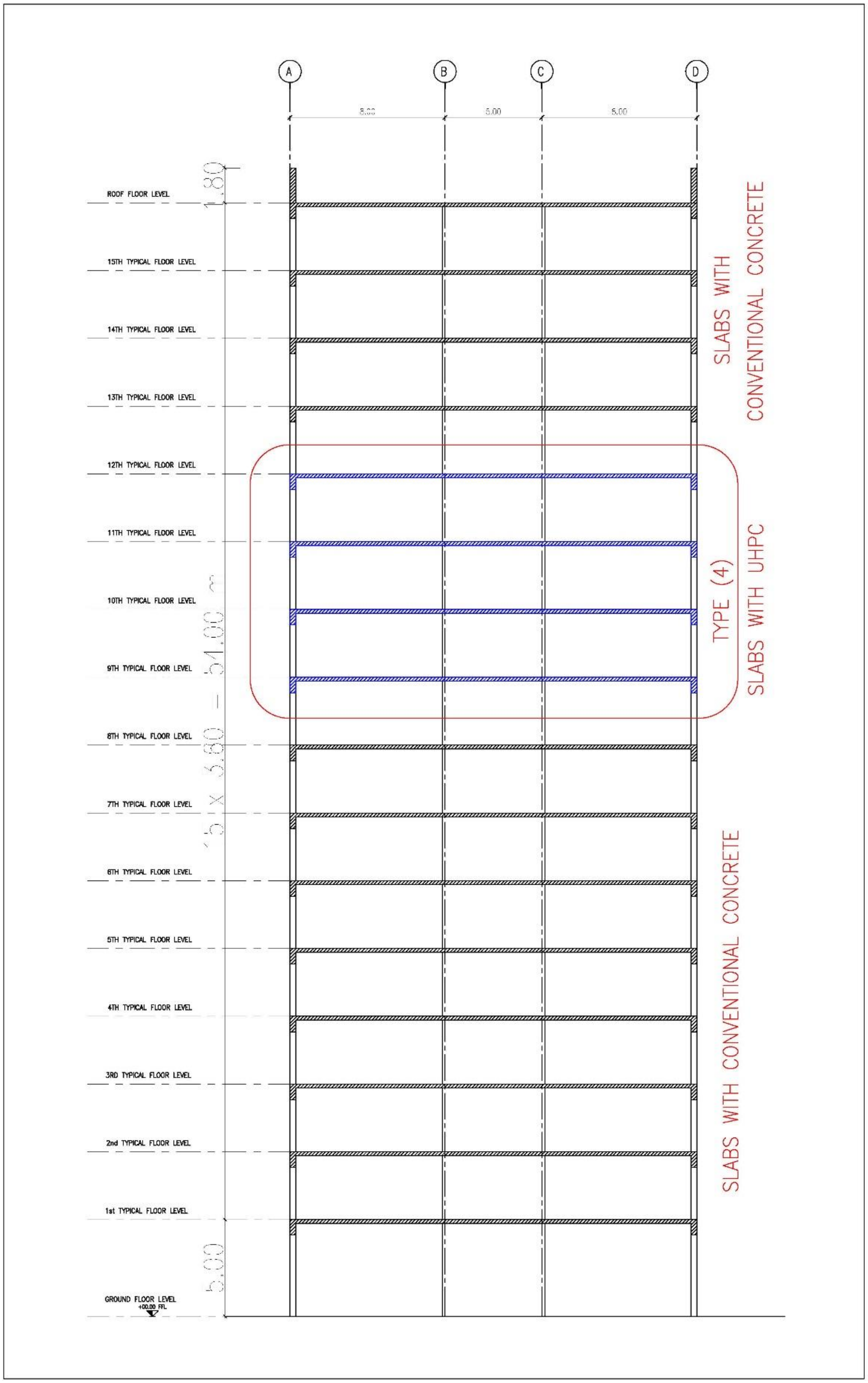

Figure 3.12.5 Structure model 5 – Type (4), with UHPC in 3rd quarter

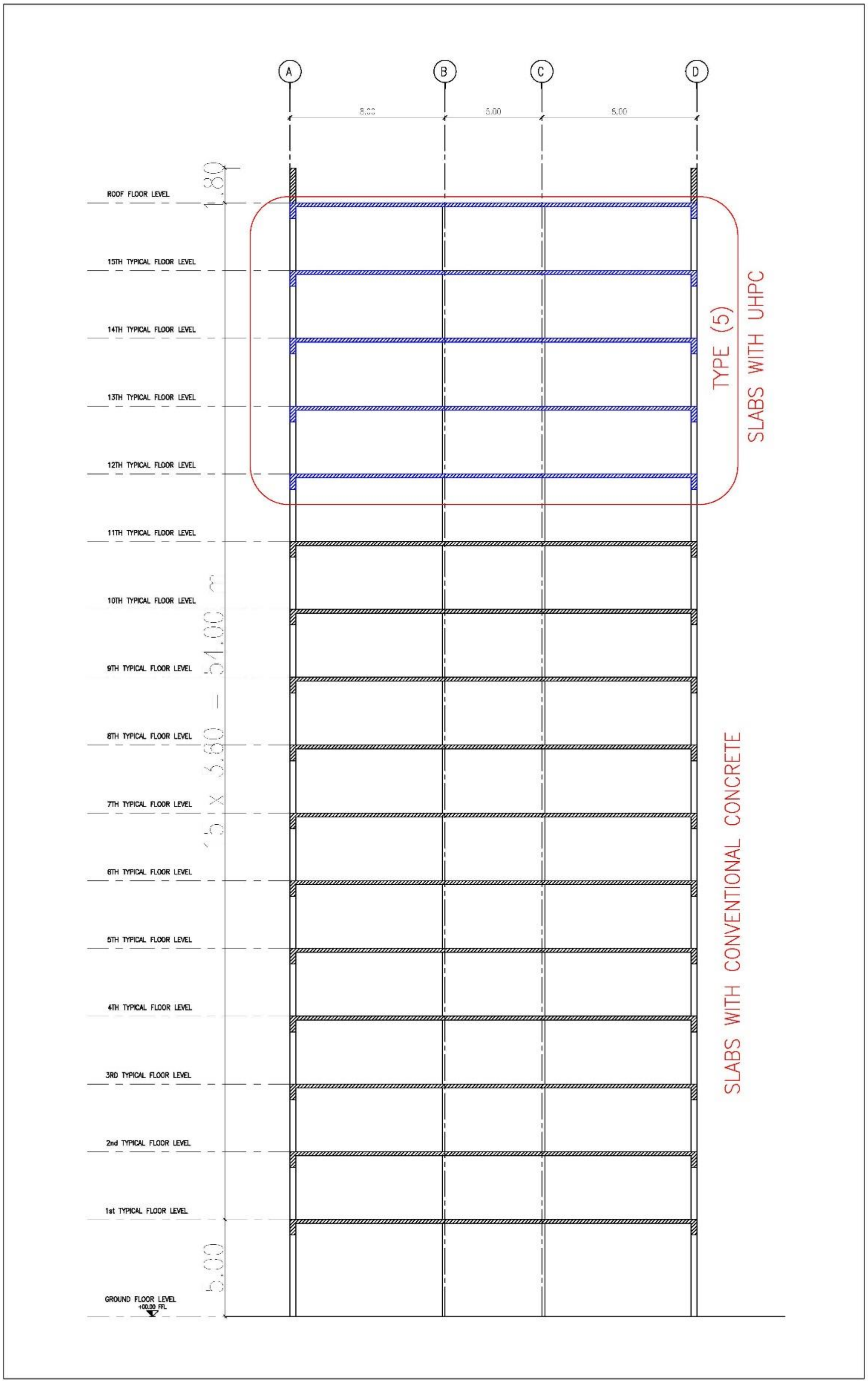

Figure 3.12.6 Structure model 5 – Type (5), with UHPC in last quarter

3.13 Structure model 6 – 20 story (material approach)

The last structure model in this thesis is structure consists of 20 stories, the 3d model presented on Figure 3.13.1Figure 3.11.1. The same procedures is occur in this structure model. The number of models in each structure model is five types and there are two ways of using UHPC approach in slabs as described before, the first way is without using any UHPC in all structure as shown on Figure 3.13.2Figure 3.11.2. Second way is based on use of UHPC on the quarters of the whole structure as shown on Figure 3.13.3, Figure 3.13.4, Figure 3.13.5 and Figure 3.13.6Figure 3.11.6.

Data for 20 story flat slab building Table 3.13.1

<table>
<tr><td>1</td><td>Total number of stories</td><td colspan="2">20 story</td></tr>
<tr><td>2</td><td>Total height of building</td><td colspan="2">73.40 m</td></tr>
<tr><td>3</td><td>Slab thickness</td><td colspan="2">20 cm</td></tr>
<tr><td>4</td><td>Grade of concrete</td><td colspan="2">C40</td></tr>
<tr><td rowspan="5">5</td><td rowspan="5">Location of thickened slab</td><td>Type 1</td><td>No thickened slab</td></tr>
<tr><td>Type 2</td><td>1st & 2nd & 3rd &4th &5th (first quarter)</td></tr>
<tr><td>Type 3</td><td>6th &7th & 8th &9th & 10th (second quarter)</td></tr>
<tr><td>Type 4</td><td>11th & 12th &13th &14th &15th (third quarter)</td></tr>
<tr><td>Type 5</td><td>16th &17th &18th &19th &20th (last quarter)</td></tr>
<tr><td>6</td><td>Grade of Ultra High Performance Concrete</td><td colspan="2">C150</td></tr>
</table>

Table 3.13.1 Structure model 6

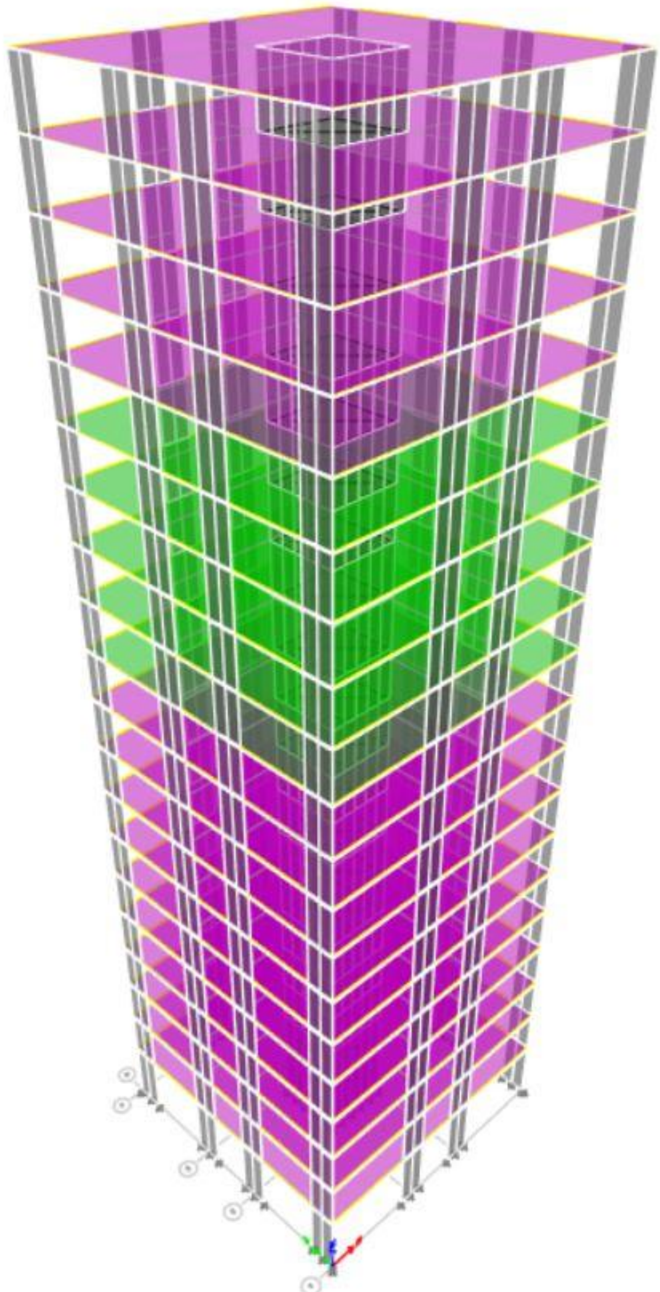

Figure 3.13.1 Structure model (6) - 3D model layout (20) story structural building

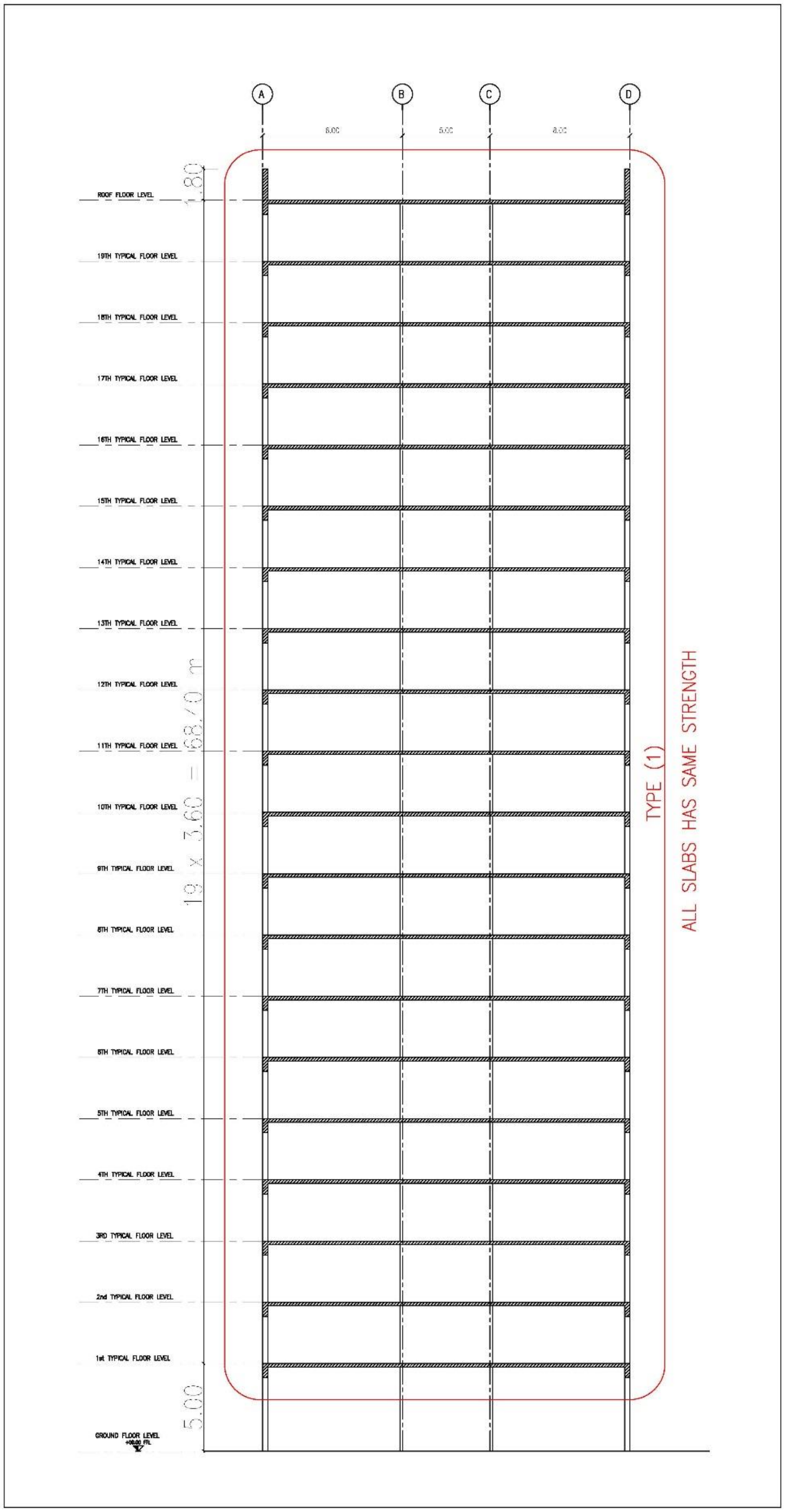

Figure 3.13.2 Structure model 6 – Type (1), without UHPC

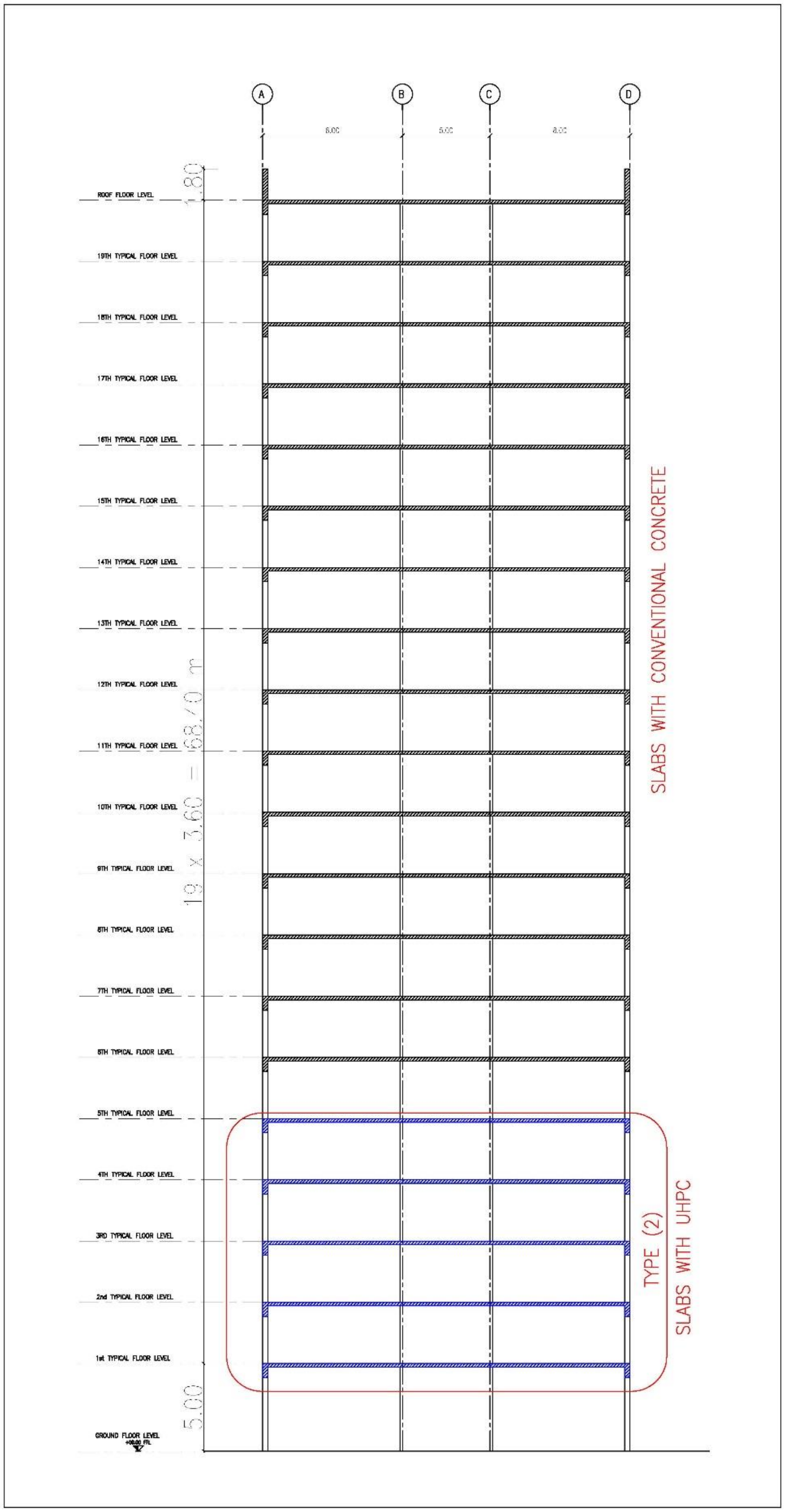

Figure 3.13.3 Structure model 6 – Type (2), with UHPC in 1st quarter

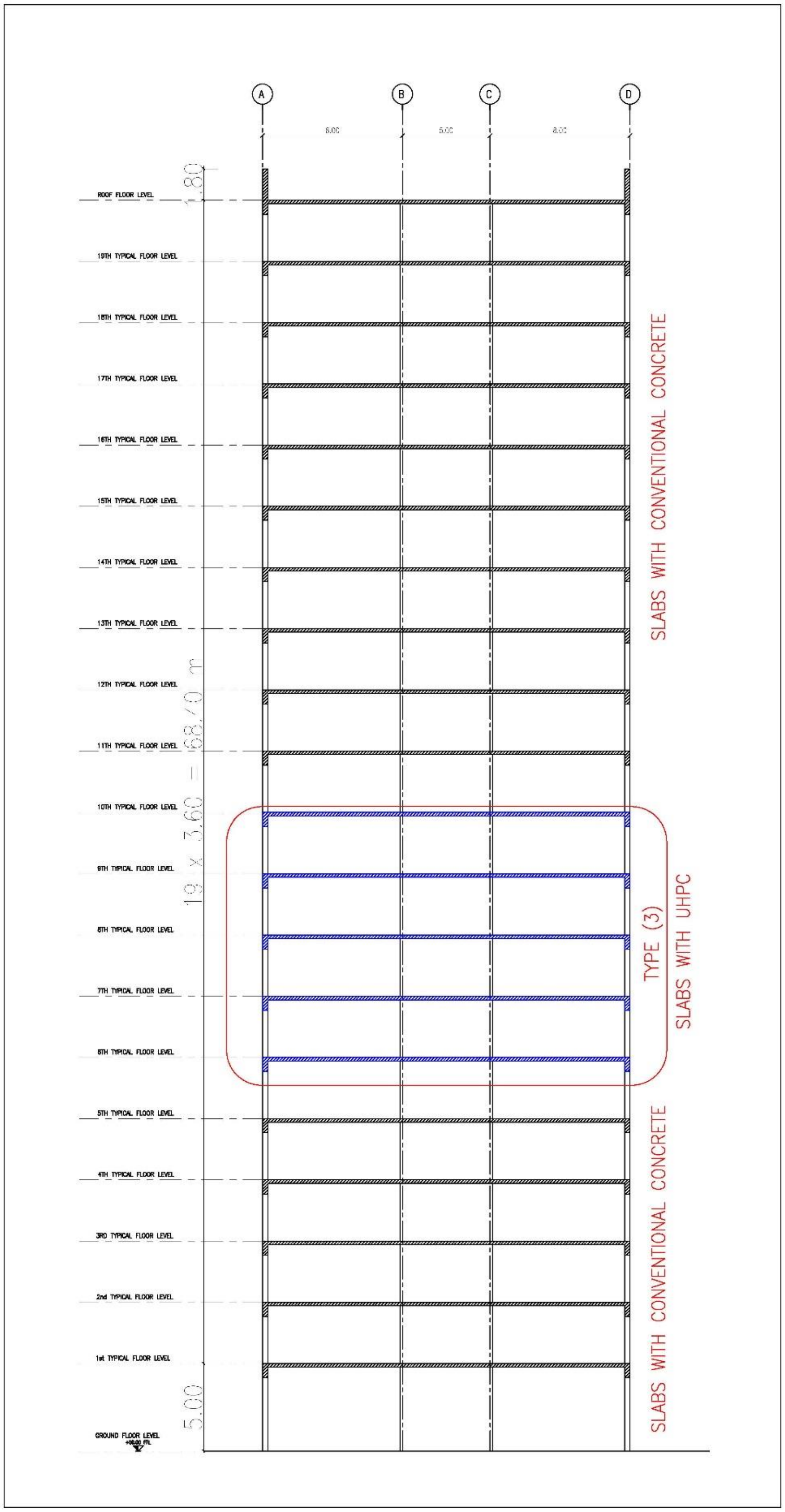

Figure 3.13.4 Structure model 6 – Type (3), with UHPC in 2nd quarter

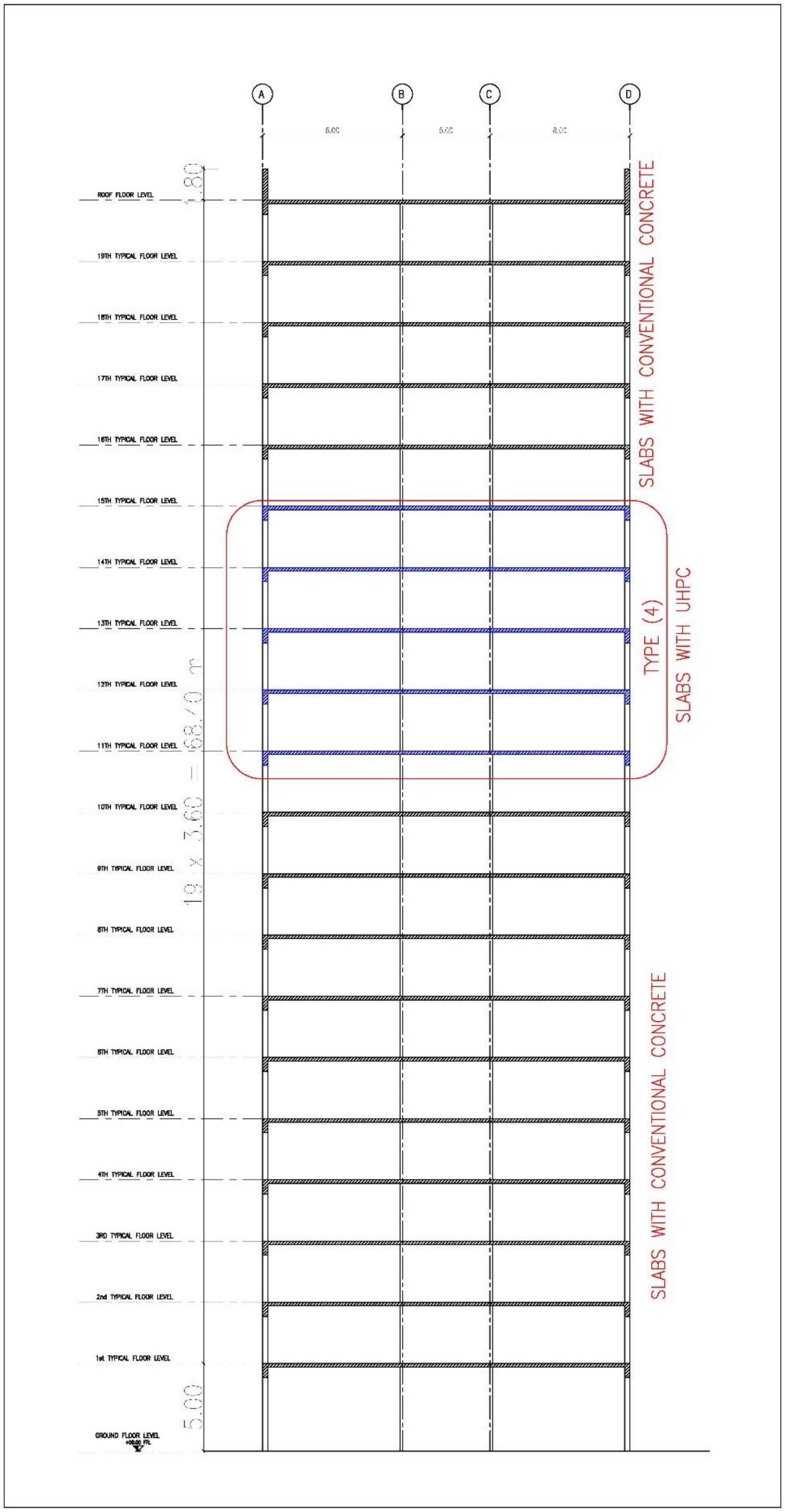

Figure 3.13.5 Structure model 6 – Type (4), with UHPC in 3rd quarter

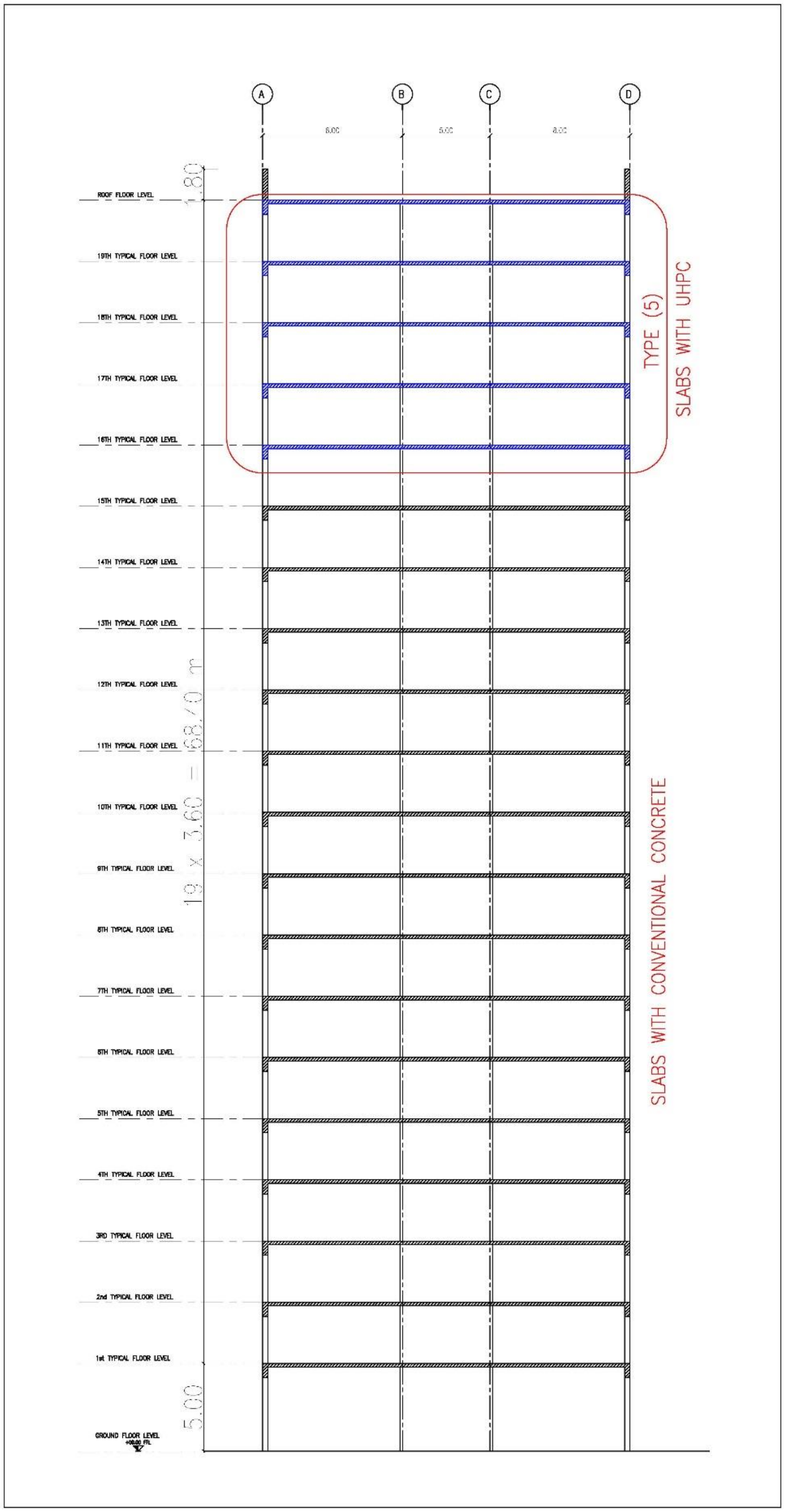

Figure 3.13.6 Structure model 6 – Type (5), with UHPC in last quarter

Chapter 4 Research Result

4.1 Introduction

This chapter presents the results extracted from in ETABS models for the case and their corresponding results. Model results were extracted from ETABS and were exported to MS Excel to plot graphs.

The results demonstrate the drift values for all models, shear force diagrams for each model and the total displacement values versus the seismic force.

4.2 Result of structure model 1 – 12 story (stiffness approach)

4.2.1 Drift results:

The following figures demonstrate the behavior of 12 story building structure. Figure 4.2.1 compares between the seismic drift of thickened slabs in the quarters of the building and the behavior of the structure without using any thickened slabs.

The Figure 4.2.1 shows the five different types shown on Table 3.8.1 using the stiffness approach. Four cases of study (type 2: type 4) are plotted with the main structure without any thickened slab type 1 to observe the difference.

The results shows that drift is nearly linear increase till at least the mid height or third quarter of structure, depends on the location of thickened slab and suddenly it inversely decrease towards the top of the structure as shown on Figure 4.2.1, drift value of type (1) which is the basic case is increasing with parabolic shape till the 9^{th} floor (0.005239) and then reduces to reach value of (0.004989) at 12^{th} floor, type (2) has a similar behavior of type (1) and also reach the value of (0.00507) at 9^{th} floor and then reduces to reach value of (0.004854) at 12^{th} floor, type (3) is similar till 4^{th} floor and increasing with inverse parabolic shape compared with type (1) till reach the value of (0.00466) at 8^{th} floor and then reduces to reach value of (0.004493) at 12^{th} floor, type (4) has similar parabolic shape increasing till the 6^{th} floor till reach the value of (0.004496) at 6^{th} floor and then it has an inverse parabolic shape till reach the value of (0.004562) at 11^{th} floor and then reduce again to reach (0.004412) at 12^{th} floor and finally type (5) has a complete parabolic shape with the apex value of (0.005132) at 8^{th} floor and the value of (0.004111) at 12^{th} floor.

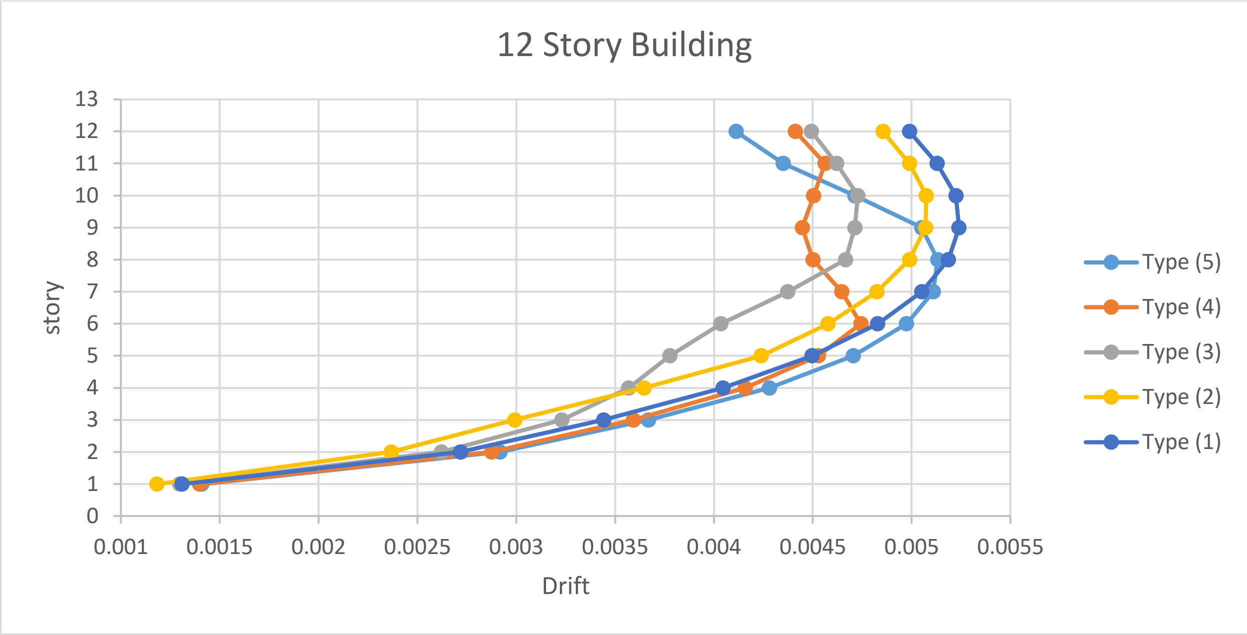

Figure 4.2.1 Structure model 1, drift (quarter division).

The result of two different cases using slab thickness of two - / - three times the main slab thickness at 1/3 and 2/3 of the overall height of building structure are plotted along with the main structure without any thickened slab to observe the difference as shown on Figure 4.2.2

The results shows type (6) is increasing with similar behavior as type (1) till reach the value of (0.004812) at 7^{th} floor and then has inverse parabolic shape between 7^{th} floor and 10^{th} floor to reach a value of (0.004924) at 10^{th} floor and then reduces to reach value of (0.004685) at 12^{th} floor, next type is type (7) which is almost similar behavior of type (6) but with lesser drift value, type (7) reach the value of (0.00467) at 7^{th} floor and then has inverse parabolic shape between 7^{th} floor and 10^{th} floor to reach a value of (0.004743) at 10^{th} floor and then reduces to reach value of (0.004505) at 12^{th} and last type is type (8) which is almost similar behavior of type (6) but with lesser drift value, type (8) reach the value of (0.004512) at 7^{th} floor and then has inverse parabolic shape between 7^{th} floor and 10^{th} floor to reach a value of (0.004546) at 10^{th} floor and then reduces to reach value of (0.004304) at 12^{th}.

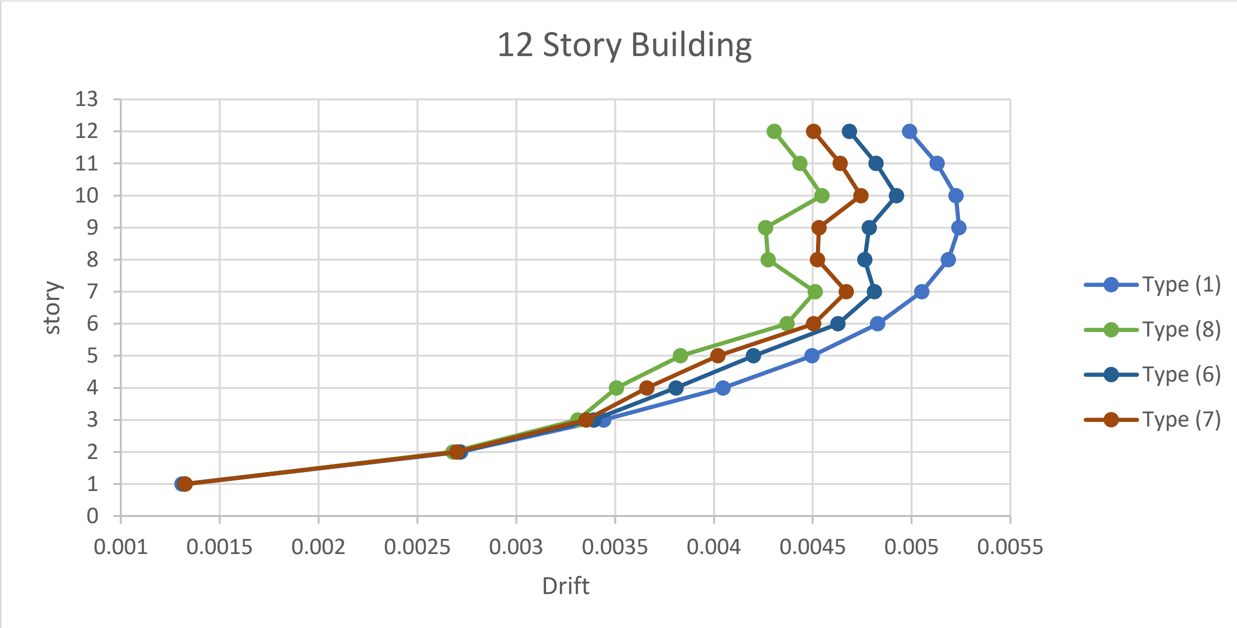

Figure 4.2.2 Structure model 1, drift (1/3 & 2/3 height) division

In order to make a better comparison between the results, the lowest two types (type 3, 6 and 7) from both figures above are selected and to be combined into one curve to specify and observe the optimum case as shown on Figure 4.2.3

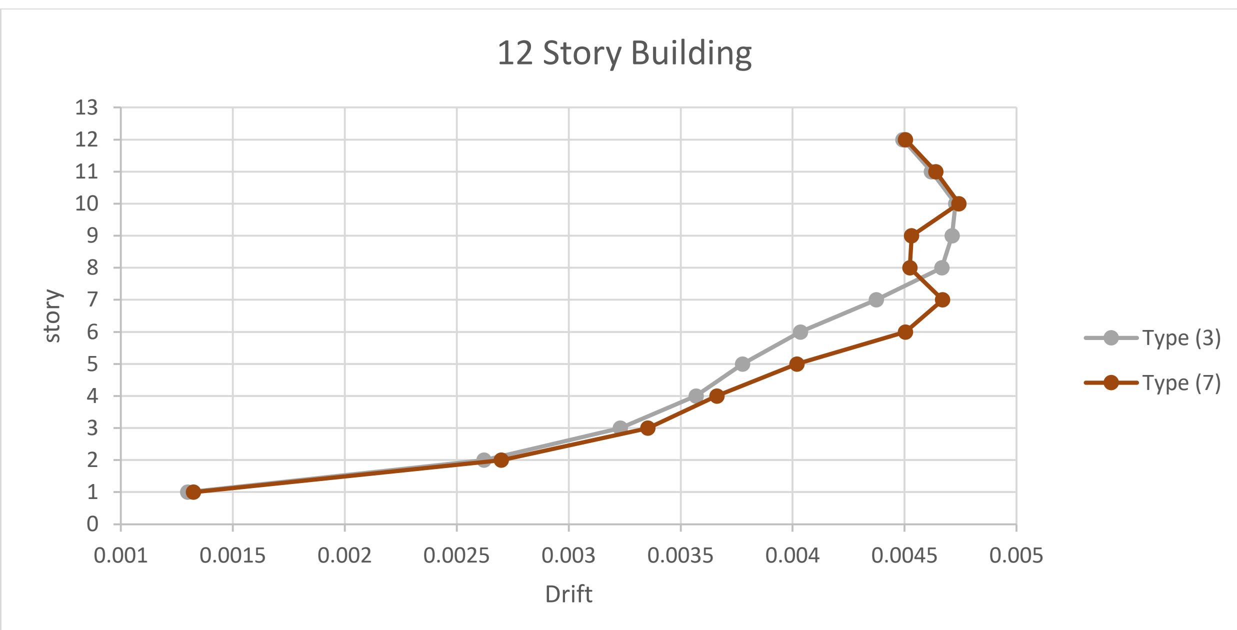

Figure 4.2.3 Structure model 1, drift (over all)

4.2.2 **Shear force results:**

The following curves illustrates the results of shear force distribution along with story on the desired study model 1. Four different cases using the first concept are plotted with the main structure (without any thickened slab) to observe the difference as shown on Figure 4.2.4

The results shows all models has nearly linear relation between the shear force and height of the structure, for the reference case type (1) has a base shear value of 3924KN and 829KN at 12th floor, type (2) has a value of 4267 KN at base and 869KN at 12th floor, type (3) has a value of 4348 KN at base and 847KN at 12th floor, type (4) has a value of 4379 KN at base and 839KN at 12th floor and type (5) has a value of 4314 KN at base and 990KN at 12th floor

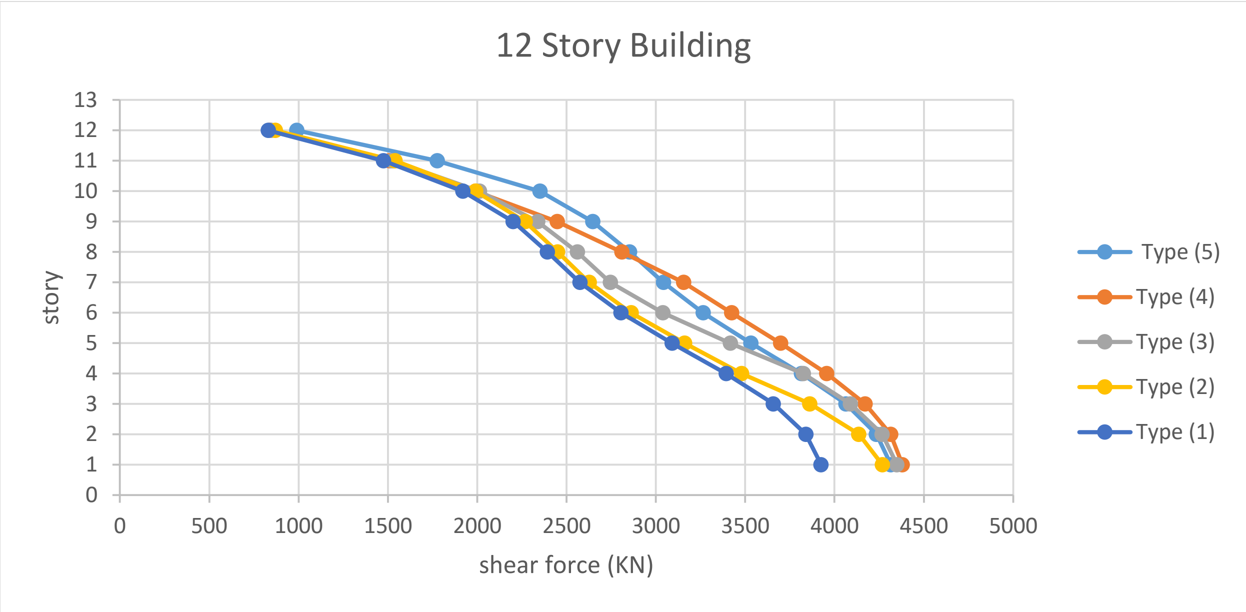

Figure 4.2.4 Structure model 1, shear force (quarter division)

The result of two different models using slab thickness of two - / - three times the main slab thickness at 1/3 and 2/3 of the overall height of building structure are plotted along with the main structure without any thickened slab to observe the difference as shown on Figure 4.2.5

The shear force distribution shape is nearly linear with different line slope. As shown before type (1) has a base shear value of 3924KN and 829KN at 12th floor, type (6) has a value of 3953 KN at base and 846KN at 12th floor, type (7) has a value of 4059 KN at base and 846KN at 12th floor and the last type is type (8) has a value of 4552 KN at base and 846KN at 12th floor.

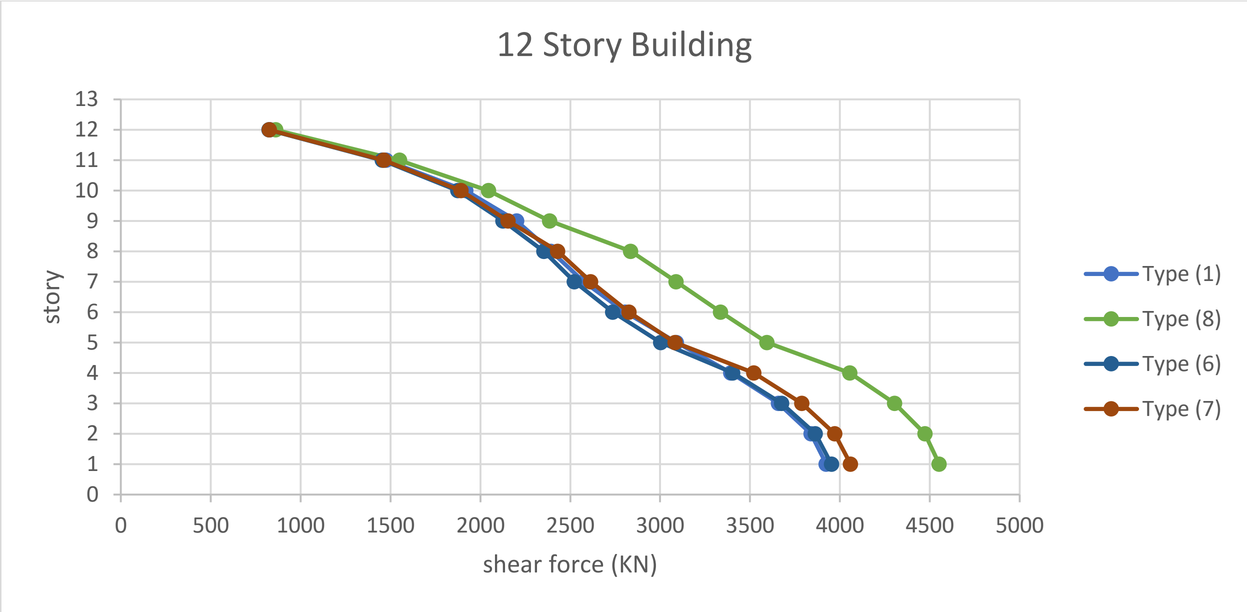

Figure 4.2.5 Structure model 1, shear force (1/3 & 2/3 height) division

In order to simplify the results, the most critical two type (type 3 and type 7) are selected and to be combined into one curve to specify and observe the optimum case. Figure 4.2.6

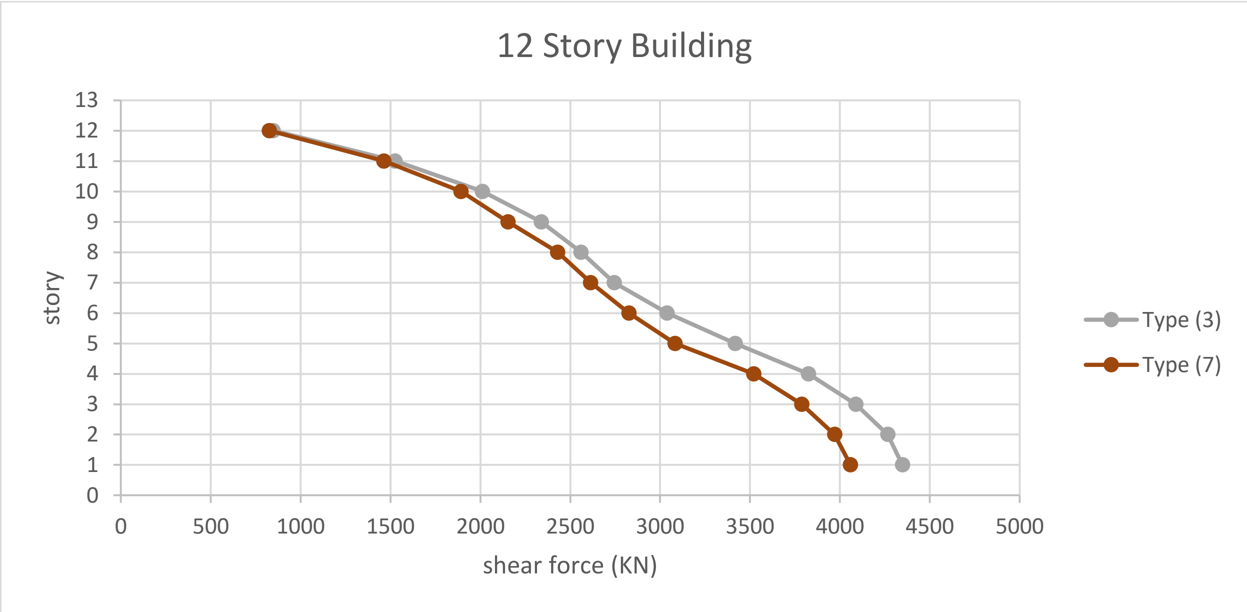

Figure 4.2.6 Structure model 1, shear force (over all)

4.2.3 Displacement results

The following curves illustrates the results of displacement distribution along with story on the desired structure model 1. Four different types using the first concept are plotted with the main structure (without any thickened slab) to observe the difference of total displacement between cases as shown on Figure 4.2.7

The displacement relation with height is nearly linear for all types. As mentioned before, type (1) is the reference type, the maximum displacement for type (1) till type (5) is 183mm, 172mm, 164mm, 172mm, and 179mm respectively.

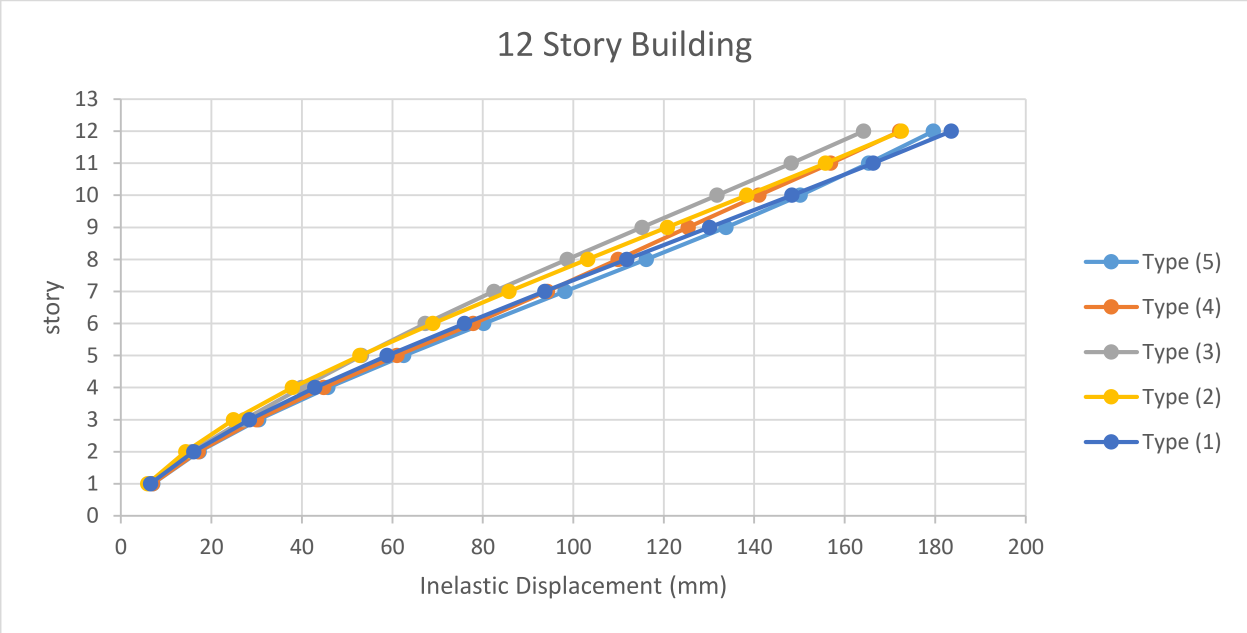

Figure 4.2.7Structure model 1, displacement (quarter) division

The result of two different models using slab thickness of two - / - three times the main slab thickness at 1/3 and 2/3 of the overall height of building structure are plotted along with the main structure without any thickened slab to observe the difference as shown on Figure 4.2.8

The relation is linear same all previous types and the displacement of type (6) is 172mm , 166 mm for type (7) and 159mm for type (8).

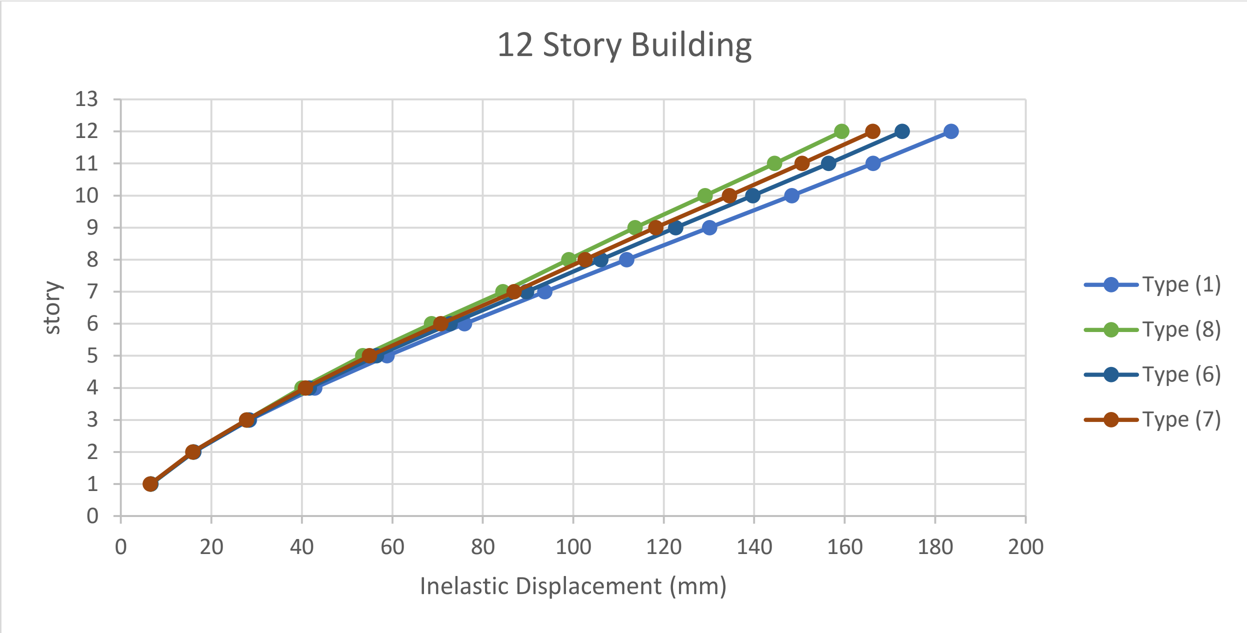

Figure 4.2.8 Structure model 1, displacement (1/3 & 2/3 height) division

In order to make a better comparison between the results, the lowest two types (type 3 and type 7) from both figures above are selected and to be combined into one curve to specify and observe the optimum as shown on Figure 4.2.9.

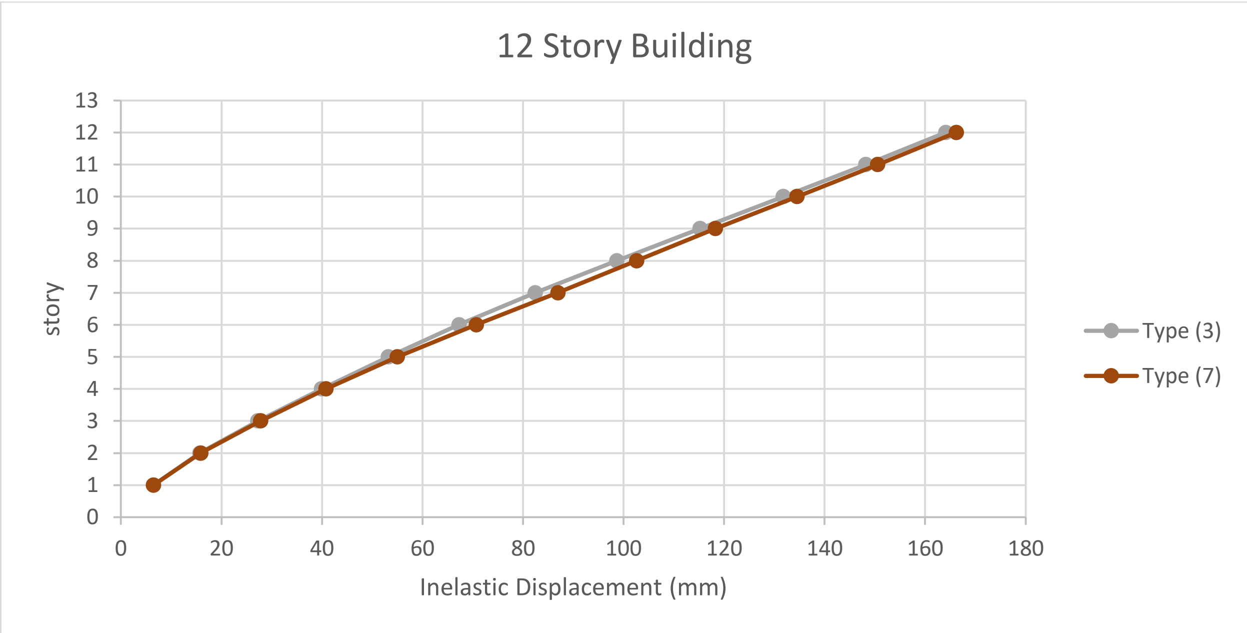

Figure 4.2.9 Structure model 1, displacement (overall) division

4.3 Result of structure model 2 – 16 story (stiffness approach)

4.3.1 Drift results:

This section demonstrate the behavior of 16 story building structure. It illustrate the same study shown on previous section but for higher structure (16 story). Four different models using the first concept (using slab thickness with two times the main slab thickness on specified locations). Four structure models are plotted with the main structure without any thickened slab to observe the difference Figure 4.3.1.

The Figure 4.3.1 shows the five different types shown on Table 3.9.1 using the stiffness approach. Four cases of study (type 2: type 4) are plotted with the main structure without any thickened slab type 1 to observe the difference.

As discussed on structure model 1, the results of structure model 2 shows that drift is nearly linear increase till at least the mid height or third quarter of structure, depends on the location of thickened slab and suddenly it inversely decrease towards the top of the structure as shown on Figure 4.3.1, drift value of type (1) which is the basic case is increasing with parabolic shape till the 12th floor (0.006279) and then reduces to reach value of (0.005959) at 16th floor, type (2) has a similar behavior of type (1) and also reach the value of (0.005828) at 13th floor and then reduces to reach value of (0.00556) at 16th floor, type (3) is similar till 5th floor and increasing with inverse parabolic shape compared with type (1) till reach the value of (0.005282) at 13th floor and then reduces to reach value of (0.00556) at 16th floor, type (4) has similar parabolic shape increasing until the 8th floor to reach value of (0.005802) and then it has an inverse parabolic shape till reach the value of (0.004562) at 14th floor and then reduce again to reach (0.005359) at 16th floor and finally type (5) has a complete parabolic shape with the apex value of (0.00621) at 9th floor and the value of (0.004685) at 16th floor.

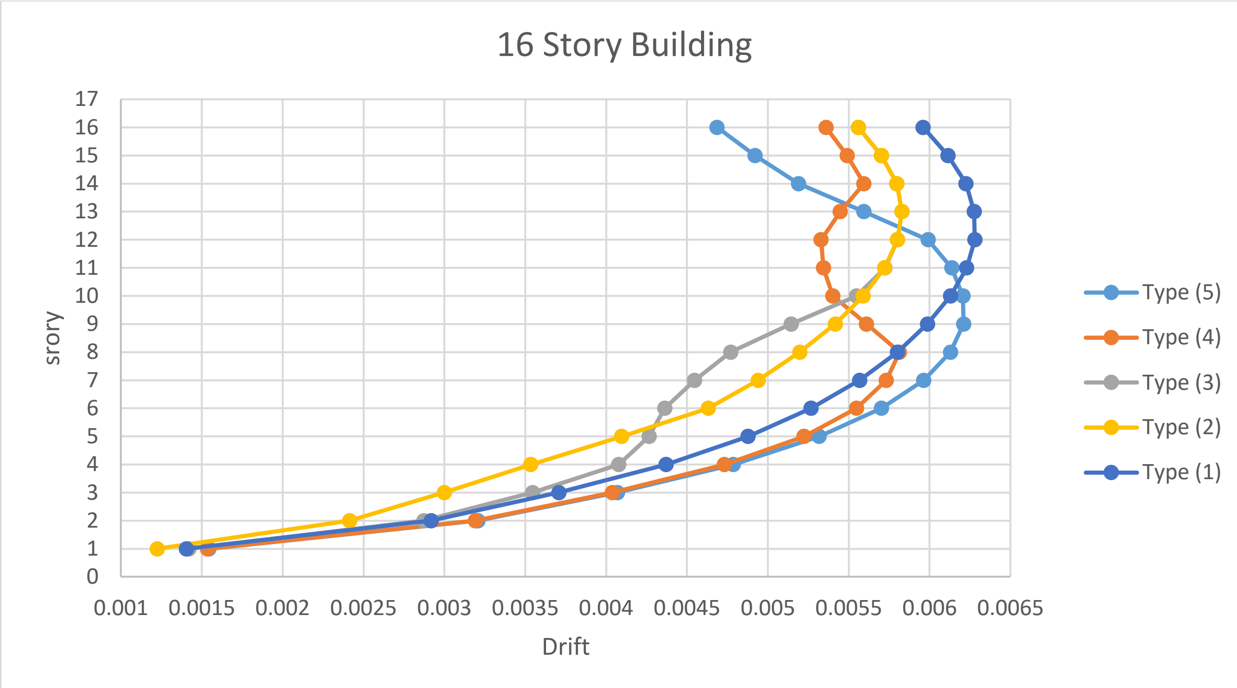

Figure 4.3.1 Structure model 2, drift (quarter division)

Two different models using the second concept (using varies slab thickness two / three times the main slab thickness located on 1/3 & 2/3 the overall height of building structure). The results of study are plotted with the main structure without any thickened slab to observe the difference as shown on Figure 4.3.2.

The results is similar to the result observed on structure model 1. The result of structure model 2 shows type (6) is increasing with similar behavior as type (1) till reach the value of (0.005867) at 10th floor and then has inverse parabolic shape between 10th floor and 13th floor to reach a value of (0.005697) at 13th floor and then reduces to reach value of (0.005671) at 16th floor, next type is type (7) which is almost similar behavior of type (6) but with lesser drift value same as observed in type (6), type (7) reach the value of (0.004188) at 4th floor and then reduces sharply to reach a value of (0.004262) at 5th floor and then it increase again until reach the value of (0.005521) at 10th, then it has inverse parabolic shape between 10th floor and 13th floor to reach a value of (0.005571) at 13th floor and then reduces to reach value of (0.005297) at 16th floor and last type is type (8) which is almost similar behavior of type (6) but with lesser drift value same as observed in type (6), type (8) reach the value of (0.00405) at 4th floor and then reduces sharply to reach a value of (0.0039) at 5th floor and then it increase again until reach the value of (0.005124) at 10th, then it has inverse parabolic shape between 10th floor and 13th floor to reach a value of (0.005112) at 13th floor and then reduces to reach value of (0.004862) at 16th floor.

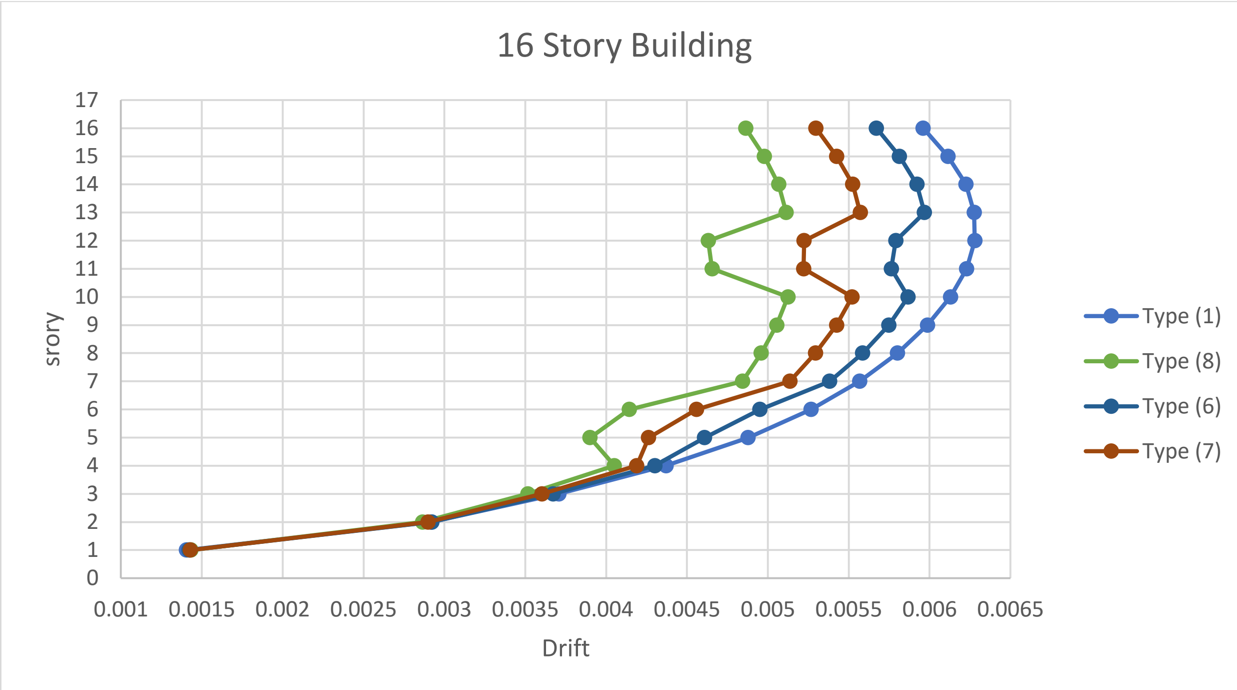

Figure 4.3.2 Structure model 2, drift (1/3 & 2/3 height) division

In order to simplify the results, the lowest values (type 3 and 7) is combined into one curve to specify and observe the optimum case as shown on Figure 4.3.3.

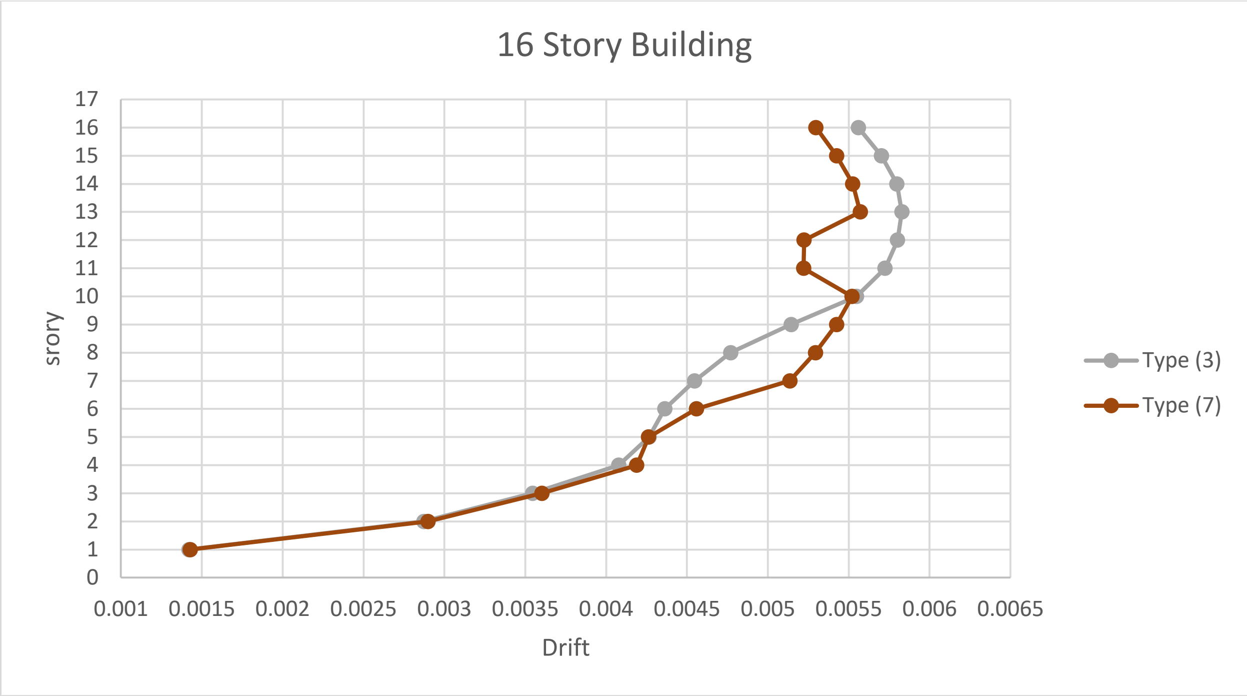

Figure 4.3.3 Structure model 2, drift (Overall)

4.3.1 Shear force results

The following charts illustrate the results of shear force distribution along with story on the desired study concept 1. Four different models using the first concept are plotted with the main structure (without any thickened slab) to observe the difference ass shown on Figure 4.3.4.

The results shows all cases has nearly linear relation between the shear force and height of the structure same as Structure model 1 , for the reference case type (1) has a base shear value of 4170 KN and 829KN at 16^{th} floor, type (2) has a value of 4496 KN at base and 840KN at 16^{th} floor, type (3) has a value of 4660 KN at base and 833KN at 16^{th} floor, type (4) has a value of 4561 KN at base and 860KN at 16^{th} floor and type (5) has a value of 4547 KN at base and 967KN at 16^{th} floor.

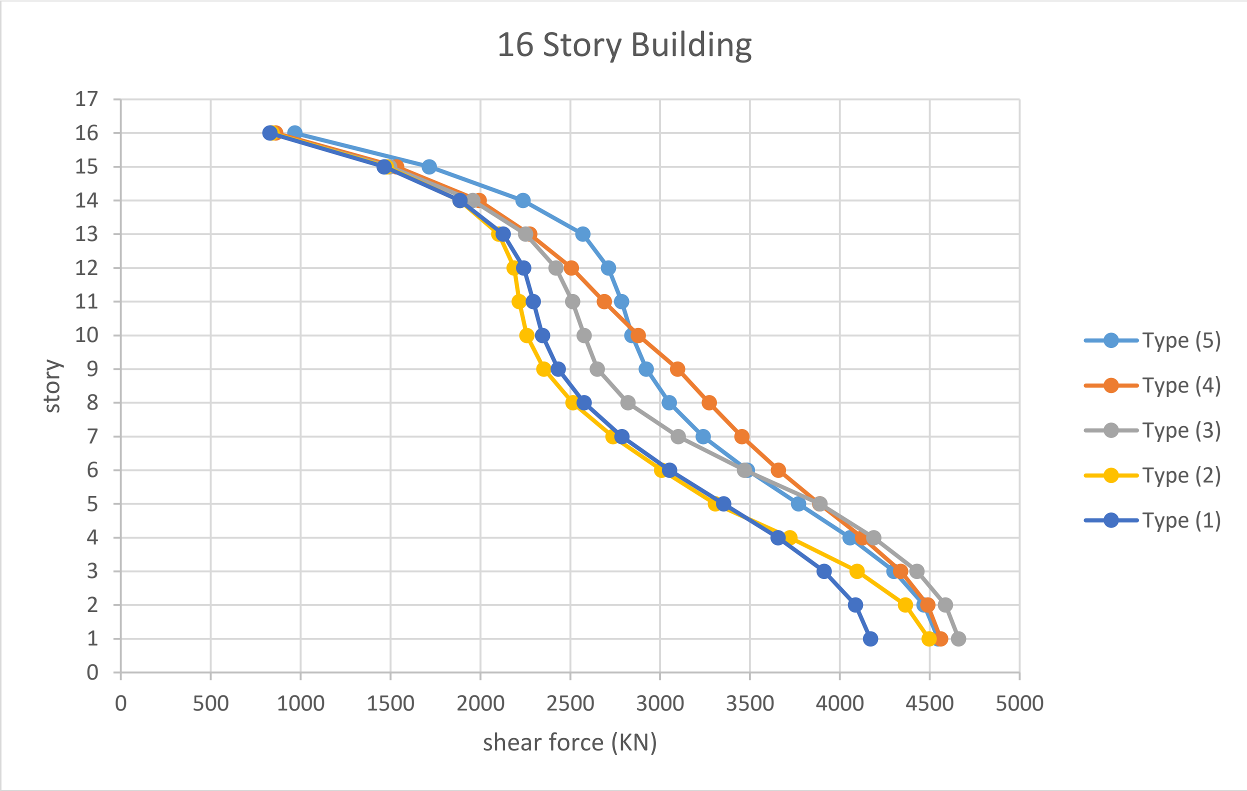

Figure 4.3.4 Structure model 2, shear force (quarter division)

The result of two different models using slab thickness of two - / - three times the main slab thickness at 1/3 and 2/3 of the overall height of building structure are plotted along with the main structure without any thickened slab to observe the difference as shown on Figure 4.3.5.

The shear force distribution shape is nearly linear with different line slope. Type (1) has a base shear value of 4170 KN and 829KN at 16th floor, type (6) has a value of 4365 KN at base and 839KN at 16th floor, next type is type (7) has a value of 4389 KN at base and 841 KN at 16th floor and the last type is type (8) has a value of 4866 KN at base and 851 KN at 16th floor.

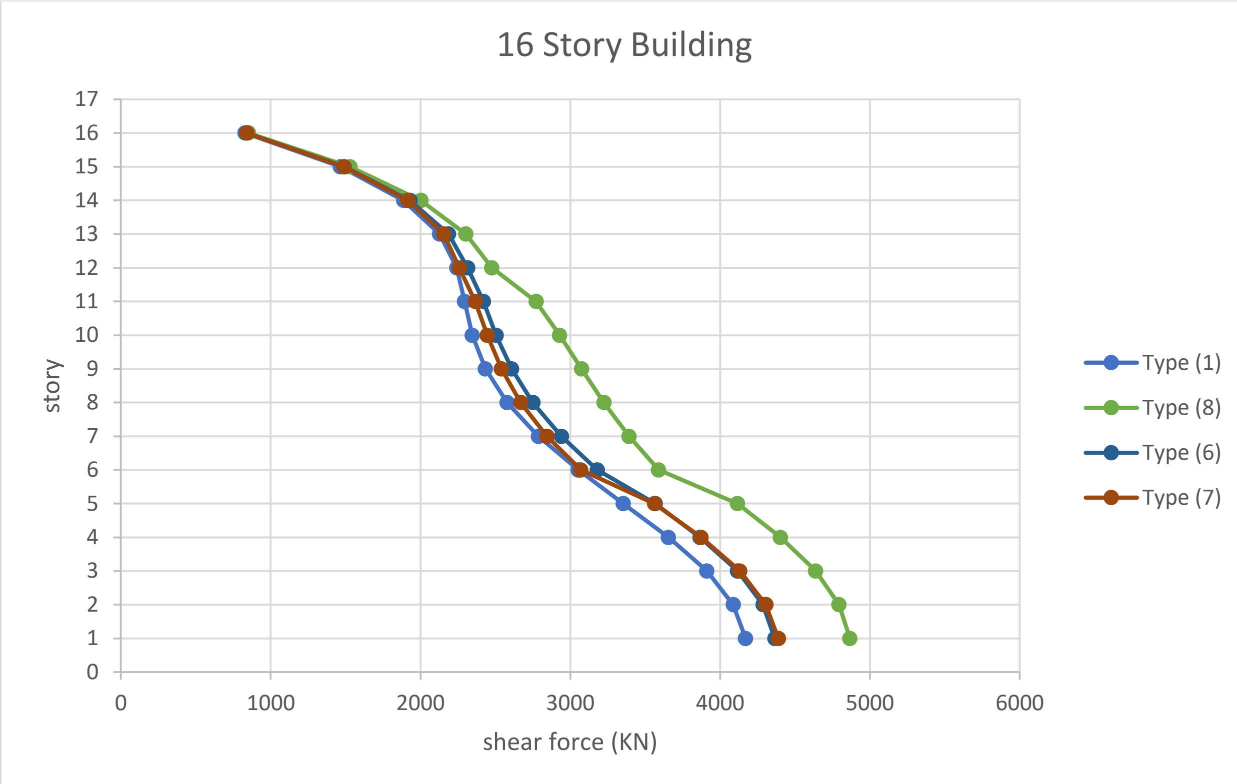

Figure 4.3.5 Structure model 2, shear force (1/3 & 2/3 height) division

In order to simplify the results, the most critical two types (type 3 and type 8) are selected and to be combined into one curve to specify and observe the optimum case as shown on Figure 4.3.6.

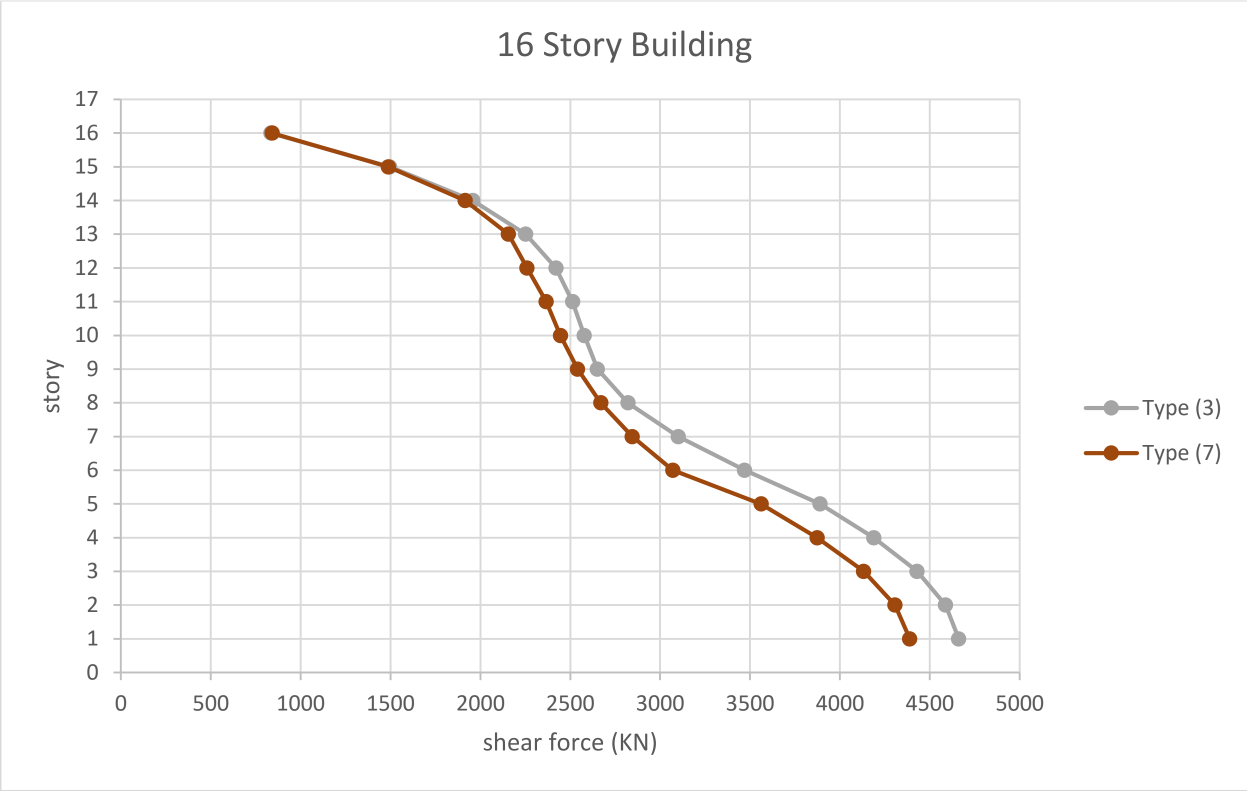

Figure 4.3.6 Structure model 2, shear force (overall)

4.3.2 Displacement results

The following curves illustrates the results of displacement distribution along with story on the desired structure model 2 and same shown in previous structure model 1, four different types (type 1,2,3 and 4) are plotted with (type 1) the main structure (without any thickened slab) to observe the difference of total displacement between cases as shown on Figure 4.2.7.

The displacement relation with height is nearly linear for all types with maximum values at the top of structure equals the following , the maximum displacement for type (1) till type (5) is 286mm, 254mm, 256mm, 275mm, and 283mm respectively.

Figure 4.3.7Structure model 2, displacement (quarter) division

The result of two different type of structure model 2 using slab thickness of two - / - three times the main slab thickness at 1/3 and 2/3 of the overall height of building structure are plotted along with the main structure without any thickened slab to observe the difference as shown on Figure 4.3.8.

The displacement distribution shape is nearly linear with different line slope. Type (1) has a maximum displacement value 286 mm at the 16th floor, type (6) has a value of 272 mm at 16th floor and the last type is type (8) has a value of 235 mm at 16th floor.

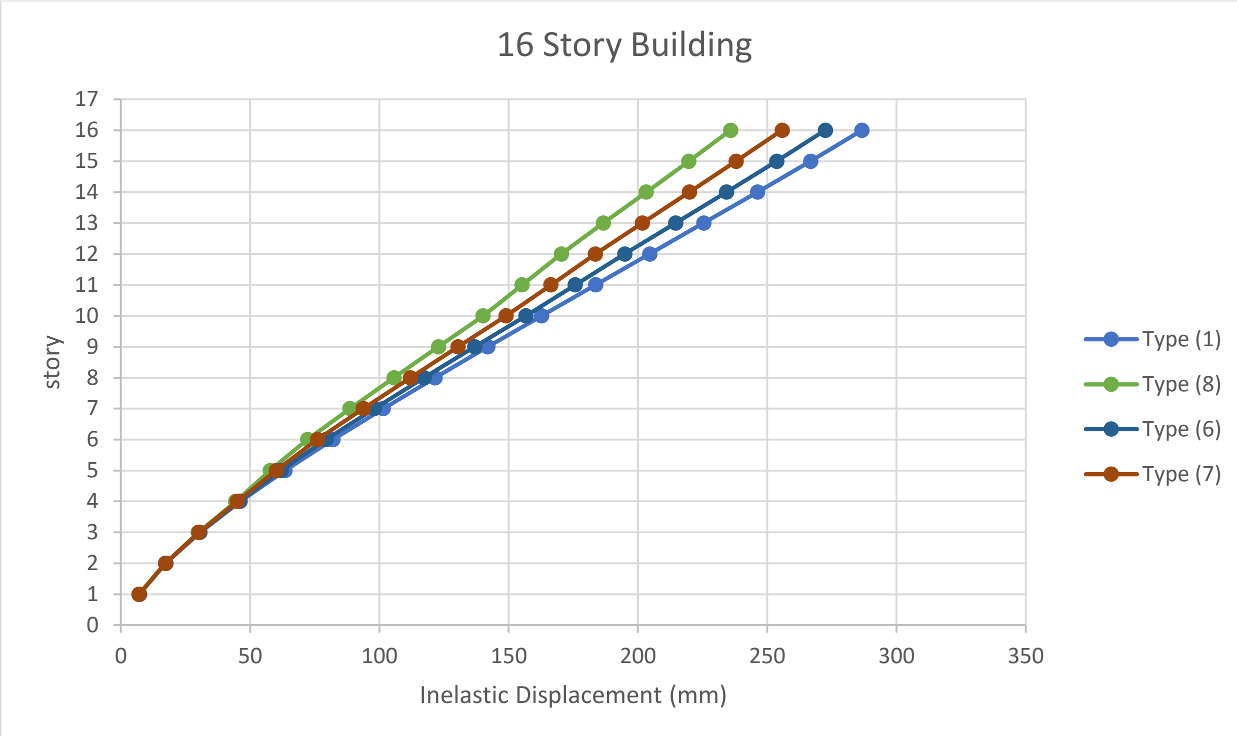

Figure 4.3.8 Structure model 2, displacement (1/3 & 2/3 height) division

In order to simplify the results, the most critical two types (type 3 and type 8) are selected and combined into one curve to specify and observe the optimum case as shown on Figure 4.3.9.

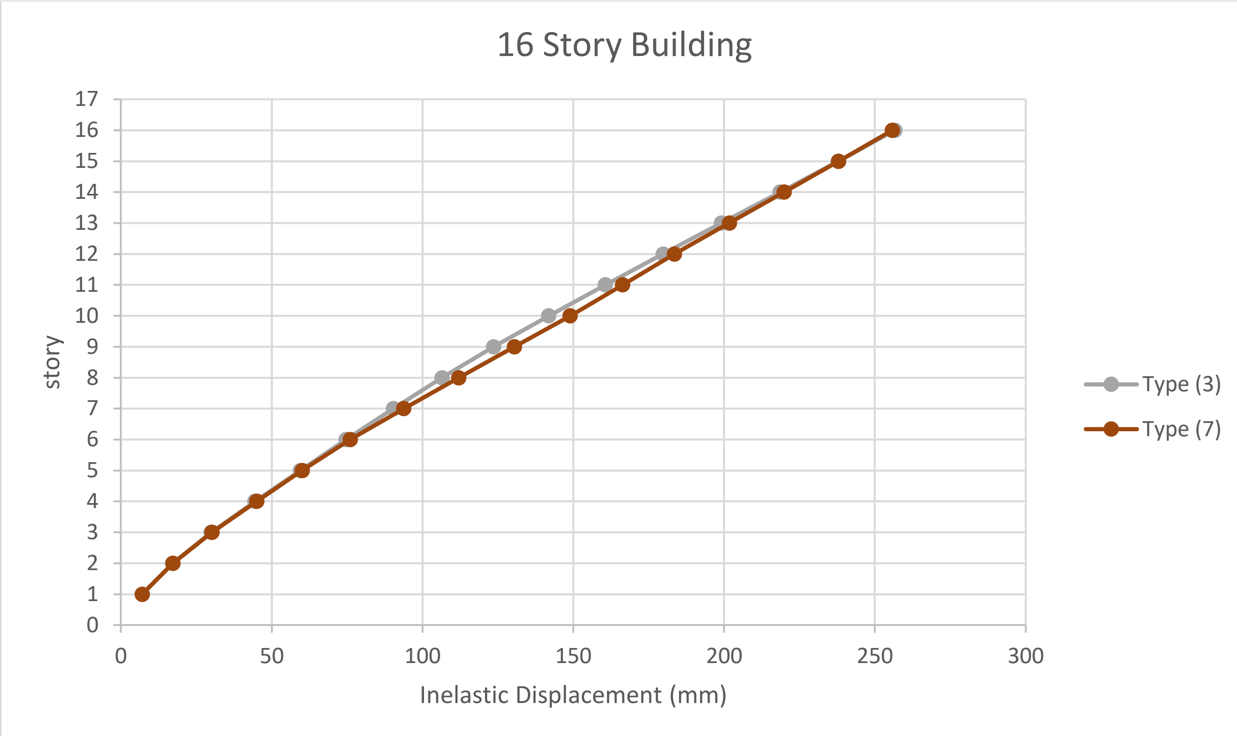

Figure 4.3.9 Structure model 2, displacement (overall)

4.4 Result of structure model 3 – 20 story (stiffness approach)

4.4.1 Drift results:

This section demonstrate the behavior of 20 story building structure. It illustrate the same criteria of the two previous section but for higher structure (20 story). The more height of the structure, the more complexity of the study and observation so more trial done on 20 story building structure to obtain the optimum location of the thickened slab.

First comparison is to plot the results of four different cases using the first concept (using slab thickness with two times the main slab thickness on the quarter of the structure). Four structure models are plotted with the main structure without any thickened slab to observe the difference as shown on Figure 4.4.1.

As discussed on both previous two case studies, the result of structure model 3 shows that drift is nearly linear increase till at least the mid height or third quarter of structure, depends on the location of thickened slab and suddenly it inversely decrease towards the top of the structure as shown on Figure 4.4.1 Structure model 3, drift (quarter division), drift value of type (1) which is the basic case is increasing with parabolic shape till the 15th floor (0.007946) and then reduces to reach value of (0.007407) at 20th floor, type (2) has a similar behavior of type (1) and also reach the value of (0.007137) at 15th floor and then reduces to reach value of (0.006753) at 20th floor, type (3) is similar till 5th floor that reach a value of (0.005424) and increasing with inverse parabolic shape compared with type (1) till reach the value of (0.007053) at 12th floor and then the parabolic shape is inverted again to the original curvature and value of drift increases to reach value of (0.007137) at 20th floor, type (4) has similar parabolic shape increasing until the 9th floor to reach value of (0.007353) and then it has an inverse parabolic shape till reach the value of (0.006841) at 17th floor and then reduce again to reach (0.006541) at 20th floor and finally type (5) has a complete parabolic shape with the apex value of (0.007954) at 11th floor and the value of (0.005524) at 20th floor.

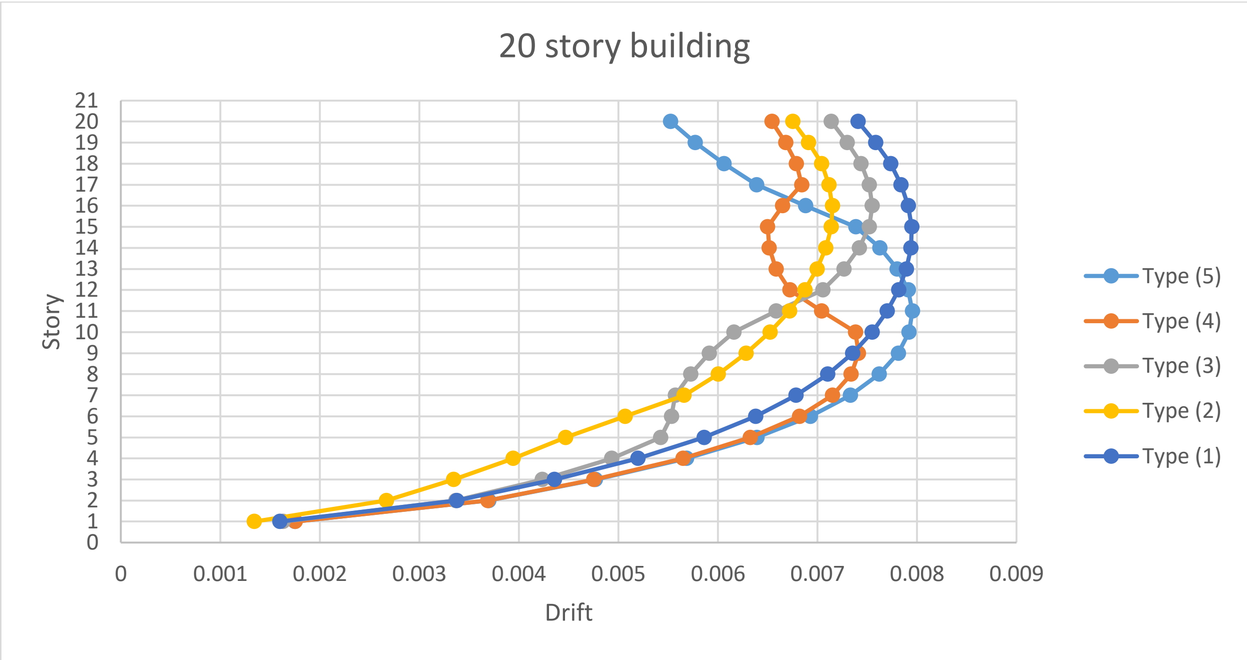

Figure 4.4.1 Structure model 3, drift (quarter division)

Three different models using the second concept (using varies slab thickness located on 1/3 & 2/3 the overall height of building structure). The results of study are plotted with the main structure without any thickened slab to observe the difference as shown on Figure 4.4.2

The results is similar to the result observed on structure model 1 and structure model 2. The result of structure model 3 shows type (6) is increasing with similar behavior as type (1) till reach the value of (0.006263) at 6th floor, then has inverse parabolic shape between 6th floor and 9th floor to reach a value of (0.007122) at 9th floor, then curve is parabolic increase to reach value of (0.007569) at 13th floor, then has inverse parabolic shape again between 13th floor and 16th floor to reach a value of (0.007553) at 16th floor and then it reduces to reach value of (0.007103) at 20th floor. Next type is type (7) which is almost similar behavior of type (6) but with lesser drift value, that is same behavior observed in Structure model 1 and cases study 2, the shape of drift and parabolic curvature is same as observed in type (6), type (7) reach the value of (0.005975) at 6th floor, then has inverse parabolic shape between 6th floor and 9th floor to reach a value of (0.006626) at 9th floor, then curve is parabolic increase to reach value of (0.006903) at

13th floor, then has inverse parabolic shape again between 13th floor and 16th floor to reach a value of (0.006811) at 16th floor and then it reduces to reach value of (0.006456) at 20th floor. Last type is type (8) which is also almost similar behavior of type (6, 7) but with lesser drift value, that is same behavior observed in structure model 1 and structure model 2, the shape of drift and parabolic curvature is same as observed in both types (6, 7), type (8) reach the value of (0.005567) at 6th floor, then has inverse parabolic shape between 6th floor and 9th floor to reach a value of (0.005994) at 9th floor, then curve is parabolic increase to reach value of (0.006114) at 13th floor, then has inverse parabolic shape again between 13th floor and 16th floor to reach a value of (0.005937) at 16th floor and then it reduces to reach value of (0.005698) at 20th floor

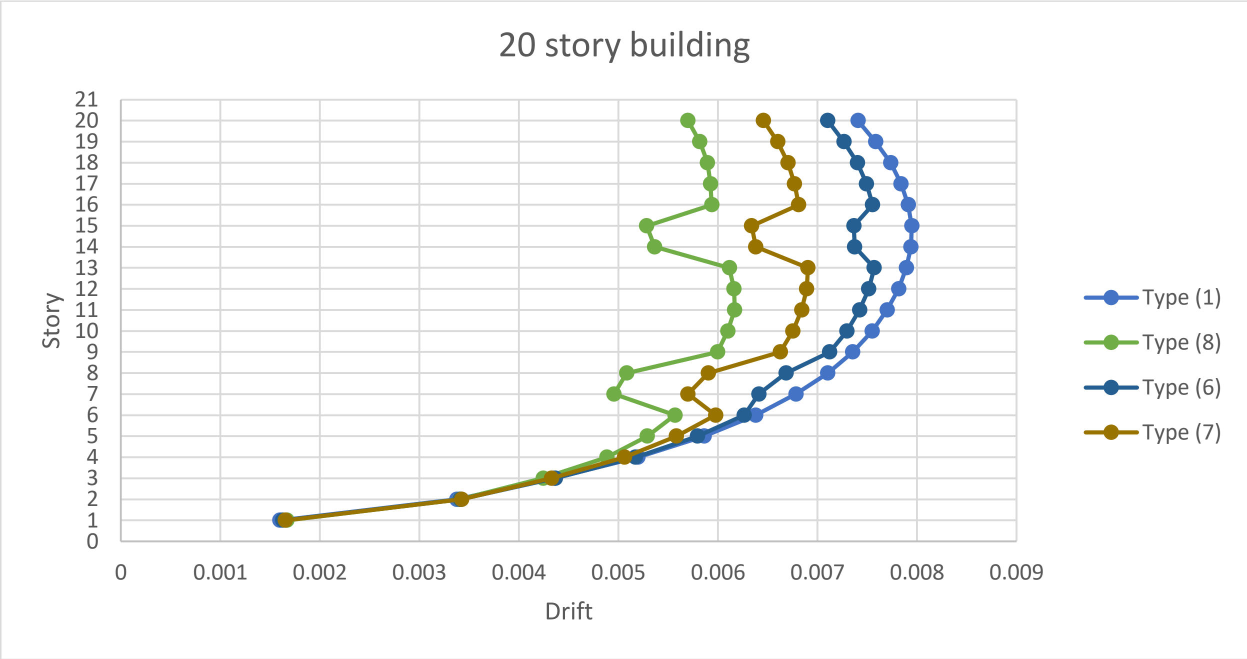

Figure 4.4.2 Structure model 3, drift (1/3 & 2/3 height) division

It is explained earlier that since structure has more height, the more complexity of the study and observation. Thus it is good idea to do more trial on 20 story building structure to obtain the optimum location of the thickened slab.

Thus, third comparison when using the five times the main slab thickness on 1/3 height and 1/2 height with and plot the results on a chart shown on Figure 4.4.3.

The result of type (9) and type (10) in Figure 4.4.3 shows type (9) is increasing with similar behavior as type (1) till reach the value of (0.006464) at 9th floor, then has inverse parabolic shape between 9th floor and 12th floor to reach a value of (0.006664) at 12th floor, then curve is parabolic increase to reach value of (0.00686) at 20th floor. Last type is type (10) which is almost similar behavior of type (9) it top of the structure, the drift reaches the value of (0.005162) at 6th floor, then has inverse parabolic shape between 6th floor and 10th floor to reach a value of (0.005863) at 9th floor, then curve is parabolic increase to reach value of (0.00686) at 20th floor.

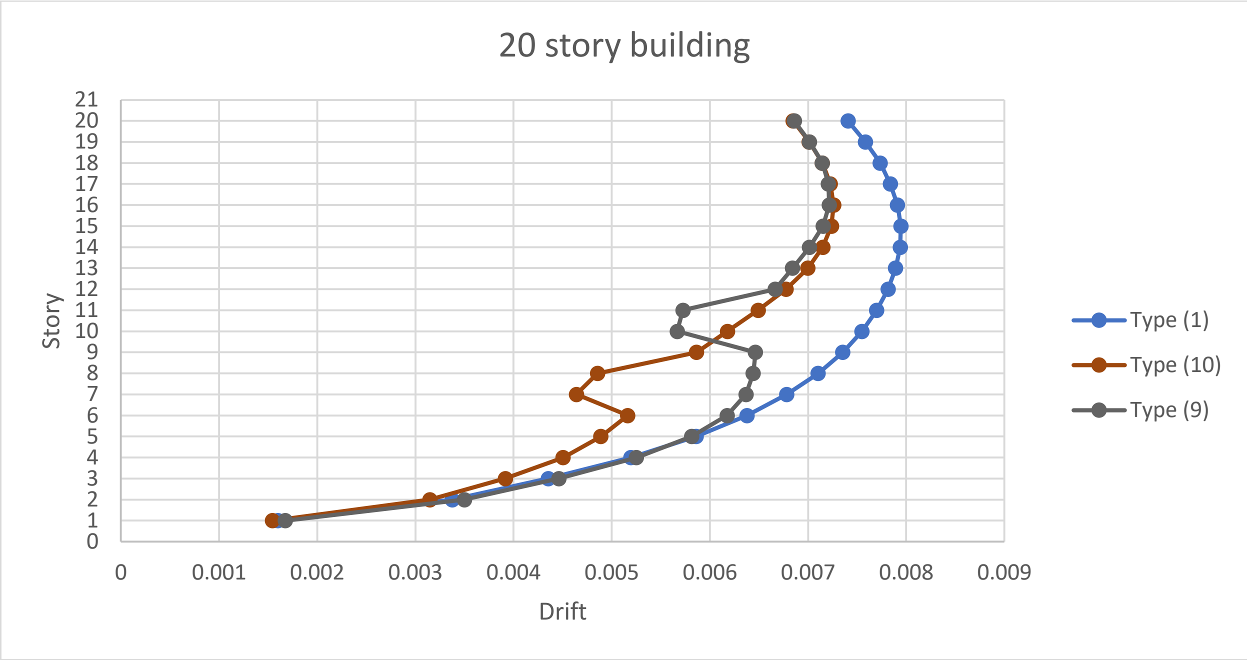

Figure 4.4.3 Structure model 3, drift 5 times slab thickness (1/3 & 1/2 height) division

In order to make a good comparison between the all cases from type (1) to type (10) to simplify the results. The more optimum types are selected and combined into one chart. The chosen types is type (2), type (3) and type (7) and the results is shown on Figure 4.4.4.

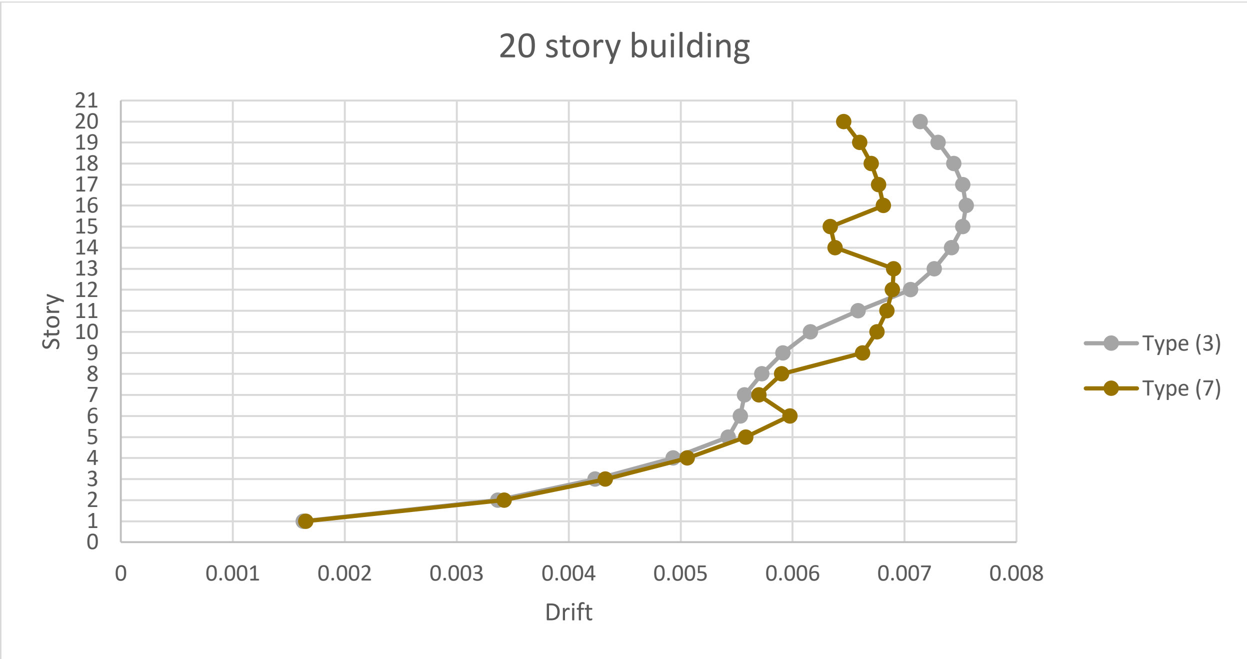

Figure 4.4.4 Structure model 3, drift (1st, 2nd quarter & 1/3, 2/3height) division

Last comparison to simplify to the results is shown on Figure 4.4.5 between types (2), (3) and (9). The chosen types from criteria of quarter division and 1/3 and 2/3 division with two times and five times of main slab thickness as shown on Figure 4.4.5

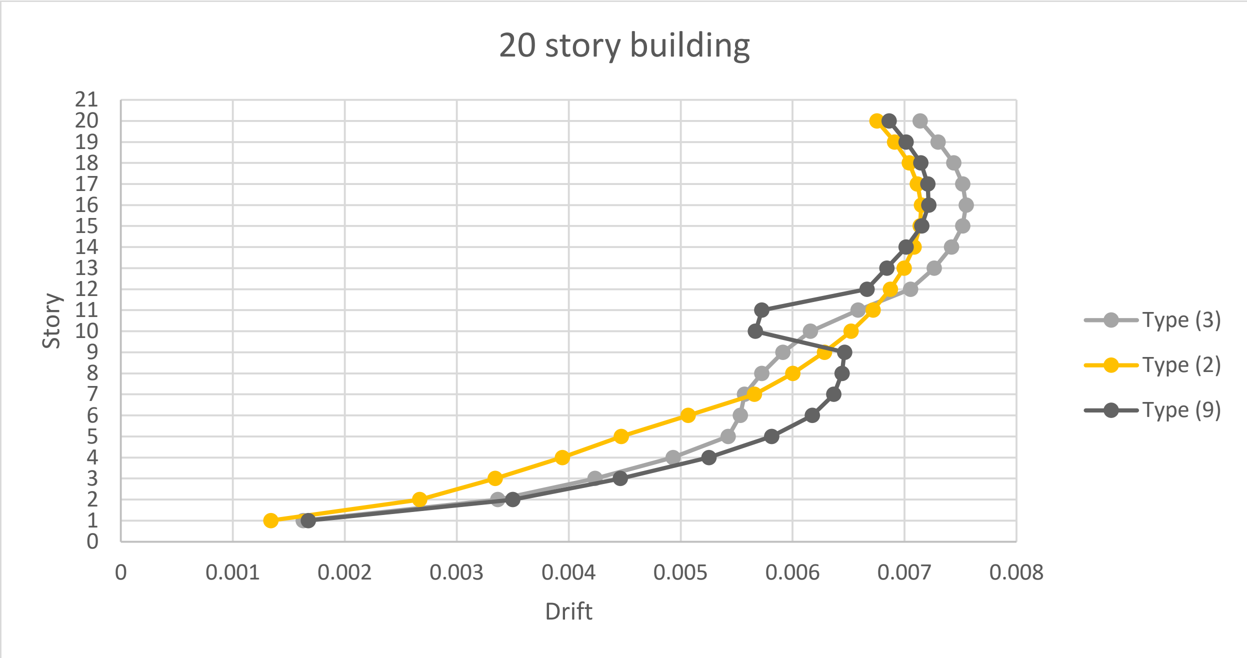

Figure 4.4.5 Structure model 3, drift (over all)

4.4.2 Shear force results

The following charts illustrate the results of shear force distribution along with story on the desired study concept 1. Four different cases using the first concept are plotted with the main structure (without any thickened slab) to observe the difference as shown on Figure 4.4.6

The results shows all cases has nearly linear relation between the shear force and height of the structure same as structure model 1 and structure model 2 , for the reference case type (1) has a base shear value of 4595 KN and 812KN at 20th floor, type (2) has a value of 5032 KN at base and 832KN at 20th floor, type (3) has a value of 5079 KN at base and 792 KN at 20th floor, type (4) has a value of 5029 KN at base and 852 KN at 20th floor and type (5) has a value of 4985 KN at base and 951KN at 20th floor.

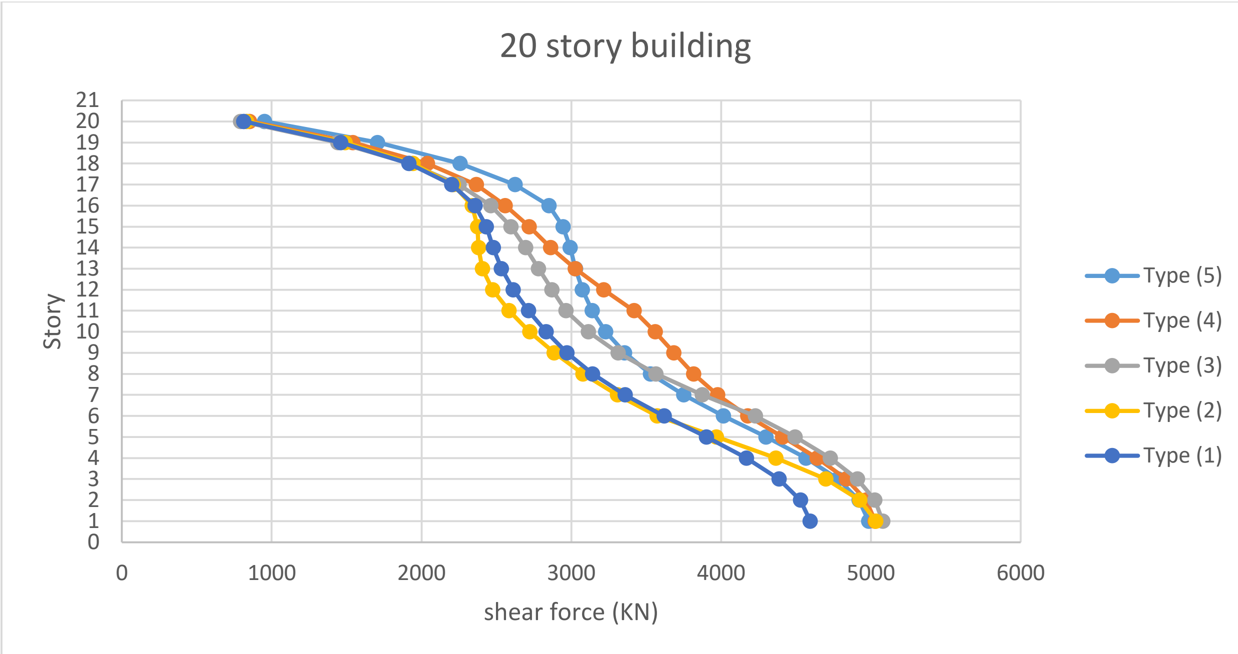

Figure 4.4.6 Structure model 3, shear force (quarter division)

Four different models using the concept of two/ five times the slab thickness located on 1/3 &2/3 height and also five times the main slab thickness located on 1/3 & 1/2 height of the structure building are modeled and the results of study are plotted with the main structure without any thickened slab to observe the difference as shown on

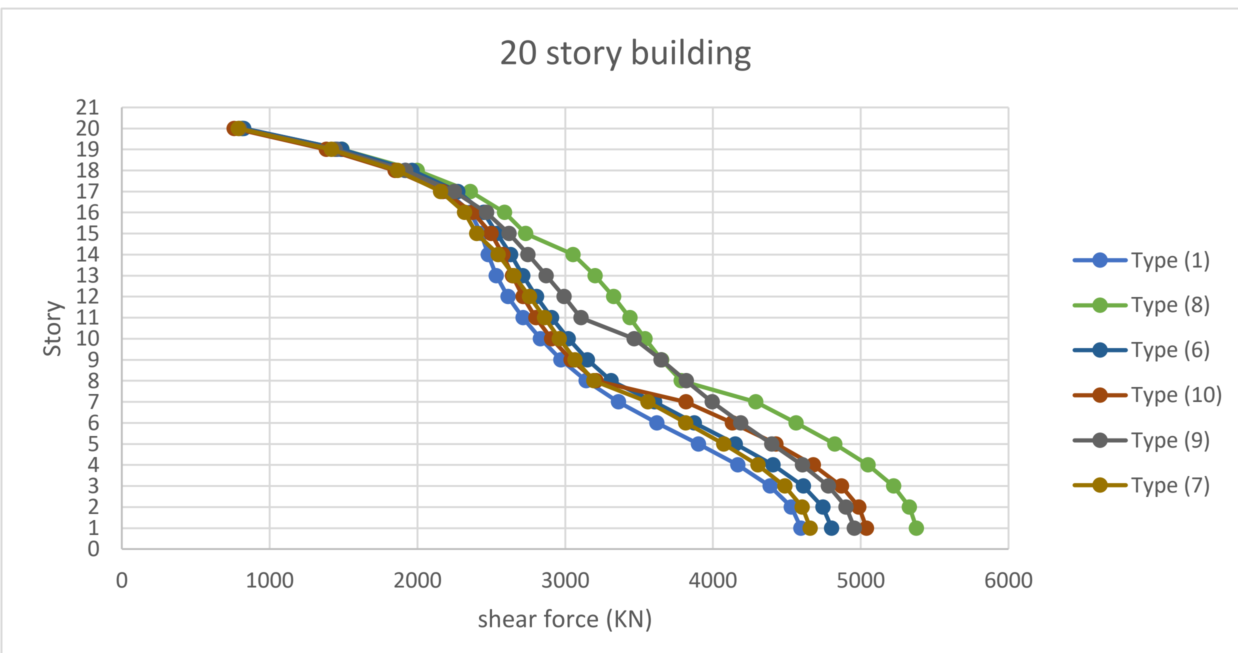

Figure 4.4.7 Structure model 3, shear force (1/3 &1/2 & 2/3 height) division

The shear force distribution shape is nearly linear with different line slope. Type (1) has a base shear value of 4595 KN and 812 KN at 20th floor, type (6) has a value of 4803 KN at base and 824 N at 20th floor, type (7) has a value of 4658 KN at base and 786 KN at 20th floor, type (8) has a value of 5377 KN at base and 813 KN at 20th floor, type (9) has a value of 4957 KN at base and 795 KN at 20th floor and type (10) has a value of 5040 KN at base and 759 KN at 20th floor.

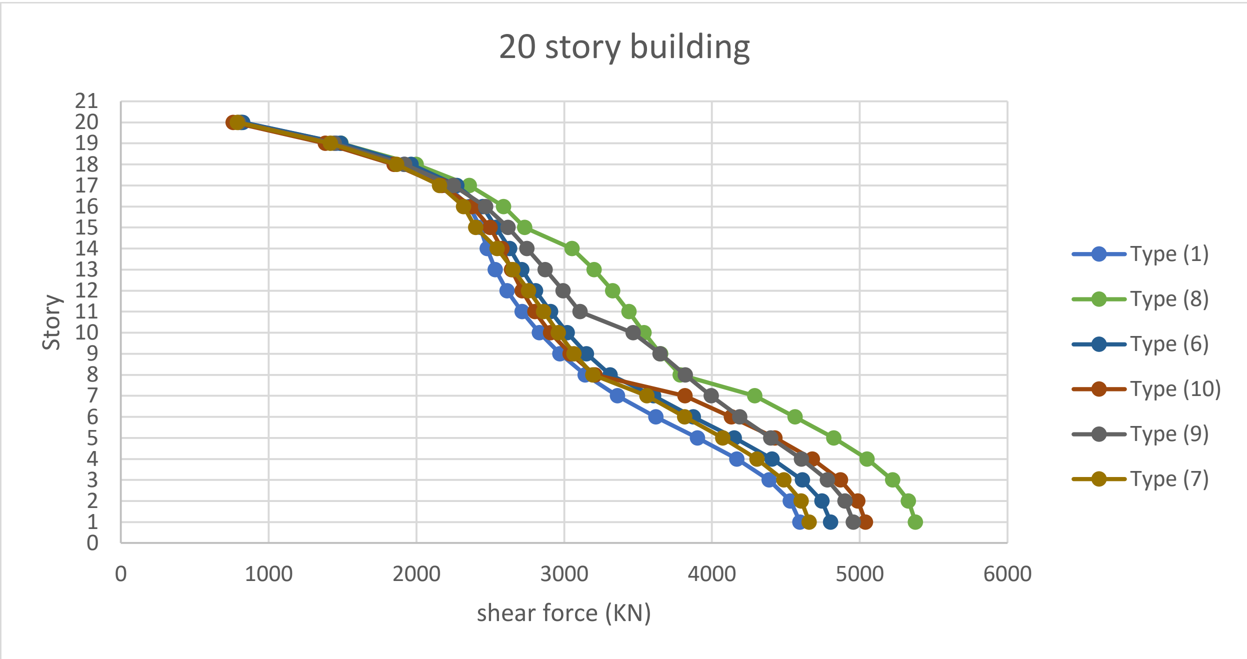

Figure 4.4.7 Structure model 3, shear force (1/3 &1/2 & 2/3 height) division

In order to simplify the results, the most critical two types (type 2, type 3 and type 7) are selected and to be combined into one curve to specify and observe the optimum case as shown on Figure 4.4.8

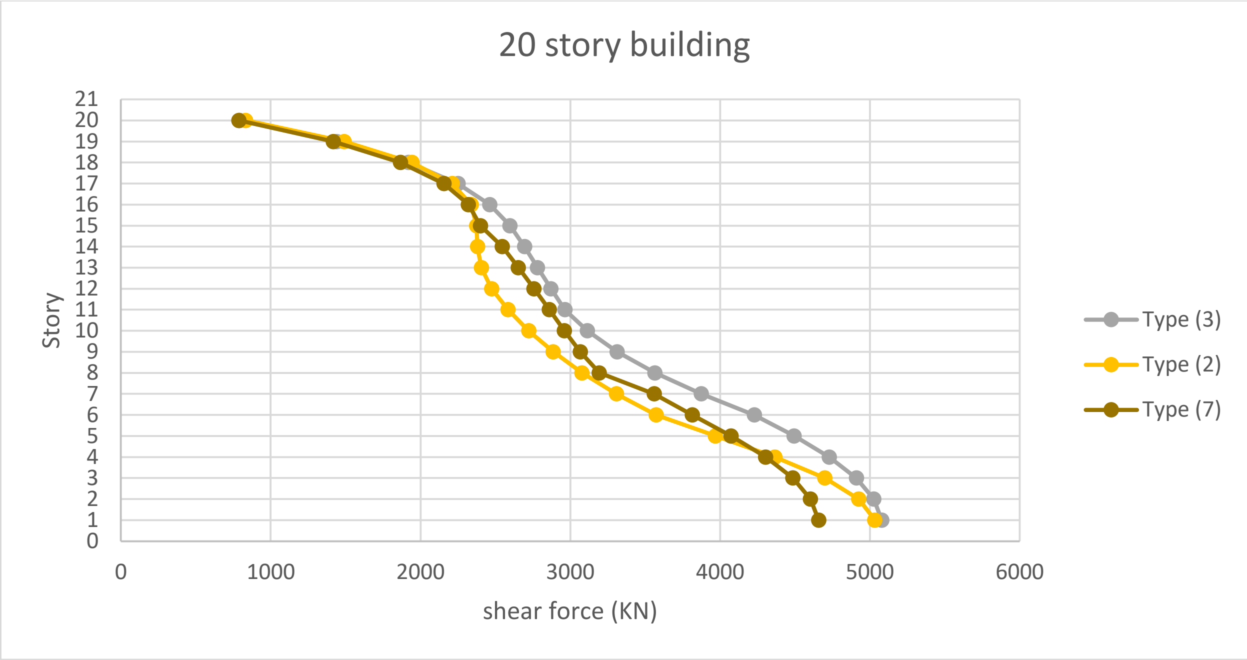

Figure 4.4.8 Structure model 3, shear force (overall)

4.4.3 **Displacement results**

The following curves illustrates the results of displacement distribution along with story on the desired study case 3 and same shown in previous two case studies 1and 2, four different types (type 2, 3, 4 and 5) are plotted with (type 1) the main structure (without any thickened slab) to observe the difference of total displacement between cases as shown on Figure 4.4.9

The displacement relation with height is nearly linear for all types with maximum values at the top of structure equals the following , the maximum displacement for type (1) till type (5) is 456 mm, 388 mm, 411 mm, 430 mm, and 444 mm respectively.

Figure 4.4.9 Structure model 3, displacement (quarter) division

The result of more four different type of structure model 3 (type 6, 7, 8, 9 and 10) using slab thickness of different times the main slab thickness at 1/3, 1/2 and 2/3 of the overall height of building structure are plotted along with the main structure without any thickened slab to observe the difference as shown on Figure 4.4.10

The displacement distribution shape is nearly linear with different line slope. Type (1) has a maximum displacement value 456 mm at the 20^{th} floor, the maximum displacement for type (6) till type (10) is 437 mm, 399 mm, 355 mm, 411 mm and 386 mm respectively.

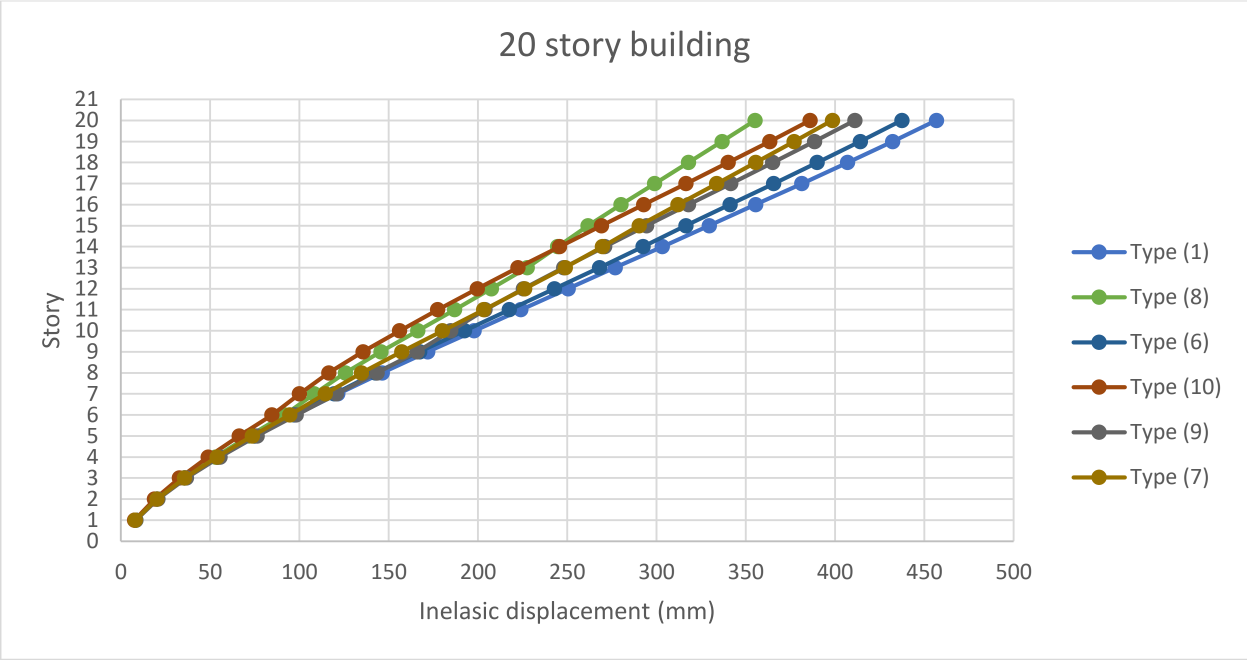

Figure 4.4.10 Structure model 3, displacement (1/3 & 2/3 height) division

In order to simplify the results, the most critical two types (type 2, type 3 and type 9) are selected and combined into one curve to specify and observe the optimum case as shown on Figure 4.4.11

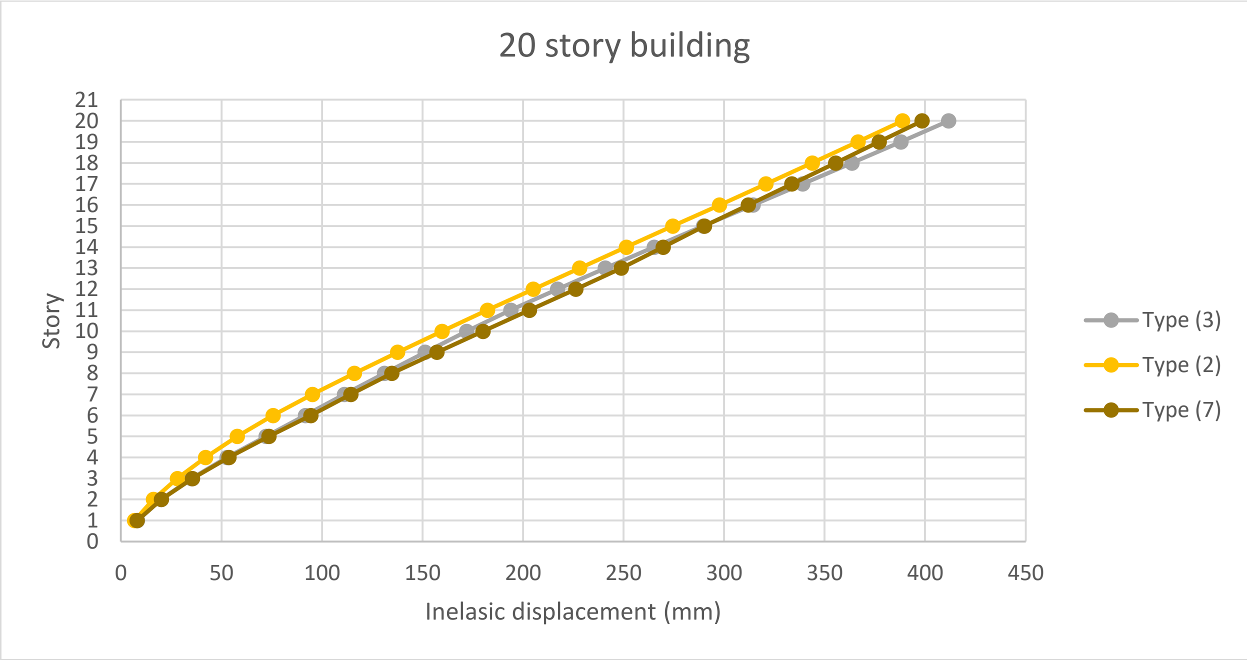

Figure 4.4.11 Structure model 3, displacement (overall)

4.5 Result of structure model 4 – 12 story (material approach)

4.5.1 Drift results

Another approach of study of the behavior of 12 story building structure is plotted. The seismic drift with corresponding to the story of the building with respect to material difference in specified locations. Different types of structures are modeled on E-tabs and results are combined on the following figures.

Four different models using the first concept (using Ultra High Performance Concrete in each quarter of structural building). Four models of study are plotted with the main structure with using normal concrete to observe the difference as shown on Figure 4.5.1

The results shows that drift is parabolic for all types, the apex value is same for all types and occurs at 9th floor, the drift value of type (1, 2, 3, 4 and 5) at 9th floor is (0.00524, 0.005186, 0.005097, 0.004966 and 0.005024) respectively while the values at the 12th floor is (0.00499, 0.004943, 0.004862, 0.004782 and 0.004608) respectively.

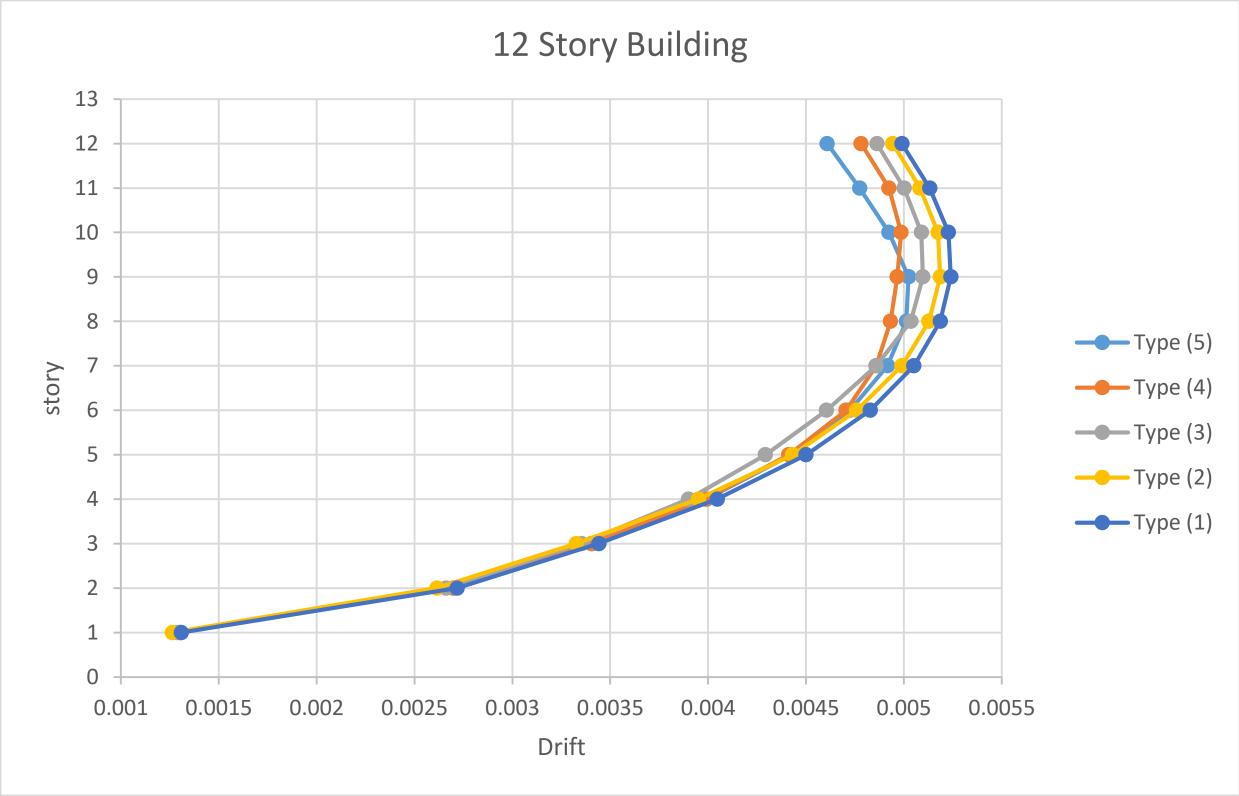

Figure 4.5.1 Structure model 4, drift (quarter division)

4.5.2 Shear force results

The following chart shows the results of shear force distribution along with story on the desired study concept 2, structure model 4. The results are plotted to observe the difference as shown on Figure 4.5.2

The results shows all cases are almost same and all has nearly linear relation between the shear force and height of the structure, the results of type (1, 2, 3, 4 and 5) are (3740 KN, 3739 KN, 3740 KN, 3749 KN and 3737KN) at the base and value of (812 KN, 811KN, 808 KN, 810 KN and 801 KN) at 12th floor.

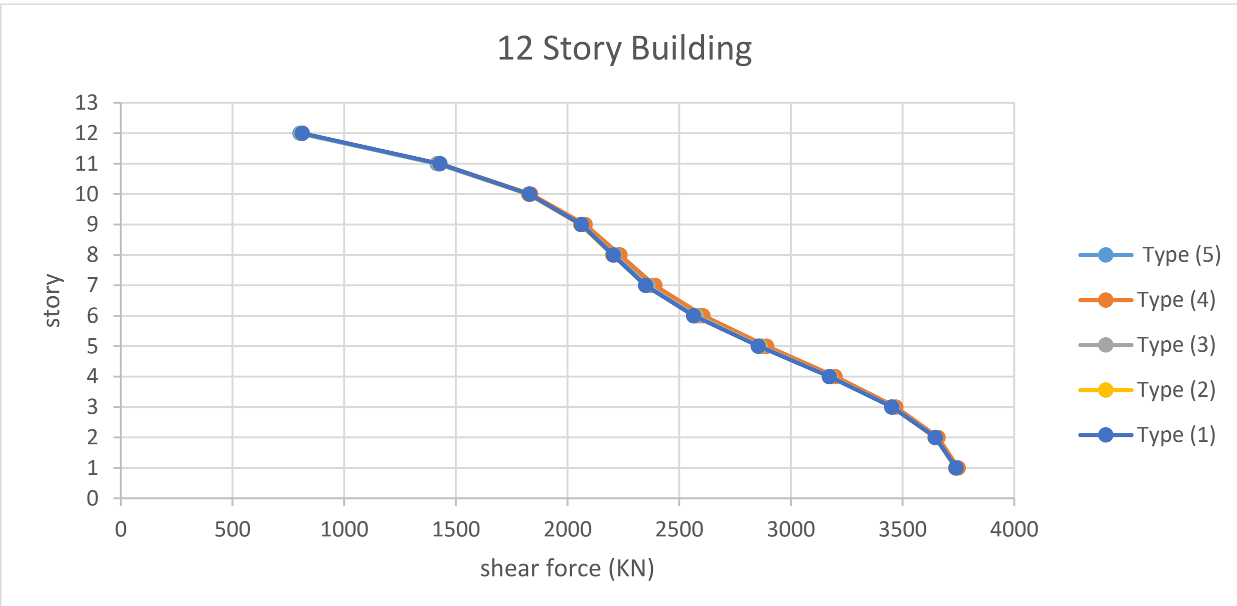

Figure 4.5.2 Structure model 4, shear force (quarter division)

4.5.3 Displacement results

The following chart shows the results of displacement distribution along with story on the desired study concept 2, Structure model 4. The results are plotted to observe the difference as shown on Figure 4.5.3

The results shows all cases are almost same and all has nearly linear relation between the displacement and height of the structure, the results of type (1, 2, 3, 4 and 5) are (183 mm, 183 mm, 181mm, 178 mm and 177 mm) at 12th floor.

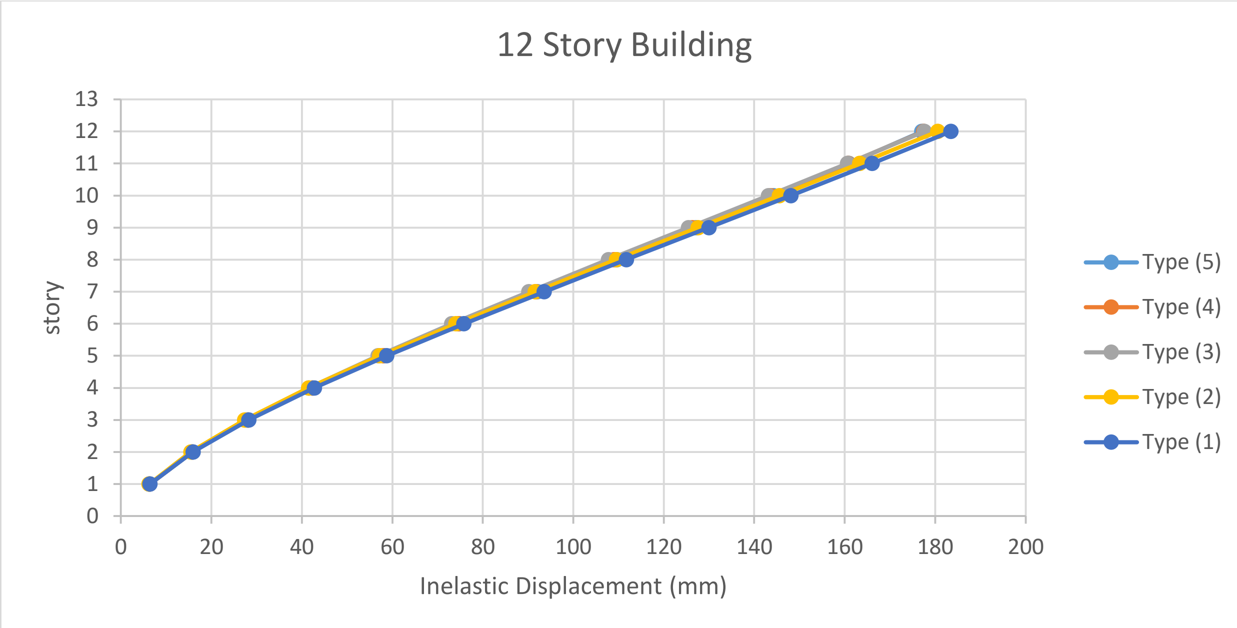

Figure 4.5.3 Structure model 4, inelastic displacement (quarter division)

4.6 Result of structure model 5 – 16 story (material approach)

4.6.1 Drift results

The second approach of study of the behavior of 16 story building structure is illustrated in this section. The seismic drift with corresponding to the story of the building with respect to material difference in specified locations. Four different cases using the first concept (using Ultra High Performance Concrete in each quarter of structural building). Four cases of study are plotted with the main structure with using normal concrete to observe the difference as shown on Figure 4.6.1Figure 4.5.1

The results shows that drift is parabolic for all types, the apex value is same for all types and occurs at 12th floor, the drift value of type (1, 2, 3, 4 and 5) at 12th floor is (0.00624, 0.006191, 0.006098, 0.005921 and 0.005983) respectively while the values at the 12th floor is (0.005933, 0.005883, 0.00581, 0.00572 and 0.005417) respectively.

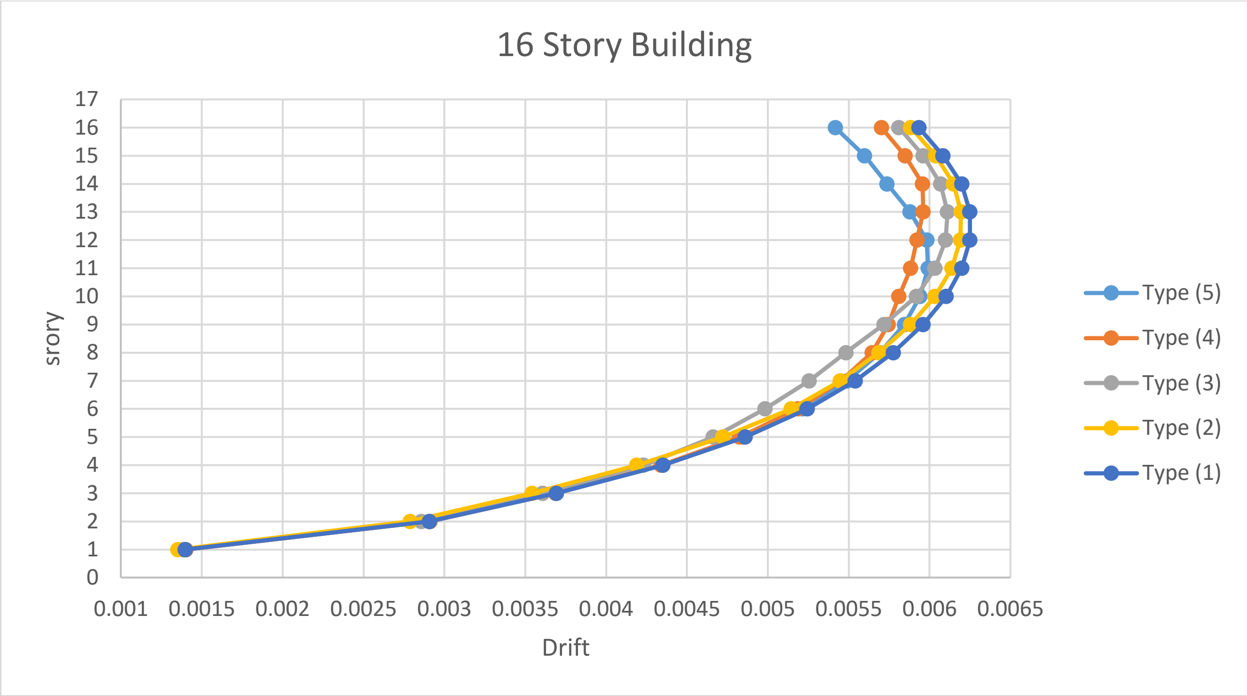

Figure 4.6.1 Structure model 5, drift (quarter division)

4.6.2 Shear force results

The following chart shows the results of shear force distribution along with story on the desired study concept 2, structure model 5. The results are plotted to observe the difference as shown on Figure 4.6.2.

The results shows all cases are almost same and all has nearly linear relation between the shear force and height of the structure, the results of type (1, 2, 3, 4 and 5) are (4023 KN, 4043 KN, 4043 KN, 4044 KN and 4043 KN) at the base and value of (817 KN, 819KN, 816 KN, 822 KN and 817 KN) at 16^{th} floor.

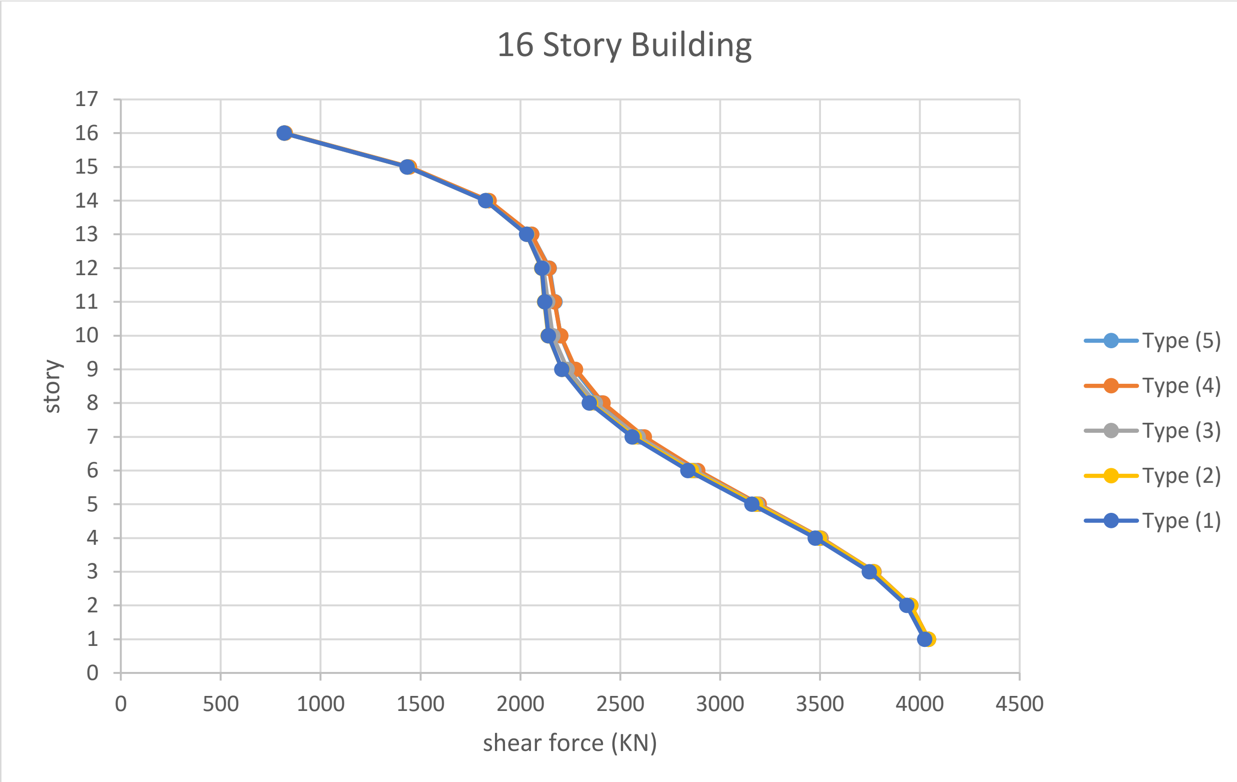

Figure 4.6.2 Structure model 5, shear force (quarter division)

4.6.3 Displacement results

The following chart shows the results of displacement distribution along with story on the desired study concept 2, structure model 5. The results are plotted to observe the difference as shown on Figure 4.6.3.

The results shows all cases are almost same and all has nearly linear relation between the displacement and height of the structure, the results of type (1, 2, 3, 4 and 5) are (287 mm, 280 mm, 276 mm, 277 mm and 276 mm) at 16^{th} floor.

Figure 4.6.3 Structure model 5, inelastic displacement (quarter division)

4.7 Result of structure model 6 – 20 story (material approach)

4.7.1 Drift results

Same as before, the second approach of study is performed on 20 story building structure and the analysis result is illustrated in this section. The seismic drift with corresponding to the story of the building with respect to material difference in specified locations. Four different cases using the first concept (using Ultra High Performance Concrete in each quarter of structural building). Four cases of study are plotted with the main structure with using normal concrete to observe the difference as shown on Figure 4.7.1Figure 4.5.1

The results shows that drift is parabolic for all types, the apex value is same for all types and occurs at 15th floor, the drift value of type (1, 2, 3, 4 and 5) at 12th floor is (0.007939, 0.007792, 0.007688, 0.007396 and 0.007146) respectively while the values at the 12th floor is (0.007404, 0.00728, 0.007211, 0.007034 and 0.006607) respectively.

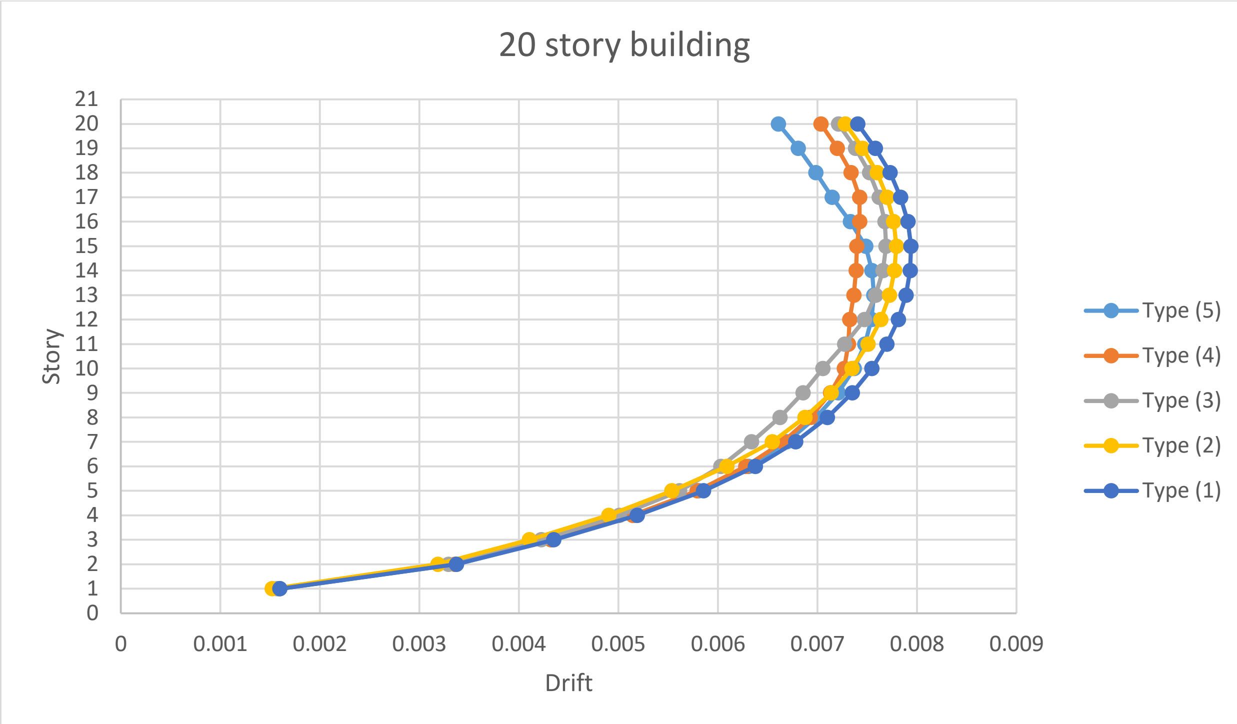

Figure 4.7.1 Structure model 6, drift (quarter division)

4.7.2 Shear force results

The following chart shows the results of shear force distribution along with story on the desired study concept 2, structure model 6. The results are plotted to observe the difference as shown on Figure 4.7.2

The results shows all models are almost same and all has nearly linear relation between the shear force and height of the structure, the results of type (1, 2, 3, 4 and 5) are (4289 KN, 4289 KN, 4287 KN, 4291 KN and 4291 KN) at the base and value of (781 KN, 778 KN, 773 KN, 782 KN and 774 KN) at 20th floor.

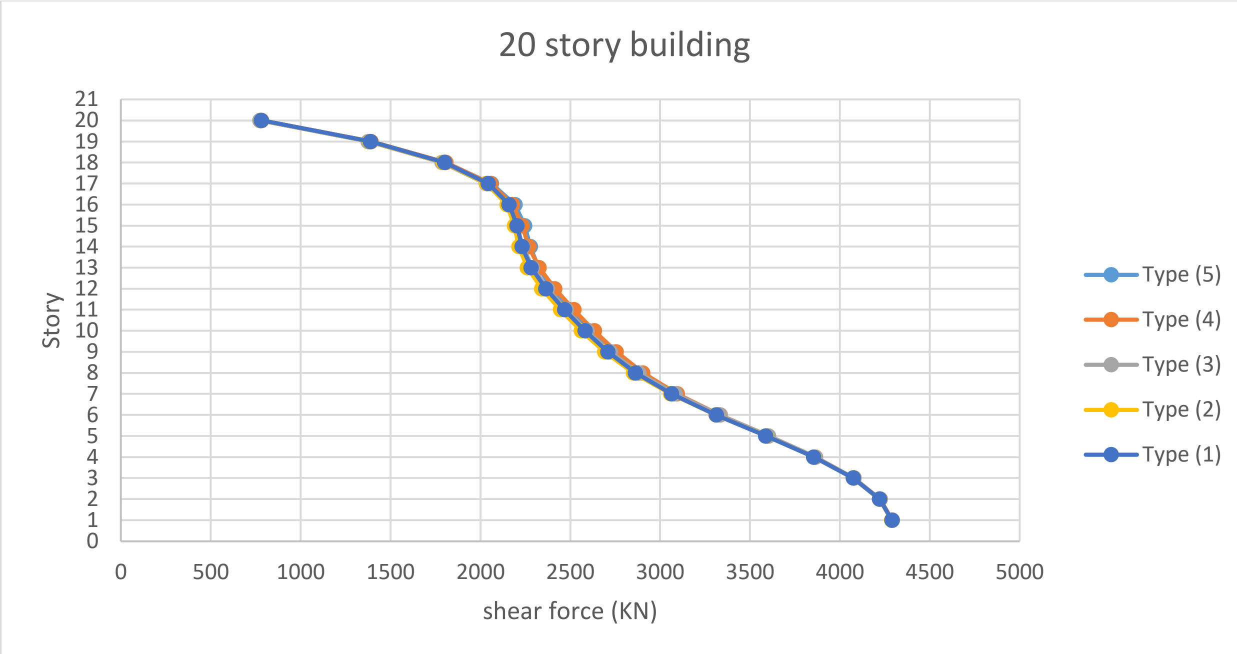

Figure 4.7.2Structure model 6, shear force (quarter division)

4.7.3 Displacement results

The following chart shows the results of displacement distribution along with story on the desired study concept 2, structure model 6. The results are plotted to observe the difference as shown on Figure 4.7.3

The results shows all models are almost same and all has nearly linear relation between the displacement and height of the structure, the results of type (1, 2, 3, 4 and 5) are (456 mm, 442 mm, 436 mm, 436 mm and 435 mm) at 16th floor.

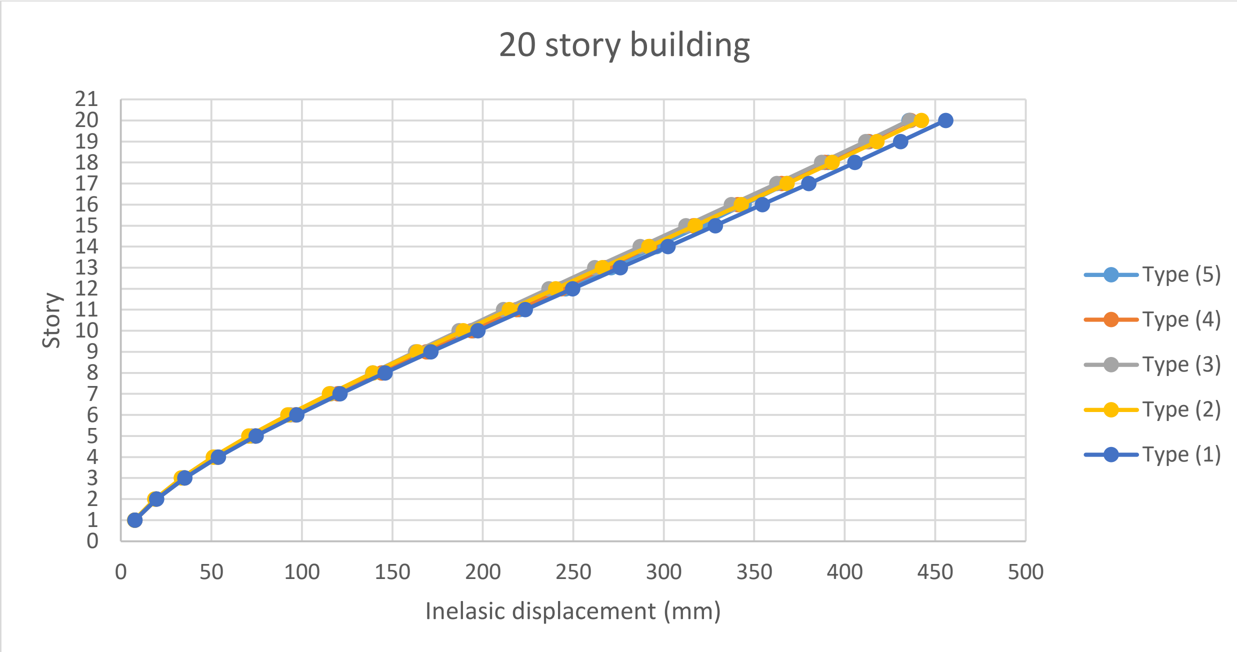

Figure 4.7.3 Structure model 6, inelastic displacement (quarter division)

Chapter 5 Discussion

5.1 Introduction

This chapter presents a discussion on the results illustrated in chapter 4 of this research. This discussion is focused on understating the charts of both two approach (stiffness approach and material approach) and trying to establish an empirical method that a designer could use in the field to enhance the structural behavior of the structure.

5.2 Stiffness approach

5.2.1 Drift observation and discussion

The drift of all basic structural models, type 1 for all three cases, have the similar curve.
All of them have parabolic shape and the apex of those parabola lies on 9th floor for Structure model 1, 12th floor for Structure model 2 and 15th floor for Structure model 3, which mean the apex lies on ¾ of overall height of structure.

Concept of quarter distribution

Type 3 is observed the optimum solution between type (2, 3, 4 and 5) which means using slab thickness with two times the main slab thickness at second quarter of the structure give the lowest values of drift. Type 5 of all structural models is observed the worst solution between type (2, 3, 4 and 5) which means using slab thickness with two times the main slab thickness at fourth (last) quarter of the structure give the highest values of drift.

Concept of one third and two third distribution

Using slab thickness located at 1/3 and 2/3 the height of structure building is alternative solution, the results show that the more thickened slab at those levels the less value of drift is obtained. Type (8) is observed the optimum solution between types (6, 7 and 8) while type (6) is observed the worst solution.

Furthermore, to have a good comparison between both alternative solutions, the amount of total thicknesses of two types shall be same to have a good comparison. (Type 3 and type 7) in Structure model 1, 2 and 3 have same amount of total thicknesses of all slabs, it is important to stat a quick relation between both types. This relation is we need to divide the total thicknesses of all slab (without thickening) by 8 and then add the result to the main slab at desired 1/3 and 2/3 the total height. For example, consider we have 16 story structure building with main slab thickness of 20 cm and we need to lump the thickened added mass into the slab at desired 1/3 and 2/3 the total height, we will calculate the total thickness of slabs as follows 16 * 0.2=3.2m, then divide 3.20 by 8 = 0.4m, then we will add this 0.4m to the main slab thickness 0.2 which mean slab will be 0.60 m.

Comparing between (Type 3 and type 7) in Structure model 1, 2 and 3 shows the drift values for both cases are almost same till 4^{th} floor, the difference occurs after from 4^{th} floor as following:

1. For structure model 1 (12 story), (type 3) has lesser drift values than (type7) till7^{th} floor while after 7^{th} floor (type 7) has lesser drift values than (type3) till 10^{th} floor and the last remaining two floors no differences between the two cases.
2. For structure model 2 (16 story), (type 3) has lesser drift values than (type 7) till10^{th} floor while after 7^{th} floor (type 7) has lesser drift values than (type3) till the 16^{th} floor (top level of structure).
3. For structure model 3 (20 story), (type 3) has lesser drift values than (type 7) till10^{th} floor while after 7^{th} floor (type 7) has lesser drift values than (type3) till the 10^{th} floor and after 10^{th} floor till 20^{th} floor , the drift is same for both cases.

- This result means when using thickened slab in the second quarter (type 3) leads to obtain lesser drift value at approximately the mid height of the structure. In on the other hand using thickened slab located on the 1/3 and 2/3 the height of structure with thickness equal to (main slab thickness + all slab thicknesses/8) leads to obtain lesser drift value at approximately the upper part of the structure.
- The more slab thickness used, the less drift values could be obtained, the drift curve is very close to be uniform after 4^{th} floor, this phenomena appear on (type 8) in structure model 3.

5.2.2 Shear force observation and discussion

Generally all models has nearly linear relation between the shear force and height of the structure. Basically the base shear value is proportional with the own weight of the structure which means the more thick slab used in the structure the more weight we expect. The ELF method basically distribute the base shear in respect to the floor weight and floor to floor height.

Concept of quarter distribution

For structure model 1, type 1 has a base shear of 3924 KN while for type 2, 3, 4 and 5 is varies between 4267 KN to 4379 KN. This variance is (8.7 %: 11%) more than type1.

For structure model 2, type 1 has a base shear of 4170 KN while for type 2, 3, 4 and 5 is varies between 4496 KN to 4660 KN. This variance is (8 %: 11.75%) more than type1.

For structure model 3, type 1 has a base shear of 4595 KN while for type 2, 3, 4 and 5 is varies between 4985 KN to 5079 KN. This variance is (8.4 %: 9.7%) more than type1.

Concept of one third and two third distribution

For structure model 1, type 1 has a base shear of 3924 KN while for type 6, 7 and 8 is varies between 3953 KN, 4059KN and 4552 KN. This variance is (0.7 %, 3.44% and 16 %) more than type1 respectively.
For structure model 2, type 1 has a base shear of 4170 KN while for type 2, 3, 4 and 5 is varies between 4496 KN to 4660 KN. This variance is (8 %: 11.75%) more than type1.
For structure model 3, type 1 has a base shear of 4595 KN while for type 2, 3, 4 and 5 is varies between 4985 KN to 5079 KN. This variance is (8.4 %: 9.7%) more than type1.

- This result means using thickened slab results in increasing the base shear of any structure model. This results is expected since the base shear is proportional to the dead load of the structure. The results also shows the more thick slab used the more base shear is obtained.

5.2.3 Displacement observation and discussion

The displacement of all basic structural models have the similar curve. The displacement is proportional to height of structure, the displacement is cumulative value that mean the total displacement at second floor is equal to the net displacement of first floor and the net displacement of second floor. Thus, the highest displacement value always occurs at the top of the building.

Concept of quarter distribution
For structure model 1, type 3 has the lowest displacement value (164 mm) while type 5 has the highest displacement value (179 mm).
For structure model 2, type 2 has the lowest displacement value (254 mm) while type 5 has the highest displacement value (283 mm).
For structure model 3, type 3 has the lowest displacement value (388 mm) while type 5 has the highest displacement value (444 mm).

Concept of one third and two third distribution
For structure model 1, type 8 has the lowest displacement value (159 mm) while type 6 has the highest displacement value (172 mm). Comparing between type 3 and type 7, type 3 has lower value (164 mm) than type 7 (166 mm).

For structure model 2, type 8 has the lowest displacement value (253 mm) while type 6 has the highest displacement value (272 mm). Comparing between type 2 and type 7, type 2 has lower value (254 mm) than type 7 (255 mm).

For structure model 3, type 8 has the lowest displacement value (355 mm) while type 6 has the highest displacement value (437 mm). Comparing between type 3 and type 7, type 3 has lower value (388mm) than type 7 (399 mm).

This results shows the type 3 is the better than all other types in respect to using the same equivalent concrete sections. The results also shows the more concrete section used in slab leads to reduce the total displacement of the structure.

5.3 Material approach

5.3.1 Drift observation and discussion

The drift of all basic structural models 4, 5 and 6 have the similar curve, all of them have parabolic shape and the apex of those parabola lies on 9th floor for structure model 1, 12th floor for structure model 2 and 15th floor for structure model 3, which mean the apex lies on ¾ of overall height of structure.
This is the same observation on previous case 1, 2 and 3 which means the drift shape is not depend on the strength or material of the structure and drift always has the parabolic shape and the apex and the apex always lies on ¾ of overall height of structure.

For structure model 4, the highest drift value at 9th floor is type 2 (0.005186) while the lowest type is 4 (0.004966), the difference is 4.4%

For structure model 5, the highest drift value at 12th floor is type 2 (0.006191) while the lowest type is 4 (0.005921), the difference is 4.5%

For structure model 6, the highest drift value at 15th floor is type 2 (0.007792) while the lowest type is 5 (0.007146), the difference is 9.04%

The results shown for structure model 4 and 5 the difference is lower than type 6 which means that using UHPC doesn't have the large effect on the seismic drift on medium rise building (12 story and 16 story) while it has a more effect on high rise buildings.

5.3.2 Shear force observation and discussion

Generally all models has nearly linear relation between the shear force and height of the structure. As stated before, the base shear value is proportional with the own weight of the structure. Since UHPC and normal concrete have the same density, the expected weight of all types is same.

For structure model 4, the highest base shear value occurs for type 4 (3749 KN) while the lowest type is 2 (3739), the difference is 0.002%
For structure model 5, the highest base shear value occurs for type 2 (4043 KN) while the lowest type is 4 (4044), the difference is 0.00002%
For structure model 5, the highest base shear value occurs for type 4 (4291 KN) while the lowest type is 4 (4289), the difference is 0.00006%

The results shows UHPC doesn’t have any effect on base shear of the structure.

5.3.3 Displacement observation and discussion

The displacement of case studies have the similar curve. The displacement is proportional to height of structure, as stated before the displacement is cumulative value. Thus, the highest displacement value always occurs at the top of the building.

For structure model 4, the highest displacement value occurs for type 2 (183 mm) while the lowest type is 4 (177 mm), the difference is 2.25 %
For structure model 5, the highest displacement value occurs for type 2 (280 mm) while the lowest type is 5 (276 mm), the difference is 1.15 %
For structure model 6, the highest displacement value occurs for type 2 (442 mm) while the lowest type is 5 (435 mm), the difference is 1.61%

The results shows location of slab with UHPC is not have a major effect on the displacement of the structure.

Chapter 6 Conclusion and recommendation

6.1 Introduction

This chapter presents the conclusions of this study with its two approaches as well as states the topics that could be studied for future thesis.

6.2 Conclusions:

6.2.1 Stiffness approach

- All structure building in this study when exposed to seismic force have parabolic curves of drift.
- Maximum drift value lies always at ¾ of overall height of the structure.
- The optimum location of using thickened slab is the second quarter for all Structure model.
- Using thickened slab at the locations of 1/3 & 2/3 of the height give better behavior for structural building.
- The more thickened slab at the locations of 1/3 & 2/3 of the height, the less drift values is obtained
- Consider thickened slab in quarters need to lumped at1/3 & 2/3 of overall height with same overall cumulative thicknesses of slabs, the following formula could be used (the main slab thickness + total cumulative thickness of slab/8).
- Consider compare between the concept of quarter and lumped the mass at 1/3 & 2/3 of overall height, the quarter concept shows a better values till the first 1/3 of overall height and the third, two third concept shows a better values on the above 2/3 of overall height.
- Generally, the more thick of thickened slab, the less value of drift could be obtained.
- Shear force is uniformly distributed with the height for all structural building in this study.
- An increase of 9% of shear force when use concept of thickened slab in quarters.
- Increase of shear force value when use thickened slab located on 1/3&2/3 of overall height rely on the amount of thickened slab used. The more section size the more base shear is obtained.
- Displacement for all models has a linear relation with height.
- Reduction of total displacement is 10 %, 10 % and 14 % for 12, 16 and 20 story respectively with respect to thickened slab on quarter of building
- Reduction of total displacement is 15 %, 12 % and 14 % for 12, 16 and 20 story respectively with respect to thickened slab lumped the mass at 1/3 & 2/3 of overall height equals to quarter concept of building.

6.2.2 Material approach

- All structure building in this study when exposed to seismic force have parabolic curves of drift.
- Maximum drift value lies always at ¾ of overall height of the structure.
- The reduction in seismic drift is 4 %, 4 % and 9 % for 12, 16 and 20 story respectively with respect to use UHPC criteria.
- Very low difference on shear force when use concept of thickened slab in quarters.
- Location of slab with UHPC is not have a major effect on the displacement of the structure.

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