Steel and Concrete Composite Structure as an Alternative Building Construction Material and its Application on High Rise Building Construction in Ethiopia

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May, 2016

A Research Thesis

Submitted in Partial Fulfillment of the Requirements

For the Degree of Masters of Science

In Construction Technology and Management

Addis Ababa, Ethiopia

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DECLARATION

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Abstract

The Ethiopian construction industry is showing a boom following the countries continuing economic progress. The country has also aimed to join middle income world in 2025.

Construction industry is one of the major industries that contribute to the aimed development by acting as a motor in all other sectors.

In order to enable the construction industry assists the development plan, it requires adopting alternative technologies with respect to speed of construction, structural integrity and stability, environmental compatibility, costing minimization, adoptability of technology and so on.

The development trend is forcing local and international people to flow to the capital Addis Ababa. As the number of inhabitants increased, the demand for housing and other infrastructures is also escalating. Therefore, it is becoming an alarming call to build high rise buildings to be able to accommodate the home seekers.

As it is proved by literatures of so many researchers from all corners of the world, reinforced concrete system of structures has weaknesses with regard to span restriction, heavier load of frame, bigger size of columns and especially, when the building height increased, the bigger will be effect of earthquake and the higher will be the cost of construction.

In order to solve such restrictions, there was a need to look for an alternative structural hybrid system having fulfilled the week sides of the RC system and Steel Structure. Steel is the best material known for its higher stiffness to be able to spanning wider and carry more load on a smaller cross section of vertical members. Also due to the connections are not as rigid as RC structure and the lesser the building weight, earthquake effects are minimized. The weak side of steel is; it is less resistant to fire and corrosive actions.

Hence a new approach called steel and concrete composite structural system had been introduced to the world a while after 2nd world war some 60 years ago with integrated property in that the concrete protects fire and corrosion while the steel contributes stiffness and span freedom. (Brian Uy, Professor of structural engineering and Director of CIES, Australia)

As it is highlighted in the literatures reviewed and this thesis itself, Steel-concrete composite structural system proved feasible for buildings higher than 14stories and for those lower than that, reinforced concrete structural system is still the best option.

But when comes to the effective use of available space, the benefit forgone due to former concept is something that needed further research which might change the trend dramatically that RC system is found to vacating 40% of the built up space compared to the steel and concrete composite system of structures.

Hence it can be said there is a visible lack of using composite structures as an alternative building construction material. The question is therefore is it not helpful to Ethiopian high rise building construction or are there problems that limited the industry not to use steel-concrete composite structures?

In this research it was tried to access all sectors of the industry and the major problems are concentrated on technological availability, the retardation in steel rolling industries and non consideration by government.

Acknowledgements

First and foremost, I thank God for giving me the opportunity to pursue my graduate study at school of Civil and Environmental Engineering, Addis Ababa University.

This research work has been demanding lots of activities tedious and time taking. Among these, the structural designing of the composite building had to be designed by a team of undergraduate students as their graduating thesis. So this was organized and advised by my advisor Dr. Esayas G/Yohannes, (Associate Prof). He had also contributed a lot by restructuring and improving the original idea. I thank him for all the knowledge and motivation he contributed.

MGM consulting Engineers and Architects and the manager, Eng. Meles Girmay, was the one who gave one of his architectural designs for the purpose of this research work and so he deserves many thanks.

All participants in this research work; Government offices of FDRE construction project management institute, Ministry of Mines, ministry of Industry and Addis Ababa city administration are found highly organized and cooperative through their information desk. Bank managers, Insurance company managers, steel engineering companies, designing engineers and construction engineers will take their appropriation for availing the information required.

The last but not least, Ato Yehualaeshet Nigussie, a member of the SCC designing team graduated on 2014/15, had been there for me in all courses of the research work.

Table of Contents

List of Figures

List of Tables

List of Abbreviations

SCC = Steel and Concrete Composite

RC = Reinforced concrete

CFT = Concrete filled tubes

PEC = partially enclosed composite

FEC = fully enclosed composite

ULS = Ultimate limit state

SF = Shear force

BM = Bending moment

I. INTRODUCTION

1.1. General Background

The Ethiopian construction industry, as one of the accelerators of the economic boom in the country, needs to see left and right in order to properly build the future. Construction by its very nature is to build now what will be fit and sufficient for the coming so many decades. Therefore research and development will be more crucial than ever when there is a boom in the industry.

Following the economic accelerations and other socio-economic factors, the demand for house in big cities is becoming the greater challenge for the country's economy. Especially in Addis Ababa, the capital of Africa, a sit for so many international organizations and a place where almost all the citizens want to live in, being not able to avail homes within reasonable distance from market and work places is creating sophistication in every aspect of the resident's activity.

Therefore space is one big issue that needs proper handling and utilization. Even though it is more of a town planning concept, civil engineering can contribute a lot by considering modern building industrialization concepts and involving space efficient technologies to the construction industry.

- Almost all buildings in Addis Ababa have little or no parking spaces.
- Most underground parking lots are not easy to drive in and out smoothly.
- Most building construction projects have no enough space for material handling and storage. Hence they dump all their materials and machinery on public areas and road.
- It is common to see columns in the middle of meeting holes and even in smaller rooms.

These are only some of the problems and that's why it is needed to involve alternative construction technologies to the industry.

Science is most of the time concerned with alternative and efficient ways of living. As the construction industry is also one of the benefits of science, we need to seek for alternative ways of doing things so that we can achieve a better technological advancement. The developed world is benefited from the advantages of combining Steel and concrete to form a composite structure. Compared to the reinforced concrete, it is more efficient to build long spanned and lesser cross sectioned columns so that we can be able to efficiently use land.

So it is vital to research on the relative advantages and disadvantages of SCC with respect to the extensively and exclusively used RC system and assess why it is not used as alternative construction material in Ethiopia.

1.2. Statement of the problem

The demographic report of Ethiopian statistics agency shows that a nearly tripling population growth has been registered in just 40 years' time. Especially in the last couple of years, with a growth rate of 2.89%, it becomes on the tenth level of world demographic chart. While population growth is in such progression, land remains always the same. There is high flow of people from rural areas to big cities. Therefore there is a big demand of high rise building construction and what is seen in some parts of Addis Ababa is a reflection of that demand.

As the buildings height increased, the weight of the building will also be increased with structural requirements of narrower spans, bigger cross sectioned columns and deeper beams in the conventional way RC system. More over the wasted space due to junks of concrete, the cost of construction is limiting investor's interest to escape the sky line. So statement of the problem will be what would be the comparative advantage of Steel and concrete composite structures with regard to the limitations of RC.

1.3. Research questions

The research is intended to answer the following

No	Research Questions	Research objectives
1	Is SCC system of construction better alternative with regard to structural and economical parameters?	To make comparative analysis between SCC and RC systems of construction from the point of view of Structural and economical parameters.
2	Is SCC system of construction capable of solving problems of efficient use of built up areas?	To make comparative analysis between efficient uses of built up areas between SCC and RC buildings.

1.4. Objective of the thesis

The general objective of the study is:

- To check if steel and concrete composite structural system is capable of increasing efficient use of space in building construction

The specific objectives of the study are:

- To make comparative study between SCC and RC structural systems with regard to structural parameters
- To compare cost of construction of SCC and RC buildings and to make trend analysis
- To research on why SCC technology is never been applied in Ethiopia.

1.5. Significance of the study

As it is discussed earlier, SCC system of building construction is believed to have better address limitations on RC system of building construction.

Therefore, the findings of this study will be helpful with:

- Highlighting area of investment for potential investors, government and others concerned.
- Motivating academicians to research more on the area.

1.6. Thesis organization

Following this chapter,

CHAPTER 2: provides a summary of the available literature in the area of

- space efficiency of tall buildings,
- introductive highlight of SCC technology,
- Similar comparative studies between SCC and RC made elsewhere,
- factors affecting implementation of SCC technology, such as availability and status of iron ore potential in Ethiopia and capacity of steel engineering industries,

CHAPTER 3: This chapter will cover the different types of methodology used to perform this research work.

CHAPTER 4: In this chapter, the data collected with the various methods discussed in chapter 3 will be organized, analysed and evaluated. The chapter includes

- Structural and cost comparison between SCC and RC systems of building framing
- Comparison based on efficient use of the built up area.

CHAPTER 5: In this chapter, conclusions and recommendations will be forwarded.

II. LITERATURE REVIEW

2.1. Urban space and high rise buildings

The capital city of Ethiopia, Addis Ababa, as an emerging African and World center is a key to the country's economy. The federal government and the city council need to assure the city's continuing dynamism given that its business require ideal conditions in which to operate.

Urban space is one of the key factors that play major role in the economy. To do so the country needs to insure that demand for space for office, public services and other key institutions can be met with in reasonable distance. There is a tremendous amount of building construction at all corners of the capital Addis Ababa. Due to the ambitious transformation demand of the country, it is expected that the city will be over flooded with local and international community who will want to reside inside or nearby the city.

The city master plan therefore is expected to assure the city's continued dynamism. In this context, tall buildings are becoming increasingly necessary as a result of the efficient use that they make of the limited land available.

On the contrary as population number grows, urban free space usually decreases. It is a bare fact that when the supply-demand gap getting higher, unit rate of land acquiring will be unworthy for developers.

There are major pressures on the land use of Addis Ababa that needed to be addressed right now.

- The demand for residential houses is growing and new homes will have to be built.
- Existing ghetto residential areas need critical up grading and re-construction.
- Public facilities and infrastructures need to fit to the future demand within a reasonable distance.

Therefore, it will be necessary to use the already existing free space in a more efficient way. One of the methods to efficiently use space is to build tall buildings. The city administration is revising the building height requirements as frequent as it has never been.

Tall buildings assist city administration free space usage in the following manner.

- More people can live and work on a smaller area of land.
- Government funded infrastructures like roads, water supply lines, sewage lines, electricity and other facilities can be provided to more people with a relatively less cost.
- Transportation travel distances can be minimized
- There will be enough space for play grounds, communal facilities, and green area
- Energy efficiency as a result of efficient use of infrastructures can be achieved.
- It will also be helpful to struggle against climate change.

To be able to efficiently use land, there has been a general move in the developed world from the concrete framed structures towards longer span steel beam floor systems.

Advantage of composite action between a concrete floor slab and its supporting steel beams and columns has reduced depth of steel beams and cross sectional area of columns and hence weight of tall buildings decreased by significant amount.

This doesn't mean there are no challenges in composite long spanned tall buildings. One consequence of increased spans is greater potential susceptibility to vibrations. Earthquake and/or wind loads are also length and total weight related challenges which must be limited at design stage.

In the US, the early development of steel led to its use as a favored material for high rise structures. In broad terms, steel framed buildings with rigid concrete shear wall can be economical for medium rise buildings up to 20 stories. When a vertical steel shear truss used at the central core of the building, it can be economical for up to 40 stories. A combination of central vertical shear trusses with horizontal outrigger trusses, it will be capable for up to 60 stories. For even taller buildings, it becomes essential to transfer all gravity loads to the exterior frame to avoid overturning effects. Rigid frame tubes braced tubes and bundled tube structures have been developed to reach up to over 100 stories.

Recent Development in the reliable production of high strength concrete has increased the potential for mega-frames with external mega-columns and light weight floor slabs allow for a reduction in gravity loads in ultra tall buildings.

The combination of Steel and concrete is often the most efficient form utilizing the best characters of each.

Figure 1. *COMPARISON OF VARIOUS COMPOSITE FRAMING SYSTEMS*

2.1.1. Effect of foundations of tall buildings on urban space

The form of foundations for different building types is mainly governed by reasonable cost and practicality in distributing the building loads to the underlying ground strata.

In general terms, vertical loads in low-rise structures are of low intensity and evenly distributed over the building footprint allowing the use of reinforced concrete raft foundation. In medium rise buildings, loads are intensified at column locations and small diameter piles can be adequate. But such solutions may obstruct major underground utilities or tunnels needed by future development and therefore raft solution might also be applicable. For tall buildings, the internal forces are concentrated in heavily loaded columns and structural cores requiring large diameter piles of longer length.

Therefore, in terms of sustainable construction, impacts from foundation include high volume of materials to remove, energy consumption, wastage generation, noise and vibration, effects on existing neighboring buildings, effects on underground services, pollution to the ground water and archaeological impacts.

The following is a general comparison between piled and raft foundations

	Piled foundation	Raft foundation
Excavated material	Relatively Smaller volume	Relatively large volume
Foundation	Efficient deep end bearing/friction foundations	Large volume of concrete per square meter of floor space
Energy	Additional energy for piling of rigs	
Space use	Possible to completed almost on the line of super structure	Usually foundation line is wider than superstructure line.
Adverse effects	Pilling below existing foundations	Additional loading on nearby existing foundations
	Underground services must be re-routed	Underground services may be covered over
	Smaller area of archaeological impact	Prolonged archaeological digs

Table 1 *General Comparison between piled and raft foundations*

Generally why it is necessary to build tall buildings depends on how to handle the side effects and how to be benefited from the advantages which are summarized as follows.

Advantages of building tall buildings

- Economies of scale: - design refinement and saving materials
- Standardization: - Procurement of large quantities led to efficient production and cheaper unit costs.
- Selection of materials: - Choosing environmentally friendly materials
- Land use: - more people closer to street and facilities
- Depth of plan: - Narrower floor area per m2 allows better use of day light and thermal mass.
- Horizontal access: - Efficient access per floor from the center outwards and service routing from core outwards.

Disadvantages of building tall buildings

- Safety: - working at height
- Surface area: - Greater area of façade per m2 floor area
- Floor area efficiency: - lower net gross area ratio
- Heavier structural frame
- Vertical access
- Wind effects
- Shading: - shadows on other buildings disrupt others right to light.

2.1.2. Tall buildings and technological preferences with regard to urban space

In the construction procedures of tall buildings, there is a great deal of concern with regard to what kind of technology will suit and how to deal with the side effects as illustrated above. In the building construction industry, especially with regard to structural framing, there have been two popular material preferences known as steel structures and reinforced concrete structures. Both have been practiced more than hundreds of years and developers have been researching on the shortcomings of both.

These two materials complete one another since researches show that the weakness of one can be complemented by the other. Concrete construction is good in freedom of form and shapes, easy to handle and thermal resistant while it is time-consuming during shuttering and sensitive under tensile forces. Whereas steel construction has high ratio between bearing capacity and weight, it can be done at high accuracy and it is convenient in prefabrication while it is comparatively poor in fire resistance and needs highly educated personal.

The new construction technology which is discovered some 50 to 60 years ago as a result of the combination of the two termed as "Steel and Concrete composite structure" has gained the benefits of the two and even more than that. (Brian Uy, Professor of structural engineering and Director of CIES, Australia)

Steel-concrete composite construction has gained wide acceptance world wide as an alternative to pure steel and pure concrete construction. The use of steel in construction industry is very low in Ethiopia compared to many developing countries. There is a great potential for increasing the volume of steel in construction, especially in the current development needs of Ethiopia and not using steel as an alternative construction material and not using it where it is economical is a heavy loss for the country's economy.

The following are the general advantages of composite construction.

- Composite structure has increased strength to given cross sectional dimension.
- Composite structures has increased stiffness leading to reduced slenderness and increased buckling resistance.
- Composite structures have good fire resistance and corrosion protection in case of concrete encased columns.
- Composite structures have significant economic advantages.
- In composite construction identical cross sections with different loads and moment resistance can be produced by varying steel thicknesses. Also allows the outer dimension of columns remain constant on a number of floors thus simplifying construction and architectural detailing.
- Composite members are extremely efficient for erection by industrializing the production process.
- In composite structural framings, formwork is almost not necessary.
- Composite structured buildings are known for durable finishes, good sound absorption, high energy saving and higher degree of modification and reuse of materials.
- While using composite materials for construction, it is easy to work in confined areas.
- Due to engineering properties of composite materials, it is possible to efficiently use the space available.
- Composite slabs have sufficient space within for utilities lining.

This thesis work will mainly focus on the relative advantages of composite construction over the traditional reinforced concrete construction. By tracing the international experience, it is tried to model a 15 storied building designed in both reinforced concrete and composite materials in order to see the comparative advantage and applicability of the technology in Ethiopia as an alternative.

2.2. Steel and concrete composite technology and it's practice in Ethiopia

2.2.1. Background

Steel and concrete composite technology is a system mainly composed of Composite columns system which is mainly concerned with vertical members of the structure and Steel concrete composite decking system which comprises horizontal members of beam, slab decking and concrete slab.

As it was learnt from field study and discussions made with scholars familiar with SCC, there is little application of it on slab systems of factory buildings where the columns and beams are purely steel structures and Slab made of deck sheet covered with in-situ casted reinforced concrete. Some applicants use shear studs welded to the underneath steel beams considering the significant amount of shear force that might cause slip of the concrete slab over the smooth side of the deck sheet while it is ignored on most observations.

2.2.2. Review on the elements of SCC, connections details and case studies

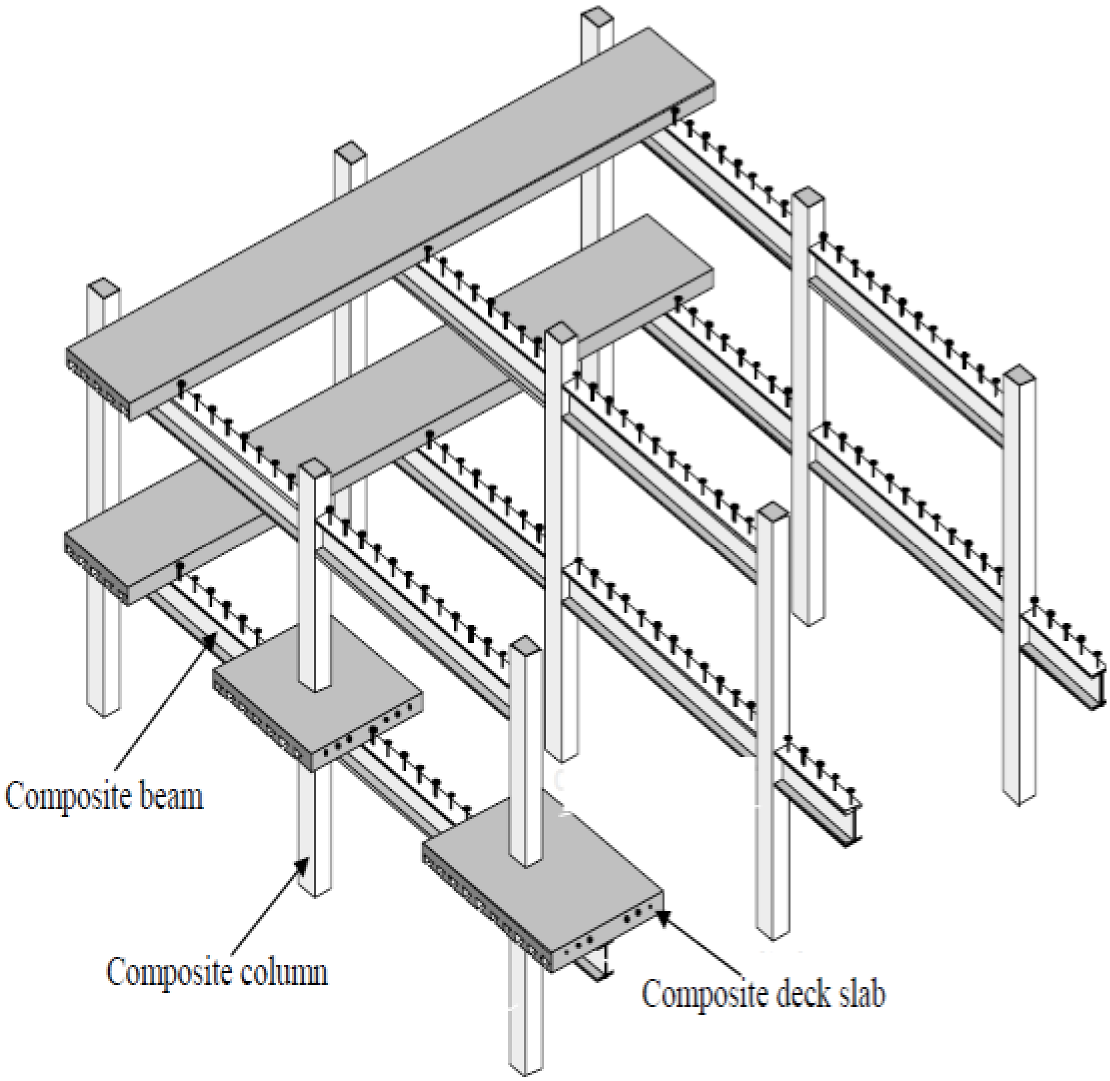


Figure 2. *Steel-concrete composite framing*

In general the use of steel and concrete composite system of structural building has five aspects of preferences.

1. Architecturally: - it is possible to have longer spans, thinner slabs, more slender columns and generous opportunity for design flexibility.
2. Economically: - it is possible to reduce total height of the building and saving area of cladding. Longer spans with the same height column free rooms, additional storeys with the same total height of building and quicker time of erection will help in cost saving. Earlier completion of the building will make it ready for use earlier thus increasing rental income.

3. Functionality: - by using principles of reinforced concrete in which the concrete protects the steel is possible also true here for fire protection.
4. Serviceability: - building flexibility is possible with regard to modification during the life of the building; modify services without violating the privacy of other occupants and accommodation of service facilities in the ceiling, within a false floor and in a coffer box running along the walls.
5. Assembly: - working platforms of steel decking; permanent shuttering for concreting, reinforcement of profiled steel sheerings; speed and simplicity of construction and quality controlled products ensure greater accuracy.

2.2.2.1. Elements of Composite System

Steel and concrete composite building system has four major elements.

1. <u>Composite column</u>

Steel concrete composite columns have large load carrying capacities, comparatively smaller cross sectional area and good fire protection. They are well known for high axial strength and flexural stiffness due to confinement of concrete by steel.

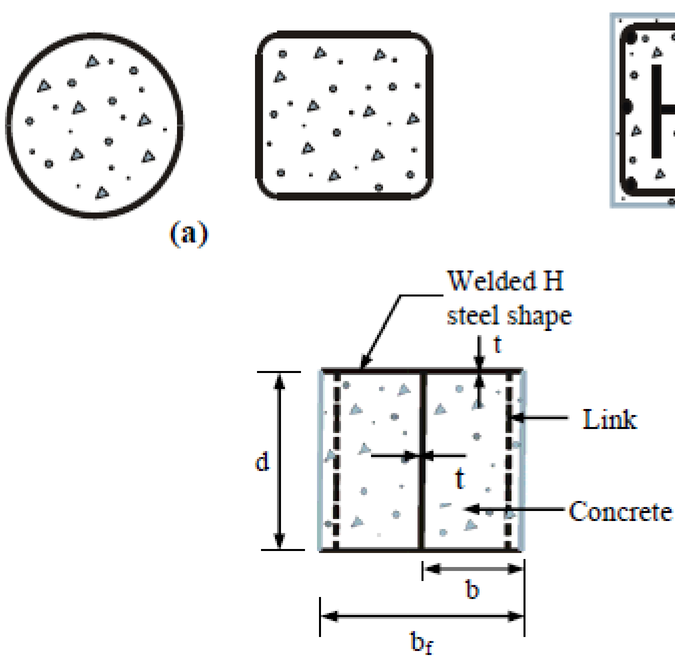


Figure 3 *Common types of composite columns, (a) concrete filled tubes; (b) fully encasedComposite column; and (c) partially encased column*

There are two major ways of designing composite columns. One is concrete filled tubes (CFT) and the other fully encased composite (FEC).

Both CFT and FEC have limitations which required additional research and development. Concrete filled tubes and fully encased composites both have limited cross sectional dimensions when standard sections are used and beam to column connections are complex.

CFT members are specifically poor in fire protection as the steel remains exposed while FEC members have their own limitations in requiring additional formwork and additional reinforcement between flanges.

In Europe in the early 1980's FEC were introduced using standard sized steel sections. Lately around 1996, a Canadian 'Canam Group' proposes a new type of composite column consisting of a thin walled, welded "H" shaped steel section built up from steel plate with concrete infill cast between the flanges. Transverse links are provided between the flanges at regular intervals to improve resistance to local buckling. The new system termed partially enclosed composite (PEC).

In PEC, additional reinforcement consisting longitudinal and transverse reinforced bars can be provided to improve ductility of these columns under cyclic loading. In this new system, since built up sections used, designers have flexibility to define new cross sectioned members which will help to increase stiffness of the steel by increasing web and flange thicknesses and use same dimension of columns on a number of floors in order to save space occupied by columns and enables architectural uniformity and simplicity of finishing.

2. Composite Decking (beam and slab)

Steel concrete composite decking system is mainly composed of Steel beams, decking steel sheets and concrete flooring. Such structure is designed to resist dead loads, live loads and temporary live loads (construction loads). Usually temporary live loads in reinforced concrete system are supported by temporary supports called false work while in composite system, the beams considered to carry such loads. (Even though it has cost implication on the overall construction cost, it is negligible compared to the avoided false work and also it will make the structure capable of carrying more loads equivalent to the temporary live loads).

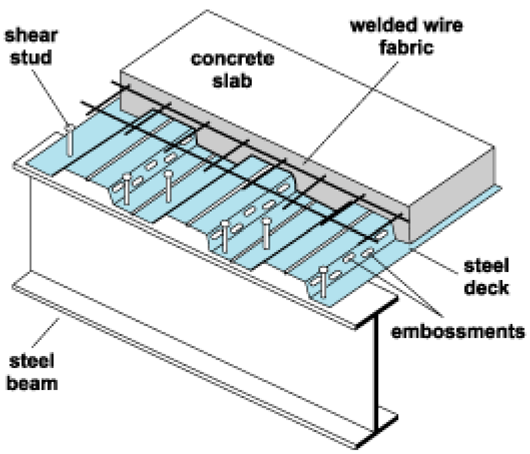


Figure 4 *Composite decking system*

Successful composite beam design requires consideration of various serviceability issues such as long term deflections and floor vibrations. In general terms, composite slabs use steel decking of 46 to 80 mm depth that can span 3 to 4.5 meter joist beam spacing without additional propping. 2.80 to 3.20 meters of joist beam spacing can withhold steel decking with a depth of 100 to 250mm.

Depending on researches made in various countries, Composite technology is by far best system for medium-rise to high-rise buildings while reinforced concrete system is still economical technology for low rise buildings up to 10-15 stories.

Mainly there are two types of composite decking depending on the relationship between the beam and the slab.

- Conventional floor system

In this system the slab rests over the steel beam. Under loading, the two components act independently and relative slip occurs at the interface.

- Composite floor system

In this system the slab and the beams connected by the help of deliberately designed shear connectors so that the slip between beam and floor can be avoided. Such shear connectors also help to minimize uplift forces acting at the steel-concrete interface and this will give pure composite action. Hence slip forces are zero at mid span and maximum at support of simply supported beam subjected to a uniformly distributed load. Hence shear is less in connectors at centre than at corners.

3. Shear connectors

The total shear force at the interface between concrete slab and steel beam is approximately eight times the total load carried by the beam. That's why the shear connectors are important elements. These shear connectors have two major benefits. One is they transmit longitudinal shear along the interface and the other is that they prevent separation of steel beam and concrete slab at the interface. (The shank and the weld at the steel beam resist the shear loads while the stud head resist uplift.

There are three types of shear connectors.

- Rigid Type

Rigid connectors derive their resistance from bearing pressure on the concrete since they are very stiff and sustain only small deformation.

- Flexible type

These connectors are welded to the flange of the steel beam. They derive their resistance through bending and so they undergo large deformation before failure.

- Bond or anchorage type

As the name implies this connectors have derived their resistance through bond and anchorage action. They are also used to resist horizontal shear and prevent slip.

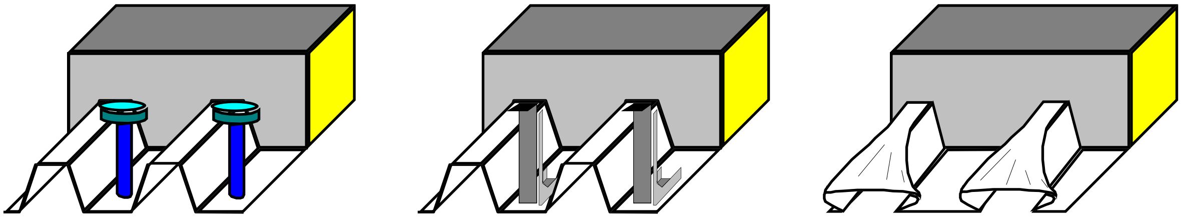


Figure 5 *Bond or end anchorage shear connectors*

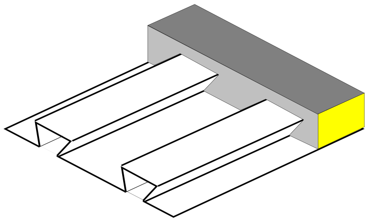


Figure 6. *Frictional connection between steel deck and concrete slab*

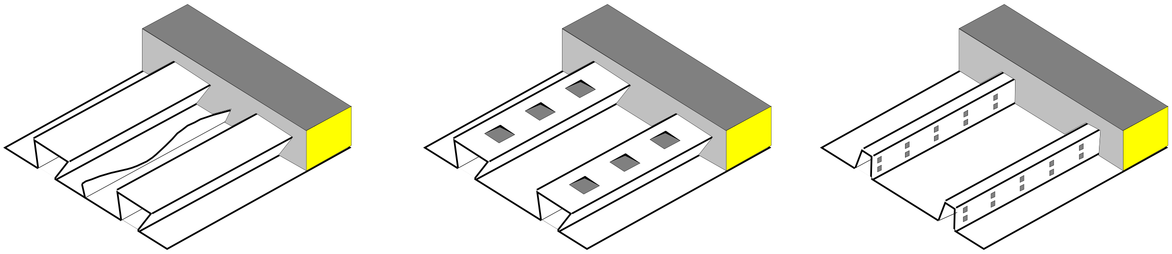


Figure 7 *Mechanical connection between steel deck and concrete slab*

4. <u>Structural connections (Joint connections)</u>

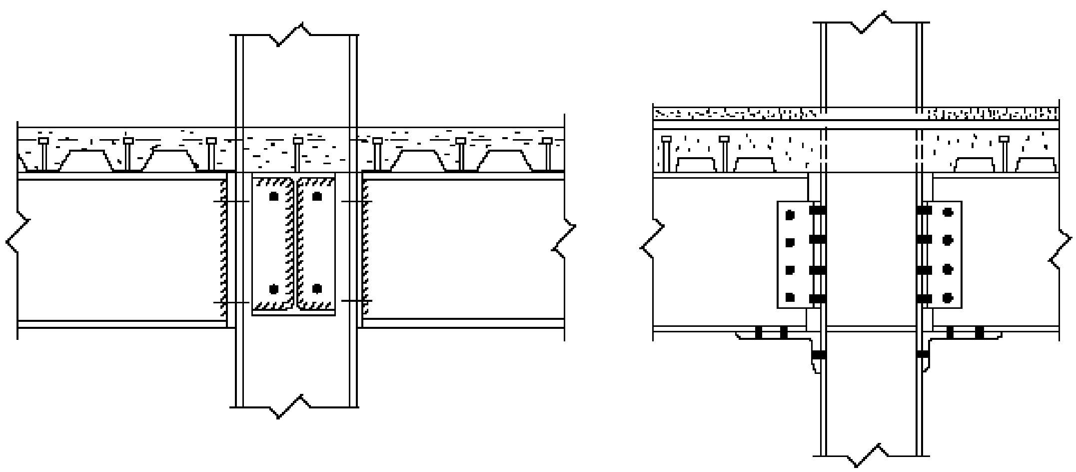
Joints design is one of the important links and weak link of the structural design. Besides the bearing capacity, energy dissipation and ductility should meet the requirements. The installation of the headed studs is very important for the steel shape and concrete to share the applied loads especially within the range of the beam-column joint. Additional to the problem among steel shape, steel bars and concrete casting should be well solved for the sake of convenience to construction.

There are two main connection areas

➢ <u>Beam –column joint</u>

The steel beam and embedded steel column could be connected by two patterns: the column through type and the beam through type.

For column through type, the steel beam and the embedded steel column connected within the joint in order to restrict the connection by the concrete. During the joint design, the face bearing plate (FBP) with the same height of the steel beam's web will be installed along the concrete surface of the composite column. Researches show that FBP could restrict the concrete of the joint core and delay the damage of the concrete as well as restrict the shear deformation of the embedded steel column's flange within the joint.



a. Flush end plate bolted to column b. Bottom angle with double web cleats

Figure 8 *Typical column through composite beam to column connections*

Two connection types are also applicable in this manner. One is flush end plate bolted to column flange and the other is bottom angle with double web cleats. The connections to edge columns should be carefully detailed to ensure adequate anchorage of reinforcing steel bars. Otherwise moment connection to exterior columns will increase moment in the columns resulting in increase of column size. Although the moment connection restrain the column from buckling by reducing the effective length, this is generally not adequate to offset the strength required to resist this moment.

For an unbraced frame subjected to gravity and lateral loads, the beam is typically bent in double curvature, hogging on one end and sagging on the other. Since concrete is assumed ineffective in tension, only the steel beam stiffness on the hogging region and composite stiffness on the sagging region needs utilizing for frame action.

For the beam through type, load transfer is through the beam and column contact surfaces. Connectors are required only for resistance against lateral movement.

- <u>Beam-concrete wall connection</u>

The composite steel beam and concrete core wall could also be connected by two methods. Face connection and embedded through connection.

During the analysis of the whole structure, the connection between steel truss (beam) and concrete wall is usually considered as in the form of hinged, while as the effect of the high strength bolts, the restraining moment still exist at the truss (beam) end. The finite element analysis indicates that the restraining moment is related with the thickness and height of the shear plate, and the net span of the truss. Research shows that the restraining moment would be larger than the calculation value which should paid attention to the design.

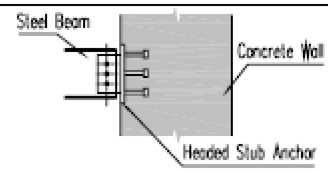
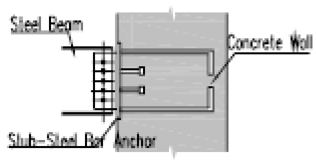
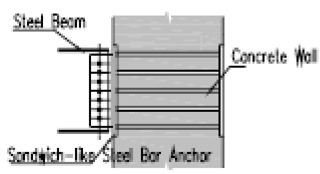
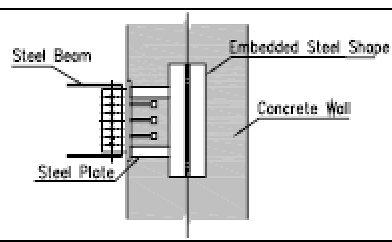
Type	Types of Steel Beam-Concrete Wall Connection	Mainly Applied to
1		Light Load Secondary Member
2		Ordinary Member
3		Major Member
4		Heavy Load Major Member

***Figure 9** Types of Beam to concrete wall connections*

The embedded anchors for the connection between steel beam and concrete wall could adopt different types according to the magnitude of load applied on the beam. Experiments show that type 1, the headed stud anchor would lead to the cracking of the concrete wall and slippage of the studs under the cyclic reversed loading. Type 2, stud-steel bar anchor and type 3, sandwich-like steel bar anchor, as well as type 4, the embedded steel shape, their failures mainly depended on the upper or lower embedded steel bars or steel plates. While type 4 its anchorage capacity, energy dissipation and ductility are better than the others, it is suggested using to the major bearing member in high seismic fortification areas.

2.2.2.2. Modes of Failure in Steel-Concrete Composite Structures

a. Behaviors of shear connectors

On the bases of the push-out test results the behavior of the different types of composite connections are characterized by the different failure modes, as follows:

1. Pull-out failures

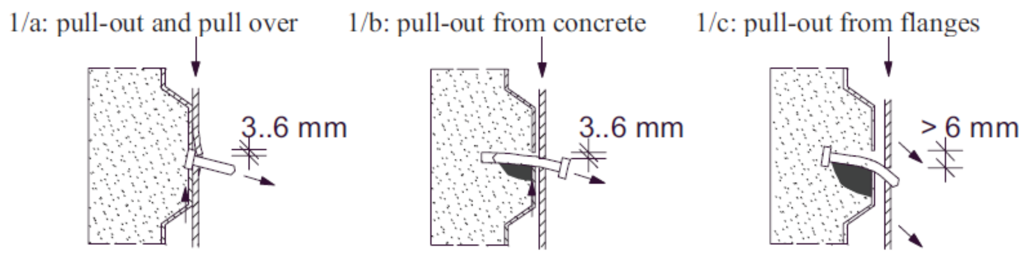


Figure 10 *Pull out failures*

Pull-out and pull-over failure (1/a) occurs when the common beam-to-sheet connection is applied. Since only the head of the screw is embedded, under relatively low force level the head pulls out from concrete. The stiffness is relatively low and the ultimate strength is approximately equivalent to the ultimate shear force of the beam-to-sheet connection without concrete. The dominancy of the steel components appears in the descending branch of the behavior: after the ultimate load level is reached, a plastic zone appears in plates and the pull over failure occurs. *Erdélyi and Dunai (2002).*

Pull-out of the screw from the concrete (1/b) is observed when the strength of the concrete is sufficient but the embedment is not effective. It is experienced in case of the "inverse" fastening, when the bolt of the screw pulls out from concrete (Erdélyi and Dunai, 2002).

The third type of the pull-out failures is when the fastener pulls out from the flanges (1/c). When the screw has sufficient ductility, the relative displacement between the concrete deck and the flanges can be increased. Due to this the screw rotates and becomes more and more tensioned. If the displacement capacity of the screw is high enough, the screw can pull out from the flanges before the failure of either component.

2. Screw failures

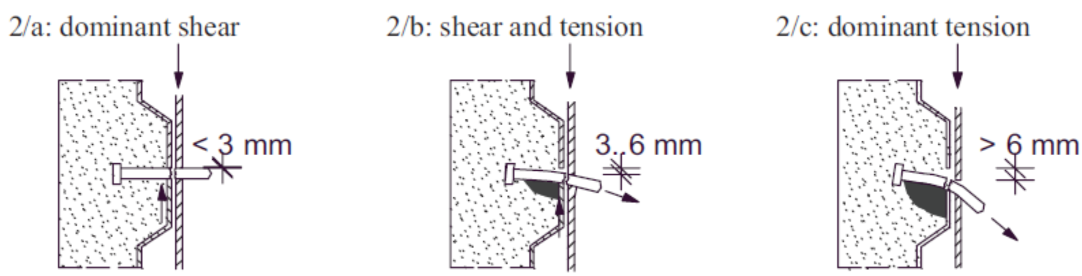


Figure 11 *Screw failures*

Screw failure occurs when the embedment is effective and the strength of the concrete is relatively higher than the strength of the screw, as illustrated in Fig. above. Two types of this failure mode are experienced depending on the displacement capacity of the screw. If it is relatively low the ultimate failure is the dominant screw shear (2/a). If the displacement capacity of the screw is relatively high the rotation of the screw can be occurred and the screw becomes tensioned. Depending on the displacement capacity of the screw the final failure will be either due to the combination of shear and tension (2/b) or dominant tension (2/c).

3. <u>Concrete failure</u>

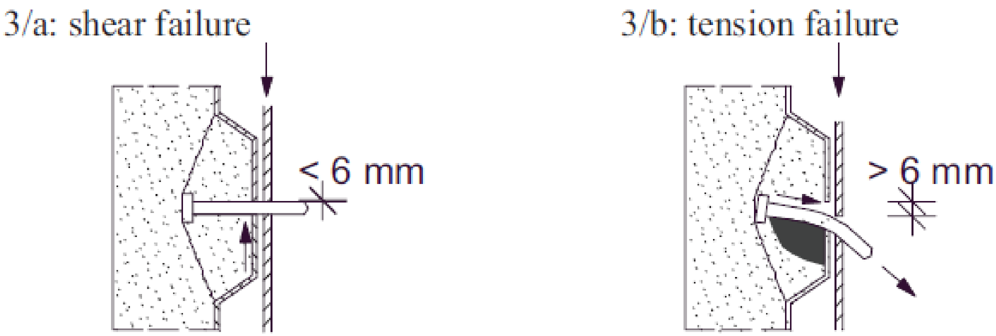


Figure 12 *Concrete failures in composite connections*

The dimension of the crack cone highly depends on the geometry of the rib. Narrow crack cone is observed when trapezoidal sheeting with positive fastening mode is applied. Due to the relatively large dimensions of the rib the behavior is similar to a deck without rib. The failed deck can be seen in Fig. above 13/c. In case of negative fastening, the crack surface is a common cone with app. 45 degrees, as shown in Fig. 13/d. It has relatively large extension when two-line fastening is applied. In Fig. 13/e, a combined failure mode is shown: the upper connection fails by the pull-out of the screws from the flanges (12/a) and the lower connection fails by the tension of the concrete (12/b).

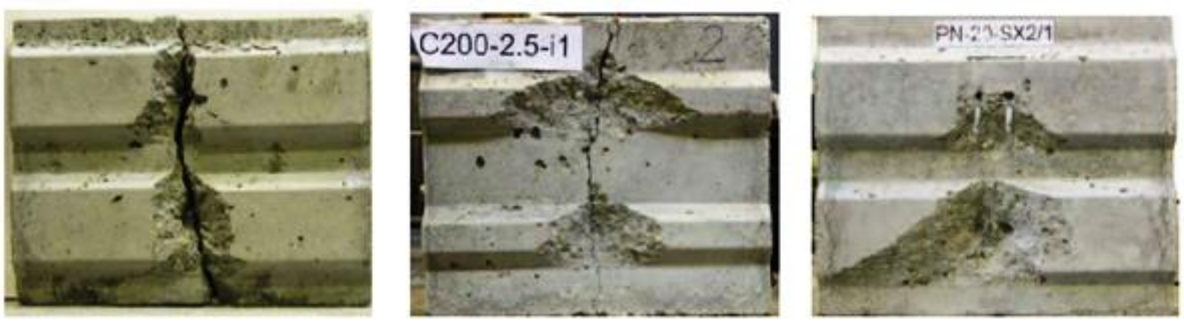


Figure 13 *Characters of concrete failures in composite connections*

b. <u>Local plate buckling</u>

The local instability phenomena that are experienced in the element ends of both steel and steel-concrete composite specimens in the case of slender welded cross-sections (Class 4 section in Euro code 3, EN 1993-1-5, 2005). The observed local buckling is symmetrical in steel and asymmetrical in composite specimens, as illustrated in Fig. below.

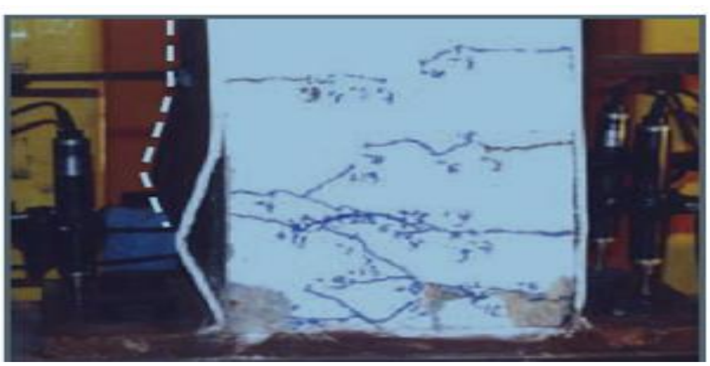


Figure 14 *Local buckling in composite column.*

Figure 15 *Local buckling in steel column.*

c. <u>Deformation on "T" members</u>

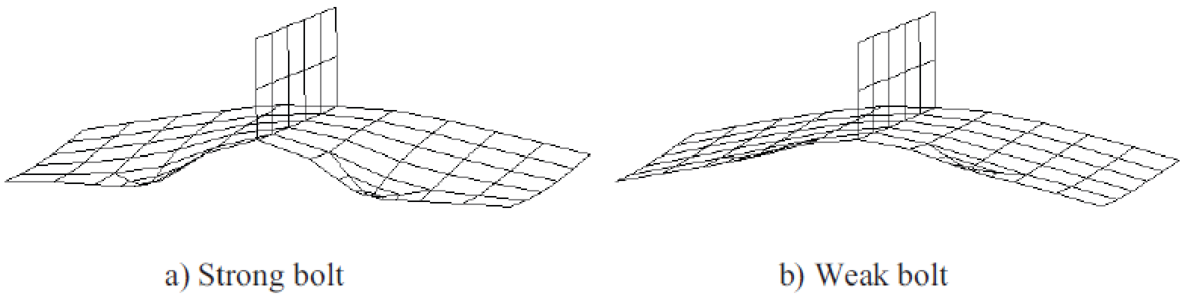


Figure 16 *Deformation of T-members*

d. <u>Moment rotation of end plate joint</u>

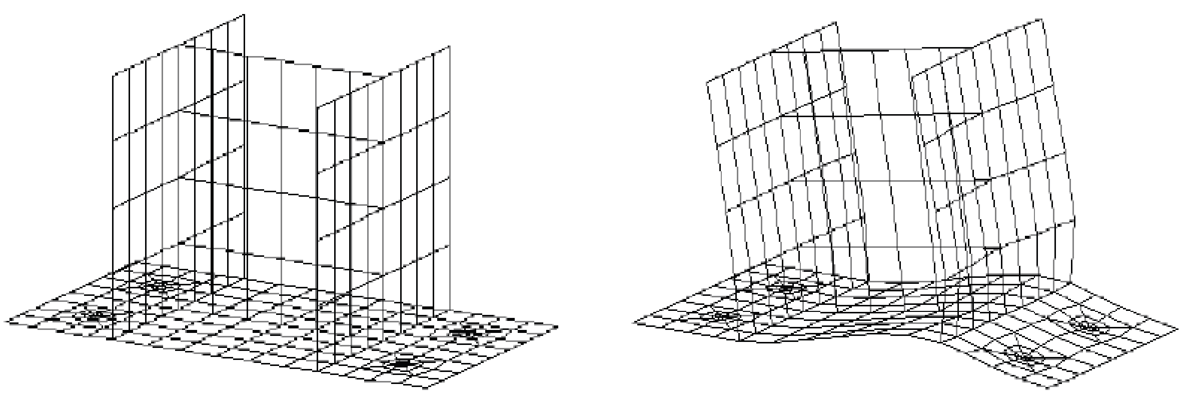


Figure 17 *Deformed geometry of end plate joint*

<u>Comparison between steel concrete composite and concrete structural systems</u>

In making decision on the viability of adopting steal concrete composite as a substitute for concrete structural systems , the following system warrant due consideration.

<u>Efficacy and Build ability</u>

Speed of construction: - off site prefabrication allows immediate erection upon arrival at site with no subsequent delay. It has also a lesser need for onsite storage area.

Quality and Reliability:-steal is homogenous and is subjected to documented quality control procedures so no re-work is necessary on site.

Design efficiency: - composite steal framed building have lighter dead load. Such buildings can be 15% to 40% lighter compared to concrete building (depending on composite or pure steal), more weight saving can be achieved if concrete core is substituted by steal bracing frame, a design which is popular in UK and US.

Flexibility and Versatility: - steal is excellent strength to weight ratio created economic use of space. Steal structure systems can span longer creating large column free areas that offer greater flexibility of floor layout.

The floor to floor height of a concrete building would have to be increased by an average of 150mm per floor to accommodate the structural and services zones. For composite steal framed building integration of structural and services zones can be achieved by forming opening through the beams to allow penetration of mechanical, electrical and sanitary services, resulting in a shorter overall floor to floor height.

Adaptability: - composite steal framed buildings allow opportunities to integrate large openings. Changes of structural leads can be easily accommodated by strengthening individual members or through additional comparatively more adaptable to future changes.

Working place health and safety:- off site fabrication of structural steel components and composite components consequently leads to a faster speed of erection on site lesser site activity means enhanced safety on site.

Build ability: - most components for a composite steal framed buildings are prefabricated and pre assembled off site. This lessons the amounts of site work and enhances the quality and precision of the site installation work with composite structures there are lesser connectors and bar benders required. Lesser general workers also required for clearance of debris as wet trades are minimized on sites.

In addition, recent innovation in construction materials such as high strength steel and concrete up to 150mpa will provide more benefits to use composite steal concrete design for multi-storied building. This will lead to material saving, lighter structure, faster construction time and increased functional areas of floors. Belting on site and factory welding will also increase productivity.

Seismic zones: - there are several advantages of steel structure in seismic zones. These include lighter weight, higher flexibility and ductility etc.

Seismic ground shaking generates internal forces with in building called internal forces. The greater the mass (weight of the building), the greater will be the internal forces generated. Weights of steel structures are generally lesser than reinforces concrete structures and therefore the seismic forces acting on steal structures are correspondingly lesser.

Steel structures are also more flexible than reinforced concrete structures. Flexible structures attract lesser seismic forces. This is because flexible structures have longer periods of vibration which result in lesser acceleration and lesser generated internal forces, stiffer structures have the opposite.

The higher weight and greater flexibility of composite structures reduces the seismic forces in the structure and its foundations. This deduction of design forces significantly reduces the cost of both super structures and foundations.

In addition the weight and flexibility, steal is also more ductile than reinforced concrete. The increased ductility of steal allows any excesses of seismic load to be more readily absorbed by greater energy dissipation due to plastic deformations of structural components.

Structural effects

Both concrete and composite steal framed buildings can be tailored to meet the performance requirements specified in codes and standards. The most appropriate framing would be dependent on factors such as building height, slenderness, geometry, floor layouts, site ground conditions etc

One of the major benefits of concrete is its massiveness provide excellent dynamic properties to reduces building acceleration and enhance human comfort. For this reason, a majority of high rise buildings adopt a hybrid frame i.e. concrete core and steal concrete composite frames around it which allows the individual benefits of concrete and steel to be utilized as an optimum solution.

Sustainability

As everyone knows, concrete requires the use of three main components; cements sand and gravel. The production of cement requires raw materials called clinker. The manufacturing process entails the use of fossil fuel and like all other manufacturing processes worldwide, carbon dioxide is emitted in to the atmosphere which is the main reason for ozone depletion.

Sand and gravel also require mining and this activity lends itself to depletion and degradation of the environment in the long term.

The production of steal undoubtedly also requires the use of fossil fuel and manufacturing process would obviously add to the emission of Green house Gases (GHG).

This is a factor that should not be brushed aside when considering steal as a substitute for concrete. However, since steal is 100% recyclable and reusable without the loss of quality while concrete is not, the use of steal will help to slow dawn the degradation of the environment in the long term.

Experience and literature of different countries shows that there are also a number of comparisons made between pure concrete and steel concrete composite technologies with regards to cost, time of construction, future adoptability, space efficiency, minimum disturbance of construction on the surrounding etc. And almost all of the studies referred for the purpose of this research show that pure reinforced concrete structure are best for up to ten storied buildings while steel and concrete composite structures are sound for above fifteen storied buildings.

2.2.2.3. Case studies made in other countries

The following are studies conducted in India, Bangladesh and England comparing Steel-concrete composite framed buildings with Reinforced concrete buildings. Selection of the papers is only based on accessibility. The studies are made all on their own objective. Hence we refer all the three separately and interpolating intermediate results, their data made on similar base line and used in the analysis chapter.

1. Research paper 1

- Title: - Comparative study of Reinforced concrete and Steel-concrete composite structures (India)

Shweta A. Wagh et al Int. Journal of engineering research and applications.

ISSN: 2248-9622, Vol. 4, Issue 4(Version 1), April 2014 page 369-376

- Objective of the study was to compare reinforced concrete structures with composite structures with regard to: -

i. Deflection
ii. Axial force and shear force
iii. Bending moment in beam and column

iv. Cost of construction

- Methodology used was Equivalent static method of analysis made on four buildings of same floor area but varying heights of G+12, G+16, G+20 and G+24. The codes implemented were IS 1983 and IS875 (Indian code)
- Findings

  Even though the buildings designed to be within the permissible limits, there was a big load difference observed between the two technologies.

  i. As the building height increases deflection increases for both. But deflection of Composite frames becomes double of that of Concrete.
  ii. With regard to Axial and shear forces, a very high increase observed on concrete frames.
  iii. The study also shows that there is a significant reduction in bending moment of columns and also a noticeable reduction on beams of composite framing.
  iv. Cost comparison of the two framings is given by the following table.

Item	Cost in percentage (composite-RC/RC)*100 in %			
	G+12	G+16	G+20	G+24
Slab	-27.9	-28.05	-14.72	-25.7
Beam	62.36	60.66	53.20	57.27
Column	13.56	-4.68	-40.89	-44.00
Footing	-44.60	-39.79	-34.05	-25.09
Total	-0.11	-5.23	-10.44	-14.76

Table 2 Cost analysis of sample project on literature no. 1

From the data found on the journal, the above table developed and the following are observations made.

- Every negative value shows composite framing is cheaper than concrete framing on that specific item.
- On the three items of work i.e. slab, column and footing of almost all buildings, composite framing is less costly than concrete.
- Only on beam construction, concrete showed advantage of cost minimization.
- With regard to total cost of all buildings, composite is cheaper on all occasions and the difference shows that there is almost 1.3% cost saving for every additional floor of composite structure. To make it more sound, it is about 22,547 USD or 450,940 Ethiopian birr saving per floor.

2. Research Paper 2

- Title: - Cost analysis of steel concrete composite structures in Bangladesh.
  Asian journal of civil engineering (BHRC) vol. 14, No. 6 (2013) pages 935-944
- Objective of the study was to investigate the cost effectiveness of steel concrete composite frames over the conventional reinforced concrete frames for building structures.

- Comparison was made on buildings with similar floor pattern but varying heights of G+6, G+12, G+18, and G+ 24.
- Findings
  The study didn't present detailed data as we see on the above case. It is only a total project cost which is shown in table below.

No	Building type	(Composite-RC/RC)*100 in %
1	G+6	19%
2	G+12	4%
3	G+18	-4%
4	G+24	-14%

Table 3 *Cost analysis of sample project on literature no. 2*

The data in the table shows the following.

i. For low rise buildings (less than G+12) the conventional reinforced concrete framing is more economic.
ii. For high rise buildings above 18floors steel concrete composite framing is economical. The building heights between G+12 to G+18 can be more or less similar cost wise so selection needed to be made on other criteria.

3. Research paper 3

- Title :- Steel still the cost effective choice
  A study made in England on two sample buildings located in Manchester and London. Building A is built on 2600m2 area for office building and building B on 18,000m2 for office too.
- The study tries to see cost of construction as well as time of completion of framing. The two buildings were made on 1985 and the cost comparison made on the years following until 2007.
- Findings
  Even though material prices are subjected to inflations, steel works found resistant to be less inflating. The gap between steel and concrete was about 10 pounds per square meter of ground floor area at the base year 1995. But it grows to 25 pounds per square meter on the year 2006 with steel has the lower register.
- Market share of steel and concrete frames with in the years shows that due to the resistance to inflation Steel's market share grows from 30% to 70 % while that of concrete downs from 50% to 18%. This shows that the England construction market prefers steel for structural works.
- With regard to time of completion of the framing works, building A with composite framing completed 2 weeks ahead of the concrete framing. The same is true for building B that composite framed structure completed 9 weeks ahead of the reinforced concrete framed structure.

In the previous sub topics, it was tried to see how to efficiently use scarcely available space in big cities and how steel and concrete composite technology would contribute in saving every single inch of land available. Other advantages of composite structural framing and little details of structural approaches and failure mechanisms in major structural element of a composite structural framing are also discussed to give highlight to future researchers in the area.

In the following part of the chapter, the potential of Ethiopian steel industry will be assessed since among concrete and steel that are the two actors in the composite system of building construction, availability of steel and capability of molding it on high level will be the other trait in trying to practice this new technology.

2.2.2.4. SCC in Ethiopia

The application of SCC can be seen in two ways as practical executions and research papers. During the core time of this research paper, a year within 2015, there was neither practical SCC construction nor comparative research work between RC and SCC systems of building frame design. A while after, a combined RC and SCC designed high rise building owned by Commercial Bank of Ethiopia emerged as the first of its kind in Addis Ababa/Ethiopia for its head quarter and this research work failed to consider it as a research material as a result of deadline of research time frame.

There had also been a field visit in most areas of the country to look for at least a partial application of SCC. The only case the researcher came across was concrete field sheet decks in some factory buildings at Saudi Star rice processing factory of Bischoftu, Raya Brewery Factory of Maichew and so on where the slabs are designed as steel structures and the concrete fulfils architectural purpose only.

Regarding research works with special focus on comparative analysis like this one had not been found on the library archives but only one paper by Berhanu Tena titled "Comparative Study on the Response of RC Frame Structure Braced with Different Steel Bracing Systems" conducted at School of Civil & Environmental Engineering Post Graduate Program of AAU with some resemblances discussed hereunder.

Research paper 4

Title: - Comparative Study on the Response of RC Frame Structure Braced with Different Steel Bracing Systems

The researcher conducted it in partial fulfilment for the requirements of his degree of masters in Civil/structural engineering at Addis Ababa University school of Civil and Environmental Engineering. The major focal point of the research work was to be able to give other Structural Steel bracing options to the conventional Shear Wall in long buildings which is used to be considered for resistance against lateral loads.

As the title of the thesis work refers, the researcher was not attempting to design SCC building, but to provide a steel tube bracing solutions (the way it is used in SCC structures) to a Reinforced Concrete structural system so that he can avoid shear walls.

Summary of research input design basis: -

i. Four categories of building height: - G+3, G+5, G+8 and G+12 each has its own structural design of a building 3bays by 5bays.
ii. Two types of braced bay arrangement: - one with bracing every other bay and the other bracing only at both sides of the four corners.
iii. Five types of steel bracing systems: - None framed, Diagonal framed, X-braced, V-braced and inverted V framed.

The researcher analyzed 40 building designs produced with a combination of the above three design basis with a special emphasis to lateral load as a result of Zone IV seismic action with the following three load transfer steps.

Step 1: the design lateral force computed first for the building as a whole

Step 2: this design lateral force distributed to the various floor levels

Step 3: the overall design seismic force obtained at each floor level distributed to individual lateral load resisting elements depending on the floor diaphragm action.

Findings: -

The research output highlighted the following basic points.

i. Evaluation and comparison based on Lateral displacement, base shear capacity, overturning moment resistance and story drift of the none braced structure against the four types of bracing patterns of all buildings showed the fact that the additional steel bracing systems imported an improved resistance to lateral pressure of the RC buildings.
ii. The comparison between the two bracing patterns, One after the other bay bracing against Corner bracing, showed that Corner bracing pattern performs better specially on X-direction while the Y-direction remains closer to each other.
iii. Comparison between the four types of bracing methods showed that X-bracing and inverted V bracing are the best among the rest with inverted V bracing is good at resistance to lateral displacement while the X-bracing showed better performance on the other comparison criteria.
iv. The research considers its limitation on RC to Steel bracing system connection mechanism and associated effects. The building shape in case of irregular architecture, alternative bracing in case the bracing overlaps on open walls, span restrictions of RC system and cost benefit analysis of the studied solution are not parts of the research objectives and therefore the reviewed research paper has little or no contribution to what this research work is about to contribute.

III. METHODOLOGY

3.1. General

This chapter will cover different aspects of methodology used while performing the research work. The need behind every data, the method used to get the most out of the best, how each sample defined and failures in the planned approach will be assessed. As the research work was progressing, there had been a need to change, modify and elaborate some of the data which apparently caused delay in completion. Each will be assessed in order to help future researchers learn from this experience.

3.2. The Study Area

This research work is aimed to bring space efficient construction technology to the building construction industry of Ethiopia specifically to the most urbanized and congested city of Addis Ababa. Among the various sub cities in Addis Ababa, the central, south and south east of the capital are given major emphasis since most tall buildings and the economic acceleration observed there. To be able to come to this point, registration of tall buildings has been done all over the town and the top 15 tallest buildings in Addis Ababa are found scattered at the up mentioned parts of the city. See appendix 1

3.3. Research Approach

Research is an active, diligent and systematic process of inquiry in order to discover, interpret and revise facts, events, behaviors or theories, or to make practical applications with the help of such facts, laws or theories. The scope of the research process is to produce some new knowledge.

The research process can take four main forms.

I. Applied form: - used since the purpose of this research is to solve practical problems instead of theoretical ones.
II. Experimental form: - used since the core point of this thesis work requires structural design and assessment of resourcefulness in the study area.
III. Qualitative form: - is also found important since this research idea is highly dependent on insight, motives and motivations of stakeholders with in the construction industry.
IV. Coo relational Form: - all the other forms and the data acquired through needs a link and this form helps in doing so.

Almost all of the data collection process used secondary sources and this might leave a weep hole on whole or part of the findings.

In this particular study, the purpose is to efficiently use urban land by building tall buildings which are capable of accommodating a number of activities and people with in a relatively smaller area of land and to evaluate the space efficiency and cost competitiveness of the traditional structural framing system (RC) construction with respect to an alternative and worldwide considered structural framing system (SCC). The data surveying includes Addis Ababa city administration lease office, Ministry of mines and energy, Industry minister, Works and urban development minister, private consulting offices, private construction companies, steel engineering companies and land brokers.

Even though the range of data sources is a challenge for a one man study, it is tried to find the best out of all.

3.4. Research Method

The methods of data collecting, processing and analyzing can be categorized in the following ways.

I. Structural design of a sample building in both SCC and RC systems, quantity surveying and cost estimation

II. Consideration and inclusion of studies made elsewhere having similar nature from the internet.

III. Comparison of the actual design with the literatures and comparison of the two framing systems with each other with regard to structural behaviors and cost of construction

IV. Compiling land owning data both from government lease and individuals selling price.

V. To limit the sample collecting area, a rank of tall buildings made by field survey and the list from first to fifteenth considered.

VI. Since composite technology is highly dependent on steel technology and availability, the Ethiopian iron ore deposit, future prospects in the mining area, steel industries and their level of industrialization studied. Magazines of the respective ministries used as a literature.

VII. Composite technology is a highly industrialized system of construction and it requires high level of knowledge and skill at all levels of the manpower hierarchy. Hence it becomes necessary to assess the knowledge level, awareness, interest and readiness of professionals in the construction industry. Questionnaires and interviews are applied in this section.

3.5. Data Source

The data sources are of two types. One is directly collected data and the other is data used collected by others listed as follows.

I. Primary sources: - The information about the rank of first to fifteenth tallest buildings in Addis Ababa, land owning prices data and detail study made on steel engineering companies can be categorized here.

II. Secondary sources: - The information's from literatures of minister offices, municipality, consulting offices, construction companies and the internet are secondary sources.

3.6. Data Collection

Demographic variables: - the demographic variables related to the research work are listed as follows.

Education and experience: - Participants of the research questionnaire are civil engineers working in construction firms with experience of participating in high rise building construction, structural engineers working in consulting firms with experience of participating in designing of at least one high rise building, Graduating class students of AAIT under graduates.

Building related variables: - High rise buildings with range of 15 stories including basement floors

Organizational variables: -

Governmental: - Ministry of works and urban development, Ministry of mines, Ministry of industry, Addis Ababa city administration

Nongovernmental: - Construction companies, Consulting companies, steel engineering companies, high rise building owners, Banks and Insurance companies.

Web sites/Internet: - Research papers having same nature, international steel market, and international composite system manufacturers.

Others: - traditional brokers working between land owners and buyer

3.7. Limitations in Proper Data Sampling and Data Collection

During the data collection process, the following challenges affected the proper sampling of the research work.

- Questionnaires have not been returned by some attendants.
- Most construction and consulting companies are either busy or negligent to return the questionnaires back filled.

- Most grade one construction companies are owned by architects and they usually sublet the structural design part to other individual structural engineers or firms and they don't have enough access to the structural details. Trying to communicate with the subcontractors becomes breath taking.
- Even though the information desk of governmental offices is found highly organized and open to users, most of the data readily available are not to the required depth and it was demanding to go door to door to the sources of data.
- Private importers and suppliers of steel sections are limited in number being not enough for proper sampling. The section properties of the materials are also not as per any of the internationally accepted standards like the UK, EU, US, Indian and the like. The pricing is also not following any trend. When compared to the international market, it has high inflation for no logical breakdown. It seems only related to scarcity. So the national market price is totally rejected from this research work but included in appendix just as documentation.
- Since there has never been a composite production company in the country, the pricing of the designed composite building parts consider indirect method of pricing.
- As the designing of the composite building is assisted by 2015 graduating class students of AAIT, It was not efficiently designed on connections and methods of minimizing weight of steel sections was not adopted in the following manner.
    - Dry rolled sections are not considered
    - Due to time constraint, sizes of column sections were clustered to three and four floors by considering the maximum.
    - Cost breakdowns were also clustered to three and four floors by considering the maximum
    - Due to the base architectural design framing restrictions, it was not possible to use freedom of spanning to the optimum extent.
    - It was possible to use pile foundation to minimize cost of earthwork and heavy raft foundations as a result of heavily loaded columns and so the cost comparison does not show the extent possible.

    - Cost estimation base prices collected from the available breakdown practiced for the conventional RC process. In doing so the benefit of industrialization is not sufficiently considered.

IV. ANALYSIS AND DISCUSSION

4.1 General Characteristics of the Designed Building in RC and SCC Framing Systems

The sample building is a multipurpose building designed by MGM consults for one of its undisclosed client. It has 2B+G+4. Since the time span for conducting this research work is not convenient to design multiple buildings with different stories, it is tried to correlate trend analysis of the reviewed literatures from India, Bangladesh and England showing 15 storied building is the reference point where steel-concrete composite framing wins clear economical advantage over the reinforced concrete system. The original architectural design upgraded to 2B+G+12 so that the total number of stories will be 15.

It is also assumed to use input data for structural design to be closer to that of referred studies in the above three countries so that correlation between them gives a perfect sense.

4.1.1. Analysis Based on Structural Properties

A typical mixed use building has been chosen for the feasibility study of steel concrete composite design in Addis Ababa. The typical floor plan of the building is shown in Fig.19 below. The design and analysis of the structure is conducted in single G+12 building in both SCC and RC systems. The finite element software "ETABS" is used to carry out the structural analysis of both RC and SCC.

The design of the reinforced concrete building performed using Ethiopian code EBCS-1 and EBCS-2 1995. For the design of SCC building, a one way beam supported slab is selected as a gravity load resisting system whereas the beam-column frame combined with RC shear wall is used as lateral load resisting system.

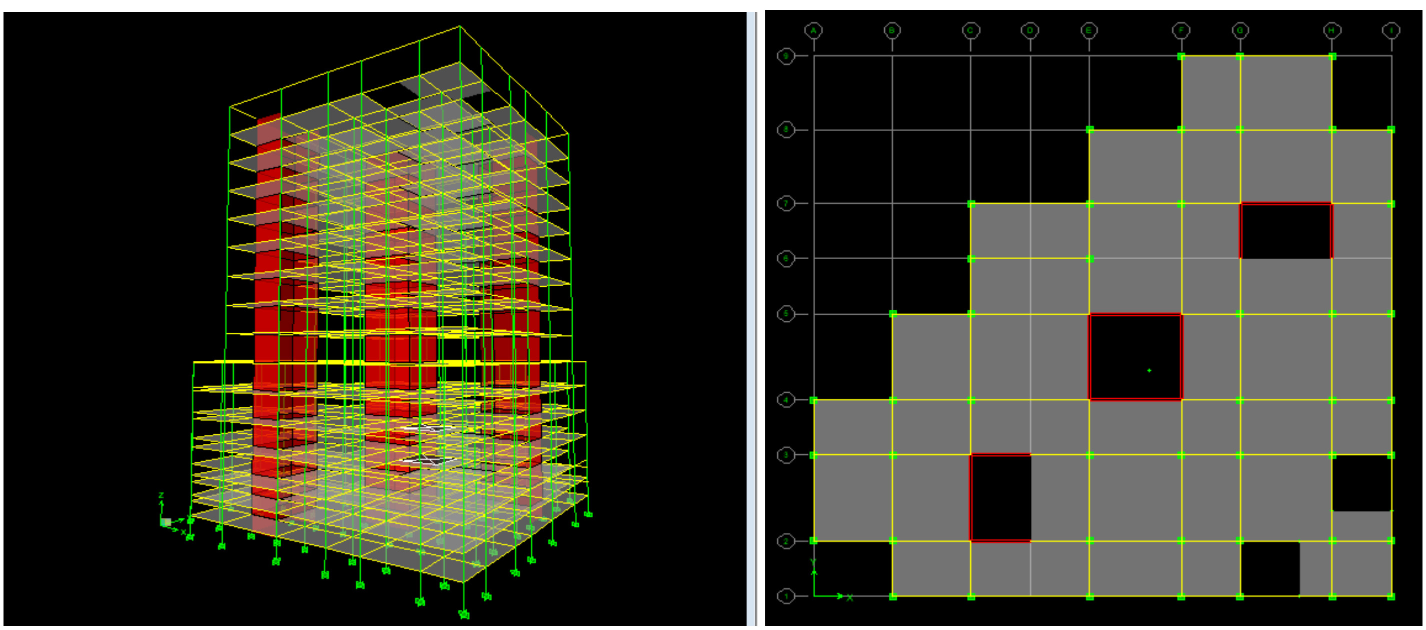


Figure 18 *Floor plan and 3D of the designed building*

The following are design data used for the designing of SCC and RC structure.

No	Data name	SCC	RC
1	Plan dimension	44m x 44m = 1936m2	
2	Total building height	57.82 m	
3	Height of each story		
	3.1. Base of Footing pad to B2	2.5 m	
	3.2. B2	2.7 m	
	3.3. B1	2.7 m	
	3.4. G+0 to G+12	3.84 m	
4	Beams (Composite)	main beams	Secondary beams
	B1	HE 140M	HE 260A
	B2	HE 180M	HE 180M
	B3	HE200M	HE 140M
	B4	HE 340B	HE 140M
	B5	HE 340B	HE 120 AA
	B6	HE 400B	
	B7	HE 360M	
	B8	HE 400M	
5	Columns (Composite)		
	C1	206 X 204 UC 52	
	C2	HD 260 X 68.2	
	C3	HD 260 X 172	
	C4	HD 325 X 245	
	C5	HD 400 X 318	
	C6	HD 400 X 463	
6	Slab thickness	140 mm (SCC)	230 mm (RC)
7	Seismic Zone	II	
8	Wind speed	22m/s	
9	Soil condition	Medium soil	
10	Importance factor	1	
11	Zone factor	0.1	
12	Floor finish	1KN/m2	
13	Wall thickness	20mm	
14	Live load		
	B1 to G+3	5KN/M2	
	G+4 to G+12	3KN/M2	
15	Reinforcing steel grade	S-300	
16	Density of concrete	25KN/M3	
17	Density of wall	14KN/M3	
18	Damping ratio	5%	

Table 4 *Design input data for structural analysis of both SCC and RC buildings*

Based on the structural data found from analysis and design of the typical building, the following comparison made.

I. Drift of the total building structure

From the total number of load combinations, the ones with the maximum lateral force in X and Y coordinates selected and the resultant considered for comparison. The load combinations are CEQX2 of the X direction and CNEQY1 for the Y direction. The table below shows resultant values calculated using Pythagoras formula.

Floor Level	RC drift resultant in mm	SCC drift resultant in mm
12th	0.000924968	0.030413279
11th	0.000950606	0.030831901
10th	0.000971959	0.031176263
9th	0.000990013	0.031464466
8th	0.001001639	0.031648675
7th	0.001000118	0.03162465
6th	0.000983493	0.031360688
5th	0.000945669	0.030751733
4th	0.000879054	0.029648845
3rd	0.000796244	0.028217801
2nd	0.000688654	0.026242227
1st	0.000554838	0.023554996
Ground	0.00041264	0.020313549
1st Basement	0.000302063	0.017379957
2nd Basement	0.000174003	0.013191015

Table 5 *Deflection in RC and SCC buildings design*

The data found from ETABS copied on to EXCEL sheet for graphing and Fig. 20 below shows that there is a big difference in drift between the two building systems but within the allowable limit. This shows that SCC system of framing is capable of resisting bigger amount of drift force.

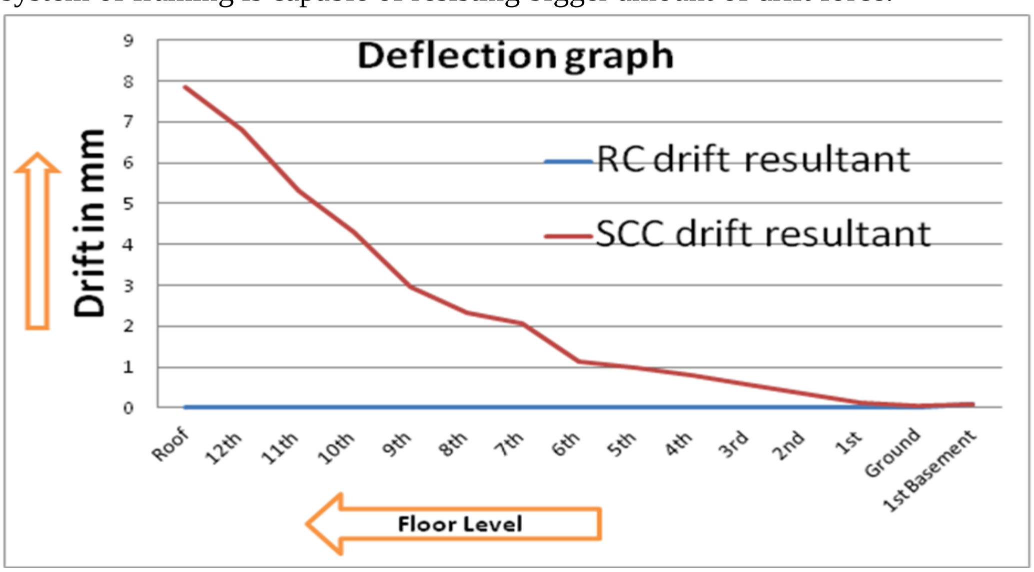


Figure 19 *Deflection of SCC and RC building*

Considering the drift amount is extremely lower in both designs than the referred documents, it is doubtful that there is excessive use of lateral load resisting shear walls during designing.

II. Total shear force comparison

The total base shear as shown by Fig. 21 below shows that comparatively higher base shear force registered on the reinforced concrete building. The graph showed a double sloped trend line due to the fact that the built up area decreases at 4th floor.

Floor Level	**Total Shear Force. in KN**	
	RC (KN)	Composite (KN)
Roof	2265	2559
12th	12871	7526
11th	24178	12734
10th	35107	17988
9th	46066	23266
8th	57072	28583
7th	68137	33948
6th	79273	39369
5th	90493	44805
4th	108218	52216
3rd	129203	65082
2nd	150323	78001
1st	171602	91045
Ground	192662	103651
1st Basement	214238	116136
2nd Basement	217075	118876

Table 6 *Total Shear Force of SCC and RC building*

The capacity of shear resistance in the SCC building is twice that of the RC building even with smaller cross sectioned structural members.

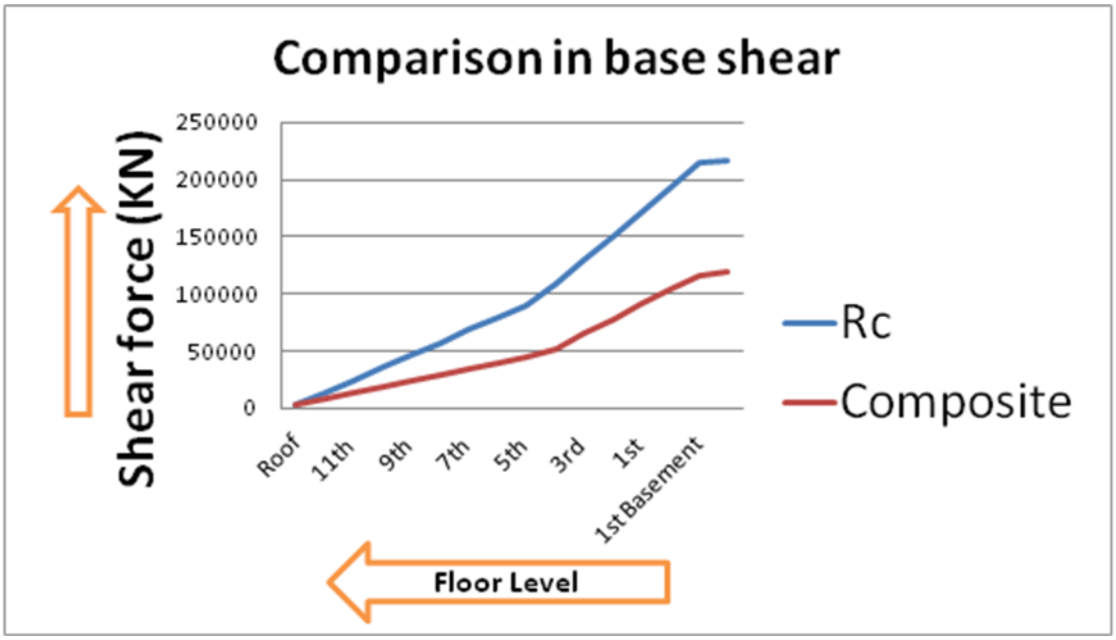


Figure 20 *Graph showing trend of total Shear Force of SCC and RC*

III. Total axial force in columns

The total axial load had been selected based on selecting a combination that gives the maximum loading in ultimate limit state.

Floor Level	**RC column 33 (ULS)KN**	**Composite col. 1 (ULS)KN**
Roof	2265	2559
12th	12871	7526
11th	24178	12734
10th	35107	17988
9th	46066	23266
8th	57072	28583
7th	68137	33948
6th	79273	39369
5th	90493	44805
4th	108218	52216
3rd	129203	65082
2nd	150323	78001
1st	171602	91045
Ground	192662	103651
1st Basement	214238	116136
2nd Basement	217075	118876

Table 7. *Total axial load*

In same way as that of the base shear comparison, the RC carries almost twice that of the SCC building. This shows that due to high decrease in total weight of the building, even with decreased number of columns and cross sectional area, the critical column carries half of that of the RC critical column on the same position.

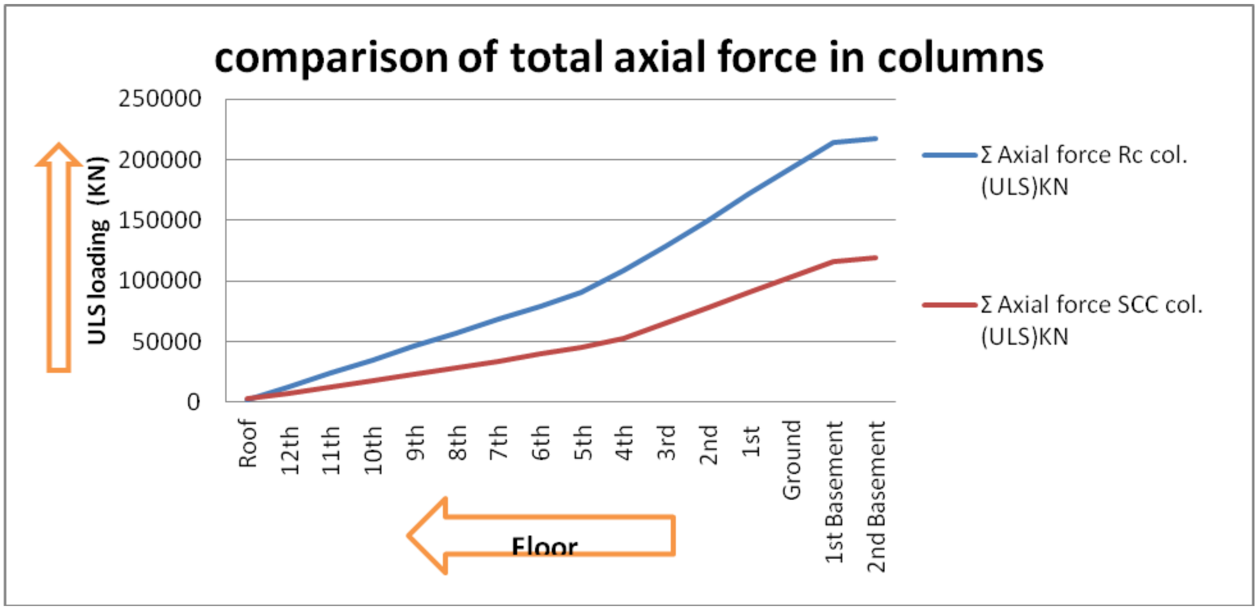
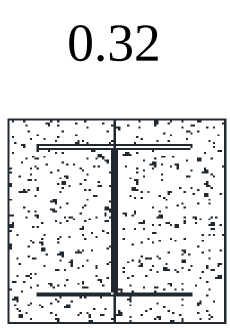
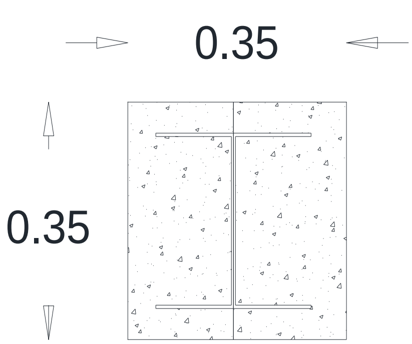


Figure 21. *Graph showing trend of axial load on critical columns of SCC and RC*

The following two tables 11B and 11C included to show the designed cross sectional area of SCC columns to be able to illustrate the distribution of column types of the SCC building and their cross sectional area over the length of the columns.

<table>
<tr><th colspan="6">SCC COLUMNS</th></tr>
<tr><th rowspan="2">Column Type</th><th rowspan="2">Shape (dim. In m)</th><th rowspan="2" colspan="2">Dimensions (mm)</th><th colspan="2">Location</th></tr>
<tr><th>Area on the floor</th><th>Floor Level</th></tr>
<tr><td rowspan="8">C1</td><td rowspan="8"></td><td>EU Section Designation</td><td>HD260x54.1</td><td rowspan="8">Short building at wings GF-3rd

long building 10th12th</td><td rowspan="8">Column type 5

Column type 3</td></tr>
<tr><td>h (steel)</td><td>260</td></tr>
<tr><td>b (steel)</td><td>244</td></tr>
<tr><td>H (conc.)</td><td>320</td></tr>
<tr><td>B (conc.)</td><td>320</td></tr>
<tr><td>tw (steel)</td><td>6.5</td></tr>
<tr><td>tf (steel)</td><td>9.5</td></tr>
<tr><td>d (steel)</td><td>177</td></tr>
<tr><td rowspan="8">C2</td><td rowspan="8"></td><td>EU Section Designation</td><td>HD260x68.2</td><td rowspan="8">Short building at wings B2-B1 GF-3rd

long building 8th-12th 5th-9th</td><td rowspan="8">Column type 4 5

Column type 2 3</td></tr>
<tr><td>h (steel)</td><td>250</td></tr>
<tr><td>b (steel)</td><td>260</td></tr>
<tr><td>H (conc.)</td><td>352</td></tr>
<tr><td>B (conc.)</td><td>352</td></tr>
<tr><td>tw (steel)</td><td>6.5</td></tr>
<tr><td>tf (steel)</td><td>9.5</td></tr>
<tr><td>d (steel)</td><td>177</td></tr>
</table>

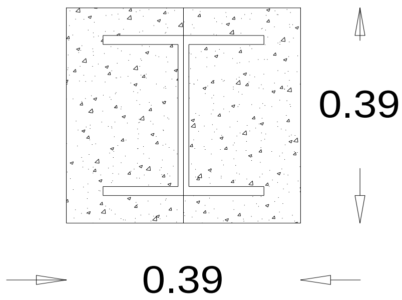
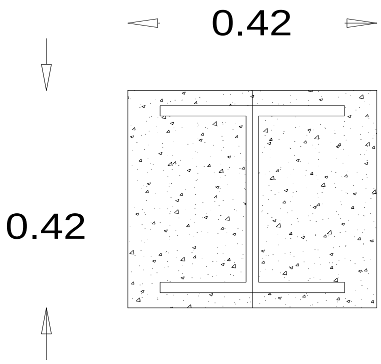
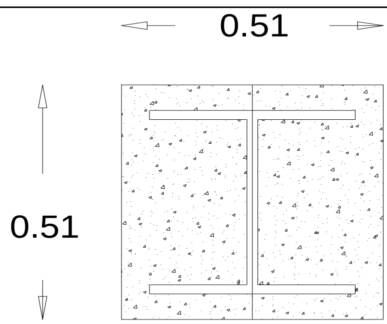
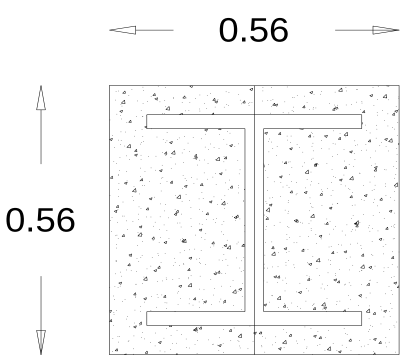
C3		EU Section Designation h (steel) b (steel) H (conc.) B (conc.) tw (steel) tf (steel) d (steel)	HD260x172 290 268 390 390 18 32.5 177	Short building at wings B2-B1 long building 7th-12th GF-7th GF-4th	Column type 5 Column type 1 2 3
C4		EU Section Designation h (steel) b (steel) H (conc.) B (conc.) tw (steel) tf (steel) d (steel)	HD320x245 359 309 417 417 21 40 225	Inner core long building 4th-6th B2-B1	Column type 1 Column type 2,3
C5		EU Section Designation h (steel) b (steel) H (conc.) B (conc.) tw (steel) tf (steel) d (steel)	HD400x318 399 401 510 510 24.9 39.6 289.8	Inner core long building 1st -3rd Floors	Column type 1
C6		EU Section Designation h (steel) b (steel) H (conc.) B (conc.) tw (steel) tf (steel) d (steel)	HD400x463 435 412 555 555 35.8 57.4 290.2	Inner core long building B2-GF	Column type 1

Table 8. *Column cross sections c1-c6 of SCC*

COLUMN CROSS SECTION FOR EACH TYPE OF COLUMN AT EACH FLOOR

FLOOR	COL TYPE 1	COL TYPE 2	COL TYPE 3	COL TYPE 3	COL TYPE 3
12 TH	3	2	1		
11 TH	3	2	1		
10 TH	3	2	1		
9 TH	3	2	2		
8 TH	3	2	2		
7 TH	3	3	2		
6 TH	4	3	2		
5 TH	4	3	2		
4 TH	4	3	3		
3 RD	5	3	3	1	2
2 ND	5	3	3	1	2
1 ST	5	3	3	1	2
GROUND	6	3	3	1	2
1ST BASEMENT	6	4	4	2	3
2ND BASEMENT	6	4	4	2	3

TABLE 9. *COMBINATIONS OF COLUMN CROSS SECTIONS ON EACH FLOOR.*

Considering the structural floor plans attached at Appendix 3 and Table 11D below, one can understand the linear comparison made between RC and SCC structural columns with regard to their load carrying capacity.
Based on the very assumption that once the design loads of the building uniformly distributed on to the area of the floor slabs, there will be a direct proportion between floor area and number of columns.
The floor area to number of columns ratio of the two buildings show that SCC column carries almost twice axial load as that of RC column where it is required to have one RC column for every 24.5m2 floor area while the SCC column can be assumed for up to 41.3m2 floor area or 168% of that of the RC building. Such a huge increment on load carrying capacity of the SCC column is achieved while summation of cross sectional area of the SCC columns per floor is 1.76m2 or only 13.27% of that of RC columns as it is shown in Table Appendix 3.

Floor Category	Floor Area	RC Building		SCC Building		% load carrying capacity of SCC w.r.t. RC
		No. of columns	Floor area to columns ratio	No. of columns	Floor area to columns ratio	
B2-4th Floor	1438	58	**24.79**	36	**39.94**	**161.11**
5th-12th Floor	1024	42	**24.38**	24	**42.67**	**175.00**
Top tie beam	1024	25	**40.96**	18	**56.89**	**138.89**

TABLE 10. *RELATIVE LOAD CARRYING CAPACITY OF SCC COLUMNS*

IV. Maximum moment carrying beams

To compare the moment carrying capacity of the RC and SCC buildings is not an easy task due to the fact that the composite slab designed as one way slab and non continuous since the structural connection pattern demands so. When comes to the RC building, all one way vs. two way slabs and continuous vs. discontinued beams are available and so the moment pattern is irrelevant.

Floor Level	ULS (KN-M)	ULS (KN-M)
	M Max. RC beam	M Max. SCC beam
12th	19.489	-1401
11th	19.376	-1395
10th	19.264	-1395
9th	19.154	-1395
8th	19.029	-1394
7th	18.859	-1393
6th	18.726	-1393
5th	18.297	-1390
4th	18.973	-1364
3rd	18.421	-1747
2nd	17.942	-1707
1st	17.467	-1699
Ground	17.146	-1708
1^{st} Basement	16.752	-1693

Table 11. *Maximum moment in beams of SCC and RC*

Since almost all moment in beams is a function of slab loads and slab loading of B2 to G+4 (shops) and G+5 to G+12 (offices) have same loading combination, the graphs show almost horizontal line.

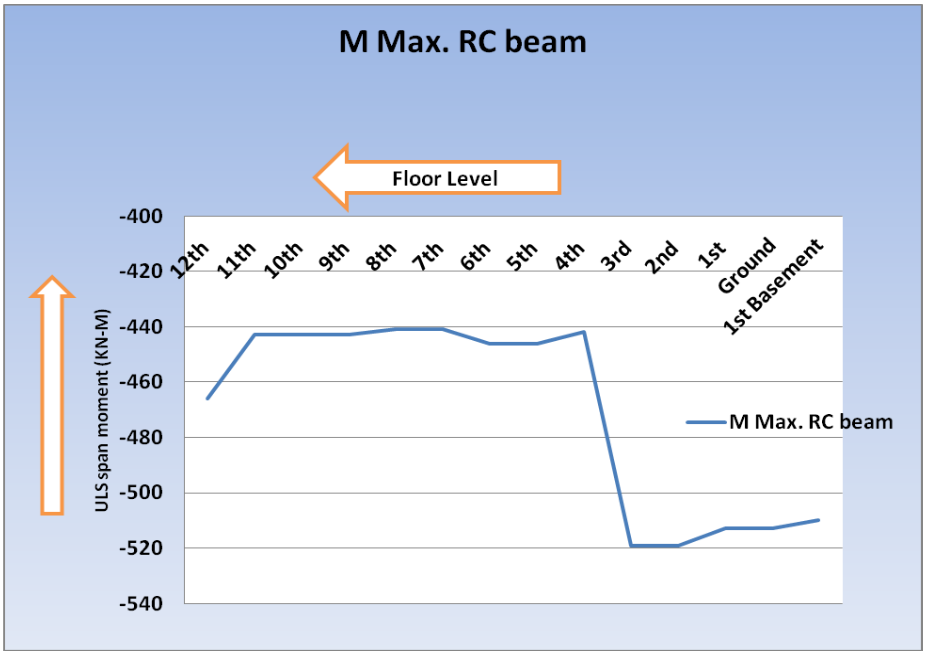


Figure 22. *Maximum moment graph of RC building*

The reason why moment diagram of RC beam shown separately is that due to scaling, the moment curve of RC building on the joint graph doesn't show realistic shape.

When the moment carrying capacity comparison made, the moment carrying capacity of the SCC building is by far better than RC building. It has about 1500KN-M extra moment carrying capacity for a relatively smaller beam depth.

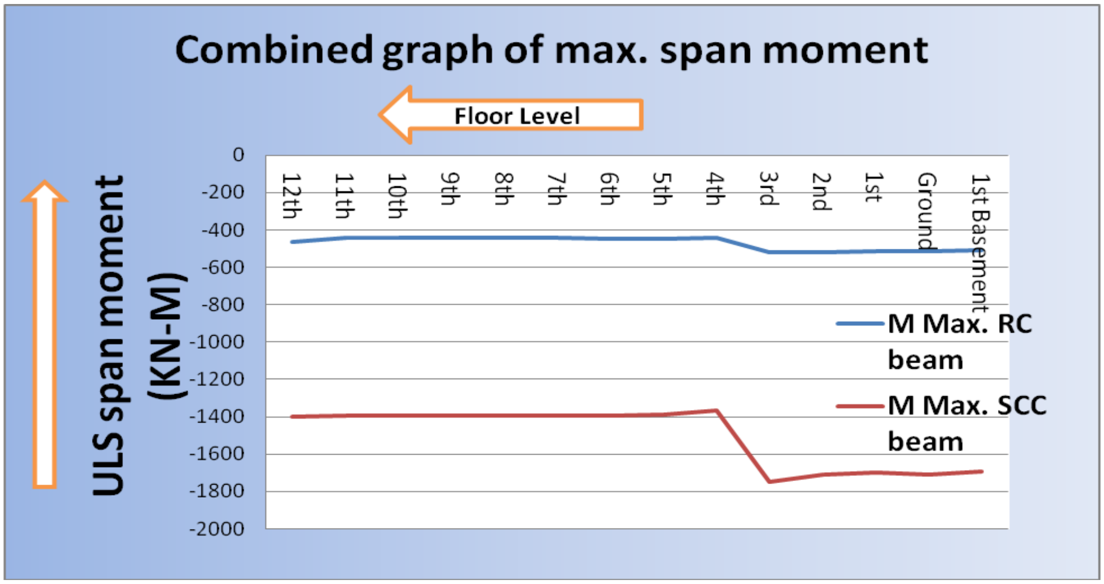
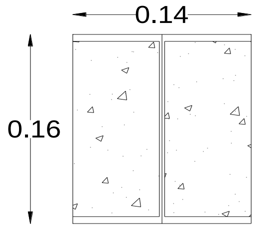
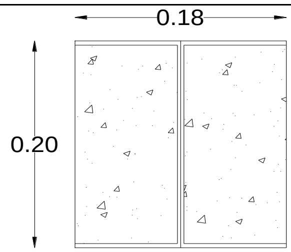
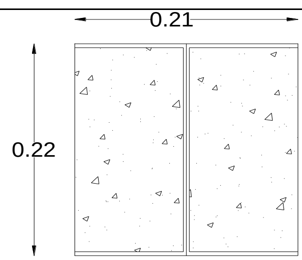
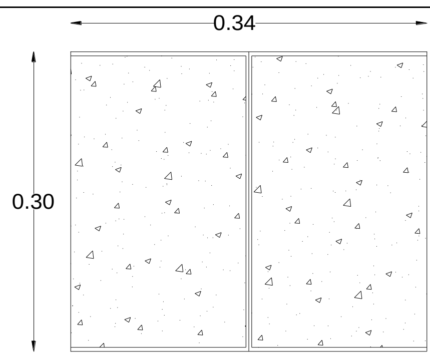


FIGURE 23. *MAXIMUM MOMENT COMPARISON GRAPH FOR SCC AND RC*

<table>
<tr><th colspan="5">SCC MAIN BEAMS</th></tr>
<tr><th rowspan="2">Beam Type</th><th rowspan="2">Shape (dim. In m)</th><th rowspan="2">Dimensions (mm)</th><th colspan="2">Location</th></tr>
<tr><th>Span (m)</th><th>Floor Level</th></tr>
<tr><td>B1</td><td>
</td><td>EU Section Designation: HE 140 M
h: 160
b: 146
tw: 13
tf: 22
d: 92</td><td>4.5m</td><td>5th-12th Floor</td></tr>
<tr><td>B2</td><td>
</td><td>EU Section Designation: HE 180M
h: 200
b: 186
tw: 14.5
tf: 24
d: 122</td><td>4.5m</td><td>B1-4th Floor</td></tr>
<tr><td>B3</td><td>
</td><td>EU Section Designation: HE 200M
h: 220
b: 206
tw: 15
tf: 25
d: 134</td><td>6m</td><td>5th-12th Floor</td></tr>
<tr><td>B4 & B5</td><td>
</td><td>EU Section Designation: HE 340 B
h: 340
b: 300
tw: 12
tf: 21.5
d: 243</td><td>6m

7m</td><td>B1-4th Floor

5th-12th Floor</td></tr>
</table>

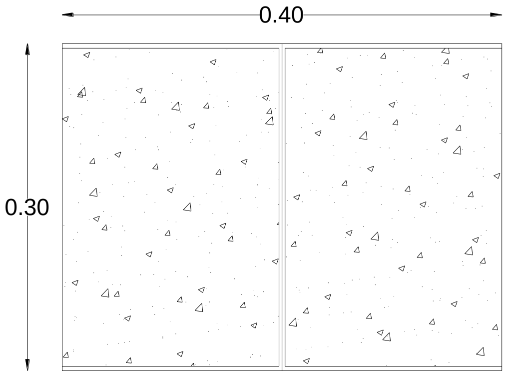
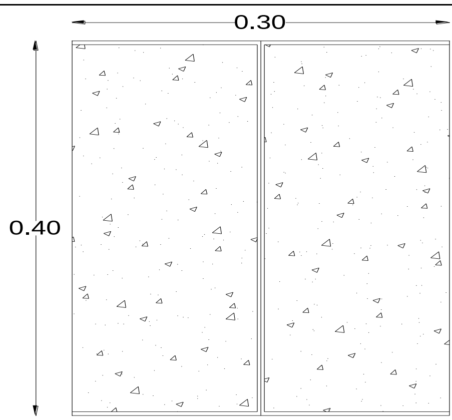
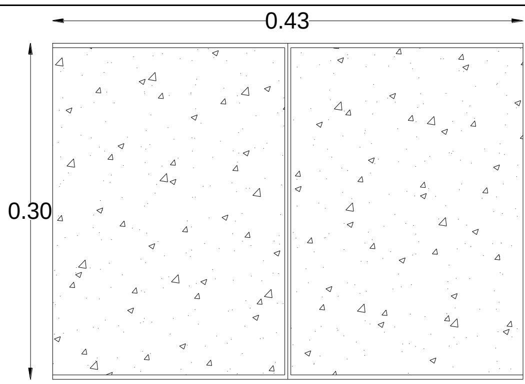
B6		EU Section Designation: HE 400 B h: 400 b: 300 tw: 13.5 tf: 24 d: 298	9m 7m	5^{th}-12^{th} Floor B1-4^{th} Floor
B7		EU Section Designation: HE 360M h: 395 b: 308 tw: 21 tf: 40 d: 261	11m	B1-4^{th} Floor
B8		EU Section Designation: HE 400M h: 432 b: 307 tw: 21 tf: 40 d: 298	11m 9m	5^{th}-12^{th} Floor B1-4^{th} Floor

TABLE 12. *MAIN BEAM CROSS SECTIONS B1-B8 OF SCC.*

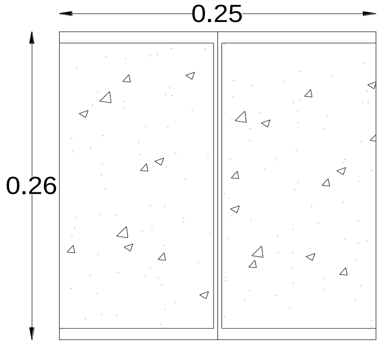
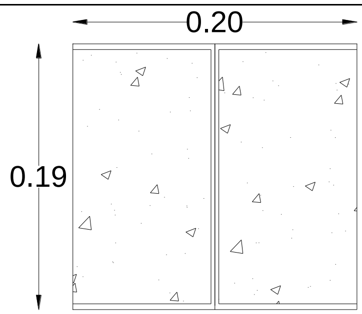
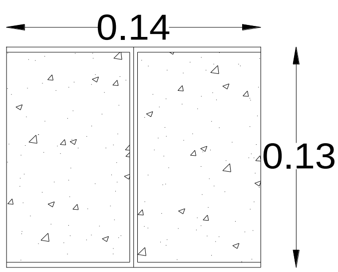
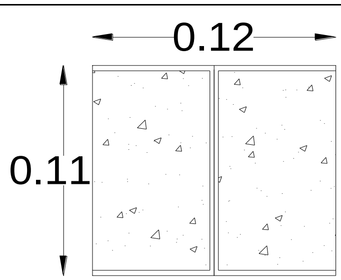
SCC SECONDARY BEAMS				
Beam Type	**Shape (dim. In m)**	**Dimensions (mm)**	**Location**	
			Span (m)	**Floor Level**
A		EU Section Designation: HE 260 A h: 260 b: 250 tw: 7.5 tf: 12 d: 177	11m	B1-12th Floor
B		EU Section Designation: HE 200AA h: 186 b: 200 tw: 5.5 tf: 8 d: 134	9m	B1-12th Floor
C & D		EU Section Designation: HE 140AA h: 128 b: 140 tw: 4.3 tf: 6 d: 92	7m & 6m	B1-12th Floor
E		EU Section Designation: HE 120AA h: 109 b: 120 tw: 4.2 tf: 5.5 d: 74	4.5m	B1-12th Floor

Table 13. *MAIN BEAM CROSS SECTIONS A-E OF SCC.*

The maximum depth of beam in RC building is the 900mm for 9m span while it is 550mm for 11.5m span in RCC building.

The design failed to show the maximum span length possible to achieve in RCC because of the limitation of the architectural design. As the literatures shows it was possible to extend spans up to 15 to 20 meters. But the decrease in span depth indirectly showed the efficiency of RCC structure to shorten the building height by 7.94 meters or it is also possible to increase floor to ceiling clear height by 530mm on each floor.
The following table shows the types of beam spanning on both buildings and how frequent they are used in order to show their spanning capability.

Span length	RC Building		SCC BUILDING	
	Av. Tot. Span of B1-4th F & 5th-12th F	% span use/Floor	Av. Tot. Span of B1-4th F & 5th-12th F	% span use/Floor
4.5	157.50	**38.32**	40.50	15.20
6	48.00	11.68	24.00	9.01
7	147.00	35.77	10.50	3.94
9	58.50	14.23	54.00	20.26
11	0.00	0.00	137.50	**51.59**
Beams length/ Floor (M)	**411**		**266.50**	

Table 14. *COMPARISON ON SPAN RESTRICTION BETWEEN RC AND SCC BEAMS***.**

Summation of the total length of beams per floor on table 12D above shows that SCC building uses fewer but longer beams which are only 65% of the beam length in RC building mainly because of the fact that more than half of the beams in SCC are 11m while nearly 50% of the beams in RC building spanning equal or less than 6m.

4.1.2. Analysis based on cost of structural framing

I. Cost per item of work

Among the items of work brought for comparison, (excavation and earth work, concrete work, formwork, reinforcement bar, structural steel and steel sheet profiled decking) only the first four are available in the RC structure. The shear wall quantity is omitted from this comparison since it is almost equal in both.

No	Name of building element	Composite building	RC building	Difference in birr	Difference in %
1	excavation and earth work	3,660,084.11	2,969,661.92	690,422.19	23.25
2	Concrete work	18,617,940.51	30,893,764.83	(12,275,824.32)	(39.74)
3	formwork	4,770,453.14	7,992,095.96	(3,221,642.82)	(40.31)
4	re-bar	6,251,164.38	29,330,935.69	(23,079,771.31)	(78.69)

5	structural steel	37,616,839.27	0	37,616,839.27	100
6	decking	4,468,551.41	0	4,468,551.41	100
	Total building cost	75,385,032.83	71,186,458.40	4,198,574.42	5.90

Table 15 *Total cost of SCC and RC based on items of work*

The figures in the table above are included aiming to show comparison of SCC and RC buildings with regard to the common material items. Except in the case of foundation excavation work, RCC building showed higher deduction of concrete, formwork and reinforcement bar quantities which are almost compensated by the structural steel and decking. But on the overall, the RC building is less costly by 5.9%.

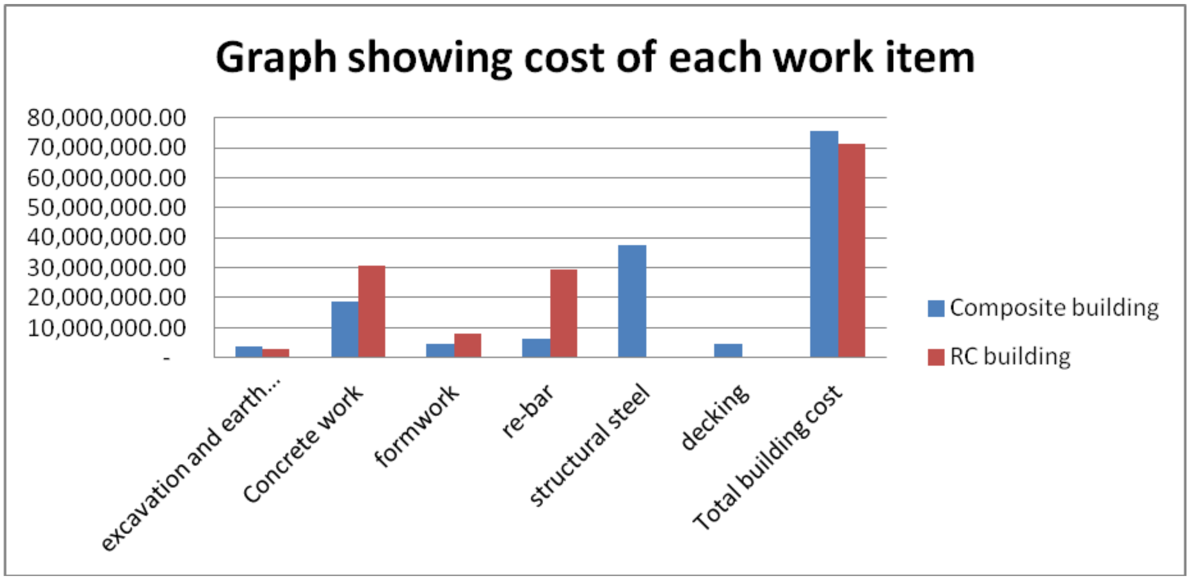


Figure 24 *Graph showing comparison of total cost of SCC and RC buildings based on items of work*

In order to see the cost trend, it is therefore found necessarry to compare the two systems based on cost per floor analysis.

II. Cost per floor floor level

No	Floor Level	Composite building	RC building	Difference In birr	Difference in %
1	Foundation	7,189,595.54	4,516,391.01	2,673,204.53	59.19
2	B2	1,966,200.54	1,528,965.19	437,235.35	28.60
3	B1	5,267,625.30	3,550,049.31	1,717,575.99	48.38
4	Ground F.	5,465,279.93	3,580,895.69	1,884,384.24	52.62
5	1st Floor	4,628,495.89	4,202,515.57		10.14

				425,980.31	
6	2nd Floor	4,628,495.89	4,579,718.44	48,777.44	1.07
7	3rd Floor	4,775,102.90	5,086,776.78	(311,673.88)	(6.13)
8	4th Floor	4,598,799.88	5,086,776.78	(487,976.89)	(9.59)
9	5th Floor	3,463,370.81	4,371,369.33	(907,998.52)	(20.77)
10	6th Floor	3,560,088.55	4,690,104.07	(1,130,015.53)	(24.09)
11	7th Floor	3,518,849.59	3,894,075.26	(375,225.67)	(9.64)
12	8th Floor	3,515,029.24	4,122,660.73	(607,631.49)	(14.74)
13	9th Floor	3,515,029.24	4,122,660.73	(607,631.49)	(14.74)
14	10th Floor	3,571,059.24	4,428,735.07	(857,675.83)	(19.37)
15	11th Floor	3,571,059.24	4,054,299.03	(483,239.79)	(11.92)
16	12th Floor	3,460,054.71	3,907,569.59	(447,514.87)	(11.45)
	Total	66,694,136.46	65,723,562.56	970,573.91	1.48

Table 16 *Total cost of SCC and RC buildings based on floor levels*

Based on the two graphs below showing individual cost per floor representation and trend of cost floor to floor, it becomes clear where the RC building gets the advantage to be less costly.

The columns of the composite building are small in number and so are heavily loaded. Due to that, the excavation depth and depth of the footing pad needed to be extremely deeper for punching shear requirements. Had the foundation been designed as piled instead of raft, it would have been lesser cost of RCC observed due to decreased building weight.

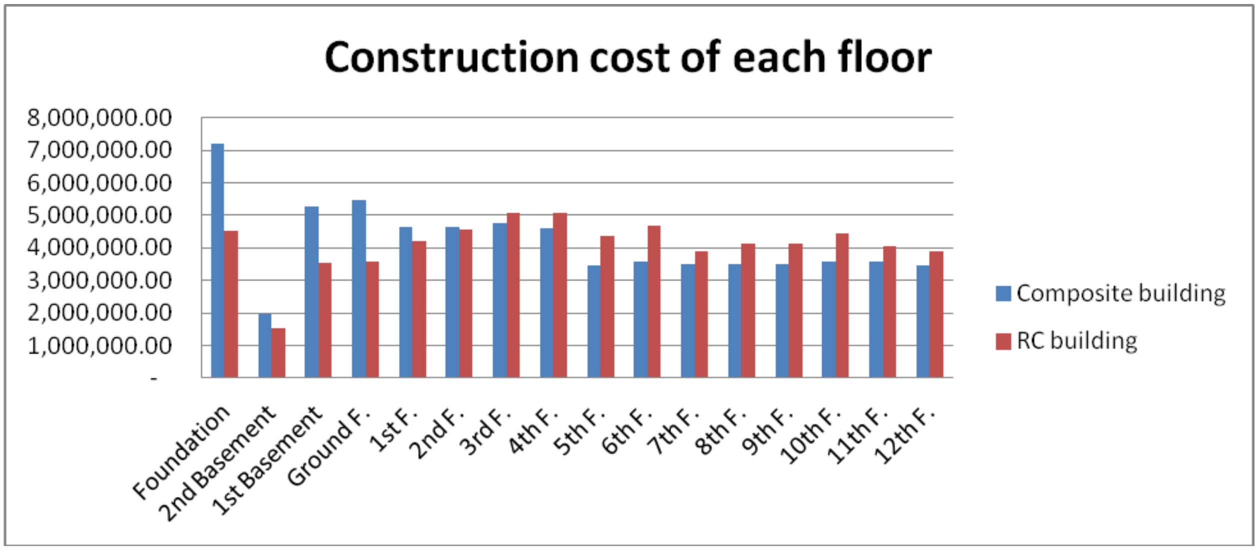


Figure 25 *Graph showing cost per floor level of SCC and RC buildings*

However, The graph in Fig 26 showed the fact that Starting from the fourth floor the SCC building cost per floor started to be lower than that of RC building. So here we need to extrapolate the figures to higher than G+12 to see where the 5.9% advantage of RC building compensated.

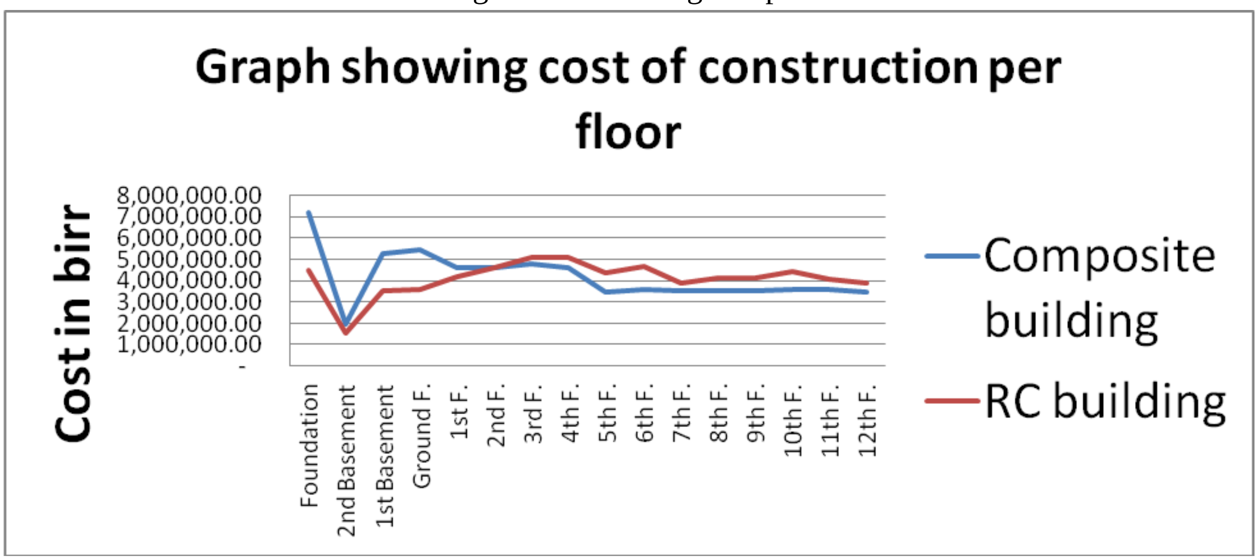


Figure 26. *Graph showing trend of cost per floor of SCC and RC buildings*

17	13th Floor	3,349,050.18	3,760,840.15	(411789.96)	(10.95)
18	14th Floor	3,238,045.65	3,614,110.71	(376065.05)	(10.41)
19	15th Floor	3,127,041.13	3,467,381.27	(340340.14)	(9.82)
	Total	69,821,177.59	69,190,943.82	630233.77	0.91

Keeping the percentage of cost deduction per floor to each building symmetrically and trying to include floors above, the cost analysis shows that the two buildings have almost equal cost of construction at G+13.

According to the litratures, RCC will have lesser cost at G+15 and what can be observed here is that at G+15, SCC cost will be lesser by 630,233.77 birr or 1% of RC building.

The other cost analysis important to see is based on comparison with regard to members of the structural framing as shown on the next section.

III. Total cost of the buildings per structural frame members

No	Structural member	Composite building	RC building	Difference in birr	Difference in %
1	Foundation	7,189,595.54	4,516,391.01	2,673,204.53	59.19
2	Column	9,893,987.18	10,561,723.52	(667,736.34)	(6.32)
3	Beam	33,344,697.85	25,306,925.88	8,037,771.98	31.76
4	Slab	14,846,013.78	25,848,322.82	(11,002,309.04)	(42.56)
5	Shear wall	8,377,137.55	5,319,704.85	3,057,432.70	57.47
	Total	73,651,431.91	71,553,068.08	2,098,363.83	2.93

Table 17 *Cost of structural members of SCC and RC buildings*

Each member of the structural framing has direct impact on the overall cost comparison. As discussed on the structural analysis section, Foundation cost and shear wall cost showed higher cost of RCC where the structural design is susceptible to be designed uneconomically.

On the other occasions, as proved by various researchers mentioned in the literature, composite beams seam universally expensive when designed with RCC system of structures and the opposite is true on columns.

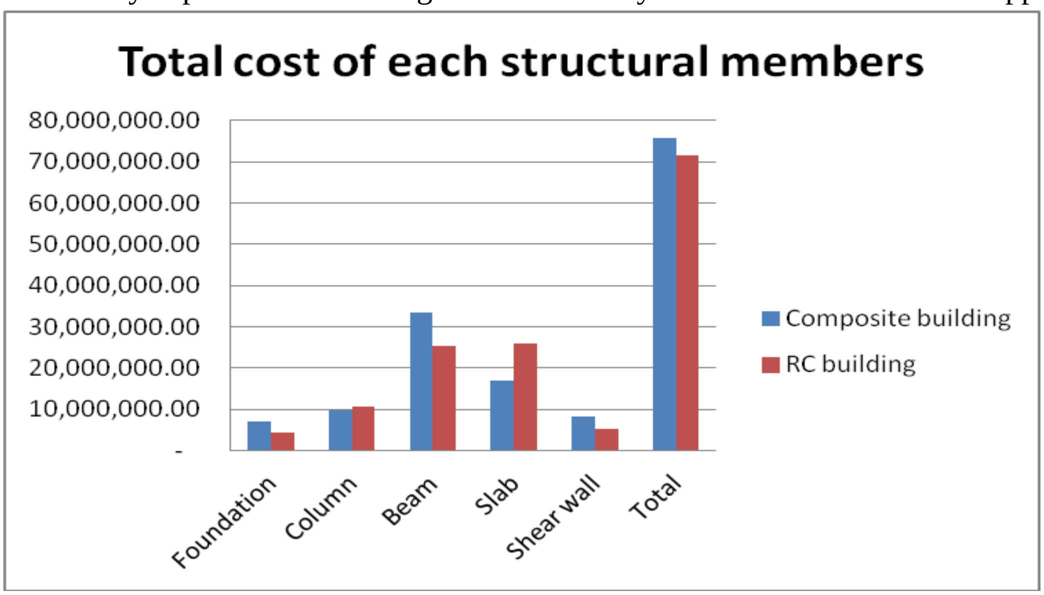


Figure 27. *Graph showing structural elements cost comparison*

Hence, detailed cost analysis is necessary on each structural member that will be discussed in the proceeding sections.

IV. Cost of Beams

No	Floor level	Composite Building	RC Building	Difference in birr	Difference in %
1	2nd basement beam	364,067.45	383,435.87	(19,368.41)	(5.05)
2	1st basement beam	2,723,373.11	1,539,452.15	1,183,920.96	76.91
3	Ground F. beam	2,723,373.11	1,539,452.15	1,183,920.96	76.91
4	1st Floor beam	2,745,754.60	1,696,921.27	1,048,833.33	61.81
5	2nd Floor beam	2,745,754.60	1,696,921.27	1,048,833.33	61.81
6	3rd Floor beam	2,769,414.69	1,865,020.77	904,393.92	48.49
7	4th Floor beam	2,769,414.69	1,865,020.77	904,393.92	48.49
8	5th Floor beam	1,966,330.78	1,651,865.57	314,465.21	19.04
9	6th Floor beam	2,017,582.47	1,721,629.98	295,952.49	17.19
10	7th Floor beam	2,017,582.47	1,721,629.98	295,952.49	17.19
11	8th Floor beam	2,029,104.80	1,840,665.49	188,439.31	10.24
12	9th Floor beam	2,029,104.80	1,840,665.49	188,439.31	10.24
13	10th Floor beam	2,043,275.81	1,933,684.70	109,591.11	5.67
14	11th Floor beam	2,043,275.81	1,933,684.70	109,591.11	5.67
15	12th Floor beam	2,043,275.81	1,933,684.70	109,591.11	5.67
	Total	33,030,685.04	25,163,734.88	7,866,950.16	31.26

Table 18. *Cost comparison of beams of SCC and RC building*

As it is clearly seen in the table above (Table 16), except on the occasion of second basement, SCC system of beam structures showed relatively higher cost than that of RC system of beams.

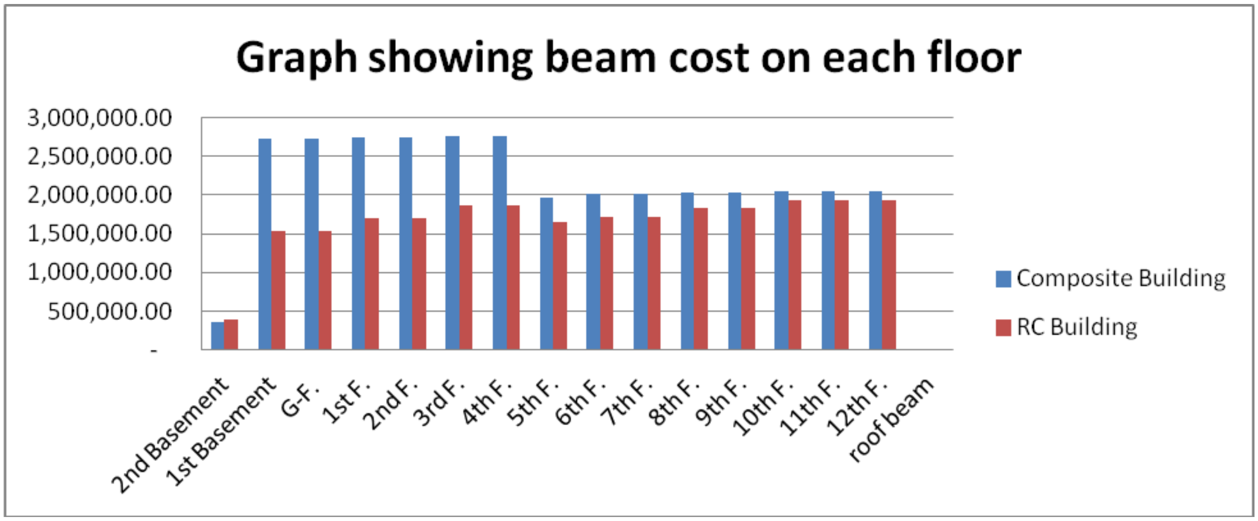


Figure 28. *Graph showing beam cost comparison of SCC and RC per floor*

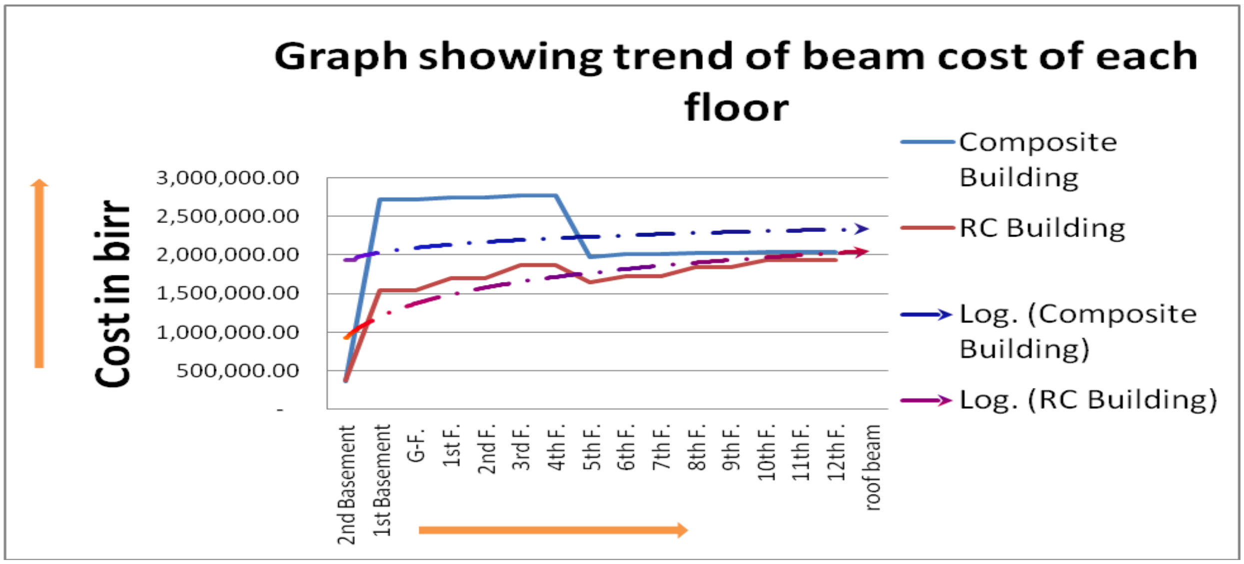


Figure 29. *Graph showing trend of beam cost of SCC and RC*

But, what can be observed from slope of the RCC curve on figure above (Fig. 29) is again similar sections used repeatedly on floors first basement to 4th and 5th to 12th floors. This is believed to be due to time constraint on the students participated on the design of the RCC building. It will also be helpful to consider the same logical error affected the structural analysis on section 4.1.1(IV).

With the above consideration in mind, it is possible to use interpolation for the exaggerated cost figures of beams from first basement to fourth floor. Following the trend of the other part of the graph, the actual cost exceeded by RCC will come down to 3,824,244 birr instead of 7,866,950.16 which is 15.2% instead of 31.26% shown on table 16 above.

This in other words will make the overall RCC building cost lower by the specified amount and in that case RCC might even become relativelly cheeper as of the 12th floor.

V. Cost of columns

No	Floor level	Composite building	RC Building	Difference in birr	Difference in %
1	footing column	249,040.29	366,609.67	(117,569.39)	(32.07)
2	2nd basement column	713,031.33	212,355.05	500,676.28	235.77
3	1st basement column	713,031.33	248,497.38	464,533.95	186.94
4	Ground F. column	910,685.96	279,343.76	631,342.20	226.01
5	1st Floor column	853,156.68	703,304.18	149,852.50	21.31
6	2nd Floor column	853,156.68	1,080,507.06	(227,350.37)	(21.04)
7	3rd Floor column	847,405.53	1,207,468.05	(360,062.53)	(29.82)
8	4th Floor column	671,102.51	1,207,468.05	(536,365.54)	(44.42)
9	5th Floor column	599,072.44	1,207,468.05	(608,395.61)	(50.39)
10	6th Floor column	624,306.64	1,349,690.94	(725,384.31)	(53.74)
11	7th Floor column	583,067.68	553,662.13	29,405.55	5.31
12	8th Floor column	468,707.81	565,755.02	(97,047.21)	(17.15)
13	9th Floor column	468,707.81	565,755.02	(97,047.21)	(17.15)
14	10th Floor column	483,591.00	636,480.22	(152,889.22)	(24.02)
15	11th Floor column	483,337.00	262,044.18	221,292.83	84.45
16	12th Floor column	372,586.47	115,314.74	257,271.73	223.10
	Total	9,893,987.18	10,561,723.52	(667,736.34)	(6.32)

Table 19 *Column cost comparison between SCC and RC buildings*

The comparison made with regard to cost of columns is also not perfectly stabilished. As one can see from the trend graph shown on fig. 30, it is clear that there is some unforseen mistake on quantity surveying or designing procedure of the columns between first basement to sixth floors.

The columns from first basement to the first floor looks under estimated while third to sixth floors seemed over estimated.

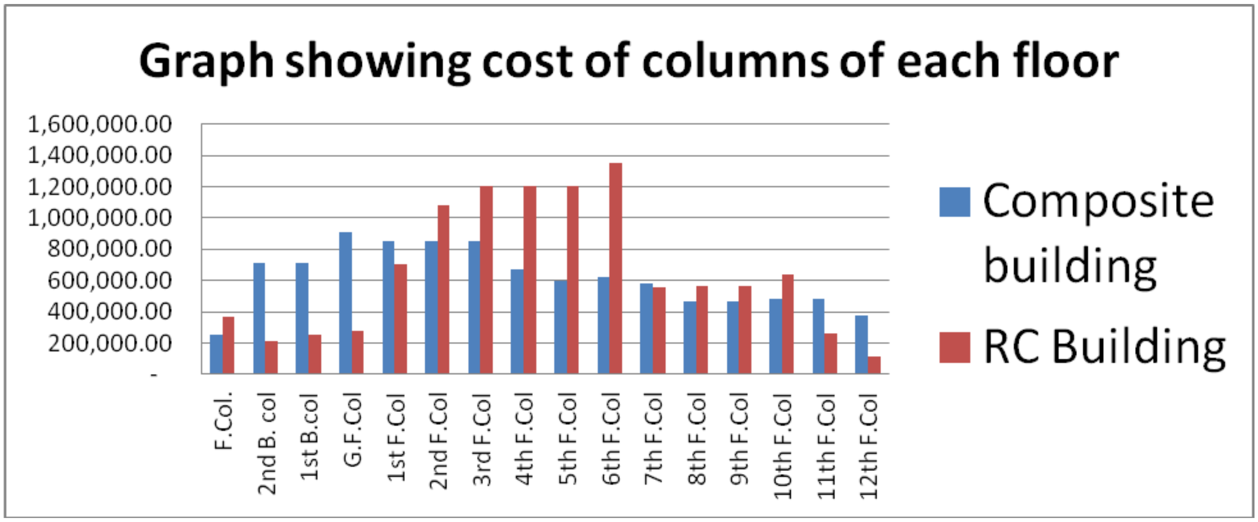


Figure 30. *Graph showing column cost comparison of each floor*

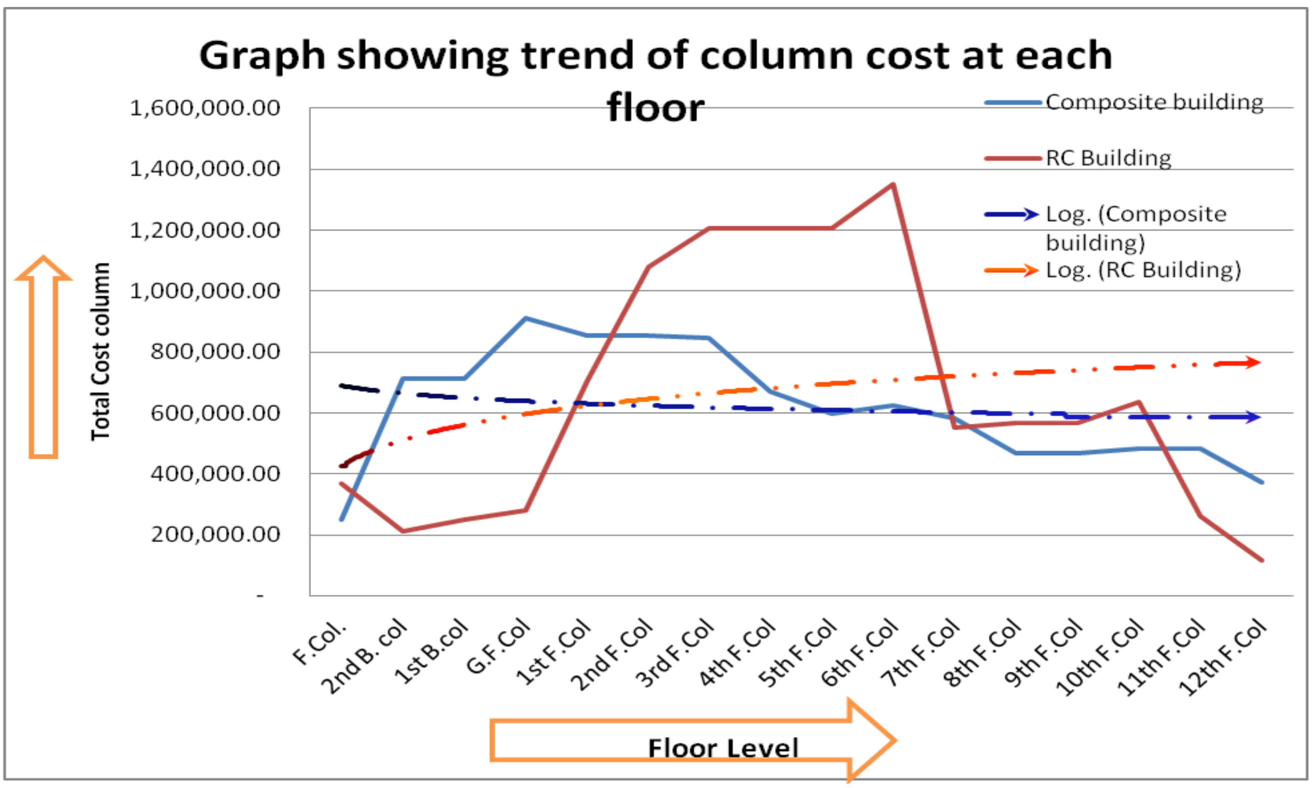


Figure 31. *Graph showing trend of column cost of SCC and RC buildings*

Appliying interpolated cost figures on these portions of the varried values showed the fact that there will not be significant change on the overall cost of columns where RCC is still less costly by 6.32%. However, it has significant effect on the overall building cost per floor urging points of ammendement on the design and analysis.

VI. Cost of flooring

A. Based on item of work

No	Work item	Composite building	RC building	Difference in birr	Difference in%
1	Concrete work	7,778,610.78	11,059,019.38	(3,280,408.60)	**(29.66)**
2	formwork	-	1,802,819.07	(1,802,819.07)	**(100.00)**
3	re-bar	2,598,851.59	12,986,484.38	(10,387,632.78)	**(79.99)**
4	structural steel	-	-	-	
5	decking	4,468,551.41	-	4,468,551.41	
	Total	**14,846,013.78**	**25,848,322.82**	**(11,002,309.04)**	**(42.56)**

Table 20. *Cost comparison of items of works in slab systems of SCC and RC buildings*

According to the values of costing per items of works involved on the flooring work, one can see the cost advantages of RCC highly based on the omittion of formwork and minimization of reinforcing steel bars. On all items except decking steel sheet, RCC system of slab work showed significant discount there by saving more than ten million birr.

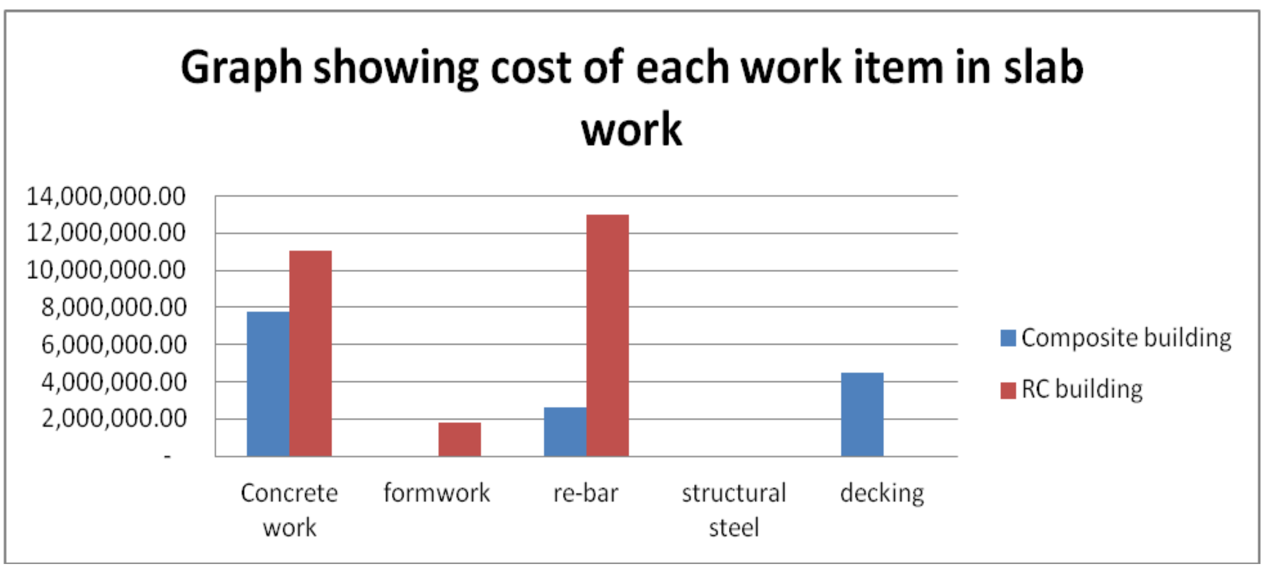


Figure 32. *Graph showing cost of items of work in the slab system*

B. Based on floor level

No	Floor Level	Composite Building	RC Building	Difference in birr	Difference in %
1	2nd basement slab	650,182.96	933,174.27	(282,991.31)	(0.30)
2	1st basement slab	959,359.65	1,762,099.78	(802,740.13)	(0.46)
3	Ground F. slab	959,359.65	1,762,099.78	(802,740.13)	(0.46)
4	1st Floor slab	1,029,584.60	1,802,290.12	(772,705.52)	(0.43)
5	2nd Floor slab	1,029,584.60	1,802,290.12	(772,705.52)	(0.43)
6	3rd Floor slab	1,158,282.67	2,014,287.95	(856,005.28)	(0.42)
7	4th Floor slab	1,158,282.67	2,014,287.95	(856,005.28)	(0.42)
8	5th Floor slab	897,967.58	1,512,035.70	(614,068.12)	(0.41)
9	6th Floor slab	918,199.44	1,618,783.15	(700,583.71)	(0.43)
10	7th Floor slab	918,199.44	1,618,783.15	(700,583.71)	(0.43)
11	8th Floor slab	1,017,216.62	1,716,240.21	(699,023.59)	(0.41)
12	9th Floor slab	1,017,216.62	1,716,240.21	(699,023.59)	(0.41)
13	10th Floor slab	1,044,192.42	1,858,570.14	(814,377.72)	(0.44)
14	11th Floor slab	1,044,192.42	1,858,570.14	(814,377.72)	(0.44)
15	12th Floor slab	1,044,192.42	1,858,570.14	(814,377.72)	(0.44)
	Total	14,846,013.78	25,848,322.82	(11,002,309.04)	(6.32)

Table 21. *Cost per floor comparison of SCC and RC building slabs***.**

With the exception of cost of slab on first and second floors of SCC where figures seemed to be under estimated, the slab cost estimation showed perfect trend. Since the area of the building decreases as of fifth floor, there is a sudden negative slope on the graph between fourth and fifth floors. And since on site concreting cost is highly height dependent, it is logical to see posative sloped curve as the building height increased.

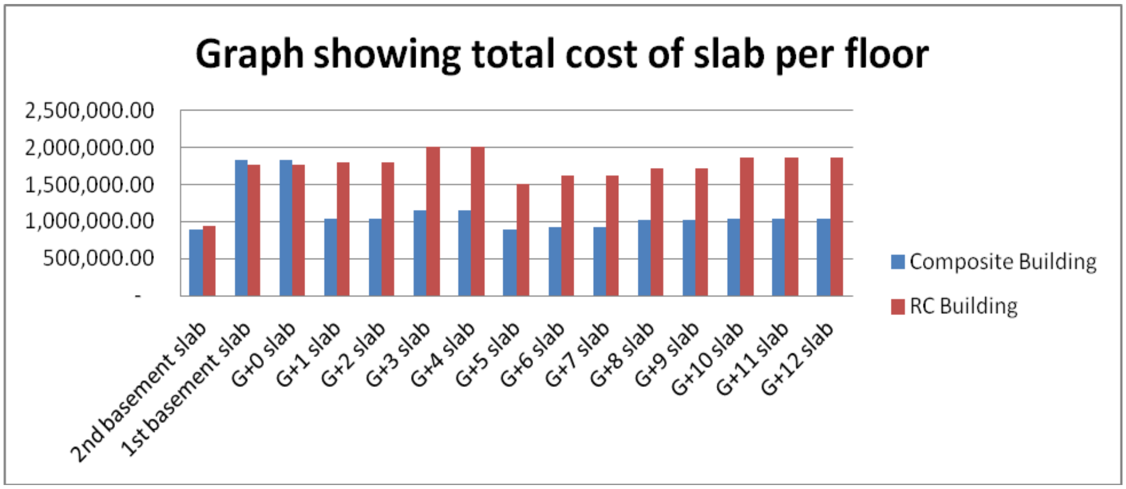


Figure 33. *Graph showing comparison of slab cost of SCC and RC per each floor*

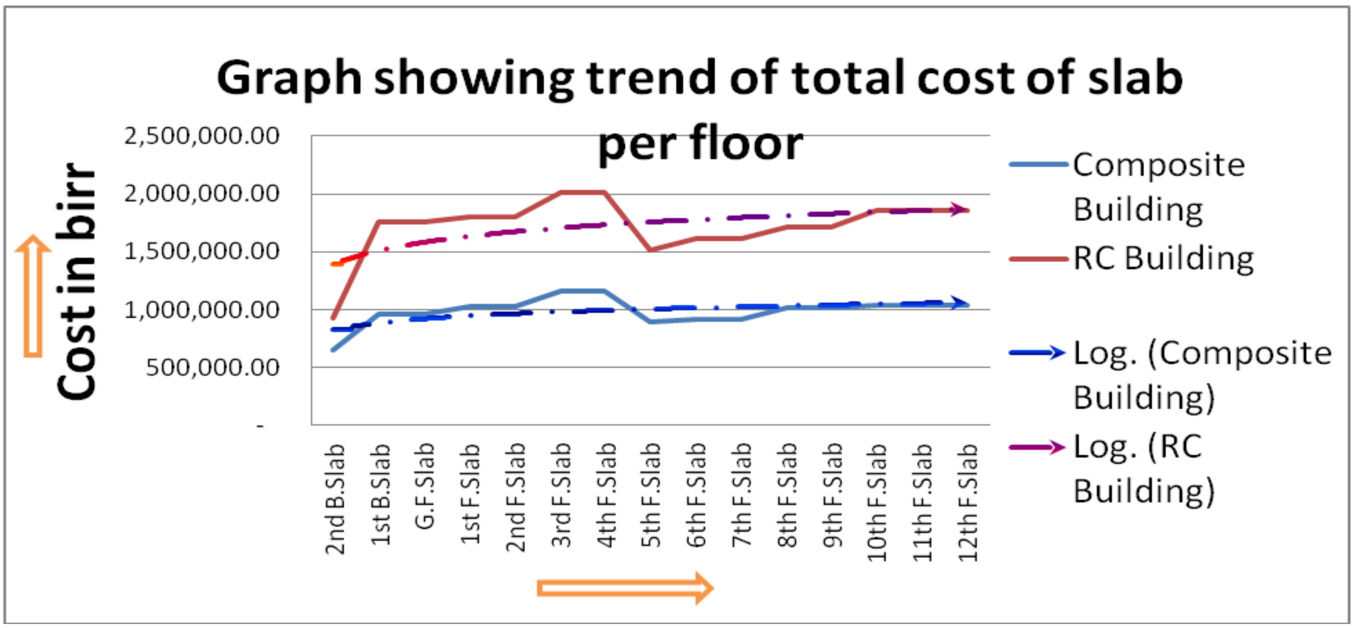


Figure 34. *Graph showing trend of slab cost of SCC and RC per floor*

4.2. Analysis Based on Space Efficiency

The major concept behind the search for alternative structural framing system is the efficient use of the built up space. There are two major ways of identifying this. One is using direct comparison of the area occupied by columns and the other is by using indirect ways of measuring the effects of span restrictions.

4.2.1. Direct Method of Analyzing Efficient Use of Space

What have been done was taking summation of cross sectional area of columns at every floor of both SCC and RC buildings. The average area occupied by columns on every floor is 15.08m2 for RC and 2.61m2 for SCC. The difference appears to be 12.47m2 per floor or a total of 187m2 on all floors.

If we can convert this in to monetary value by using the land owning price as shown on table 22 below, It will give minimum of 2,524,500.00 birr and maximum 11, 181, 042.29. In any of these approaches, the composite system of structural framing is efficient in using the available space.

RC Col. Length (m)	Floor Level	Column types of RC building (qty) Cross Sectional Area of Beam (m2)					Av. RC Col. A (m2)	Building Height Buildup (m)
		Type 1	Type 2	Type 3	Type 4	Type 5		
	Roof beam							0.5
3.11	Col	4	3	10				3.11
	12th F	0.25	0.36	0.25			0.27	0.6
3.11	Col	13	7	10				3.11
	11th F	0.25	0.36	0.25			0.28	0.6
3.11	Col	13	7	10				3.11
	10th F	0.49	0.36	0.25			0.38	0.6
3.11	Col	13	7	10				3.11
	9th F	0.49	0.36	0.25			0.38	0.6
3.11	Col	13	7	10				3.11
	8th F	0.49	0.36	0.25			0.38	0.6
3.11	Col	13	7	10				3.11
	7th F	0.49	0.36	0.25			0.38	0.6
3.11	Col	13	7	10				3.11
	6th F	0.49	0.49	0.36			0.45	0.6
3.11	Col	13	7	10				3.11
	5th F	0.49	0.49	0.36			0.45	0.6
3.11	Col	13	7	10				3.11
	4th F	0.49	0.49	0.36			0.45	0.6
3.11	Col	13	7	10	8	1		3.11
	3rd F	0.49	0.49	0.36	0.09	0.25	0.37	0.6
3.11	Col	13	7	10	8	1		3.11
	2nd F	0.49	0.49	0.36	0.09	0.25	0.37	0.6
3.11	Col	13	7	10	8	1		3.11
	1st F	0.64	0.64	0.36	0.09	0.25	0.45	0.6
3.11	Col	13	7	10	8	1		3.11
	G F	0.64	0.64	0.36	0.16	0.36	0.46	0.6
3.11	Col	13	7	10	8	1		3.11
	B1	0.64	0.64	0.36	0.16	0.36	0.46	0.6
2.1	Col	13	7	10	8	1		3.11
	B2	0.64	0.64	0.36	0.16	0.36	0.46	0.4
Total height of the RC building (m)								**55.95**

Table 22. *Table showing total building height of RC building*

SCC Column Length (m)	Floor Level	Column types of Composite building (qty) Cross Sectional Area of Beam (m2)						Building Height Buildup (m)
		Type 1	Type 2	Type 3	Type 4	Type 5		
	Roof beam							0.24
3.84	Col.	3	2	1				3.55
	12th F Bm	0.15	0.1	0.15				0.285
3.84	Col.	3	2	1				3.55
	11th F Bm	0.15	0.1	0.15				0.285
3.84	Col.	3	2	1				3.55
	10th F Bm	0.15	0.1	0.15				0.285
3.84	Col.	3	2	2				3.55
	9th F Bm	0.15	0.1	0.15				0.285
3.84	Col.	3	2	2				3.55
	8th F Bm	0.15	0.12	0.15				0.285
3.84	Col.	3	3	2				3.55
	7th F Bm	0.15	0.12	0.15				0.285
3.84	Col.	4	3	2				3.55
	6th F Bm	0.15	0.12	0.17				0.285
3.84	Col.	4	3	2				3.55
	5th F Bm	0.15	0.15	0.17				0.285
3.84	Col.	4	3	3				3.55
	4th F Bm	0.15	0.15	0.17				0.285
3.84	Col.	5	3	3	1	2		3.55
	3rd F Bm	0.15	0.15	0.26	0.1	0.12		0.285
3.84	Col.	5	3	3	1	2		3.55
	2nd F Bm	0.15	0.15	0.26	0.1	0.12		0.285
3.84	Col.	5	3	3	1	2		3.55
	1st F Bm	0.15	0.15	0.26	0.1	0.12		0.285
3.84	Col.	6	3	3	1	2		3.55
	G F Bm	0.15	0.15	0.31	0.1	0.12		0.285
3.84	Col.	6	4	4	2	3		3.55
	B1 Bm	0.17	0.17	0.31	0.1	0.12		0.285
3.84	Col.	6	4	4	2	3		2.11
	B2 Bm	0.17	0.17	0.31	0.15	0.12		0.285
Total height of the SCC building (m)								**56.325**

Table 23. *Table showing total building height of SCC building*

The two buildings have almost equal building height; i.e. RC building 55.85m and SCC building 56.32m. But, when compared with respect to getting a clear floor height, SCC building gives a better one with an average of 3.84m per floor while the RC building is limited to 3.11m.

RC Col. Length (m)	Floor Level	No RC columns per Floor	Area RC Col/Floor (m2)	Total F. area (m2)	Av. RC span (m)	Av. Col. dim. (m)	Av. RC Clear span (m)	Av. RC beam depth (m)	Clear ht b/n Floors (m)
	Roof							0.53	
3.11	Col	17	4.58	1024	5.36	0.52	4.84		2.58
	12th F							0.53	
3.11	Col	30	8.27	1024	5.36	0.53	4.83		2.58
	11th F							0.53	
3.11	Col	30	11.39	1024	5.36	0.62	4.74		2.58
	10th F							0.53	
3.11	Col	30	11.39	1024	5.36	0.62	4.74		2.58
	9th F							0.53	
3.11	Col	30	11.39	1024	5.36	0.62	4.74		2.58
	8th F							0.53	
3.11	Col	30	11.39	1024	5.36	0.62	4.74		2.58
	7th F							0.53	
3.11	Col	30	13.4	1024	5.36	0.67	4.69		2.58
	6th F							0.53	
3.11	Col	30	13.4	1024	5.36	0.67	4.69		2.58
	5th F							0.53	
3.11	Col	30	13.4	1024	5.36	0.67	4.69		2.58
	4th F							0.53	
3.11	Col	39	14.37	1438	6.122	0.61	5.51		2.58
	3rd F							0.53	
3.11	Col	39	14.37	1438	6.122	0.61	5.51		2.58
	2nd F							0.53	
3.11	Col	39	17.37	1438	6.122	0.67	5.45		2.58
	1st F							0.53	
3.11	Col	39	18.04	1438	6.122	0.68	5.44		2.58
	G F							0.53	
3.11	Col	39	18.04	1438	6.122	0.68	5.44		2.58
	B1							0.53	
2.1	Col	39	18.04	1438	6.122	0.68	5.44		1.57
	B2								
Tot Col. Area of RC building			**198.84**		**Av. Clear span of the RC building**		**5.04**	**Av. Clear ht.**	**2.58**
								Cum. Height of beams	**7.94**

Table 24. *Table showing span length, column size and beam depth of RC building*

SCC Column Length (m)	Floor Level	No of SCC columns per Floor	Area of SCC Col/Floor (m2)	Total area of Floor (m2)	Av. SCC Beam length (m)	Av. SCC Column dim. (m2)	Av. Clear span SCC (m)	Av. Stl beam depth (m)	Clear ht b/n SCC Floors (m)
	Roof							0.29	
3.84	Col.	6	0.80	1024	7.95	0.24	8.10		3.55
	12th F							0.29	
3.84	Col.	6	0.80	1024	7.95	0.24	8.10		3.55
	11th F							0.29	
3.84	Col.	6	0.80	1024	7.95	0.24	8.10		3.55
	10th F							0.29	
3.84	Col.	7	0.95	1024	7.95	0.24	8.10		3.55
	9th F							0.29	
3.84	Col.	7	0.99	1024	7.95	0.24	8.10		3.55
	8th F							0.29	
3.84	Col.	8	1.11	1024	7.95	0.24	8.10		3.55
	7th F							0.29	
3.84	Col.	9	1.30	1024	7.95	0.24	8.10		3.55
	6th F							0.29	
3.84	Col.	9	1.39	1024	7.95	0.24	8.10		3.55
	5th F							0.29	
3.84	Col.	10	1.56	1024	7.35	0.24	8.10		3.55
	4th F							0.29	
3.84	Col.	14	2.32	1438	7.35	0.24	8.10		3.55
	3rd F							0.29	
3.84	Col.	14	2.32	1438	7.35	0.24	8.10		3.55
	2nd F							0.29	
3.84	Col.	14	2.32	1438	7.35	0.24	8.10		3.55
	1st F							0.29	
3.84	Col.	15	2.62	1438	7.35	0.24	8.10		3.55
	G F Bm							0.29	
3.84	Col.	19	3.50	1438	7.35	0.24	8.10		3.55
	B1 Bm							0.29	
3.84	Col.	19	3.60	1438	7.35	0.24	8.10		3.55
	B2 Bm								
Tot Col. Area of SCC building			**26.38**		**Av. Clear span (m)**		**8.10**	**Av. Clear ht. (m)**	**3.55**

Table 25. *Table showing span length, column size and beam depth of SCC building*

Considering span length of beams with respect to their depth the design outputs show that RC building can span only up to an average of 5.04m with an average beam depth of 830mm whereas SCC building showed an average span length of 8.10m with an average depth of 430mm.

One can understand that 6.75m or 12% of total height of the RC building is lost in the RC beams since RC beams needed deeper section to carry the intended design loads and comparatively they are span restricted.

4.2.2. Indirect Comparison of Efficient Use of Space

There seems no accurate direct method of evaluating the discomfort caused due to columns coming in middle of floors and unwanted partitioning styles aimed to illuminate visual obstruction of such columns.

In this thesis, it is tried to consider the floors as parking lots. By trying to park the maximum numbers of cars possible, it is tried to make comparison between the SCC and RC buildings as detailed on the figures fig.35 A and B below.

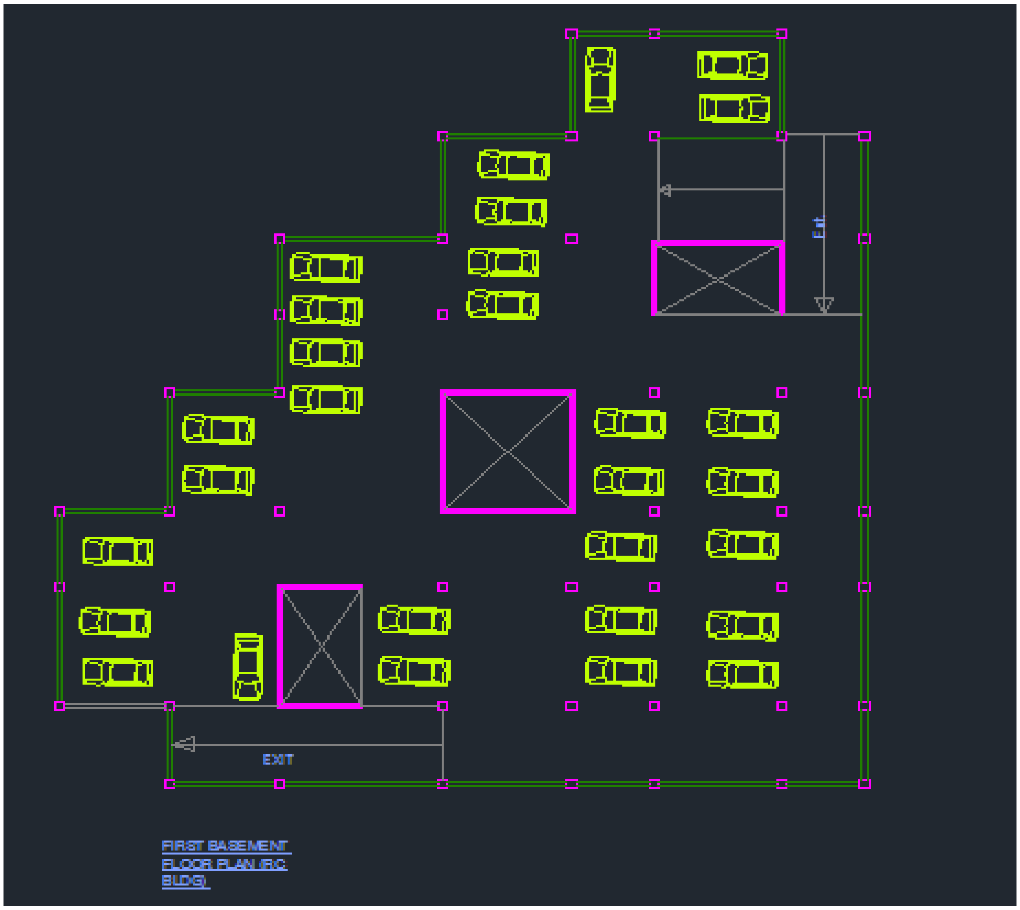


Figure 35. *Efficiency of parking of RC building*

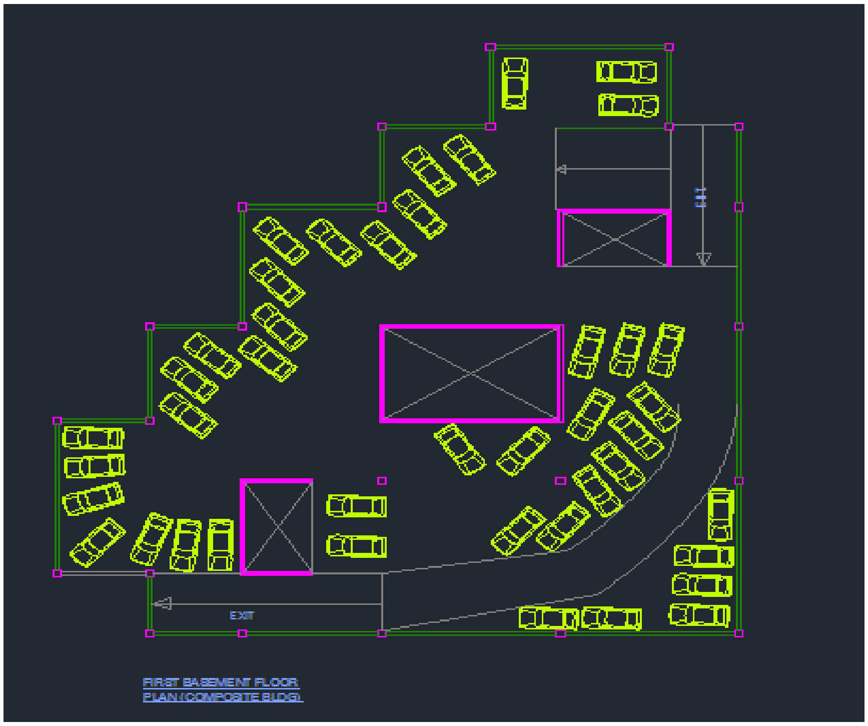


FIGURE 36. *EFFICIENCY OF PARKING OF SCC BUILDING*

Floor level	Reinforced concrete building			Composite building		
	No of cars parked	**area of one car (Including clear space)**	**Total area occupied by cars**	**No of cars parked**	**area of one car (Including clear space)**	**Total area occupied by cars**
B2	29	10.252	297.308	41	10.252	420.332
B1	29	10.252	297.308	41	10.252	420.332
Total			**594.62**			**840.66**
Space efficiency of Composite with respect to RC in %						**141.0%**

Table 26. *Comparison of efficient space use between SCC and RC buildings*

Wider spans and distant columns give freedom of building space use. Be it an office area, residential, meeting hall or parking floor, comparison can be made based on the maximum possible accommodation of the intended floor for its specific designed purpose.

With this regard, one of the points well observed in most high rise buildings in the city of Addis was building space wasted at parking basements. Even though span restrictedness of concrete structures is not all the reason for the wasted parking areas in basements, it was visualized that most spans on such buildings are narrow for two cars and wider for one car when proper clearance from structures and in between is considered. Such clearances are also vital to curve in and out of the parking lane.

Consider the space management of basement areas for car parking. The data on table 26 is organized from the architectural layout as shown on Fig. 35 and 36. The relative efficiency of the SCC basement floors found to be capable of carrying 141% of car parking capacity of the RC building.

4.2.3. Efficient use of built up space in monitory terms

The table above gives the total area efficiently used by the cars parked and the result shows that the RC building is able to park 29 cars per wider floors while SCC building accommodates 42. With this regard, The SCC building is better than the RC by 40%. In monetary value, this efficiency expressed as follows.

40.85 / 100 * 3639.46 = 1485m2 per the total number of floors.

Considering the two types of land owning prices studied from the market, minimum of 20,047,500.00 or maximum of 88,682,715.0 Ethiopian birr additional value will be achieved by considering SCC structural framing.

This concept will show a tremendous value when future value of this amount is considered for 99 lease years.

Since the issue of efficient use of built up space is directly related to price of land it became necessary to search data about the land owning prices in Addis Ababa.

To be able to do this all over the city is one research work by itself. Therefore, in order to make the sampling area narrower, it was found necessary to do another field research questioning where the tallest buildings in Addis Ababa are. By doing so a rank of 15 tallest buildings in Addis Ababa compiled and all are found between south, south east and central part of Addis Ababa. The following can be learnt from the process.

1. Most tall buildings will continue to be built at these areas until these areas saturate
2. The cost of land on these areas will continue booming due to the demand.

Hence, land owning prices collected in two ways as it is practically done in the city. One is by asking the municipality lease office. The other is by asking brokers on various areas and trying to find average figures of all. Table 22 below shows average of the studied prices list. See appendix 4 for the details.

No	Location in Addis	Land owning price 2013	Land owning price 2014	Land owning price 2015	Land owning price 2016
		2013 Av.	2014 Av.	2015 Av.	2016 Av.
1	Bole	8,000.00	12,250.00	13,250.00	15,000.00
2	Kazanchis	7,750.00	8,000.00	10,500.00	16,000.00
3	CMC	4,250.00	5,500.00	7,500.00	9,750.00
4	Mexico	7,750.00	8,000.00	10,500.00	16,000.00
5	Merkato	6,000.00	6,750.00	13,000.00	16,000.00
6	Nifas silk	4,250.00	4,250.00	5,500.00	8,250.00
	Av. South and South east Addis Ababa lease price	**6,333.33**	**7,458.33**	**10,041.67**	**13,500.00**
	Av. South and South east Addis Ababa private selling price	**16,500.00**	**21,166.67**	**29,666.67**	**59,791.67**

Table 27. *Table showing land owning price in South and South East of Addis Ababa*

The next task was to study the trend of the land owning cost. Usually the land availed by the government is not that much attractive to investors due to the fact these areas are far from main roads. But when comes to land owned by individuals, they tend to sell their land for so many reasons but with ultimate price possible. In this thesis, all comparisons made in average values of both private sellers price and government price.

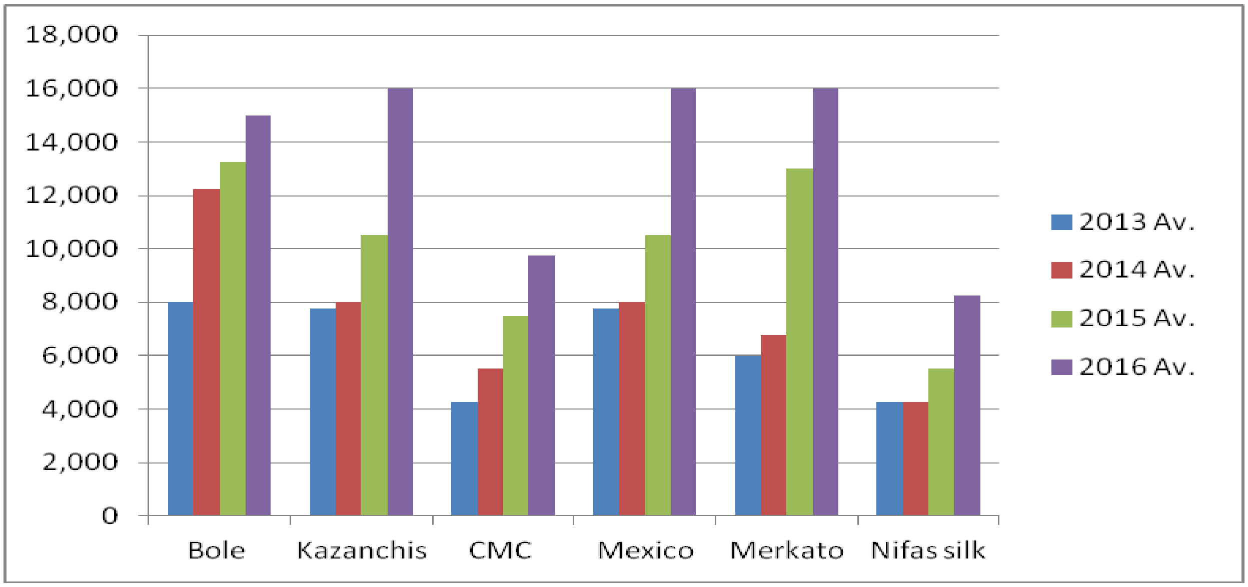


Figure 37. *Land owning prices in South and South East parts of Addis Ababa*

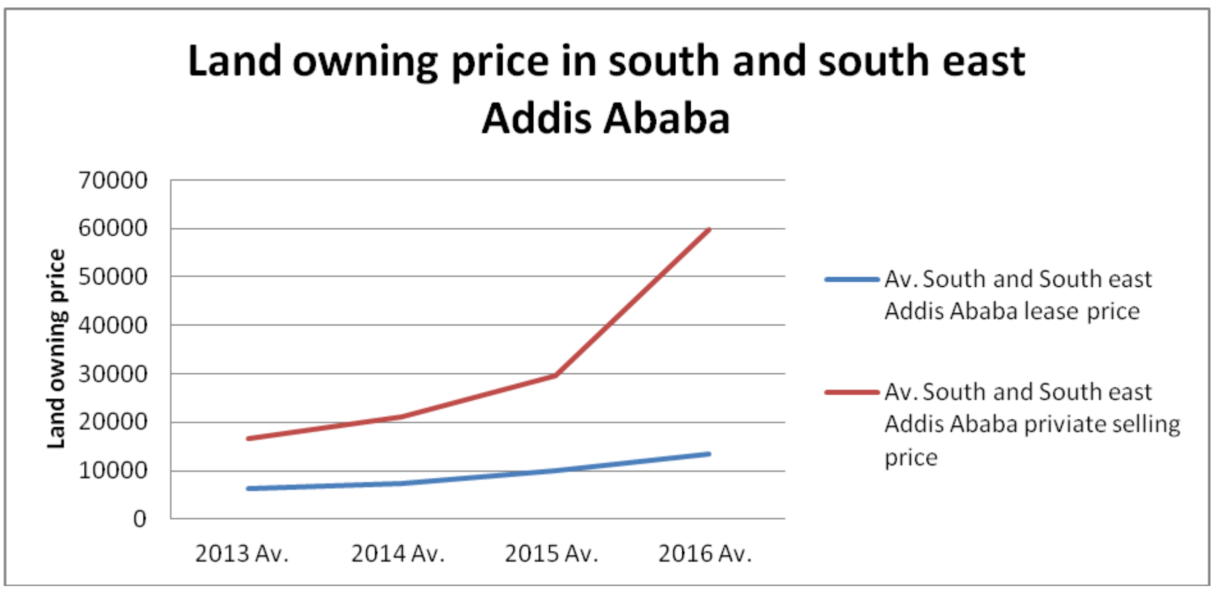


Figure 38. *Trend of lease and private sellers land price*

As it is clearly seen from the chart on fig.37, the private selling price rate of increase is escalating every year while the government facilitated lease price is somewhat in a gentle progression. Considering the future price level of land is progressing in such trend, it is vital to use built up spaces in a more efficient and economical way and SCC system of structural framing is incomparable with this regard.

4.3. Analysis of data gathered through questionnaire

In order to make a firm conclusion about importance and applicability of an alternative building construction system, it is better to access opinions of actors and stakeholders with in the construction industry.

Questionnaire and interview questions had been prepared to address opinions of Governmental appointees, consultancies and their designing engineers, contractors and their construction engineers, steel industrialists, bank and insurance companies representatives.

The following are summery of the opinions.

4.3.1. Summary of Opinions of Professional Engineers

Two sets of questionnaire had been distributed to designers and construction engineers basically similar with some differences based on their work specifics. The discussions are summarized as follows.

Questionnaire selectively distributed to 25 designing and 30 site engineers. 12 designing engineers and 10 construction engineers responded which accounts only 40% of the sample.				
No	**Question**	**Response**	**Agreement in %**	**Additional remarks**
1	Have you ever designed/construct long building			
		Yes	66.67	
		No	33.33	
2	Building categorization			
	Low rise (%)	G+0 to G+6	58.33	
	Medium rise (%)	G+7 to G+12	50.00	
	High rise (%)	G+13 to G+100+	83.33	
3	Challenges in RC system design work			
	Columns coming closer to each other	yes	100.00	Some respondents do not agree with the inclusion of “to much formwork” and ”to much chiseling/plastering ” as challenge in designing with RC system for the reason they think it is possible to minimize such items in RC system and also SCC is not totally free from it.
	Columns obstructing parking spaces	yes	100.00	
	Columns coming in the middle of a room	yes	100.00	
	Column size bigger not to fit rooms functions	yes	100.00	
	Too much formwork	Yes	66.67	
	Too much chiseling and plastering	Yes	66.67	
4	What are causes for challenges in No. 3	Technological limitation		
		limited perception on technology		
		limited inter organizational planning		

		limited coordination between stakeholders		
5	Experience in advising client to alternative systems of structure	yes	33.33	
		no	66.67	
	Challenges on those who said yes	Fear of cost of new technologies by client		
		Fear of client on logistics		
		Fear of new systems		
6	If respondents ever think SCC can solve RC limitations	yes	58.33	
		no	41.67	
7	Those who said yes to q-6 put reason why SCC not practiced in Ethiopia Despite its benefits.			
	Knowledge gap of professionals	Yes	100.00	
	Material/Resource availability	Yes	71.43	
	Technological availability	Yes	100.00	
	Interest of investors	Yes	85.71	
	Availability of codes and standards	Yes	28.57	
	Government directions	Yes	100.00	
	Cost of industrialization	Yes	100.00	
8	If the technology is readily available do you think you can design/construct in SCC right now	yes	33.33	65% of respondents saying yes require expertise guidance
		No	66.67	
9	Those who said no asked how long will it take to practice and design/construct efficiently	Between 3 to 12 months	62.50	
10	If non availability of iron ore and/or non processing steel to the requirements of	yes	66.67	They believe what makes RC popular is almost all ingredient materials are locally available

	SCC have influence on practicing SCC technology			
		no	33.33	Japan and most Europe are good at it having little or no resource
				Most aggregates in road and rail way construction are imports
11	If Universities in Ethiopia played role in teaching, promoting and influencing students and stakeholders With regard to SCC technology	yes	33.33	They believe universities are not spoon feeders and such advancements require self drive of scholars.
		no	66.67	Universities influenced by market
				Universities follow Government priorities (E.g. Railway Eng. Program started after government planned to build)
				Regional university lecturers lack knowledge and readiness. (Such universities assign 1st degree graduates to teach under graduates)
				Laboratories are not properly equipped to perform researches
12	If this research work and other similar activities will have impact in promoting alternative structural systems like SCC	yes	75.00	55 % of them believe it will not be achievable in the near future unless government interest involved
		no	25.00	

Table23. *Summary of questionnaire distributed to Designing and construction engineers*

4.3.2. Summary of opinions of Governmental appointees

This interview has been made with the executive director of FDRE construction project management institute.

No	Research question	Response
1	SCC technology requires industry with more than one plant lines. One is the steel forming and the other is packing it in concrete case. Investors might get encouraged if government give the following as a privilege	Government usually supports investors to bring in helpful technologies. But, since the mentioned privileges belong to the public, the projects must have positive impact on the public at large. The following are some of the preconditions.

	Land lease free or with minimal rate	transformation friendly
	Duty free to plant and facilities	considerable labor participation
	Tax grace period	less impact on foreign currency
	Considering it on Government projects	continuity and economical viability
		Environmental friendly
2	The technology might require government to work with universities with regard to capacity building	Government is ready to involve but with short and long term strategic plans.
3	It might also be necessary to give capacity building to private sectors like Consultants, Contractors, suppliers, local steel engineering industries and so on.	It will be a question of coming up with a convincing idea and once it is proved to satisfy public and government needs, capacity building is little part of what can be done. In general, the manufacturing industry is given the highest attention and same is true for anyone moved to invest on production of SCC framing.

Table 28. *Summary of interview made with executive director of FDRE construction project management institute.*

During this interview, it was also confirmed that steel and concrete composite technology (SCC) has never been practiced in Ethiopia. During the course of this research work, it is learnt that recently, some partial applications of SCC structural members observed in the Ethiopian construction industry.

- For the tallest building in the country, H.Q of Commercial Bank of Ethiopia, SCC columns are adopted.
- Some factory buildings like Raya brewery considered SCC flooring complete with Shear studs welded to the beam system even though the beam itself is not composite.
- One column on the Federal police H.Q is also made to be SCC member.

4.3.3. Analysis on Ethiopian Steel Industries and the Market Condition

According to site visits and discussions made with higher expertise of steel rolling factories, the following observations included.

- All the ten steel rolling factories are in a medium production scale with furns size less than 8 meters.
- Due to scarcity in scrap materials they are importing steel pallets.
- The absence of iron ore extraction made the cost of steel higher in Ethiopia.
- The imported steel market is highly inconsistent waving between 20 birr and 70 birr. This implies that the market condition is showing monopoly and price fixing.
- If technologies like SCC are extensively used in Ethiopia, steel companies might get encouraged and importing steel will not be higher than the present trend.

4.3.4. Summary of Opinions of Banks and Insurances

No	Research question	Response
1	How banks define their clients attitude towards new technologies	The current experience in the construction sector shows a boom. Contractors are seen attracted to new technologies mainly as a result of getting experience from globalization and foreign contractors working in Ethiopia
2	If banks are requested to avail lone and foreign currency for projects like SCC industry	The basis are mostly dependant on the capacity of the investor with regard to
		➢ liquid enough to run the project
		➢ managerial and organizational capacity
		➢ viability of the project with respect to profitability, cash flow and others calculated on the basis of discounted net present value, internal rate of return, payback period and other social and economic benefits
		Even though banks serve first come first served basis, the manufacturing industry has priority as given by government.
3	SCC production plant might require higher cash flow at start. What would be banks role in release of loans	once the bank is sure of the project viability, the banks shall be willing to the following
		➢ Give a grace period one or two years exemption from payment of the principal
		➢ Extension of loan period up to ten years
		➢ Adjustment of periods of payment
4	If banks encourage their engineering personnel to be familiar with such technologies	When there is the need, banks train and educate their engineering personnel to the required extent.
5	Such technologies might require purchase of intangible resources like knowledge and training. Joint venture is one way. Will it affect bank's consideration	Bank loan procedures are constant with country's legal requirements and economic policies.

Table25. *Summary of questionnaire distributed to bankers*

	Insurance coverage required	Availability in Ethiopia
1	All in risk through the production process	confirmed
2	All in risk during transportation of products to site	confirmed
3	All in risk while erecting the structure	confirmed
4	All in risk of the produced structure	confirmed
5	All in risk of technological failure	confirmed
6	All in risk coverage in case of buildings durability	confirmed

Table 29. *Insurance coverage availability for projects like SCC*

V. CONCLUSION AND RECOMMENDATIONS

4.1. Conclusion

Space in cities like Addis Ababa is a huge resource which needs proper handling. The price of land is becoming extremely expensive and being not able to use the space available will be a loss. One of the ways to do so is by using alternative technologies in our design and construction procedures.

Steel and concrete composite system of structural framing is getting world wide acceptance as an alternative to pure steel and pure concrete systems of structural framings some 60 years ago. In Ethiopia, there had not been any move to use this technology until the Chinese contractor CSCECE adopted composite columns for the building it constructed for Commercial Bank of Ethiopia.

Even though the technology is believed to have better qualities worldwide, it had not been taken seriously in Ethiopia

- The structural analysis of the two buildings shows that SCC system of structural frames are capable of carrying much more loads with smaller cross sectioned frames and longer spans.
- The cost comparison shows that SCC system is less costly for buildings of G+15 and above. For lower storied buildings, since cost of industrialization dominates economy of scale, RC system is less costly than SCC.
- With regard to efficient use of built up area, the comparison shows that SCC system saved 1% of the total area due to smaller cross sectioned columns and as proved by exemplifying parking pattern, SCC uses 141% of the area used by RC system.
- The land owning price in Addis Ababa is escalating with a geometric progression that as free space getting occupied, these land owning price figures might double in few years time. In order to compensate such costs, it is vital to use land as efficient as possible.
- The analysis through questionnaire showed the general opinion of most actors in the industry. Since SCC production facility, if happened to be built in Ethiopia, is a manufacturing industry, it will have all the privileges given by government, banks and insurances. The main challenge will be availability of iron ore. According to the information collected from FDRE Ministry of Mines, there is sufficient strong iron ore deposit in various parts of Ethiopia. But none of them get the chance to be mined. The existing few steel rolling companies are working under capacity and equipped with outdated technologies. They need to be sure on the demand of the market in order to invest more on modernizing the existing plants. Here it looks like the key is with government. Since it is investing more on housing projects and other mega projects, facilitating the market ground for such technologies will help all interested.
- Market price has been studied focusing on some steel sections. The analysis shows that the list steel price in Ethiopia is double of that of the international market. When there are many suppliers for a specific steel section, the price level is between 20 to 30 birr. For the huge steel sections, only fewer suppliers are found in the market and the price ranges between 45 to 70 birr per kilograms. Engineering properties of steel on such market are also not known. With this regard, it is hopeless to think about SCC technology implementation in Ethiopia.
- The role of universities is important in at least narrowing the knowledge gap on engineering professionals. Even though most designers participated in this research work are familiar with ideas of this technology, to be able to practically participating on actual projects is somewhat tougher.

4.2. Recommendations

The general recommendations of this research work are as follows.

- It will be better to have technological readiness for SCC technology as it is only a matter of time the country will be in need of it. Therefore government must focus on reinforcing the steel rolling industries and work for the mining of iron ores. It is also better if future housing projects consider use of SCC technology as it will be helpful in cost effectiveness, speed of construction, proper space utilization, freedom of partitioning and most importantly, technological readiness for the aimed transformation.
- Universities should work on their students to narrow the knowledge gap with regard to Building industrialization through such technologies as SCC. It will also be better if it is included in civil engineering programs with a better intensity.
- Investors and the biggest contractors in the industry should at least start to figure out such technologies as SCC since there is future potential to be benefited from.
- The steel rolling industries are the ones who can grab the earliest benefit of such technologies. Their production level can be upgraded and modernized with a minimal cost compared to new investors. Knowing this, they must maximize their production and if needed, they are the ones supposed to invest on technology transfer, awarding scholarship for academicians, supporting universities with all aspects of research and development and test the SCC system as a pilot project knowing it would be their potential market.
- SCC technology is a potential area for researchers. There are lots of points in this technology requiring research and development. Hence academicians need to specialize on many more details of this technology.
- The following points remain potential area for future researchers
  1. This research considers similar isolated footing structures for both RC and SCC buildings. As a result the cost of footing on SCC appears higher than RC building. But actually the total building load of SCC is smaller than RC and so does the cost. Had it been pile foundation used at SCC building, the heavily concentrated loads on SCC columns would have been transferred to the ground with a significantly lesser cost.
  2. At the end of service time, buildings are supposed to be demolished. There is significant amount of reusable steel scrap from demolished SCC buildings since more than 55% of it is steel and as indicated in the literatures more than 90% of the original steel is reusable with or without remolding.
  3. It is tried to refer in the literatures that the most frequent failure mechanisms in SCC are related to connection detailing and slip between steel and concrete interfaces and this needs further research.
  4. The Joint model applied in this research is rigid in RC and flexible in SCC. But literatures suggested a semi-rigid model which requires further research.
  5. Cost saving advantage of SCC due to industrialization is not considered because of the fact that there is no such industry in Ethiopia and it becomes impractical to assume foreign experience. Hence the benefit of non using of formworks and false work, speed of construction, finishing perfection and avoidance of significant amount of plastering work are not covered in this research.

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VII. APPENDICES

Appendix 1

Rank	Name of owner	No. of stories			
		Basement	Mezzanine	Above G+0	Total floors
1	Commercial Bank of Ethiopia	4	0	47	51
2	Zemen Bank	2	0	37	39
3	United Bank	4	0	35	39
4	Nib Bank	4	1	32	37
5	African Union	3	0	26	29
6	Wegagen Bank	3	2	23	28
7	Nani Building	2	0	21	23
8	Dashen Bank	3	1	18	22
9	Awash Bank	2	0	19	21
10	Abcynnia tower	1	1	18	20
11	G.H. Cimex	1	0	16	17
12	Debrework Tower	1	0	15	16
13	Yobek tower	1	0	15	16

Table I. *Rank of tall buildings in Addis Ababa*

Appendix 2

Questionnaire

A- To Consultancies or Engineers of consultants

1. Have you ever designed a long building? Yes No

   If yes how many floors? ___________ how high is one floor? _______

2. If we need to categorize the buildings in Addis Ababa between Low rise, Medium rise and High rise, how do you think it should be categorized?

   Low rise= G+0_______ to G+ _____

   Medium rise = G+ ______ to G+_____

   High rise = G+_______ to G+_____

   Clarify the basis of categorization ____

3. Which of the following points are challenges to your design works of high rise buildings?

   i. Columns coming closer to each other Yes No

   ii. Columns obstructing parking grounds Yes No

   iii. Columns coming in the middle of a room Yes No

   iv. Columns size bigger not to fit to rooms functions Yes No

4. Have you ever think of what brings theses challenges?

   ____

5. Have you ever think of other solutions to solve these problems

   ____

6. Have you been experiencing advising your clients about alternative technologies with regard to structural framing? Yes NO If yes please elaborate your experiences and the most common challenges ____

7. Steel and concrete composite structures are believed to have better solve the above problems. Have you ever think of that?

   Yes No

8. If "Yes" which of the following do you think are the reason/s this technology is not practiced in Ethiopia? Include notes for each if any

   i. Knowledge gap of professionals Yes No

   ____

ii. Material availability Yes No

____

iii. Technology availability Yes No

____

iv. Interest of investors Yes No

____

v. Availability of Codes and standards Yes No

____

vi. Government directions Yes No

____

vii. Cost of industrialization Yes No

____

9. If the technology is readily available in Ethiopia, do you think you can design composite structures right now? Yes No

____

10. If no, how long will it take to you to practice and design? _________________

11. Do you think none availability or none processing of steel from ore to final end product will have effect on practicing of this technology in Ethiopia? Yes No

____

12. Do you think Universities in Ethiopia played the role expected from them with regard to teaching, promoting and influencing students and other stakeholders? Yes No ____

13. Do you think this research work and other similar activities will have impact on promoting Steel and concrete composite technology as an alternative construction technology in Ethiopia Yes No

____

14. If there is any issue you want to add beyond the directions given by this questionnaire ____

C. To Banks

This research work is about promoting an alternative building construction technology called Steel and Concrete composite structure. It is more concerned with high rise building framing (Skeleton) composing foundation, columns, beams and slabs to be made in a way that have never been practiced in Ethiopia.

The basics of the technology is that Steel sections with shapes of “I”, “H”, “C”, “O”, “□”, “L” and others sandwiched in a concrete covering to be considered as a monolithic material.

Most high-rise buildings in the developed world are believed to be more economical, fast construction, better earthquake resistant and wider column free spaces because they are made of this technology.

While we are studying this technology and its application in Ethiopia, we needed to assess stakeholder’s attitude and awareness for such technologies.

Since Banks have a big impact on client’s preferences and importing of technologies, the following questionnaire is aimed to address your role in the construction industry.

15. How do you define your client’s attitude towards experiencing new technologies? ____
16. If a client requested a lone of foreign currency to adopt such a new technology to the country, what are the basis to help them achieve what they wanted? ____
17. Most of the elements of this Steel and Concrete composite construction are to be produced in a factory and transported to the construction site for assembly. Therefore it will allow less material depositing on construction sites and requires higher degree of mechanization both in the factory and the construction site. As the initial costs are higher, the cash flow might be different from the usual way of releasing loans. Will your methods be flexible according to the technological requirements? ____
18. Is your engineering department and the professionals with in encouraged to be familiar with such technologies? ____
19. In order to bring such technologies, it may require a purchase of intangible resource (Knowledge and methods) and joint ventures of foreign companies with local ones. What will be your procedures on such occasions? ____
20. If this technology has a chance to come to Ethiopia, the factory planted may require relatively longer period of time to start to be profitable. Are you flexible in determining lower interest rates and longer period of returning? ____
21. If you have any other information to give beyond the directions given by this questionnaire please ____.

Questionnaire

These questionnaires are prepared only for academic purpose.

D. To Insurance companies

This research work is about promoting an alternative building construction technology called Steel and Concrete composite structure. It is more concerned with high rise building framing (Skeleton) composing foundation, columns, beams and slabs to be made in a way that have never been practiced in Ethiopia.
The basics of the technology is that Steel sections with shapes of "I", "H", "C", "O", "□", "L" and others sandwiched in a concrete covering to be considered as a monolithic material.
Most high-rise buildings in the developed world are believed to be more economical, fast construction, better earthquake resistant and wider column free spaces because they are made of this technology.
Most of the elements of this Steel and Concrete composite construction are to be produced in a factory and transported to the construction site for assembly. Therefore it will allow less material depositing on construction sites and requires higher degree of mechanization both in the factory and the construction site. Even though the in-factory procedures are not that much different from other industries already practiced in Ethiopia, the onsite procedures may involve risks of working at height, faults of lifting equipments and negligence of fitters and/or operators.
While we are studying this technology and its application in Ethiopia, we needed to assess stakeholder's attitude and awareness for such technologies.
Since insurance companies have a big impact on client's preferences and importing of technologies, the following questionnaire is aimed to address your role in the construction industry.

1. How do you define your client's attitude towards experiencing new technologies in a way that avoid risks of equipments, machinery and human working on the projects and/or residing around project/factory?

   ____

2. The following are potential risks which may occur on the process of implementing this technology.

   i. Like all other factories this technology involves processing of steel and concrete in factory and transporting the products to the project sites. Do you think this whole process can be covered?
      - Yes it can be fully covered
      - No it cannot be covered
      - It can be partly covered

   If such activity is possible to be partly covered, what parts of it cannot be covered and why?

   ____

   ii. Due to the weight of the factory produced items is very huge, all the process is machine intensive and it may involve high risks on equipments, machinery, the material itself, human working on the project or moving around. Do you think this whole process can be covered?
      - Yes it can be fully covered
      - No it cannot be covered

- It can be partly covered

If such activity is possible to be partly covered, what parts of it cannot be covered and why?

____

iii. In order to create investors awareness the main challenge will be to put confidence in investors' heart. So there might be a need to guarantee the technology so that if it fails owners will be compensated with all investment cost, time value of money, benefit forgone due to the loss, etc. Do you think this whole process can be covered?

- Yes it can be fully covered
- No it cannot be covered
- It can be partly covered

If such activity is possible to be partly covered, what parts of it cannot be covered and why?

____

iv. Again investors might still have doubts on the technology that after the buildings constructed and started to serve for the intended purpose, it might be fully or partly malfunction. Hence those who bring such technology might need to give warranty for the design life time of the building. Do you think this can be covered?

- Yes it can be fully covered
- No it cannot be covered
- It can be partly covered

If such activity is possible to be partly covered, what parts of it cannot be covered and why?

____Some insurance policies are not locally practiced (due to nature of the risk, principles of insuring, capacity of insurance companies, due to country policies, etc) but possible in other countries. If there is such coverage among the above ones, please specify here under and reasons for not covering locally.

____

v. If you have anything to say beyond the direction given by this questionnaire, please write down hereunder. Attach pages if lines are not enough.

Questionnaire Given to ______________________________
Contact Name _____________________________________
These questionnaires are prepared only for academic purpose.

E. To FDRE Ministry Of Works and Urban Development

This research work is about promoting an alternative building construction technology called **Steel and Concrete composite structure**. It is more concerned with high rise building framing composing foundation, columns, beams and slabs to be made in a way that have never been practiced in Ethiopia.
The basics of the technology is that Steel sections with shapes of “I”, “H”, “C”, “O”, “□”, “L” and other steel sections hot rolled and/or cold formed, sandwiched in a concrete covering to be considered as a monolithic member.

Most high-rise buildings in the developed world are believed to be more economical, fast construction, better earthquake resistant and wider column free spaces because they are made of this technology.

While we are studying this technology and its application in Ethiopia, we needed to assess the countries potential in row materials especially iron production, capacity of steel industries to produce bigger steel sections, Government policies to support the technology transfer, financial and other supports on pilot projects and re-evaluation of policies, regulations and rules for its success.
The following are key information that will help us understand government inputs.

1. In order to bring this technology, it is necessary to plant two types of factory processes. One is the steel members and connection mechanism fabrication and the other is to sandwich it with concrete. Therefore the following are helpful if made available from government. Land for the factory, Duty free for the plant and accessories, longer tax grace period, privilege in case of a need for foreign experts/companies and soon.

   Is your government willing and ready to help investors on the above?
   ____

2. The technology may require working together with university researchers and giving a scholarship chance to graduate engineers, technicians and factory planting and process foreman. To what extent will you be involved? ____

3. Engineering consultants, contractors and others may require capacity building and we believe this can be achieved by giving additional courses in engineering faculty syllabus, short term courses and seminars and preparing guidelines and manuals in the universities. In order to do so, the universities may require additional budget to experimental studies. To what extent will you/your government involve? ____

4. If you have any additional question, suggestion or information to contribute to this research work, please ____ .

Questionnaire Given to ______________________________
Contact Name ______________________________________
These questionnaires are prepared only for academic purpose.

F. To Consulting companies that designed high rise buildings

This research work is about promoting an alternative building construction technology called **Steel and Concrete composite structure**. It is more concerned with high rise building framing composing foundation, columns, beams and slabs to be made in a way that have never been practiced in Ethiopia.

The basics of the technology is that Steel sections with shapes of “I”, “H”, “C”, “O”, “□”, “L” and other steel sections hot rolled and/or cold formed, sandwiched in a concrete covering to be considered as a monolithic member.

Most high-rise buildings in the developed world are believed to be more economical, fast construction, better earthquake resistant and wider column free spaces because they are made of this technology.

While we are studying this technology and its application in Ethiopia, we needed to assess stakeholder’s interest, attitude and awareness for such technologies.

The following are key information that will help us understand and differentiate between the most commonly used reinforced concrete structures and Steel and concrete composite structures.

Since we understand the fact that Steel and concrete composite design have never been practiced in high rise buildings in Ethiopia, the information we are seeking from you is only about reinforced concrete framed structures.

22. Select any three high rise buildings designed by your office and fill the format below. (it is more helpful if the building has 15 stories and above including basement and mezzanine. But not mandatory)

No.	**Criteria**	**Building 1**	**Building 2**	**Building 3**	**Average**
1	Name of bld. (optional)				
2	Client (optional)				
3	Contractor (optional)				
4	Location (optional)				
5	Total area of the site				
6	Total built up area at ground floor				
7	Total area occupied by columns at GF				
	Total area of shear wall				
8	Total no of stories including basement and mezzanine				
9	Total height of the building				
10	Average floor to floor height				
11	Maximum base area of column at GF				
	Average clear height of rooms (Floor finishing to roof slab finishing)				
12	Minimum base area of column at GF				
13	Maximum beam length at GF				
14	Minimum beam length at GF				

15	Corresponding Maximum beam depth				
16	Corresponding minimum beam depth				
17	Total structural weight of the building				
	Select the critical column of your designed building and answer questions 18-21 accordingly.				
18	Max. Axial force in Z direction {KN}				
19	Maximum shear force in X direction {KN}				
20	Maximum shear force in Y direction {KN}				
21	Maximum bending moment {KN-M}Along the building				
	Maximum bending moment {KN-M}across the building				
22	Total cost estimated for beams (if possible)				
23	Total cost estimated for columns (if possible)				
24	Total cost estimated for slabs (if possible)				
25	Total cost estimated for Footing (if possible)				
26	Average total cost of structure per square meter of built up area at GF (if possible)				

We appreciate your cooperation on this research work and if you have any other helpful information that is not mentioned in our request, you can include here under.

Questionnaire Given to ______________________________

Contact Name _____________________________________

These questionnaires are prepared only for academic purpose.

G. To Steel engineering/Manufacturing companies

This research work is about promoting an alternative building construction technology called **Steel and Concrete composite structure**. It is more concerned with high rise building framing composing foundation, columns, beams and slabs to be made in a way that have never been practiced in Ethiopia.

The basics of the technology is that Steel sections with shapes of "I", "H", "C", "O", "□", "L" and other steel sections hot rolled and/or cold formed, sandwiched in a concrete covering to be considered as a monolithic member.

Most high-rise buildings in the developed world are believed to be more economical, fast construction, better earthquake resistant and wider column free spaces because they are made of this technology.

While we are studying this technology and its application in Ethiopia, we needed to assess the countries potential in row iron production, capacity of steel industries to produce bigger steel sections and limitations/challenges on the area.

The following are key information that will help us understand the existing and future steel producing and engineering potential of our country since the technology under study will come up with a huge demand of steel.

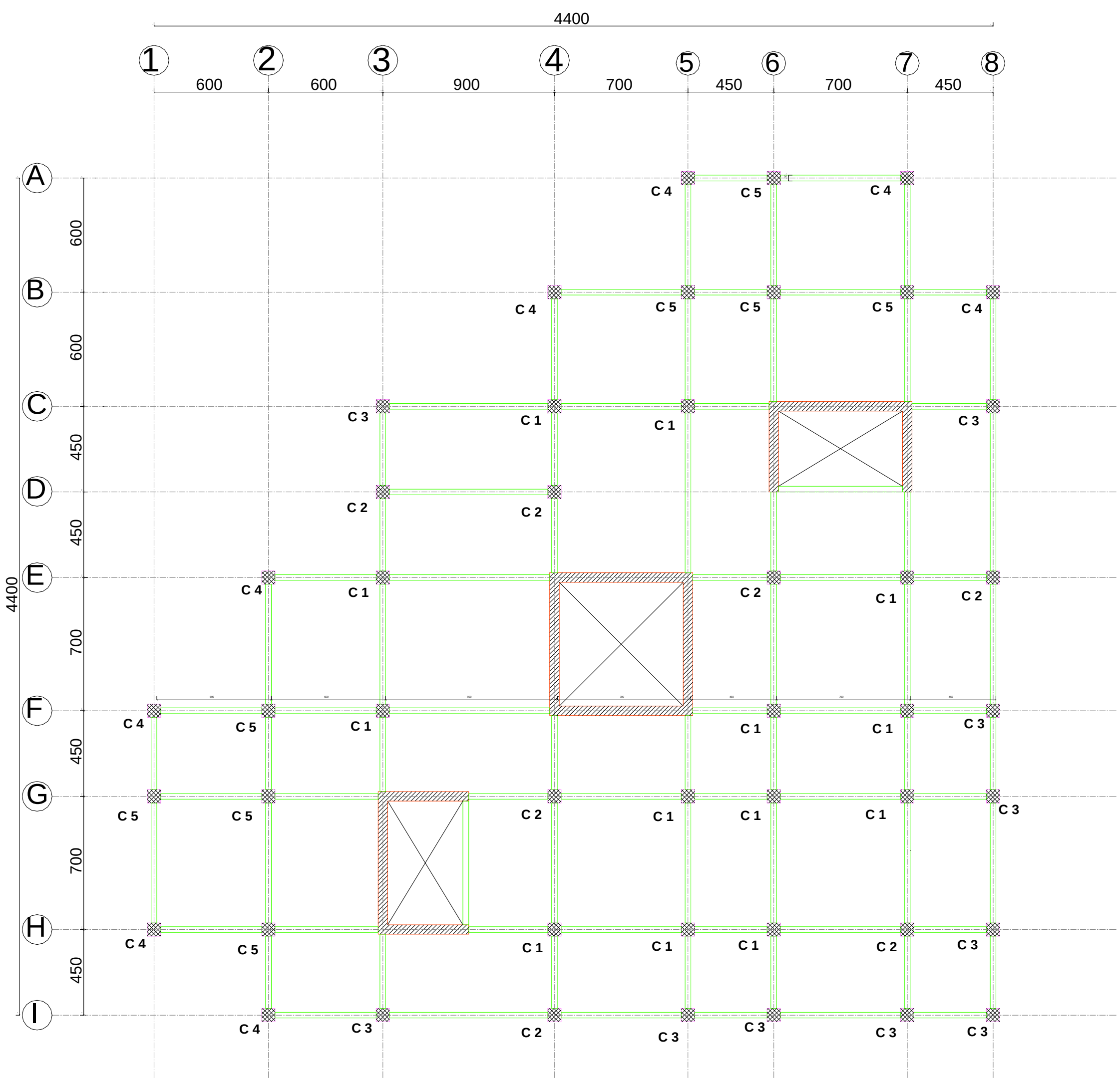
1. What kind of steel sections are your products

No	**Questionnaire**	**Productions by type**				
		1	2	3	4	Remark
1	Types(Grade) of steel you used					
2	Source of row material (imported, local industries or others)					
3	Steel grade					
4	Composition (Iron families)					
5	Types of products (Sections) you produce (e.g. I section, H section, C section, etc) Mention sizes if possible					
6	Flexibility of thickening (Range of thickening the flange, web etc)					
7	Flexibility of shape (range)					

8	Flexibility of size (Range of enlarging the web, flange or any)					
9	Yearly volume of production					
10	Future expansion of capacity in volume, type, shape and size					
11	Capacity of custom made production and your requirement from client					
12	What are the basics of price setting					
13	How much is your kilogram selling price per average					
14	I observe the selling price in the local market of imported steel is higher than yours. What do you think is the reason					
15	What shall be done by Government, Steel industries and others to maintain the steel price variation stable and fair					
16	Do you think none availability of iron mining in Ethiopia affects your price setting? By how much?					
17	Please write here any information you may have					

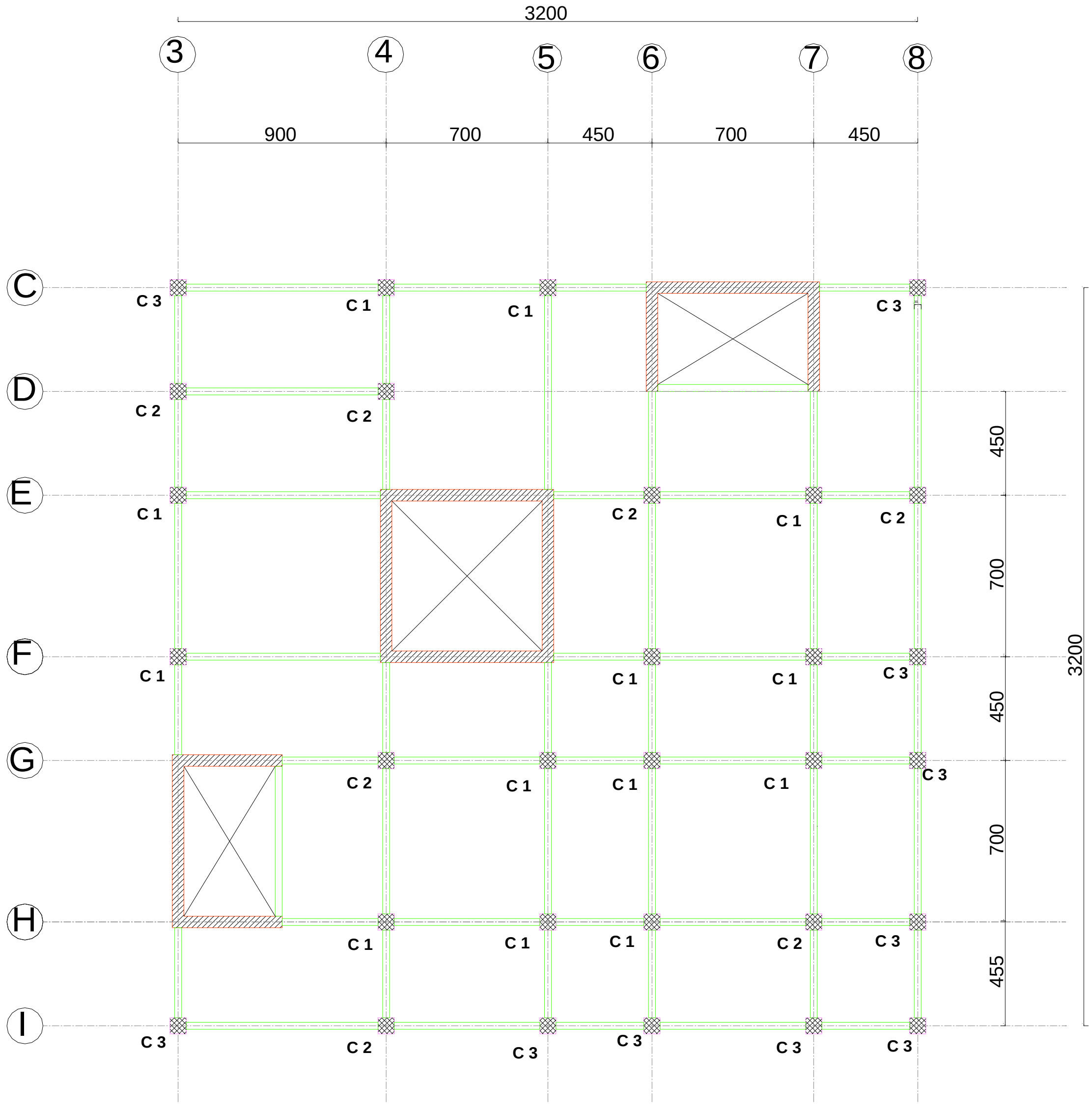
Appendix 3

Drawings



RC BUILDING THIRD FLOOR PLAN, BEAM AND COLUMN LAY OUT

FigI. *RC floors plan representing B2-4th Floor*



RC BUILDING FIFTH FLOOR PLAN, BEAM AND COLUMN LAY OUT

FigII. *RC floor plan representing 5th Floor-12th Floor*

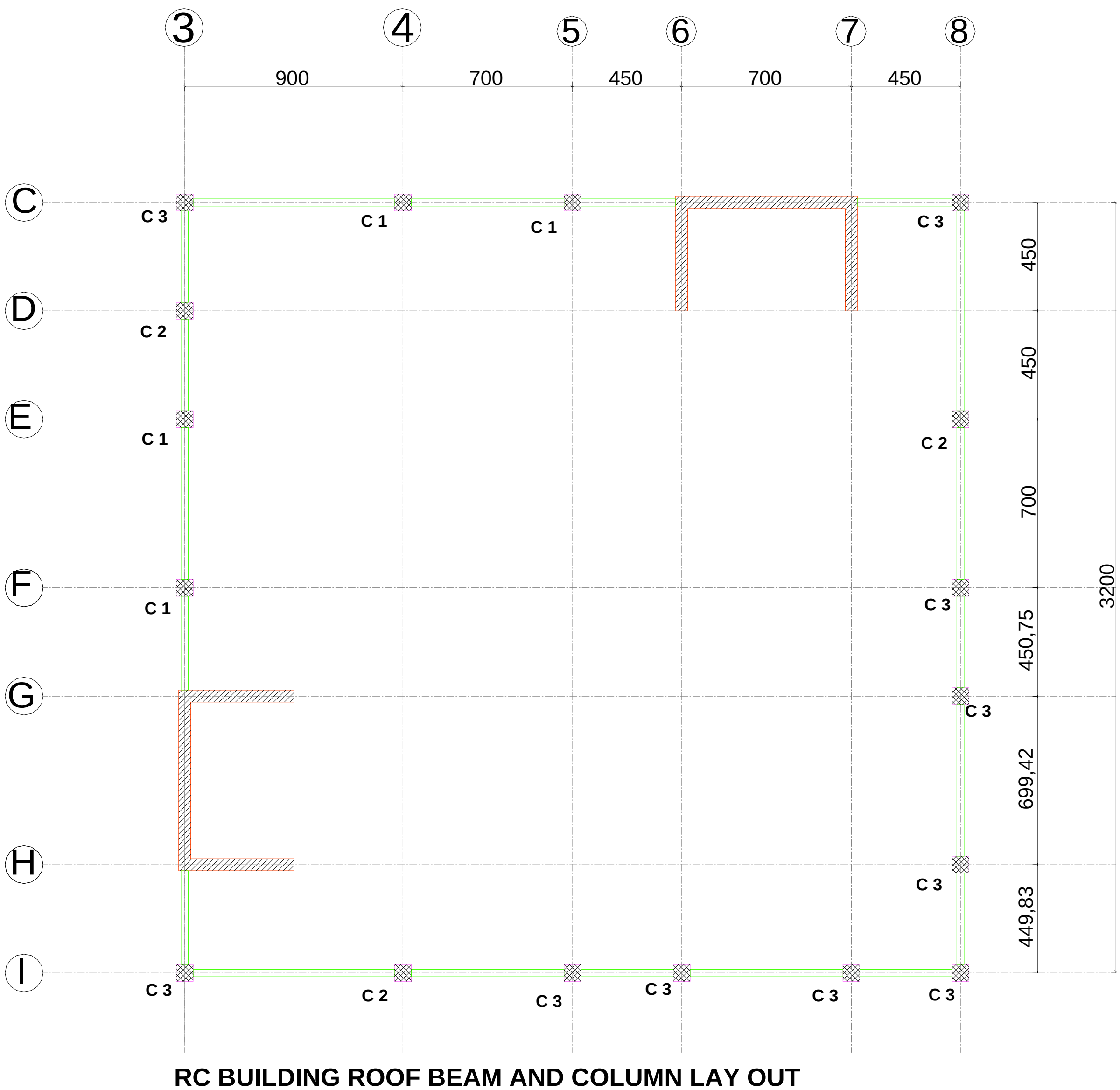
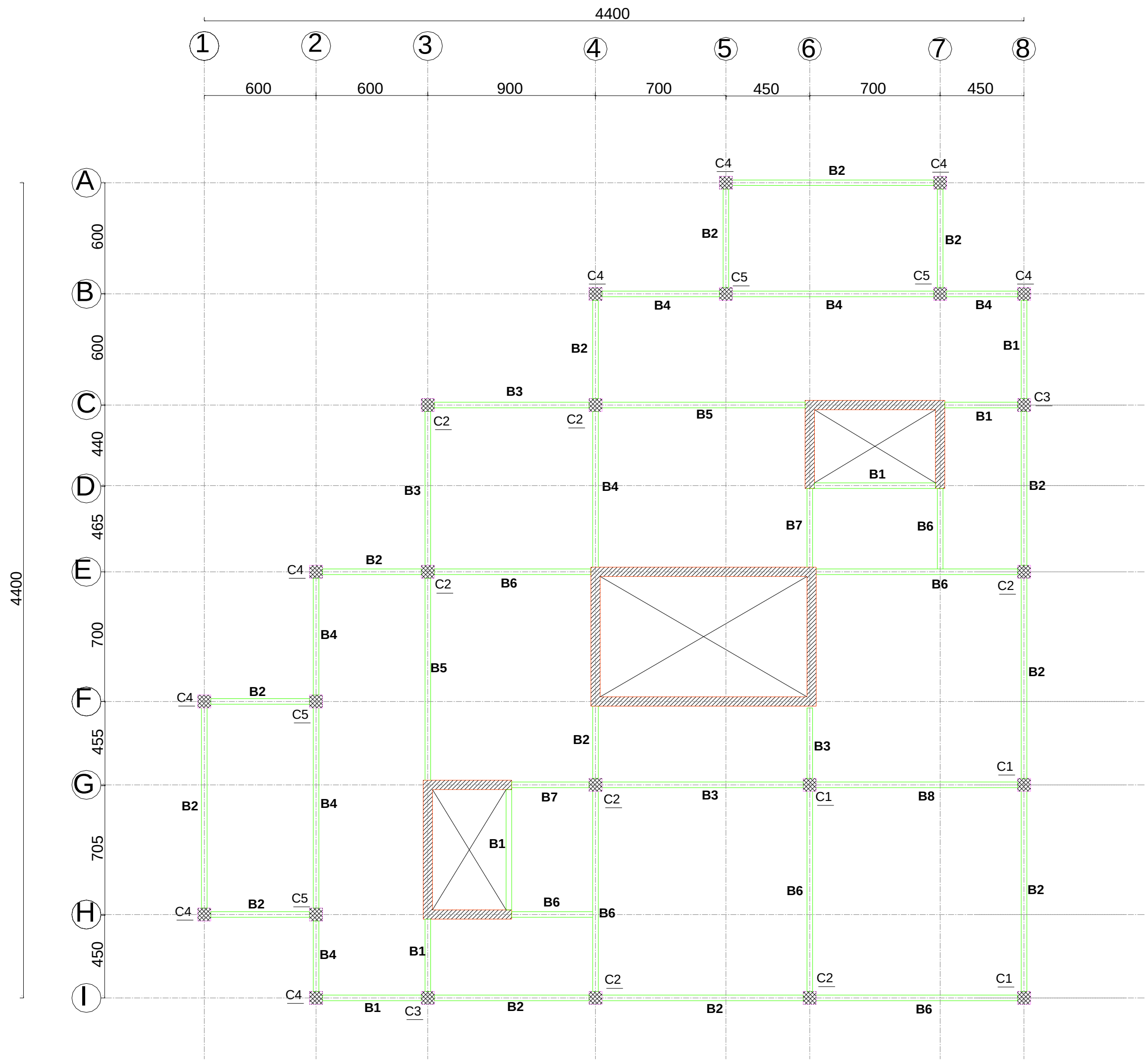
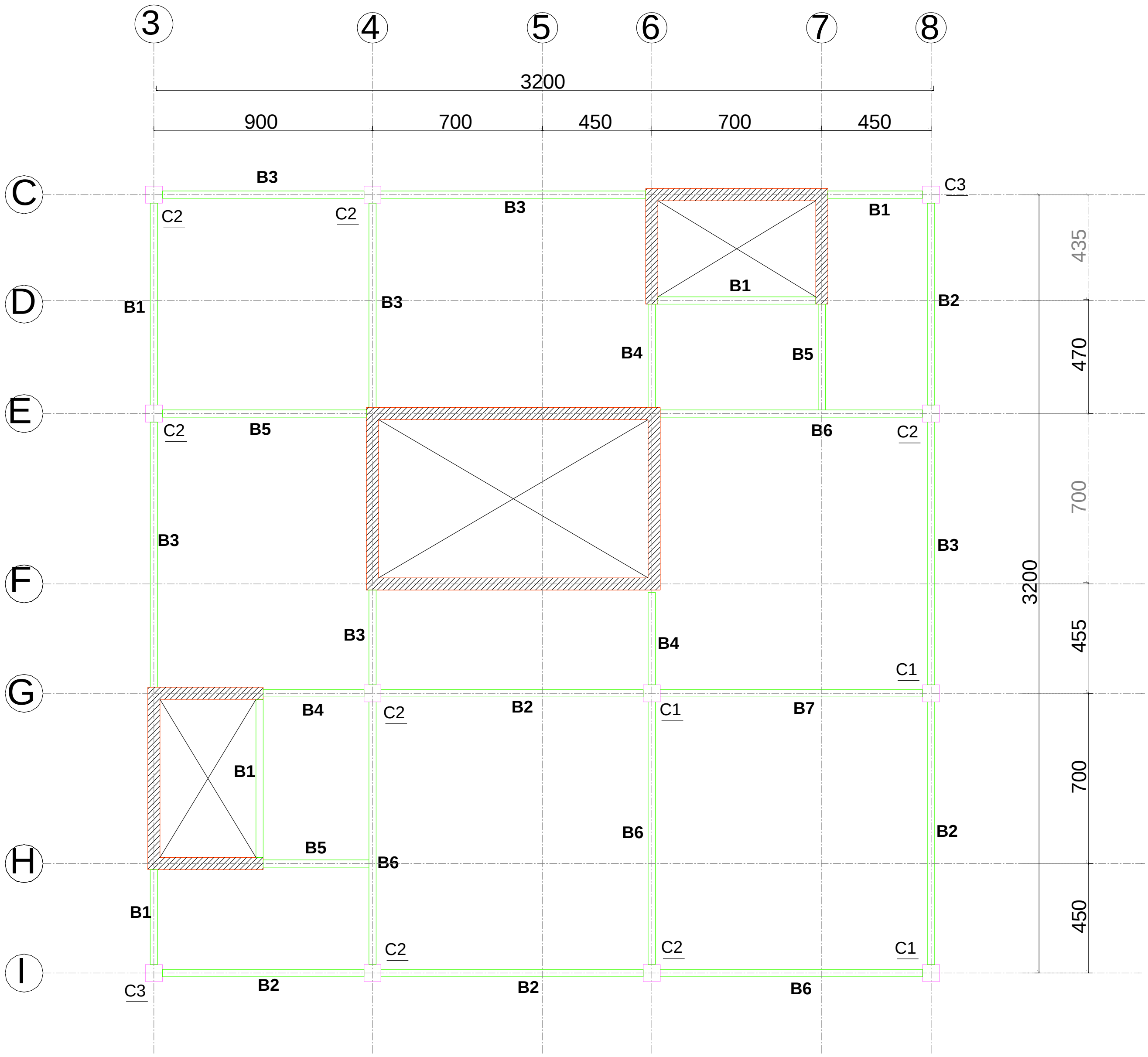


Fig III. *RC Floor plan representing top tie beam*



SCC BUILDING THIRD FLOOR BEAM AND COLUMN LAY OUT

Fig. IV. *SCC Floor plan representing B2-4th floor*



SCC BUILDING FIFTH FLOOR BEAM AND COLUMN LAY OUT

Fig. V. *SCC Floor plan representing* 5^{th}*-*12^{th} *floor*

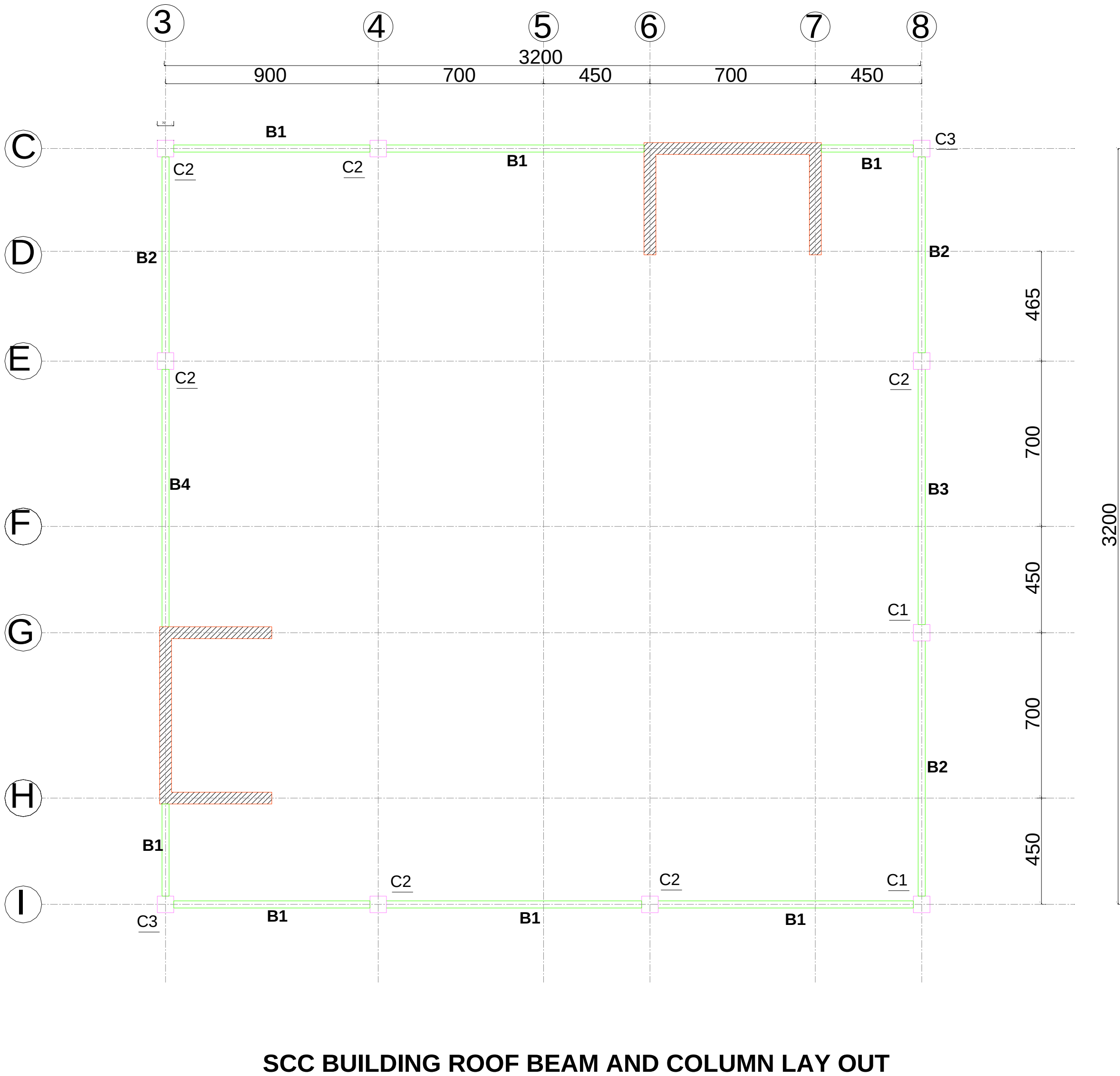


Fig. VI. *SCC Floor plan representing top tie beam*

	RC building						SCC building					
	B2-4th F		5th-12F		Top beam		B2-4th F		5th-12F		Top beam	
Span length	**Count**	**∑ Span (m)**	**Count**	**∑ Span (m)**	**Count**	**∑ Span (m)**	**Count**	**∑ Span (m)**	**Count**	**∑ Span (m)**	**Count**	**∑ Span (m)**
4.5	38	171	32	144	10	45	10	45	8	36	2	9
6	16	96	0	0	0	0	8	48	0	0	0	0
7	24	168	18	126	6	42	2	14	1	7	0	0
9	7	63	6	54	3	27	6	54	6	54	4	36
11	0	0	0	0	0	0	16	176	9	99	6	66
Total length	85	498	56	324	19	114	42	337	24	196	12	111
Average Span		**5.86**		**5.79**		**6.00**		**8.02**		**8.17**		**9.25**
Tot. Area to no. of beams ratio												
Tot. A	1438		1024				1438		1024			
No of beams	85		56				42		24			
A/No. of beam	**16.92**		**18.29**				**34.24**		**42.67**			
Tot. area to length of beams ratio												
∑beams	498		324				337		196			
A/L of beam	**2.89**		**3.16**				**4.27**		**5.22**			

Table II. *Comparison on spanning between RC and SCC*

Appendix 4

Comparison chart for government lease and individuals selling price

No		Land owning price 2013			Land owning price 2014			Land owning price 2015			Land owning price 2016		
		Gov. lease min	Gov. lease max	private sellers	Gov. lease min	Gov. lease max	private sellers	Gov. lease min	Gov. lease max	private sellers	Gov. lease min	Gov. lease max	private sellers
1	Bole	4000	12,000.00	10,000	5500	19,000.00	16,000	7500	19,000	30,000	8,000.00	22,000.00	50,000
2	Kazanchis	3500	12000	8,000	4000	12000	12,000	6000	15000	20,000	12000	20000	35,000
3	CMC	2500	6000	3,000	3000	8000	7,000	4500	10500	10,000	7500	12000	15,000
4	Mexico	3500	12000	10,000	4000	12000	12,000	6000	15000	18000	12000	20000	50000
5	Merkato	6000	6000	60,000	3500	10000	70,000	12000	14000	75000	14000	18000	150000
6	Nifas silk	2500	6000	8,000	2500	6000	10,000	3000	8000	25000	4500	12000	58,750
	Average	**3666.67**	**9000**	**16500**	**3750**	**11166.67**	**21166.66667**	**6500**	**13583.33**	**29666.66667**	**9666.667**	**17333.33**	**59791.66667**

Table III. *Government lease and private sellers land price*

Appendix 5

Item No	Type of material	Section dimensions						Suppliers 2015 price index/6m			Suppliers 2015 price index/kg		
		web width	**flange width**	**Web thickness**	**Flange thickness**	**cross section**	**weight /meter**	**A**	**B**	**C**	**A**	**B**	**C**
1	H section 100x100x5x6	0.1	0.1	0.005	0.006	0.0017	13.345	3,500.00	3480	3500	43.71	43.46	43.71
2	H section 200x200x8x10	0.2	0.2	0.008	0.01	0.0056	43.96	18,500.00	18000	18200	70.14	68.24	69.00
3	H section 300x300x10x14	0.3	0.3	0.01	0.014	0.0114	89.49	29,000.00	29500	29200	54.01	54.94	54.38
4	H section 125x125x5x6	0.125	0.125	0.005	0.006	0.002125	16.68125	5,900.00	6000	5850	58.95	59.95	58.45
5	I section 300x125x8x10	0.3	0.125	0.008	0.01	0.0049	38.465	15,000.00	15200	15100	64.99	65.86	65.43
6	I section 240x120x8x10	0.24	0.12	0.008	0.01	0.00432	33.912	9,300.00	9500	9450	45.71	46.69	46.44
7	I section 200x100x5x7	0.2	0.1	0.005	0.007	0.0024	18.84	4,800.00	5000	4900	42.46	44.23	43.35
8	C section 120x55x6x5	0.12	0.055	0.006	0.005	0.00127	9.9695	2,200.00	2100	2300	36.78	35.11	38.45
9	C section 200x75x6x5	0.2	0.075	0.006	0.005	0.00195	15.3075	4,700.00	4650	4650	51.17	50.63	50.63
10	C section 160x65x7x5	0.16	0.065	0.007	0.005	0.00177	13.8945	3,300.00	3280	3250	39.58	39.34	38.98
	Type of material	Thickness	Inner dim	Outer dim.		cross section	Weight/meter	A	B	C	A	B	C
11	Hollow section RHS 80x80x3	0.003	0.074	0.08		0.000924	7.2534	1,000.00	950	950	22.98	21.83	21.83
12	Hollow section RHS 60x60x3	0.003	0.054	0.06		0.000684	5.3694	680.00	720	700	21.11	22.35	21.73
13	Hollow section RHS 200x200	0.005	0.19	0.2		0.0039	30.615	3,900.00	3950	4000	21.23	21.50	21.78
	Type of material	Length	width	thickness	Area	volume	Weight/m2	A	B	C	A	B	C
14	Sheet metal 10mm	2	1	0.01	2	0.02	78.5	4,200.00	4100	4150	26.75	26.11	26.43
15	Sheet metal 12mm	2	1	0.012	2	0.024	94.2	4,700.00	4500	4800	24.95	23.89	25.48
16	Sheet metal 15mm	2	1	0.015	2	0.03	117.75	6,200.00	6180	6180	26.33	26.24	26.24

Table IV. *Steel price from Teklehaimanot suppliers shop*