COMPARISON OF REINFORCED IN-SITU CONCRETE AND STRUCTURAL STEEL IN MULTI-STOREY BUILDING FRAMEWORK CONSTRUCTION

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1 Introduction

The paper aims to identify and illustrate the major factors that govern the selection of the framing option in the construction of multi-storey buildings. Five commonly used framing options for the construction of multi-storey buildings in the UK are

- structural steel,
- reinforced in-situ concrete,
- pre-cast concrete,
- load bearing masonry and
- timber.

However, the last three options do not have a significant amount of market share. Structural steel and reinforced in-situ concrete dominates the framing market of multi-storey buildings. Therefore, this paper is limited to these two framing options.The paper compares structural steel and reinforced in-situ concrete using the factors identified in the study. The paper also describes the market structure of framing options.

2 Factors influencing the selection of frame type

This paper aims to compare structural steel and reinforced in-situ concrete using the following factors:

- Cost,
- Lead Time,
- Design Possibilities,
- Fire Protection,
- Construction Scheduling,
- Environmental Issues,
- Quality Control and
- Life Cycle Costs.

However, apart from the factors mentioned above, material availability and experience and familiarity of the developer and designer with a particular material can also play pivotal role in the selection of a particular frame type.

2.1 Cost

Cost is the most important factor in the selection of structural framing options. However, it is essential to understand the concept of pure cost and total cost as sometimes a cheaper pure cost might not yield a cheaper total cost. The pure cost is the cost of solely constructing the structural frame and the total cost is the cost of the frame plus any costs incurred because of the choice of the framing solution. The choice of structural framing solution can affect not only the frame cost but also the total cost. A structural frame can affect costs elsewhere in the project. This can range from increasing costs of other elements through to increased cost of finance.

Comparative Structure Cost of Modern Commercial Buildings published by The Steel Construction Institute (SCI) in 1993 shows that for building A the frame cost for RC flat slab is £ 52 per m^2 but the net building cost is £ 564 per m^2. On the contrary, the frame cost for Slimflor deepdeck is £ 64 per m^2 but the net building cost is £ 559 per m^2. Therefore, it is not prudent to identify the cheaper option by observing only the frame cost. Rather it should be just one of a number of issues that should be considered when making the choice of frame material.

The costs of framed structures are extremely variable and can depend on many factors for example market conditions. Steel is particularly volatile and is affected by exchange rates and international competitions. As a result steel price tends to fluctuate more frequently than that of concrete. On the contrary, the price of cement, which is the main ingredient of concrete, is more stable. BCA (2007) claims that over the last 10 years average UK cement prices have risen below the rate of inflation. Moreover, it states that on average, material prices in the UK rose by 7.7% in the year to March 2007. The price of some other competing materials have risen more sharply, e.g. structural steel prices have risen by 11%.

Foundations for concrete buildings can be significantly larger than those for steel buildings due to their higher self-weight and this can be a critical factor in the selection of foundation design and their economics. Particularly where ground conditions are poor; this weight advantage can mean the difference between using spread foundations and short bored piles at considerably higher cost. On the other hand, steel frames need fire protection works and this can be a critical factor in determining the cost of the building. Moreover, in some cases, concrete can be a cheaper option due to its shorter lead time. So it is very complicated to evaluate the economically feasible framing option as many factors govern the frame cost and in turn, the project cost.

2.2 Lead Time

Lead time may be defined as the time required by the contractor from placing an order to actual construction of a particular element on site.

Structural steel is a pre-fabricated component and requires a number of factory processes. As a result steel usually requires greater lead time than concrete. It is dependent on different factors such as the availability of raw materials, fabrication time and release of detailed design.

Figures published in the Chartered Quantity Surveyor (1992) show that reinforced in-situ concrete has lead times of 2-8 weeks. On the contrary, steel has lead times of 8-14 weeks. This still seems to be true 10 years on, according to the figures published in the Construction Statistical Annual 2001 edition. A cost model study (BAR, 2006) conducted by the British Association of Reinforcement (BAR) in 2006 has found that reinforced concrete can be up to 5% cheaper than structural steel frames for typical commercial buildings. These significant cost advantages were compounded by a lead time of only 4-6 weeks for reinforced concrete compared with up to 18 weeks for steel.

2.3 Design Possibilities

Design possibilities are a major issue in the process of selection of the structural framework option. Concrete buildings can take many different shapes. On the contrary, the major advantage of steel is that it can deliver long spans of column free space.

According to Macdonald (1997) concrete is an extremely versatile structural material. The fact that reinforced concrete is available in semi-liquid form means that it can be cast into an almost infinite variety of shapes. This property, together with its strength characteristics, means that virtually any form can be created relatively easily in reinforced concrete. On the other hand, steel is a very tough material which is difficult to work and shape in the solid form.

Some other points to be taken into account are aesthetics, flexibility and adaptability. Steel beams may include web openings for aesthetic or functional purposes while still allowing the beam to carry the required load. But concrete also has advantages of its own regarding aesthetics as it can take any shape for example shell shape. A classic example of shell structure is the Sydney Opera House which is located in Sydney, Australia. The structure is an expressionist modern design, with a series of large precast concrete 'shells', each taken from the same hemisphere, forming the roofs of the structure (Wikipedia, 2007).

Not only shell structures but also undulating buildings can be constructed with reinforced in-situ concrete which takes the form of ocean waves. The unrivalled sculptural potential of concrete construction has been dramatically realized with The Wave, a distinctive 34-storey retail and residential tower on Australia’s Gold Coast. The use of four different floor layouts gives the building the look of having twisted to the right at each level while clearly evoking the movement of ocean waves. The 111m-tall tower is constructed from a series of reinforced concrete slabs of varying floorplate supported by shear wall framing (Concrete Quarterly Summer, 2007).

Figure 1: The Sydney Opera House
(Source: Wikipedia, 2007)

Figure 2: The Wave located in Gold Coast
(Source: Concrete Quarterly Summer 2007)

Steel buildings also can be visually pleasing but the present author did not find any outstanding steel building like the Sydney Opera House or the Wave.

Foster and Harrington (2000) stated that concrete often allows greater flexibility in design because of its monolithic nature and because it is not confined to standard sections. Macdonald (1997) pointed out that the nature of in-situ concrete allows alteration at a late stage in the construction process but it is not very adaptable if structural members need to be removed or strengthened during the life of a building. On the contrary, the nature of steel components means members can be removed or added to during the life of the building to alter the structural capabilities of parts of the building.

However, both structural steel and reinforced in-situ concrete have advantages in terms of design possibilities on their own. These advantages play a pivotal role in selecting a structural framework type of the building according to client's specification. If the client is looking for long span without intermediate columns, structural steel is the feasible option. On the contrary, if the client is opting for a shell structure for aesthetic reasons, concrete is the suitable option.

2.4 Fire Protection

Reinforced in-situ concrete requires no additional fireproofing treatments to meet stringent fire codes, and performs well during both natural and manmade disasters. Macdonald (1997) stated that normal reinforced concrete provides inherent fire protection for a few hours and, with slightly enhanced detailing, more than four hours can be achieved. This removes the time, cost and separate trade required for fire protection. On the contrary, steel needs extra fire protection work.

The fire proofing work for structural steel not only increases the overall cost but also consumes a considerable amount of time. In a cost model study Goodchild (1993) argued that the construction programmes for concrete schemes are up to two weeks faster than their steel equivalent because of the need to fireproof steel-work. Goodchild (1993) also stated that steelwork frames can start earlier and are erected quicker than their concrete equivalents but the fireproofing of steel work completely eliminates this early advantage.

2.5 Construction Scheduling

Construction of a reinforced in-situ concrete structure is complicated and involves the erection of framework, the precise arrangement of intricate patterns of reinforcement and the careful placing and compacting of the concrete itself. The construction process for a reinforced in-situ concrete structure therefore tends to be both more time consuming than an equivalent steel structure. Another disadvantage is the requirement for sufficient space for storage of formwork and for the assembly of reinforcement cages. Time consumed for curing of concrete is also another noteworthy disadvantage of concrete. However, shorter lead time of concrete can be a compensatory factor.

On the contrary, steel structures are assembled from prefabricated components which are produced off-site. This results in fast erection of the structure on site and enables a relatively simple erection process to be adopted.

2.6 Environmental Issues

Presently environmental pollution is a major global issue. Effects of buildings on the environment also have become a topic with increasing awareness within the construction industry, as well as the government is pushing for greener buildings. Clients are also expecting contractors and designers to be able to produce environmental friendly buildings.

Steel is potentially re-usable and a considerable amount of steel production is from scrap. Todd (1993) pointed out that steel is a highly re-cyclable material with over 50% of steel is produced from scrap. The faster construction process also reduces environmental impact.

Due to high thermal mass of concrete, concrete frames offer the benefit of passive cooling. Therefore, concrete construction can be viewed as an important element of passive green buildings. Benefits in the use of passive heating and cooling allow a reduction in the running costs. This is because the slabs will be heated or cooled during the off-peak hours.

Weight (2006) pointed out that worldwide more than 85% of steel is recycled at the end of its life and in UK construction, the re-use and recycling rates of various steel products have been estimated at 92% for rebar, 85% for hot-dip galvanized sheet and 99% for structural steel sections. However, according to BCSA (2007), 94% of steel is recycled or reused in the UK. On the contrary, concrete is harder to re-cycle, due to its mass, and is normally only re-cycled as a back-fill material. Weight (2006) also mentioned that the argument from the concrete lobby is that although the figures reflect the worldwide situation regarding the proportion of available recycled steel versus steel from virgin resources, it plays down the impact of structural steel in the UK, which predominantly uses steel from virgin sources. However, reinforced in-situ concrete also has its environmental advantages. Weight (2006) identifies the following statistics:

- 85% of aggregate travels less than 30 miles.
- 90% of cement is sourced from the UK, whereas 10% is imported.
- In the UK, almost all reinforcement is produced from recycled steel.
- All the companies that produce cement have environmental management systems in place and programmes to minimise the environmental impact from mining activities.

Haines (2007) stated that innovative cement mixes are reducing the embodied carbon dioxide of concrete whilst the growing appreciation and exploitation of concrete’s thermal mass is helping to reduce to operational carbon dioxide of buildings.

2.7 Quality control

Steel is manufactured under conditions of strict quality control and its properties can be relied upon to be within narrow specified limits. The excellent quality of structural steel provides significant advantage over reinforced in-situ concrete which is generally mixed on site and depends largely on the quality of labour.

2.8 Life Cycle Costs

For a building, life cycle cost usually includes the design cost, construction cost, maintenance cost and recycling cost.

The major issue in the selection of frame type regarding life cycle cost is the maintenance cost. Reinforced concrete provides advantages of savings in cooling and heating. Concrete's range of inherent benefits fabric energy storage, fire resistance, and sound insulation means that concrete buildings tend to have lower operating costs and lower maintenance requirements. On the other hand, recycling cost for structural steel is cheaper than reinforced concrete.

2.9 Relative advantages and disadvantages of Structural Steel and Reinforced in-situ Concrete

From the factors discussed above a number of relative advantages and disadvantages of structural steel and reinforced in-situ concrete as framing options can be identified. Table 1 compares structural steel and reinforced in-situ concrete.

Table1: Relative advantages and disadvantages of Structural Steel and Reinforced in-situ Concrete

Factors	Structural Steel	Reinforced in-situ Concrete
Foundation Cost	Lower	Higher
Price Stability	Unstable	Stable
Lead Time	Longer	Shorter
Design Possibilities	Can provide longer span without intermediate columns	Can provide structures of various shapes

Fire Protection	Requires additional fire protection works	Requires no additional fire protection work
Construction Scheduling	Can be erected at a faster pace	Relatively slow due to the time consumed for curing
Environmental Issues	Can be recycled easily	Can reduce the cost of heating and cooling of the building due to its high thermal mass
Quality Control	Better quality control than concrete as manufactured in the factories	Quality control is more difficult than structural steel as prepared on site

3 Market Structures

The lion share of the market of multi-storey building construction in the UK belongs to structural steel and reinforced in-situ concrete. Construction Markets – The Market for Structures in Multi Storey Buildings for British Steel plc (cited in Chartered Quantity Surveyor, 1992) claimed the figures shown in Table 2. However, contradictory figures are provided by British Cement Association (cited in Chartered Quantity Surveyor, 1992) which claimed that in 1991, 58% of the market for structural frames above two storeys was constructed from in-situ or pre-cast concrete or load bearing masonry.

Table 2: Market shares of frame types in the UK

Frame Type	1980	1990
Steel In-situ concrete Pre-cast concrete Masonry	33.0% 49.0% 14.0% 4.0%	51.0% 27.0% 17.0% 5.0%
Total market	8,127,000 m^2	11,386,000 m^2

(Source: Construction Markets – The Market for Structures in Multi Storey Buildings for British Steel plc, cited in Chartered Quantity Surveyor, 1992)

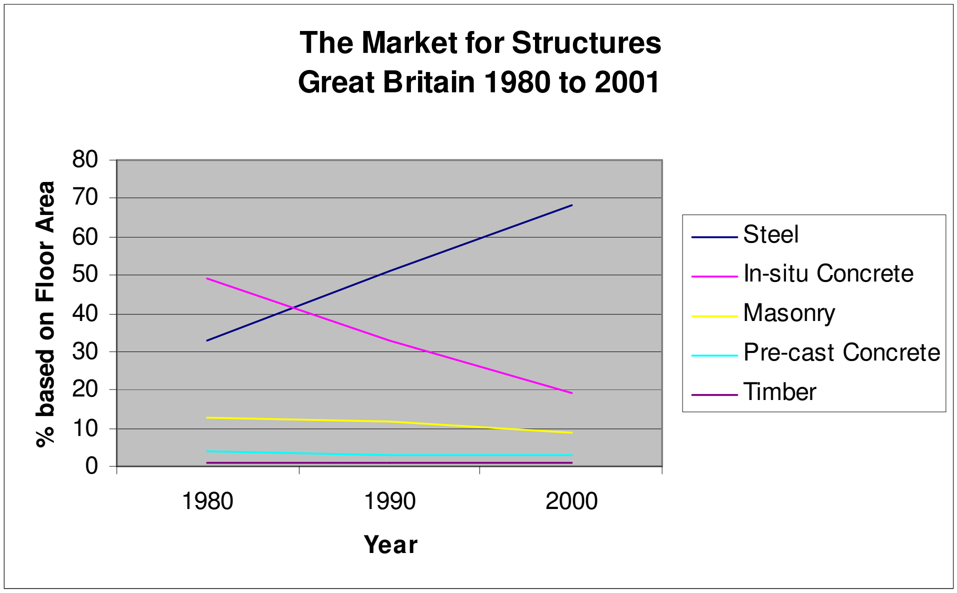

Figure 3: The Market for Structures, Great Britain from 1980 to 2001

(Source: New Steel Construction, May/June 2002, pp-40)

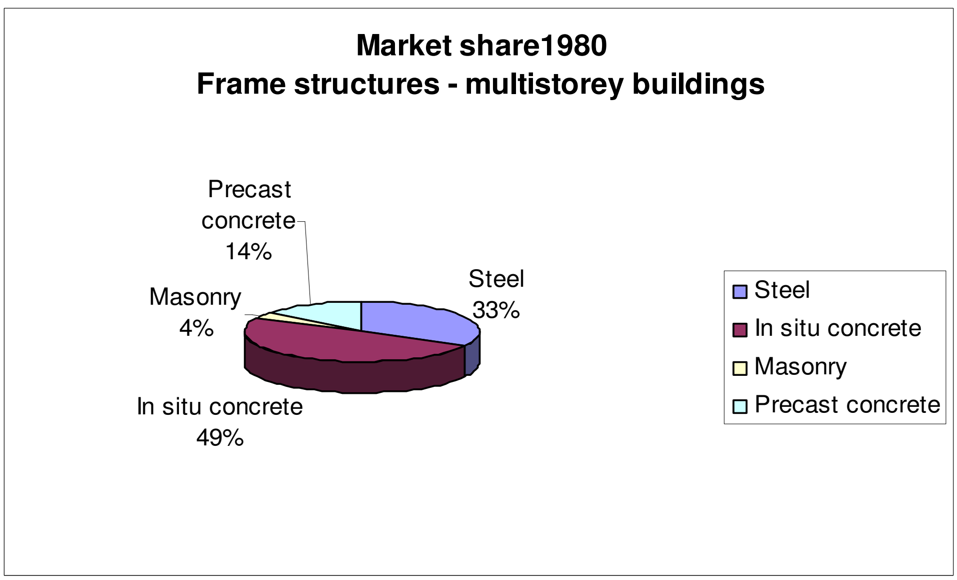

Figure 4: Market Share of Frame Structures of Multi-storey buildings in 1980 (Source: Construction Markets- The Market for Structures in Multi Storey Buildings for British Steel plc, cited in Chartered Quantity Surveyor, 1992, pp-23)

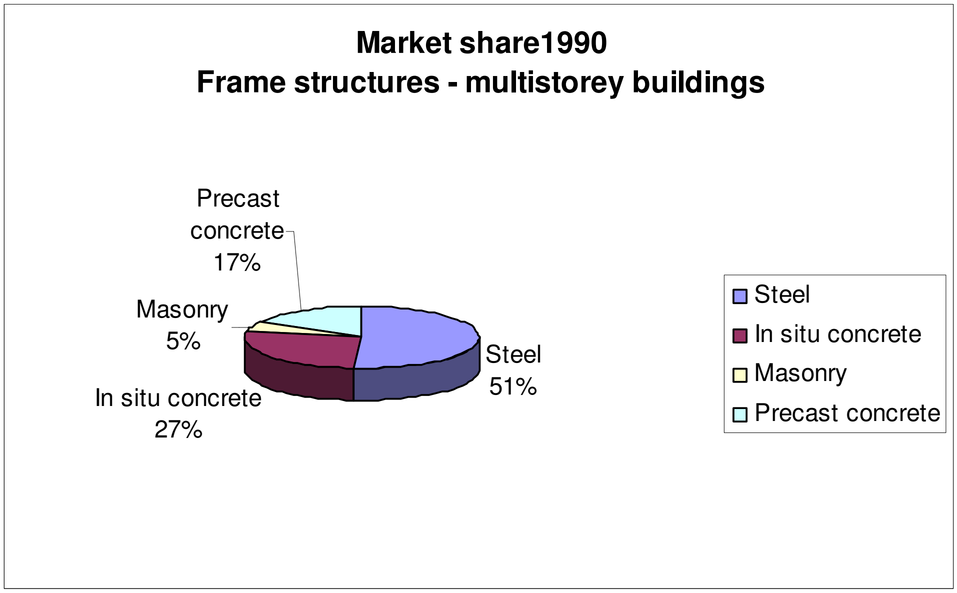

Figure 5: Market Share of Frame Structures of Multi-storey buildings in 1990 (Source: Construction Markets- The Market for Structures in Multi Storey Buildings for British Steel plc, cited in Chartered Quantity Surveyor, 1992, pp-23)

The figures (Figure: 3) published in the New Steel Construction in 2002 claims that from 1980 to 1985, in-situ concrete dominated the market in the UK, while from 1985 to 2000 the market was dominated by structural steel and in the year 2001 steel's market share rose to an all-time high of 68.2%.

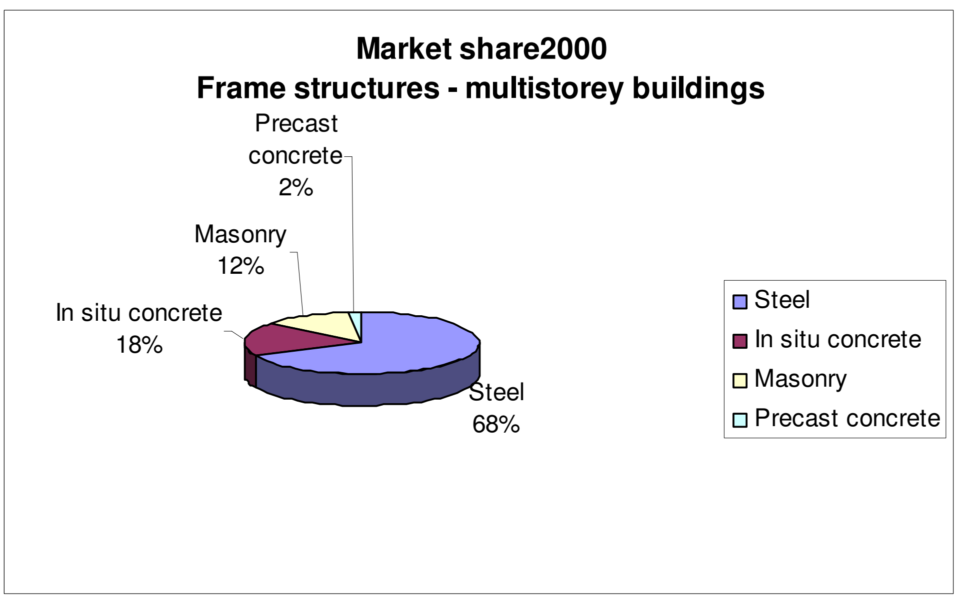

Figure 6: Market Share of Frame Structures of Multi-storey buildings in 2000

(Source: adapted from New Steel Construction, May/June 2002, pp-40)

The first two pie charts (Figures 4 and 5) were collected from the Construction Markets - The Market for Structures in Multi Storey Buildings for British Steel plc. The pie charts show the percentage of market share of steel, in-situ concrete, masonry and precast concrete. However, the pie charts do not show any percentage of timber. This is due to the very small share of timber which can be taken as negligible. The third pie chart (Figure 6) which was adapted from the data provided by the New Steel Construction (May/June 2002) and prepared by the present author also do not show any market share of timber to maintain the consistency of the pie charts, although in the source data the market share of timber is shown. These data clearly show that structural steel is the market leader at present.

The aggressive marketing strategy of professional bodies promoting steel is a major reason for steel's enormous market share in the UK construction industry. In this regard, Schorsch (1994) pointed out that British Steel has reversed builders' preferences for concrete in the construction industry of UK through an aggressive promotion campaign that both trained civil engineers in how to use steel and documented its superior lifecycle economics.

4 The BCSA annual review 2006-2007

4.1 Background

British Constructional Steelwork Association (BCSA) Limited is the national organization for steel construction industry in the UK. The principle objectives of the Association are to promote the use of structural steel work; to assist specifiers and clients; to ensure that the capabilities and activities of the industry are widely understood and to provide the members of the association with professional services in technical, commercial, contractual, quality assurance and health & safety matters. (BCSA, 2007)

4.2 Market Share

The BCSA annual review 2006-2007 claims that in 2006 structural steel achieved an all time record of 72% market share for all types of multi-storey buildings in the UK.

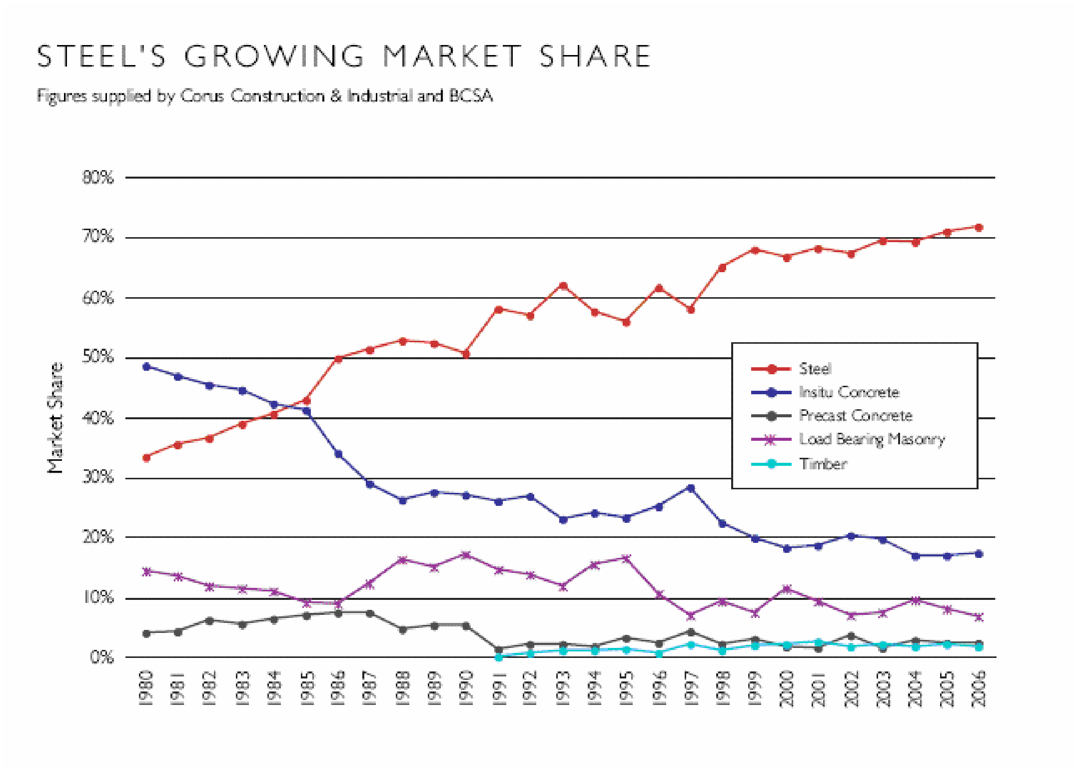

Figure 7: Steel's Growing Market Share
(Source: BCSA annual review 2006-2007, pp-28)

From Figure 7, it can be found that concrete was the market leader in early eighties. However, after mid 1984 steel not only became the market leader but also increased its market share at a rapid rate during the following years.

The BCSA annual review provides justification for the huge market share of steel by mentioning some advantages in favour of steel. The annual review claims that structural steel work has excellent sustainability credentials and steel may be continually recycled without loss of properties. It also claimed that 94% of the steel in the UK is reused or recycled. The annual review states that steel frameworks are lighter than the concrete frames and need less foundation construction. According to the review, the above mentioned advantages played a pivotal role in increasing the market share of structural steel (BCSA, 2007).

Moreover, in a study (n.d.), Concrete Advantage Forum (CAF) agrees with the fact that steel is currently the market leader. The study states that structural steel has made, and is continuing to make, into concrete's market share of the building/ construction industry. The study also states that in recent years this loss of market share of concrete is quite significant.

CAF (n.d.) argues that steel won this share by aggressively targeting the concrete industry's market, and providing answers to and/ or adopting:

- Speed of construction,
- Simplicity of design,

- Fire regulations,
- The latest technology packages for design, manufacture and erection,
- A coordinated design, programming, supply and erection system,
- The use of composite floors,
- Extensive use of computer packages.

The study also mentions that there have also been favourable changes (to the benefit of steel) in fire regulations. All of the above, plus the obvious considerations of speed, cost, and ease of design, have been factors in decisions that have led to the increasing share of steel at the expense of concrete in the building market.

5 Analysis using BCIS online service

5.1 Background

BCIS is the Building Cost Information Service from the Royal Institution of Chartered Surveyors and was established in 1962. BCIS is the UK's leading provider of cost and price information for construction and property occupancy. BCIS provides knowledge through:

- Online services,
- Publications, Bulletins and Price Books,
- Consultancy and Research (BCIS, 2007).

The BCIS online service covers a vast range of buildings in its database. BCIS Online is a web based service providing the full range of BCIS construction cost information including:

- 15000 cost analyses,
- Average prices for over 550 types of buildings,
- Daywork rates,
- Preliminary percentages,
- Tender Price and Building Cost Indices (BCIS, 2007).

5.2 Methodology

The BCIS system contains analysis of following types of buildings:

Building Function Categories

100 – Utilities, Civil Engineering Facilities
200 – Industrial Facilities
300 – Administrative, Commercial, Protective Facilities
400 – Health, Welfare Facilities
500 – Recreational Facilities

600 – Religious Facilities
700 – Educational, Scientific, Information Facilities
800 – Residential Facilities
900 – Common Facilities, Other Facilities

Under these categories there are many sub categories. To search for the desired data there are many options like type of work, gross internal floor area, primary number of storeys, air conditioning and basement. A particular search yields a number of buildings with full elemental analysis. (BCIS, 2007)

5.3 Results obtained from the BCIS online service

The search was conducted for Building Function Category 300. Under this category there were many sub categories. Category 320 – Offices was searched and new build was selected as the type of work. The above search yielded 116 buildings, out of which 72 were steel framed and 7 were concrete framed. Table 3 shows the result obtained from the search.

Table 3: Results from BCIS analysis for Offices

Frame type	Number of Building	Percentage
Steel	72	62%
Concrete	7	6%
Others	37	32%

Another search was conducted for Building Function Category 700. Under this category there were many sub categories. Category 721 – Universities was searched and new build was selected as the type of work. The above search yielded 5 buildings, out of which 2 were steel framed and 1 was concrete framed. Table 4 shows the result obtained from the search.

Table 4: Results from BCIS analysis for Universities

Frame type	Number of Building	Percentage
Steel	2	40%
Concrete	1	20%
Others	2	40%

However, these results do not reflect the true situation due to the small size of the sample. But it clearly shows that structural steel is presently the market leader in multi-storey building construction in the UK.

There are little independent data available to show which of the two main competitors have a greater market share. However, it is clear that structural steel and in-situ concrete occupy the vast majority of the market for multi-storey buildings in the UK. It appears that the balance between concrete and steel has historically been fairly even, with perhaps reinforced in-situ concrete having the advantage twenty years ago, but with structural steel gradually gaining a larger market share.

6 Conclusions

The paper attempted to compare structural steel and reinforced in-situ concrete in the construction of frameworks for multi-storey buildings. However, it is extremely difficult to conclude which material is the better framing option as both the options have their own advantages. The major advantages of steel are smaller foundation than its concrete equivalents, longer span without intermediate columns and faster erection. On the contrary, shorter lead in time and inherent capability of fire resistance are the major advantages of reinforced in-situ concrete. Therefore, these factors should be taken into account and should be evaluated with accuracy before deciding on the type of framing option for a particular building.

7 Practical Recommendations

The present author suggests the following practical recommendations regarding the matter:

- Specifiers of the frame type should consider all factors not only cost and time.

- Once the frame type is chosen the developer should maximise the benefits.

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