

Cost Effectiveness of Composite Frames in Condominium Houses

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Abstract
Steel-concrete composite construction has gained wide acceptance worldwide as an alternative to pure steel and pure concrete construction. However, this system is a relatively new concept for the construction industry in Ethiopia. Reinforced concrete members are used in the framing system for most of the buildings since this is the most convenient & economic system for low-rise as well as short beam span.However, for medium to wide-spaced column in the building frames, this type of structure is no longer economic because of increased dead load, less stiffness, span restriction and hazardous formwork. Steel-concrete composite frame system can provide an effective and economic solution to most of these problems in medium to wide spaced column buildings. An attempt has been made in this study to explore the cost effectiveness of steel-concrete composite construction by taking condominium houses currently undergoing in our country for maximum column spacing above which the steel-concrete composite frame structure is cost effective. A cost versus frequently occurred maximum column spacing variation curves along both axes shows that for closely spaced column building frames structures, the conventional reinforced concrete frame system is cheaper than its equivalent steel-concrete composite system. However, this curves show for building frames with column spacing between 9 to 10m and greater than this span along both axes, steel-concrete composite construction has economical advantages than reinforced concrete construction and 9 to 12 and greater than this storeys, again, steel-concrete composite construction has economical advantages than reinforced concrete construction in our country.
Keywords: Composite column, composite beam, composite slab, shears connectors and Etabs

Introduction

Numerous different structural systems are used today to meet performance or functional requirements in structures. One of these structural systems is steel-concrete composite construction. It is widely used in structural systems to achieve long spans, lower story heights, and provide additional lateral stiffness.

Composite construction uses the structural and constructional advantages of both concrete and steel. Concrete has low material costs, good fire resistance, and is easy to place. Steel has high ductility and high strength-to-weight and stiffness-to-weight ratios.

When properly combined steel and concrete can produce synergetic savings in initial and life-cycle costs. Currently, composite floor systems are widely utilized in steel buildings in the form of composite beams and joists (trusses) **[24].**

Steel-concrete composite systems for buildings are formed by connecting the structural steel beam to the concrete slab or profiled deck slab with the help of mechanical shear connectors so that they act as a single unit **[14]**.Composite steel-concrete construction uses steel and concrete together to obtain a system with better performance, and/or lower cost, than using either material alone. A steel-concrete composite structural member contains both structural steel and concrete elements which work together**[14].**They have gained a wide acceptance worldwide as an alternative to pure steel and pure concrete construction. Pure steel as well as pure concrete has its own advantage and disadvantage. For example; Steel construction has many value benefits and advantage over traditional reinforced building construction. Steel in composite structures are used as permanent formworks in some parts of the structures, for example; in composite slab construction. Steel frame construction offers many advantages over traditional reinforced concrete with lower costs, sustainability and flexibility being amongst the many benefits of choosing steel framed buildings over the conventional reinforced concrete building construction. However, this system is venerable to fire and other sound insulation problems. To alleviate the above mentioned problems, it is good if the steel structures are covered with reinforced concrete (i.e. steel-concrete composite).But this is relatively new concept for construction industry in Ethiopia.

To bring this technology into practice, it requires a lot of works, giving awareness's to the (Kim, 2005) different sectors of the society and conducting different researches around it.

Research Problem

At present day the costs of condominium houses are increasing at alarming rate especially that of the cost of concrete is currently very high as compared to its cost that was even a year ago. So, as known that the composite structures are light weighted and their thicknesses are low; it reduces the consumption of concrete material and accelerates the construction period, since it requires less formwork as compared to normal reinforced concrete structures.

Use of composite or hybrid material is of particular interest, due to its significant potential in improving the overall performance through rather modest changes in manufacturing and constructional technologies.

Thus, it is important to make a cost comparative study of steel-concrete composite structures with its equivalent normal reinforced concrete structure.

Scope of the Research

The scope of the research is limited to the followings:-

- Conducting structural analysis and modeling composite frames /structures with different column spacing.
- Reviewing Structural analysis of a reinforced concrete condominium structures currently used by the Addis Ababa Housing agency.
- Cost comparison of particular condominium buildings currently being constructed with that of composite structures.

Objectives of the Research

The objectives of this research are:-

- To obtain the cost effective spacing of columns/span of beams (minimum spacing of column in which composite structures is economical) below which the construction of normal reinforced concrete condominium building and above which the composite condominium building will be effective.
- To compare normal reinforced concrete condominium building frame with that of its equivalent composite condominium buildings on the bases of construction cost of materials.
- To obtain the demarcation number of storeys above which the steel-concrete composite frame will be cost effective.

Significance of the Study

A study on cost effectiveness of the composite frames and its comparison with normal reinforced concrete frames structures is very important for the following reasons:-

- It may solve the existing high cost problem associated with the current condominium building in Addis Ababa by introducing the construction of composite structures in our country with effective cost.
- It may help us to practice the use of light weighted structures that minimizes the consumption of the concrete and reinforcement as well as construction time.
- It may also enable to advertise the use and advantage of composite structures to the contractors and stockholder of the condominium buildings by exploring its cost effectiveness's.

Methodology

This study will primarily employ quantitative research methods (i.e. computer based structural analysis and use of EBCSs(Ethiopian Building Code Standards))since the research objectives are aimed to obtain the economical/ cost effective spacing of columns and the height/Stories in which the composite condominium building will be cost effective.

The summarized methods for this research are as follows:-

- Reviewing different literatures.
- Reviewing structural analysis already done at Addis Ababa housing development agency for reinforced concrete condominium buildings and quantifying its component materials for frames of the building.
- Doing structural analysis and design of steel-concrete composite frames with different column spacing and quantifying its frames.
- Comparing the results of cost of the conventional reinforced concrete condominium building frames and steel-concrete composite condominium building frames.
- Selecting the demarcation point /economical column arrangement and spacing based on current cost analysis by considering their variation and;
- Selecting the demarcation storey above which the steel-concrete composite frame structure will be cost effective based on current cost analysis by considering their variation.

Analysis and Design of Steel-Concrete Composite Frame

Analysis of Steel-Concrete Composite Frame

In this study, a reinforced concrete moment resisting building frame (20.7 meters in width and 30 meters in length and 9 storey, one basement and one terrace floor), representing conventional (condominium building) types of buildings in a relatively low risk earthquake prone zone (Zone two) has been collected from Addis Ababa Saving Houses Development Enterprise. This frame has been first analyzed and designed by equivalent steel-concrete composite frame. Second, the arrangement of columns (column spacing) has been changed twice without altering the plan as well as the whole shape of the building. Thirdly, the height of the original building has been changed to different storey for the feasibility study of steel-concrete composite construction in Ethiopia. A sample floor and roof plans of the building is shown in Fig. 5, 6, 7 and 8. The design and analysis of the frame is conducted with three different heights of the building. During this change an attempt is made to make the frames' span width and length to be conforming to architectural norms and constructional practices of the conventional buildings in Ethiopia. Analysis of steel-concrete Composite frame is conducted using ETABS 2015 version 15.0.0. For earthquake analysis, dynamic method of analysis is used.

A 9-storey (G+7 with terrace floor) of Reinforced Concrete building analyzed and designed for gravity and earthquake loads in Addis Ababa housing development Enterprise, Ethiopia is also studied. The rectangular plan of the building is 20.7 m by 30m. The story height of the building is varying but the most frequently occurred story height is 3.23 m with a total height of 29.23 m. Sample structural system and its plan layout are shown in figure 6, 7 and 8.

The equivalent steel-concrete composite frame is designed in ten different models in order to achieve the objective of the research work. The 1st model is designated as model-1X which is with column spacing of 6m along x direction. The 2nd model is designated as model-2X which is with column spacing of 7.5m along x-direction. The 3rdmodel is designated as model-3X with column spacing of 10m along x-direction. The 4th model is designated as Model-1Y which is with column spacing of 5m along y-direction. The 5th Model is designated as Model-2Y with column spacing of 7.5m along y-direction. The 6th model is designated as Model-3Y with column spacing of 10m along y-direction. The 7th model is designated as Model-1Z with number of storey of 7. The 8th model is designated as Model-2Z with number of storey of 9. The 9th model is designated as Model-3Z with number of storey of 12 and the last model is designated as Model-4Z with number of storey of 15.

Design of steel-concrete composite frame

The design axial force and bending moments on both axis for column is taken from the software analysis result and the sample trial cross-section(for each model for column the terrace and ground column) is checked for different criteria as per EUROCODE-4, EN 1994-1-1:2004 (Plastic Resistance of the section, short term loading, long term loading, Resistance the composite column under axial compression for both major and minor axis, Resistance the composite column under axial compression plus biaxial bending for both axis, column resistance against combined compression and biaxial bending).

The optimum, economic and safe section for both main beam as well as secondary/infill beam is selected from Auto select section list by the software using EUROCOD-4and the sample axis(X-axis) beam is manually checked these sections for different criteria as perEUROCODE-4, EN 1994-1-1:2004 for construction stage (plastic moment resistance of steel section, plastic shear resistance, Bending moment and vertical shear interaction, lateral torsional buckling of steel beam) and composite stage(moment resistance of the cross-section, vertical shear and bending moment and shear force interaction, shear buckling, shear connector resistance).

The analysis and design is conducted for ten models of composite frames. Since the most frequently occurred maximum column spacing along x-axis is 6m, Therefore, the 1st model along this axis is the original dimensions/model; the 2nd model is for 7.5m column spacing along this axis; the 3rd model is for 10m column spacing along this axis again. the most frequently occurred maximum column spacing along y-axis is 5m, therefore ; the 4th model is for column spacing of 5m along y-axis; the 5th model is for column spacing of 7.5m along this axis ; the 6th model is for the column spacing of 10m along again this axis ; the 7th model is frame with number of storey of 7; the 8th model is frame with number of storey of 9; the 9th model is with number of storey of 12 and the last 10th model is frame with number storey of 15. The detailed sample design is presented in this chapter and step by step design procedures in more detail are presented in Annexes for the selected sample trials/models.

Design output and Discussion

Design output

The summary of necessary outputs obtained from data from structural design at Addis Ababa saving Houses Development Enterprise for reinforced concrete frame and design results for steel-concrete composite frame of model-1X, model-2X, model-3X, model-1Y, model-2Y, model-3Y, model-1Z, model-2Z, model-3Z and model-4Z are presented in Table 2, 3, 4,5 and Table 6 respectively. To show the whole process of computation involved in the design, sample design are shown in chapter three and the detailed representative design for sample models are attached in Annexes.

Summary on Outputs

Cost Analysis

The materials volume obtained from the output of the design and current material prices are used for the cost analysis in order to identify the economical span and storey of the steel-concrete composite frames. The cost of the steel-concrete composite frame will be indirectly proportional to the span length of the beam/column spacing. The cost of substructure will be the cost of foundations, which will not vary. For cost analysis, current values of construction costs including overhead cost are used here. Table 7 below shows the unit rate for different items.

Table 1 Unit price for materials

No	Material	Unit	Unit Price(Birr)
1	Reinforcing Bars	Kg	30
2	Concrete	m^3	3,100
3	Formwork	m^2	280
4	Structural Steel	Kg	57.8

An output of the results of the two types of building frames for reinforced concrete frame with column span of 6m and that of steel-concrete composite frames of beam span ranging from 6m to 10 m along x-axis and their total associated costs are summarized and tabulated in Table 13 below.

Table 2 Total costs for different span lengths along x-direction.

No.	Column spacing(in m)	Designation	Total Cost(Birr)	
			RC frame	Composite
1	6(Original Model)	Model-1X	5,431,174.26	6,227,169.10
2	7.5	Model-2X	-	6,195,569.18
3	10	Model-3X	-	5,151,052.61

Figure 11, shows a relationship between span length and total cost of a superstructure frame for beam span length of 6m for RC frame and 6m, 7.5m and 10m for steel-concrete composite frame along x-direction.

An output of the results of the two types of building frames for reinforced concrete frame with column span of 5m and that of steel-concrete composite frames of beam span ranging from 5m to 10 m along y-axis and their total associated costs are summarized and tabulated in Table 14 below.

Table 3 Total costs for different span lengths along Y-direction.

No.	Column spacing(in m)	Designation	Total Cost(Birr)	
			RC frame	Composite
1	5(Original Model)	Model-1Y	5,431,174.26	6,227,169.10
2	7.5	Model-2Y	-	6,009,328.29
3	10	Model-3Y	-	5,151,052.61

Figure 12, shows a relationship between span length and total cost of a superstructure frame for beam span length of 5m for RC frame and 5m, 7.5m and 10m for steel-concrete composite frame along Y-direction.

An output of the results of the two types of building frames for reinforced concrete frame with number of storey of 9 and that of steel-concrete composite frames of number of storey ranging from 7 to 15 and their total associated costs are summarized and tabulated in Table 15 below.

Table 4 Total costs for different number of storeys.

No.	No of storey	Designation	Total Cost(Birr)	
			RC frame	Composite
1	7	Model-1Z	5,431,174.26	6,227,169.10
2	9	Model-2Z	-	6,100,897.69
3	12	Model-3Z	-	5,151,052.61
4	15	Model-4Z	-	4,938,897.36

Figure 13, shows a relationship between number of storey and total cost of a superstructure frame for number of storey of 9 for RC frame and number of storey of 7, 9,12 and 15 for steel-concrete composite frame.

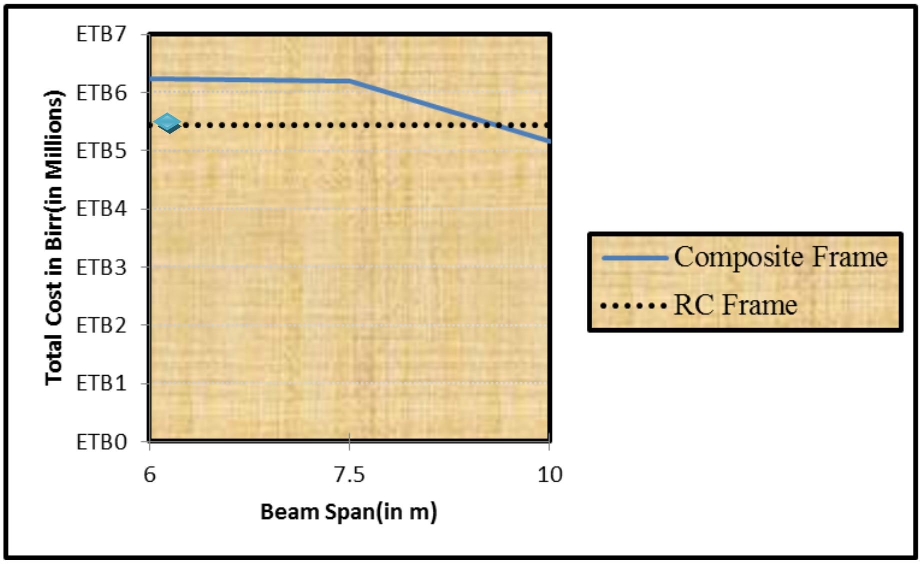

Fig. 1: Beam Span Length/Column Spacing Vs Cost graph along x-direction

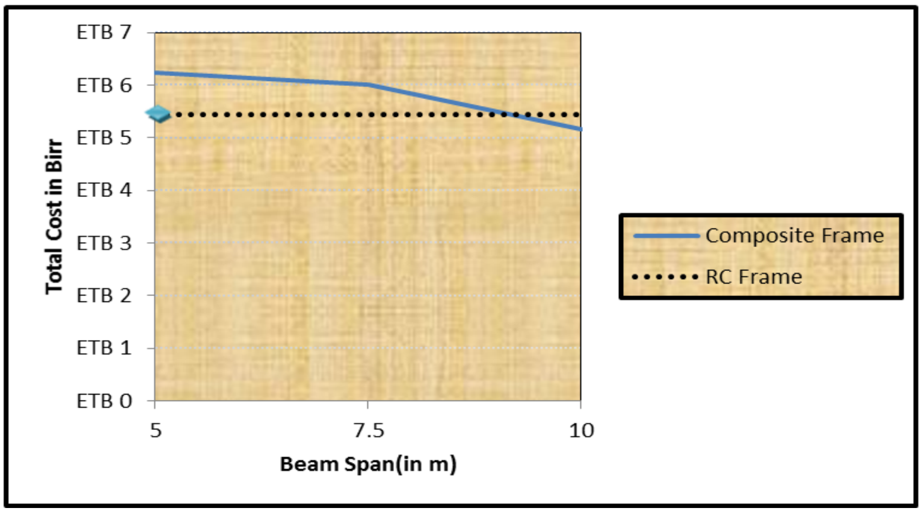

Fig. 2: Beam Span Length/Column Spacing Vs Cost graph along Y-direction

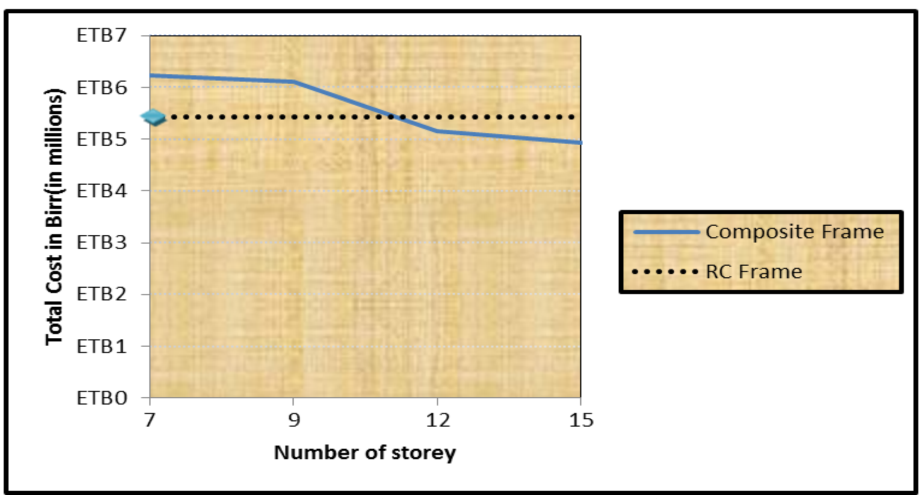

Fig. 3: Number of storeys Vs Cost graph

Discussions

The total cost of the superstructure of a building frame is considered as a criterion for the comparative study of the building frame.

Form the above tables and graph it can be pointed out that, the cost for Reinforced Concrete frame structure is assumed to be constant. And the estimated cost for steel-concrete composite frame structure has been done by varying the frequently occurred maximum column spacing along both axes that is 6m which is along x-axis and 5m which is along y-axis. At 6m column spacing along x-axis, the cost for the two frame structures has been estimated. At 7.5m column spacing along this axis, the cost for steel-concrete composite frame structure has been estimated. Again for column spacing of 10m along this axis, the cost for steel-concrete composite frame structure has been estimated and tabulated in table 13.

The cost versa column spacing has been plotted and shown in figure 11. At 5m column spacing along y-axis, the cost for the two frame structures has been estimated. At 7.5m column spacing along this axis, the cost for steel-concrete composite frame structure has been estimated. Again for column spacing of 10m along this axis, the cost for steel-concrete composite frame structure has been estimated and tabulated in table 14. The cost versa column spacing has been plotted and shown in figure 12.

At 9 storeys, the cost for the two frame structures has been estimated. At 7 storeys, the cost for steel-concrete composite frame structure has been estimated. At 12 storeys, the cost for steel-concrete composite frame structure has been estimated. Again at 15 storeys, the cost for steel-concrete composite frame structure has been estimated and tabulated in table 15. The cost versa number of storeys has been plotted and shown in figure 13. The cost for reinforced concrete frame at 6m and the cost for steel-concrete composite frame at column spacing between 9 to 10m are the same along x-axis. Again, the cost for reinforced concrete frame at 5m and the cost for steel-concrete composite frame at column spacing between 9 to 10m are the same along y-axis.

The cost for reinforced concrete frame at 9 and the cost for steel-concrete composite frame at storeys ranging 9 to 12 are the same. If the cost of concrete increases at alarming rate, the above cost effective column spacing will be decreased and vise versa. If the cost of concrete increases at alarming rate, the above cost effective number of storeys will be decreased and vise versa. If the cost of structural steel increases at alarming rate, the cost effective column spacing and number of storeys will be increased and vise versa.

Conclusion and Recommendation

Conclusion

In this study, the comparative study of Reinforced concrete frame structure and steel-concrete Composite frame structure for multistoried condominium building frame (G+7) typology is presented. Parameters considered are cost of frames for reinforced concrete frame and steel-concrete composite frames as well as column spacing and number of storeys and from that result conclusions can be drawn-out are as follows:-

- At frequently occurred maximum column spacing i.e. 6m which is along X-axis and 5m which is along y-axis, the cost for steel-concrete composite frame is much higher than that of the reinforced concrete frame or steel-concrete composite is uneconomical in our country at this column spacing.
- At 7.5m of frequently occurred maximum column spacing along both axes, again the steel-concrete composite frame is uneconomical in our country.
- Finally, it is found and concluded that when the column spacing is between 9 to 10m,the frames structure have same cost and above this column spacing the steel-concrete composite frame structure is cost effective than ordinary reinforced concrete frame and when the number of storey is 9 to 12, the frames structure have same cost and below this number of storeys, RC frame is cost effective and vise versa.
- As reviewed in different literatures, the optimum column spacing and number of storeys for steel-concrete composite frame structures is 6 to 12 meters and 10 storeys respectively and the results are within this interval.

Recommendation

The following recommendations can be drawn starting from results and conclusion:

- Since the prices of materials are fluctuating/changing dynamically, this obtained result will also change accordingly. Therefore; this result works only for limited period of time of nearly stabile price.

References

1. Ethiopian Building Code Standard:EBCS-8(1995):DESIGN OF STRUCTURES FOR EARTHQUAKE RESISTANCE. Addis Ababa: Ministry of Works and Urban Development.
2. Ethiopian Building Code Standard:EBCS-3(1995):DESIGN OF STEEL STRUCTURES. Addis Ababa: Ministry of Works and Urban Development.
3. Design of Simply-Supported Composite Beams for Strength (To Australian Standard AS 2327.1−1996).

Australia: OneSteel Manufacturing Limited ,ABN 42 004 651 325.
4. Ethiopian Builing Code Standard:EBCS-1 (1995). BASIS OF DESIGN AND ACTIONS ON STRUCTURES. Addis Ababa: Ministry of Works and Urbun Development.
5. A.Bradford, D. J. (1999). Elementary Behaviour of Composite Steel-Concrete Structural Members . London: British Library Cataloguining.
6. Aniket Sijaria, P. A. (June– 2014). Cost comprison between RC beam& steel composite beam . International Journal of Computational Engineering Research (IJCER) , 35-37.
7. Ethiopian Building Code Standard:EBCS-4(1995):Design of Composite Steel and Concrete structures. Addis Ababa: Ministry of Works and Urban Development.
8. Begum, M. (2013). Cost Analysis of Steel Concrete Composite Structures . Asian Journals of Civil Engineering , 935-944.
9. Eurocodes Development (2001): Structural Steelwork.
10. Hanoi, V. (2007). Modern design, construction and maintenance of composite steel-concrete structures: Australian experiences. International Conference on Modern Design, , 42-48.
11. JOHNSON, R. (1994). Composite Structures of Steel and Concrete (Vol. 1). London: Blackwell Scientific Publishers.
12. Lawson, R. (1994). Composite Beam Design to Eurocode 4.
13. R. Lawson, DD ENV 1994 -Eurocode 4: Design of Composite Steel and Concrete structures (p. All). Europe: British Constructional Steelwork Association Limited .
14. Marathe, D. R. (2011, December). Comparative Study of R.C.C, Steel and.composite structures.INSTITUTE OF TECHNOLOGY, NIRMA UNIVERSITY, AHMEDABAD , 382-481.
15. Shah, A. N. (2013). Comparision Of R.C.C. And Comosite Multistoried Buildings.International Journal of Engineering Research and, 3 (2), 354-359.
16. Shashikala. Koppad, D. S. (2013). Comparative Study of RCC and Composite. International Journal of Engineering and Innovative Technology (IJEIT), 3 (5), 341-344.
17. Shweta A. Wagh D. U. (2014). Comparative Study of R.C.C and Steel Concrete Composite. Shweta A. Wagh et al Int. Journal of Engineering Research and Applications, 4 (4), 369-376.
18. Ethiopian Building Code Standard :EBCS-2(1995):STRUCTURAL USE OF CONCRETE. Addis Ababa: Ministry of Works and Urban Development.
19. Tedia, A. (2014). Cost, Analysis and Design of Steel-Concrete Composite. IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE), 11 (1), 54-59.
20. Uy, P. B. (April 2010). The power of steel and concrete. Research Direction , 1-2.
21. W.Dolan, A. H. (2010).Design of Concrete Structures (4th ed.). America: McGraw Hill.
22. Yuen, L. a. (2001). A Resource Book for Structural Steel Design and Construction. Singapore : Singapore Structural Steel Society and Building And Construction Authority, .
23. Design of Steel-Concrete Composite Structures .(2013),Lecture Notes By DR. Girma Z. School of Civil and Environmental Engineering, Addis Ababa Institute of Technology,AAU.
24. Dong Keon Kim.(2005) A DATABASE FOR COMPOSITE COLUMNS.Georgia Institute of Technology, USA