LIFE-CYCLE-ANALYSIS OF STEEL- INTENSIVE SUSTAINABLE CONSTRUCTION

T. K. Bandyopadhyay*, Ph.D (Eng.), FIE (I), FIIBE (I), FIV (I), MISET (Roorkee), Chartered Engineer

ABSTRACT

Environment and sustainable development are by now familiar terms since the Rio Earth Summit a decade ago. It suggests eliminating or at least reducing unsustainable patterns of production and consumption based on relevant demographic policies. Earlier, the benefits of designing buildings could be quantified in terms of energy savings only. Now the challenge to the industry is to create buildings that are suitable for 21st century requirements and beyond. It is felt that Life cycle assessment is the most dependable measure to ascertain reliability of any construction material. Relevant standards, such as ASTM (E917) and IS (13174), and standard methods of Life Cycle Cost (LCC) analysis consider the total cost including interest during construction (IDC) on average investment, differential rentals for early completion, maintenance and repair costs, social costs, energy costs and other related costs, and the end use value rather than the direct cost alone while comparing different options. A recent study (INSDAG 2003 and 2002; Bandyopadhyay 2000) of urban commercial buildings as well as residential buildings reveals that steel-concrete composite construction will have lower LCC values over reinforced cement concrete (RCC) options. It shows that lower construction cost alone may not necessarily offer the overall cost-time combined economic viability as well as lowest LCC, which provide the optimum solution to the owner, builder and society (or nation). Steel-concrete composite construction requires shorter construction time compared to the RCC option. Early completion of the work reduces interest burden on capital invested and also fetches early rental value. Further, for lesser dead weight, cost of the foundation as well as total construction cost is lower for the steel-concrete composite construction compared to the conventional RCC construction. Thus, lower initial cost (construction cost combined with IDC) leads to more profits for the steel intensive buildings corresponding to the sales price considered. Considering the construction time gain of steel intensive buildings, LCC reduces further compared to the competitive options, when all elements of cost including maintenance, interest during construction, rental value, is considered. It shows that for lower initial as well as maintenance cost, the profits of different steel intensive buildings are greater as compared to the RCC option corresponding to the sales price considered. Hence, adaptability, assured quality, durability, flexibility, high strength and pre-fabrication coupled with other advantages e.g. recycling, reuse, and waste reduction make steel a unique material for construction. Thus, steel ought to be considered the material of choice in all “Sustainable Construction”, since it offers innovative design and construction solutions apart from satisfying the environmental benchmarks.

INTRODUCTION

Environment and sustainable development are by now familiar terms since the Rio Earth Summit a decade ago. The Rio declaration of 1992 proclaimed that in order to achieve sustainable development, environmental protection shall continue to be an integral part of the development process and cannot be considered in isolation. It also suggests to reduce/eliminate unsustainable patterns of production and consumption based on relevant demographic policies. Not withstanding the success of Johannesburg Summit, is evident that, people in general are much more aware today that environmental depletion has serious ramifications on the quality of life. This awareness has seen a greater demand by consumers for sustainable units. The Steel Sector Committee for Sustainable Construction (SSCSC) has also coordinated with the Corus Construction Centre, UK (CORUS), the Steel Construction Institute (SCI) and the British Constructional Steelwork Association (BCSA) to promote the concept of Sustainable Construction (CORUS 2001 and 2003).

Since our planet has finite limits to its capacity for self-regeneration and with the increase of world population, there is a need for international policies to support sustainable development. Thus, the

* Dr. T K Bandyopadhyay, Dy. Director General & HOD (Technical Development & Standard) Institute for Steel Development & Growth (INSDAG), Ispat Niketan, 52/1A Ballygunge Circular Road, Kolkata – 700 019, India

challenge to the industry is to create buildings that are suitable for 21st century requirements and beyond. This requires a comprehensive approach to design buildings to provide efficient usage of energy, promote resource conservation, and use environmentally better materials.

Steel is unique among major construction materials since it contains recycled content. It is completely recyclable at the end of its useful life. The document on “Recycling and Re-Use in Steel” (CORUS 2001a) clearly states that the recycling process progressively reduces the environmental burdens associated with each successive application, providing a robust foundation for sustainable development.

The American Institute of Architects (AIA) in their Environmental Resources Guide (AIA 1994) recommends that steel is environmentally less harmful than many other competitive options because of the large recycled content of steel components. Generally, steel intensive buildings/structures are considered to possess improved environmental performance (SCI 1999; Coskun 2002; IISI 2003) based on the following:

- Lower operating as well as effective embodied energy
- Better thermal performance (making energy efficient enclosures)
- Lesser volume and weight of construction material and thereby reducing the cost of transportation
- Adaptability to changes and reuse
- Comprehensive recycling of both individual buildings as well as the whole construction without any wastage
- Facility of pre-engineering and off-site prefabrication for precise tolerance
- Modular construction using light steel framing to reduce energy use particularly because air tight barrier which can be readily included in light steel framed construction, reduces heat loss (SCI 1999) through air infiltration and thus improving comfort

Thus, it is essential to create further awareness among construction practitioners, developers and end users towards the improved environmental performance of steel intensive buildings and to promote usage of steel as an efficient building material.

However, Life Cycle Cost (LCC) is an important concept, which considers the total cost incurred for a structure throughout its life instead of only the construction cost. It is felt that LCC assessment is the most dependable measure to ascertain suitability of any construction material. A building having lowest LCC will offer the most cost effective solution to the designers, planners, decision makers and investors. Also LCC offers practical solutions for sustainable construction. For example, the document (SCI 1999) by Steel Construction Institute (SCI) highlights the benefits in steel-intensive construction.

The background study for this paper, which is based on Projects (INSDAG 2002 and 2003), wherein typical commercial and residential buildings have been evaluated to calculate both direct cost and life cycle costs with respect to two alternative modes of construction: reinforced cement concrete (RCC) construction and steel intensive (steel-concrete composite) construction. The size and general specifications of each of the buildings for both the options have been considered identical.

This paper investigates commercial buildings that include a four-storey modern shopping center (66m x 18m - G+3 type) and a nine-storey modern commercial office building (72m x 18m – G+8+Basement type), both having modern amenities, state-of-the-art finishes and detailed specifications. Two Indian cities (Calcutta and Delhi) have been considered as the possible locations for construction sites at Salt Lake and Noida respectively. The proposed site is in a reasonably congested area but not in the Central Business District of the two cities where higher rental charges might have favoured the steel option.

The design carried out in INSDAG is based on latest and relevant building codes. For the steel option, modern methods of composite construction (as being practiced in UK) have been used. The life cycle costs include: direct cost, time cost, periodic maintenance cost, major repair cost, and end use value. The LCC has been assessed for two different time periods: 30 years and 80 years. The LCC summary tables have been computed based on the discounted cash flow (DCF) method considering two different discount rates: 12% (nominal discount rate) and 6% (real discount rate). “Nominal discount rate” is not treated against inflation, while “Real discount rate” is applicable if the inflation rate is deducted. In India, most of the bigger projects are taken up with borrowed/private capital. The Planning Commission uses a discount rate of 12%. The World Bank also recommended a discount rate of 12% for analysis of projects in the developing countries. Thus discount rates are calculated for borrowed capital, which is essentially the weighted average cost of capital. Considering an 80:20 debt-equity ratio (since 100% debt is normally not available), the discount rate works out to 12% (nominal), and 6% (real) considering an inflation rate of 6%. However, in the developed countries, the discount rates are much lower.

The study also carried out design (INSDAG 2003) and LCC analyses of G+20+Basement residential buildings with a maximum height of 63 meters for RCC construction as well as six combinations of steel-concrete composite construction based on different variants such as height, floor area, brick as well as lighter panel as cladding material. All the options (seven types) are compared to arrive at the optimum solution. Two different time periods are considered: 30 years and 100 years. The nominal and real discount rates considered are 12% and 8% respectively.

STUDY OF STEEL-CONCRETE COMPOSITE AND RCC BUILDINGS

Design of structural members with maximum efficiency and minimum cost is always a challenge to the architects and engineers. In composite construction, the most important and frequently encountered combination is made of structural steel and concrete. This type of composite construction has wide application in buildings (both commercial and residential construction). In this paper, a study has been made to assess the LCC of steel-concrete composite construction vis-à-vis RCC construction for structures up to about 60 meters height.

In building construction systems, the life cycle costs considers material costs right from manufacturing stage to transportation, construction, building operation as well as maintenance, demolition at the end of useful life and finally recycling. In order to make decisions based on life cycle analysis, it is essential to have high quality data, transparent and established methodology and technical rigor. . According to work carried out by CORUS (CORUS 2001b), steel data in support of life cycle assessment is among the most reliable and transparent of any construction material. This is easily available to substantiate external studies aimed at providing practical solutions for sustainable construction. The guidelines normally set on the construction are based on an environmental ethic dependent on a few core indicators as follows:

- Recyclables, minimum consumption of energy and minimization/avoidance of waste
- Utilization of renewable resources and protection of natural resources
- Protection of people and conservation of water and soil quality

Typically, the embodied energy of steel structures is very small when compared to total energy consumption of a building over its life cycle. According to Honnes et al. (2002), the following are significant when selecting the construction material of a multi-storey building:

- No operational energy benefit in the passive thermal performance of conventional buildings compared to the modern steel intensive buildings.
- Relative values of embodied energy as compared to operational energy have been assessed indicating that, on average, maintenance and use are responsible for about 75% of environmental impact whereas share of building made of composite construction (steel frame along with concrete floors) is about 6% only.

The Ministry of Non-conventional Energy Sources, Government of India (MNES), is supporting activities pertaining to sustainable construction. More than 40 such projects have been reported climate-wise to highlight the energy-efficiency measures adopted after studying macro and microclimate of the site suiting to the conditions. Though a LCC study has not been made for the project undertaken by MNES, designing and developing buildings based on sound concepts of energy efficiency and sustainability had improved resource utilization.

The primary steps adopted by MNES in this respect are:

- Introduce solar passive techniques in a building design to minimize load on conventional systems (heating, cooling, ventilation and lighting)
- Introduce energy efficient lighting as well as HVAC systems
- Usage of renewable energy systems to meet at least a part of electrical load of the building
- Usage of low energy materials and the corresponding methods of construction

But, based on recent studies (INSDAG 2002 and 2003; Bandyopadhyay 2000), using life cycle assessment techniques, this paper attempts to prove that steel intensive construction leads to a wider range of benefits including reduced maintenance costs, reduced initial cost of construction, more usable space and better occupant control over the environment than the other construction types in the study.

Applicable Codes (ASTM E 917, IS 13174) as well as the standard methods of LCC Analysis consider the total cost of a structure including interest during construction (IDC) on average investment, differential rentals for early completion (for the steel option), the maintenance and repair cost, social cost, energy cost etc, and the end use value rather than the direct cost alone while comparing different options.

Table 1 shows the cost of different building elements as a percentage of total construction cost for G+3 and G+8+Basement type buildings. Figure 1 shows LCC summary of the RCC and steel-concrete composite buildings considered for the study period of 30 years and 80 years with real discount rate and nominal discount rate as 6% and 12% (identified in the figure) respectively.

TABLE 1
Cost as percent of total construction cost for (G+3) and (G+8+B) Buildings

Building elements	Cost as % of total construction cost for (G+3) Building				Cost as % of total construction cost for (G+8+B) Building			
	Calcutta		Delhi		Calcutta		Delhi	
	RCC	Steel	RCC	Steel	RCC	Steel	RCC	Steel
Foundation system	4.48	2.83	2.02	1.39	8.01	5.42	3.36	2.59
Columns & grid beams, floors and secondary beams	7.35	12.03	7.54	12.20	7.96	15.17	8.36	15.77
Envelope (brick/wall, curtain wall etc)	33.18	31.36	34.03	31.82	12.16	11.21	12.77	11.52
Flooring and finish items	10.26	9.21	10.53	9.35	9.93	8.84	10.43	9.09
Fire protection	0.0	2.30	0.0	2.33	0.00	2.29	0.00	2.35
Miscellaneous	1.87	1.76	1.91	1.79	2.22	2.03	2.33	2.09
Plumbing & sanitary	1.18	1.11	1.21	1.13	1.09	1.00	1.14	1.03
Services and utilities	41.68	39.40	42.76	39.98	58.63	54.04	61.61	55.56
Total (percent)	100	100	100	100	100	100	100	100

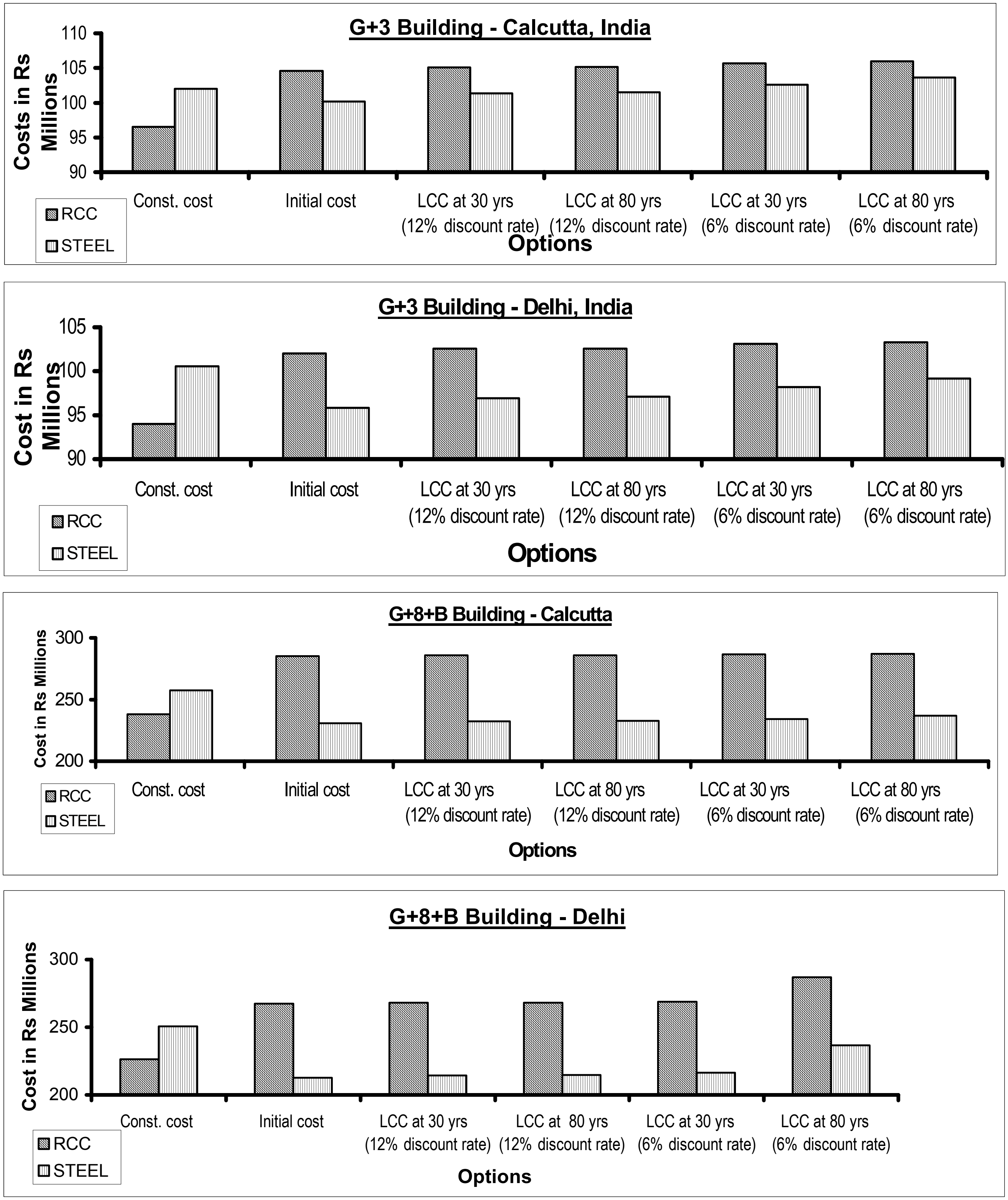


FIGURE 1 - The economics of [G+3] and [G+8+B] buildings for two cities (Calcutta and Delhi)

Initial cost includes construction cost along with IDC on average investment, and differential early rentals for steel option. Future cost includes routine inspection and regular maintenance cost, periodic maintenance cost, repair/renewal cost, and end use value of the scrap material. Life Cycle Cost (LCC) is the total effect of initial cost combined with future cost.

Table 2 includes a comparative study of net costs and percent profit of RCC (B+G+20) residential buildings compared to a number of steel-concrete composite options.

TABLE 2
Comparative Study of Net Cost and Profit of (B+G+20) Storied Residential Buildings

Option No.	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Frame Type	**RCC**	**Composite**	**Composite**	**Composite**	**Composite**	**Composite**	**Composite**
Floor-to-Floor ht. (m)	3.15	3	2.85	2.85	2.85	2.85	3
B+G+	20	20	21	20	20	21	20
Cladding Type	Brick Cladding				Lighter material (M2 Panel)		
Total Cost INR (x 10^6)	86.00	84.40	85.70	82.30	79.50	81.30	80.80
Total m^2	16150	16150	16918	16150	16150	16918	16150
Cost per m^2	5325	5226	5065	5096	4922	4805	5003
[Items % cheaper]							
Framing	0	-2.06	-6.8	-1.31	-1.04	-5.56	-0.39
Cladding	0	-11.12	-4.67	0	15.63	12.49	7.24
Foundation	0	18.05	15.35	18.78	23.51	20.98	22.47
% Cheaper than Option no. 1	0	1.86	0.35	4.30	7.56	5.47	6.05

[Total Cost – INR (x 10^6)]

IDC @11.75%	15.16	11.90	12.08	11.60	11.21	11.46	11.39

Rental Value Saved INR (x 10^6)	0.00	-12.90	-13.50	-12.90	-12.90	-13.50	-12.90

(Considering 8 months saving due to Composite Construction by a Standard Contractor}

Net Cost (INR (x 10^6)	101.16	83.38	84.25	80.98	77.79	79.23	79.27
Total Rental Value INR (x 10^6)/ Yr	19.38	19.38	20.30	19.38	19.38	20.30	19.38

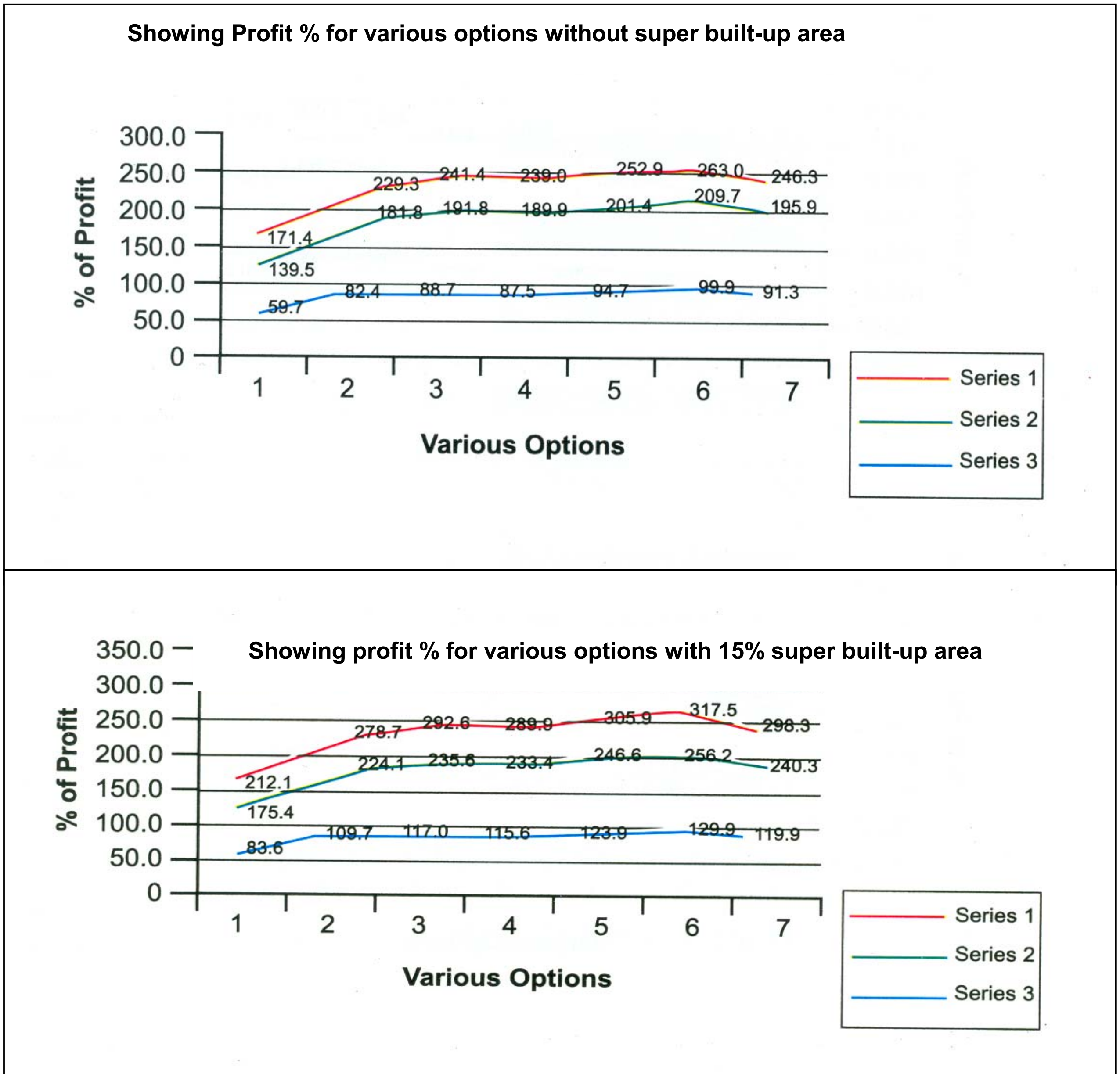
(For rental INR 100 per m^2)

Payback period - Yrs	5.2	4.3	4.2	4.2	4.0	3.9	4.1

Sales Price (INR/m^2)	17000	17000	17000	17000	17000	17000	17000

Total Sales Price INR (x 10^6) without Super built–up %	274.60	274.60	287.60	274.60	274.60	287.60	274.60
Profit INR (x 10^6)	173.40	191.20	203.40	193.60	196.80	208.40	195.30
Profit - percent	171	229	241	239	253	263	246

Figure 2 shows the percent profit for various options of steel-concrete composite as well as RCC buildings considered. This includes variations of costs for different sales prices and rental charges (with and without super built-up area).



Series 1: For sales price of INR 17000/- per m^2 and rental charge of INR 100 / per m^2
Series 2: For sales price of INR 15000/- per m^2 and rental charge of INR 80 / per m^2
Series 3: For sales price of INR 10000/- per m^2 and rental charge of INR 60 / per m^2

FIGURE 2 - Variations of Costs for different sales Prices and Rental Charges

DISCUSSION

Building having (G+3) and (B+G+8) stories

The document entitled "Economics of Two Steel Framed Urban Commercial Buildings" (INSDAG 2002) confirms that modern methods of steel-concrete composite construction have economic viability in the overall initial cost, and also lower LCC values than RCC options. It also shows that lower construction cost alone may not necessarily offer the overall cost-time combined economic viability as well as lowest LCC, which provide optimum solution to the owner, builder and society/nation as a whole. The following observations are made in the above study:

In the overall building cost, the framing cost has been found to be only about 7.5 to 16% of the total construction cost, and other building elements play substantial role in the overall construction cost of the building.

For the G+3 building, the total construction cost (excluding the cost of land) of the building under the steel intensive route has been found to be about 6–7% higher than its RCC option. Where as, for the (G+8+B) Building, the total cost of the building under the steel intensive route has been observed as about 8–11% higher than the RCC option.

Steel option has been found to be having the shorter construction time (22–35%) in both the cases. Considering the effect of construction time, interest during construction and the early rentals generated due to early completion, the steel option has been found to be overall economical on total initial cost by 4.1–6% for the G+3 building and by 19–20.5% for the (G+8+B) Building compared to the corresponding RCC option.

From the above it is observed that for the steel intensive option, the percent increase in construction cost of (G+8+B) building is more than that of the low-rise G+3 building. These two buildings however have different framing arrangement and column-spans as per the architect's drawings and the observation is not case-specific. It is also noted that the high-rise building offers better advantage/ benefit with respect to speed of construction as well as total initial cost.

Lowest life cycle cost is offered by the steel intensive option with respect to both the discount rates mentioned earlier, and also for both the locations considered: Calcutta and Delhi. However, future costs of same order of magnitude and common to both the options had been excluded from the comparative study.

Steel-concrete composite and RCC buildings having (B+G+20) stories

The document entitled "B+G+20 storied Residential Building with Steel-Concrete Composite Option" (INSDAG 2003) compares LCC of RCC buildings with various options of B+G+20 as well as B+G+21 storey buildings of composite construction for different type of claddings. The total construction time gain of steel intensive construction (for the type of buildings) is about 20%, compared to the competitive options. Faster construction (for maximum utilization of rolled and/or fabricated components) further reduces the life cycle cost of the steel intensive construction, when all elements of total cost, interest during construction, rental value, maintenance etc is considered. It has been shown that for lower initial as well as maintenance cost, the profits of different steel intensive buildings are more compared to that of RCC option corresponding to the sales price considered.

From the study it has been found that composite options with brick cladding are cheaper by about 1-4% and the same with lighter cladding material are cheaper by about 5–8% with respect to the RCC option considered. These savings are in direct construction cost only and it can be shown that due to fast-track construction, lesser maintenance cost, use of quality controlled products like steel and so on, the steel-concrete composite structures are having lesser Life Cycle Cost also. The study has also considered the interest during construction (IDC) of 11.75% which was the interest rate on house building loans in India at the time of study and also very close to the prevalent Prime Lending Rate of commercial banks. The study considered a saving of eight months time in composite construction compared to the RCC construction which consumes more time for centering and curing, the overall construction time of the RCC option being taken as three years. It has been observed that the overall profit is enormous which would attract the builders to invest in buildings having steel-concrete composite option.

CONCLUSIONS

Steel-concrete composite buildings are widely adopted in most of developed countries and this trend has started in India and other developing countries in the past few years. Though in India, not much confirming data are available on the maintenance costs of buildings; 'design for durability' and 'sustainable construction' are the two important concepts finding more and more importance.

In the past, the perceived benefits of buildings have been mainly in terms of energy savings only. Benefit of steel intensive construction is significant compared to other building materials, since apart from fast track construction, steel can play an important role in bringing about improvements as far as environmental impact in terms of resource consumption in buildings are concerned.

Life cycle assessment is the most dependable measure to ascertain reliability of any construction material. Life Cycle Cost is dependent on the total cost including interest on average investment for the construction period, additional rentals for early completion, maintenance and repair cost, social cost, energy cost etc, and the end use value rather than the direct construction cost alone.

It has been observed that multistoried buildings with heights more than 60 meters, if built in steel-concrete composite option are cheaper in direct construction cost with respect to RCC Construction. Study carried out on typical buildings (constructed under the modern methods of steel-concrete composite construction route) about 8 storey high and above, also showed economic viability in the overall initial cost itself, and based on lower LCC values over its RCC counterparts. For buildings of smaller height, even if the initial cost is higher for the steel intensive option, Life Cycle Cost is lower for reduced amount of interest burden on the project cost for shorter duration of construction. But, alternative options having lower construction cost alone may not necessarily offer the overall cost-time combined economic viability as well as lowest life cycle cost, which provides optimum solution to the builder, owner, as well as the society / nation as a whole.

It is suggested that the designers, planners, and decision makers recognize the general observation of the study and consider / adopt steel intensive construction route and also life cycle mode of costing while making the design and investment decision. For tender document/proposals of new multi-storey building projects, the consultants/ advisors/ bidders should be asked to compare cost parameters including economies of total direct cost vis-à-vis construction time related advantages for both steel intensive and RCC options.

REFERENCES

AIA 1994, American Institute of Architects - Environmental Resource Guide, AIA.

ASTM E917: 1994 - Standard Practice for measuring Life Cycle Cost of Building and Building Systems, ASTM, West Conshohocken, PA.

Bandyopadhyay, T. K., 2000, "Current Trend and Future Scope of Steel-Concrete Composite Construction in India", Engineering Foundation Conference, Vol. 1, Composite Construction IV, May 28 – June 2, 2000, Banff, Alberta Canada.

CORUS 2001a, Corus Construction Centre (CORUS) – Recycling and re use in steel, Environmental design in steel; web: www.corusgroup.com

CORUS 2001b, Corus Construction Centre - Life cycle assessment in steel construction, Environmental design in steel, 2001; web: www.corusgroup.com

CORUS 2003, Steel Construction Institute (SCI) and British Constructional Steelwork Association Ltd. (BCSA) - Sustainable steel construction – Building a better future – A summary of the UK Steel Construction Sector's sustainability strategy.

Coskun H., 2002, The advantages of steel in building construction regarding the environmental impacts of building materials, IISI, Sustainable Development in the World Steel Industry, 2002

Honess, C. V. et al. 2002, Development of a Sector Sustainability Strategy for the UK Steel Construction Industry, International Iron and Steel Institute (IISI), Sustainable Development in the World Steel Industry; www.worldsteel.org.

IISI 2002, Intl. Iron and Steel Inst. (IISI), Steel in Sustainable Construction, World Conf., Luxembourg.

INSDAG 2002, Institute for Steel Development & Growth, India Publication No. INS/PUB 023 on Economics of Two Steel Framed Urban Commercial Buildings

INSDAG 2003, Institute for Steel Development & Growth, India Publication No. INS/PUB 047 on B+G+20 storey Residential Building with Steel-Concrete Composite Option

IS: 13174: 1991; Parts 1(1991) and 2 (1994); Indian Standard Life Cycle Costing

SCI 1999, Steel Construction Institute (SCI) - Publication No. SCI – P – 174, The Role of Steel in Environmentally Responsible Buildings.