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Steel Framed Multi-Storey Buildings in the U.K.

Bâtiments-tours en acier en Grande-Bretagne

Mehrgeschossige Stahlskelettbauten in Grossbritannien

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Hugh Walker who joined the Construction Industry in 1952 is widely experienced in most aspects of steel design and construction. He is currently directing an extensive program of research and design development for multi-storey buildings. He is a member of several National and International codes and standards committees.

SUMMARY
The paper examines the reasons for the current growth in the use of steel frames for multi-storey building construction in the U.K. The advantages of using profiled steel deck and lightweight concrete composite floors and beams are given, as well as the methods of providing fire resistance. As props are not used construction is fast and the overall construction program shows that the total time saving is considerable. Overall costing indicates that the total construction costs for steel and concrete are similar, with a saving to steel from fast construction due to reduced interest charges on the capital employed.

RÉSUMÉ
Cet article explique les raisons du développement actuel de l'utilisation de l'acier pour la structure des bâtiments-tours en Grande-Bretagne. Les avantages liés à l'utilisation des planchers mixtes collaborants sont montrés, tout comme les méthodes utilisées pour atteindre la résistance au feu nécessaire. Comme aucun étayage n'est utilisé, la réduction du temps de construction est considérable. Les coûts totaux de tels bâtiments ne dépendent pas du type de structure choisi (acier ou béton armé); toutefois l'ossature métallique permet de gagner du temps lors du montage et provoque ainsi une réduction des intérêts intercalaires.

ZUSAMMENFASSUNG
Der Artikel untersucht die Gründe für die gegenwärtige Zunahme von Stahlskelettkonstruktionen bei Mehrgeschossbauten in Grossbritannien. Die Vorteile der Verwendung von profilierten Stahldecken im Verbund mit Leichtbeton werden gezeigt, wie auch die Methoden zur Erreichung des Feuerwiderstandes. Da keine Gerüste und Schalungen benötigt werden, kann schnell gebaut werden, und das gesamte Bauprogramm zeigt, dass damit beträchtlich Zeit gespart werden kann. Aus Gesamtwirtschaftlichkeitsbetrachtungen geht hervor, dass die totalen Rohbaukosten für Stahl und Beton wohl annähernd gleich hoch sind; dass aber durch die schnelle Bauweise mit Stahl Bauzinsen gespart werden können.

1. INTRODUCTION

1.1 In the United Kingdom there has been over the last few years a steady increase in the use of steel for the construction of multi-storey buildings. This has come about for a number of reasons, principally a change in the relative costs of steel and concrete frames, so that now the actual construction costs are similar, the much faster construction times that can be obtained with steel, and the relatively high interest rates chargeable on the capital required for the total project. CONSTRADO has played a very considerable part in increasing the share of steel in the multi-storey construction market; producing various design recommendations, particularly for composite construction, and has supervised detailed investigations into various aspects of construction costs. The performance of steel structures in fire and the provision of the necessary fire protection has also been studied in depth, and this is now not considered to be a problem. The cost is small and the application is not a critical path activity.

2. THE DESIGN APPROACH

2.1 Simplicity is the main aim for the steel designer. With simplicity comes a clear understanding of the behaviour of the structure under the dead and imposed loads, straightforward fabrication and fast erection. The main concept of design is that the floor acts as a horizontal membrane and is able to transfer horizontal wind loads from the floor into the vertical shear resisting system and, thence, to the foundations. A typical frame is shown in figure 1. The vertical bracing is usually placed down the lift shafts and can also be contained in the walls surrounding staircases and toilets. Where these areas are set at one end of a building balancing bracing may well be placed down an outer wall, usually hidden by decorative cladding.

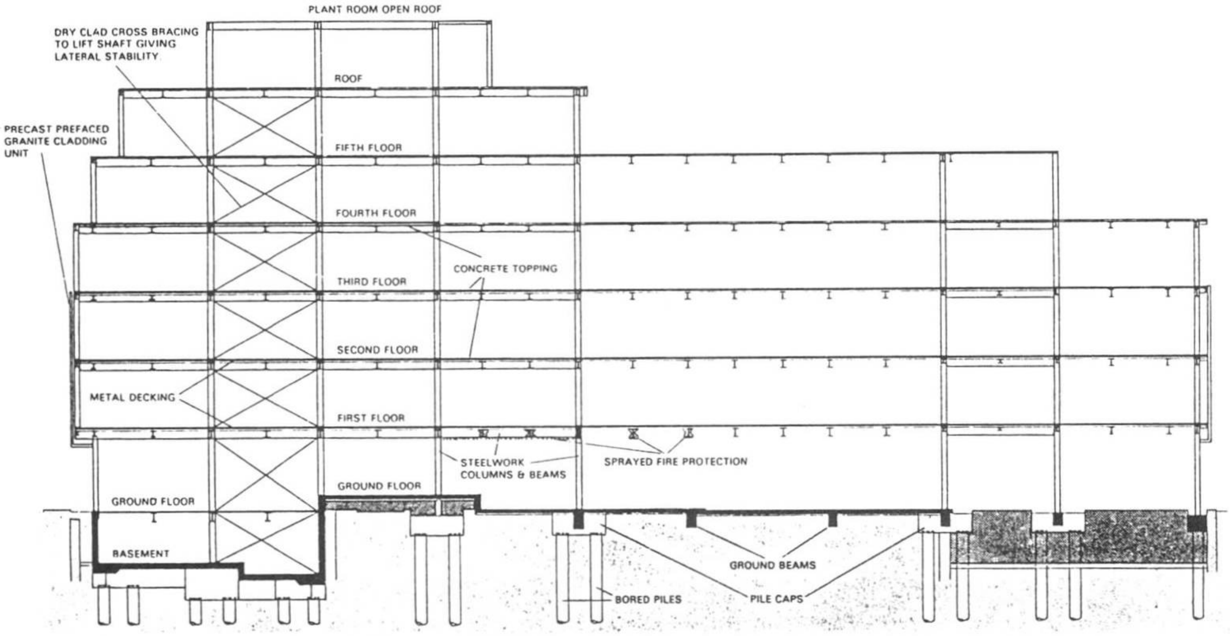


Fig. 1 Cross section showing wind bracing. (Cutlers Court, London.)

2.2 The details of construction are simple and are shown in figure 2. Simple cleats with bearing bolts are generally used, although sometimes use is made of high strength friction grip bolts. The steelwork is often supplied to site, unpainted, corrosion protection being provided by the fire protection system.

The plan shape of the building will depend upon the requirements of the site, but there are no problems in suiting steel frames to irregular plan layouts. Steel staircases are becoming widely used, and these are placed in position as erection proceeds, and are for use by the various trade operatives, this being much more convenient than ladders or other temporary access systems. Cladding is fixed from the inside so that no scaffolding is required.

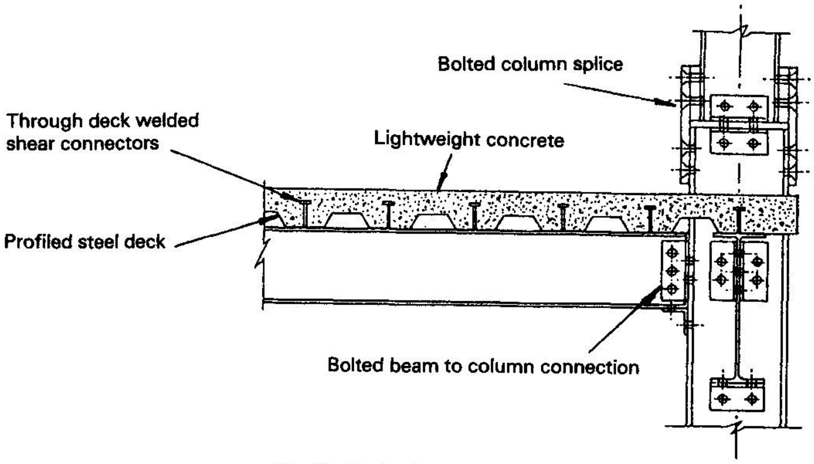


Fig. 2 Typical connection details.

3. FLOORING SYSTEMS

3.1 Floors can be provided for steel framed buildings in a number of different ways. In the past insitu concrete was often used and required formwork and propping which make it a relatively slow process. More recently precast concrete slabs with structural topping have been used, but these now have been superceeded by profiled steel decks with lightweight concrete topping which acts compositely both with the steel deck and with the support beams. This form of construction is shown in figure 3.

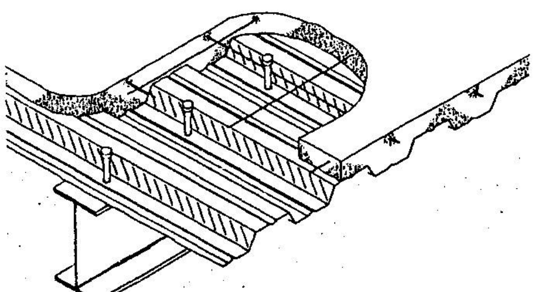


Fig. 3 Floor arrangement.

3.2 The profiled steel deck is used unpropped with supporting beam centres between 2.4m and 3.6m beam centres. The steel deck is placed by hand and, to prevent movement due to wind, lightly fixed to the supporting beams by means of self-drilling and tapping screws or by puddle welding. Shear connectors are then insitu welded through the deck and to the beams to enable the floor slab to act compositely with the support beams. Light steel reinforcement mesh is laid upon the deck and then the concrete topping is placed, usually by pumping, the final finish being obtained by power floating.

3.3 Lightweight concrete is now usually specified, it being used in preference to normal weight concrete, as it has several distinct advantages. Lightweight concrete has better fire resistance than normal weight concrete, and this enables the depth of the floor to be reduced. This reduction in thickness, coupled with reduced weight, means that the resulting concrete component of the floor is about half the weight of the equivalent normal weight concrete. For the same spacing of support beams this allows a thinner gauge steel deck to be used. It should be borne in mind that the design criteria for the steel deck alone is normally obtained during the construction process, the steel deck having to support the weight of the wet concrete together with that of the construction equipment and operatives. This lower dead weight reduces the size of the supporting beams as well as those of the columns right the way through to the foundations.

3.4 Due to indentations in the profile of the steel deck, full composite action is obtained between the steel and concrete regardless of any chemical bond that may exist. Tests have shown that the mechanical bond is usually of a high order and the composite floor can carry imposed loads much higher than those usually specified. The steel deck has a galvanised finish, although this is not strictly necessary.

4. ECONOMIC FRAME AND FLOOR DESIGN

4.1 For an economic floor design a number of factors have to be considered. These will relate to the selection of the deck profile, the type of concrete topping, the depth of the supporting beams and the determination of the number of shear connectors to obtain composite action between the beam and the floor. In the U.K. BS.5950, Part 4, Code of Practice for the "Design of Floors with Profiled Steel Sheet", enables the design of the composite floor to be carried out. For the design of the composite beam and floors no British Standard is currently available, and these are generally carried out in accordance with recommendations prepared by CONSTRADO [1]. These are based upon ECCS, U.S. and Canadian recommendations.

4.2 The total depth of construction is of great importance as this will affect the overall height of the building, and very often in city centres and other locations, height restrictions are in force. The use of universal columns as beams is well worth considering and, whilst these will not have as good a strength/weight ratio as a universal beam section, they will enable minimum construction depths to be obtained. Floor to floor heights can be obtained with steel that are comparable with those that can be obtained using concrete construction.

4.3 The shear connectors are easily fixed on site but can be an expensive item. The method of designing the composite beam must be carefully considered, and it is important that partial interaction methods are used and not full interaction as has often been done in the past.

4.4 The layout of the steel deck sheets on the framing members is important if the best economy is to be obtained. The profiled sheets can be obtained in lengths up to 15m and can be transported to site without undue difficulty. With normal beam spacing this will enable the sheets to span up to four bays, and will give the least sheet thickness. Continuous spans should be used in a descending order from 4 bays to 3, 2 or 1. The least price will be obtained by optimising the continuous spans for the overall shape of the floor layout. A typical arrangement is shown in figure 4.

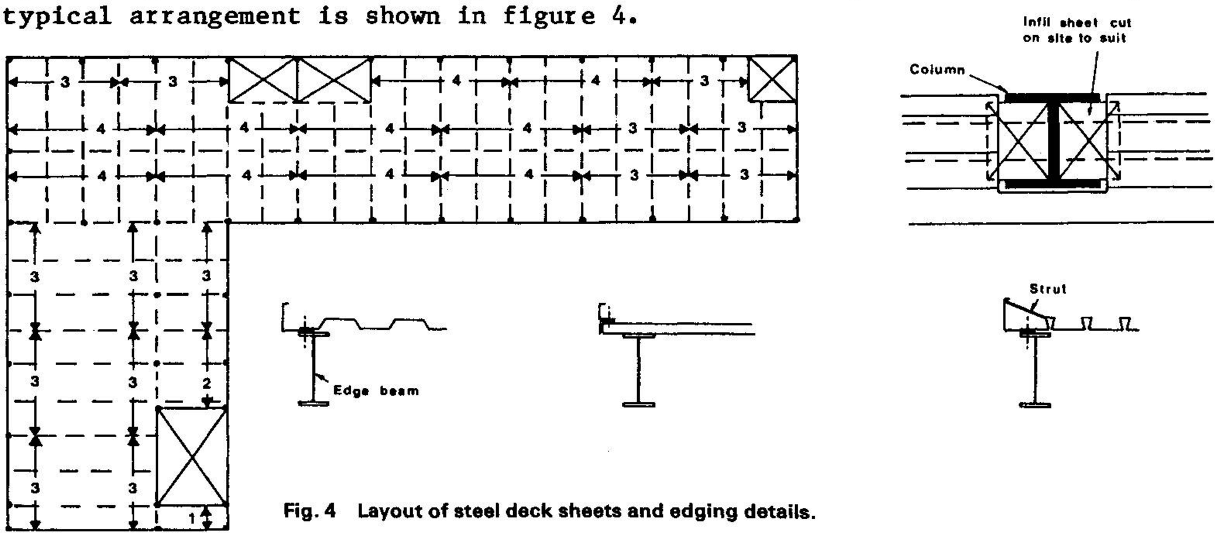


Fig. 4 Layout of steel deck sheets and edging details.

4.5 Bundles of decking are usually stacked at each floor level using the main erection crane, and these are then manually slid into their final position. It should be noted that for precast concrete slabs craneage is usually necessary for each slab. As the crane cannot be used at the same time for main frame erection, the erection time is increased.

4.6 It is usual for the main steelwork supplier to include for the supply and fixing of the deck together with shear connectors and edge trimmers, figure 4. To keep free edges straight, the edge trimmer should either be of sufficient thickness or be braced at intervals. Small pieces of galvanised steel are trimmed and fixed to fit into the column webs. When the steelwork erector leaves the site there should be no necessity for any additional timber formwork to be required. The Main Contractor should be able to proceed immediately and fix the anti-crack and fire reinforcement and then place the concrete topping, which is power floated to a final finish.

5. SERVICES

5.1 The modern office building now requires a high level of main services combined with flexibility to meet individual tenant requirements. Where columns are at 6 - 8m centres, air-conditioning ducts are easily fixed in the plenum under the floor beams, usually suspended from the underside of the composite floor using dovetail slots or special fixing attachments. Where the plenum also serves as the return air duct, then some types of fire protection using mineral wool will need a sealing coat to prevent loose fibres entering the system.

5.2 For offices which require a high level of specialised equipment such as computers, word processors, electronic typewriters, etc., computer or access floors are very often used, figure 5. This system uses floor units which are raised above the concrete surface on short steel members allowing cable systems to be laid underneath in the space provided. The floor units, usually about 600mm square can have the electrical outlets fitted into them to suit individual requirements. Should there be a change of office layout or a new tenant, then it is easy to change the cable outlet system to meet the new requirements.

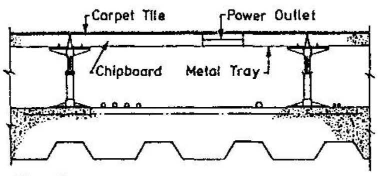


Fig. 5 Access floor.

5.3 Other systems are available where, for instance, cables are fed down partitions or poles from the ceiling above.

6. FIRE PROTECTION

6.1 Fire protection for steel-framed buildings is now a very simple and straightforward process. Where a suspended ceiling is being used, it is usual to spray the beams and column tops above the suspended ceiling with fibre or cementitious materials to give the required fire protection, whilst below the ceiling, dry lining is very often used, Figure 6. There is a considerable choice of materials and suppliers for each type of fire protection material [2,3].

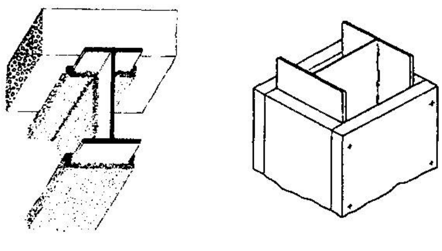


Fig. 6 Fire protection.

6.2 The fire protection is now usually applied to unpainted steel. The fire-protective materials acting also as rust inhibitors. As most fire tests are usually carried out with the protective material applied to bare steel, this eliminates a number of problems which exist when fire-protective materials are applied on top of primer-painted surfaces. If the primer paint and the fire-protection materials are not compatible, then their performance in fire can be seriously affected.

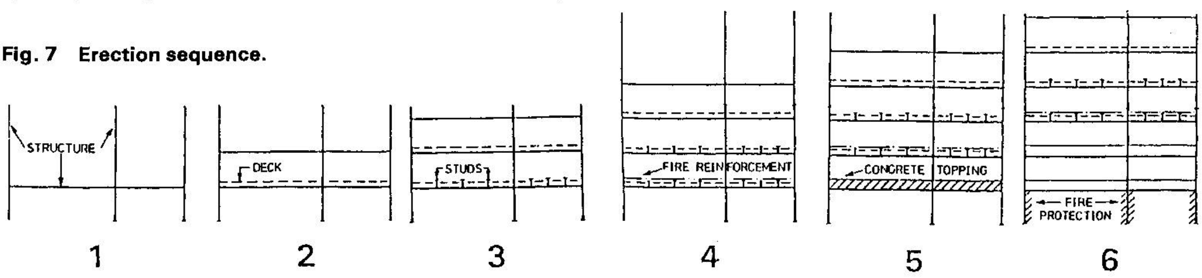
6.3 Fire resistance of the composite steel deck floor is obtained by enhancing the strength of the anti-crack reinforcement mesh which has to be placed in the concrete topping. The method of designing the composite floor to give the requisite amount of fire resistance is set out in recommendations by ECCS Commission T.3, and by CONSTRADO publication, [1]. There is no necessity to apply fire protection to the soffit of the steel deck floor. The only situation where external fire protection may be necessary is where trunking is set in the floor for cables which may decrease the effective thickness of the concrete, which would increase the temperature of the top surface of the floor beyond the specified figure.

7. COST OF CONSTRUCTION

7.1 The main reason for the considerable increase in the use of steel-framed multi-storey buildings in the U.K. is due to the lower overal cost of the completed building. The principal reason for this reduction in cost is the faster overal construction times that are obtained using steel frames with composite steel deck floors. The floor beams are placed at intervals between 2.4m and 3.6m, with 3m being the most usual span. For these spans there is no necessity for any props to be used. Also, for these spans the depth of the supporting beams can be kept to a minimum, and very often universal column sections are used to give minimum depth. The techniques used for designing the composite beams has been improved over the last few years, and this also contributes to reducing the beam size. Through deck welded insitu shear connectors and multi-span steel deck sheets also contribute to the speed of erection and economy. Simple supported beam-to-column connections allow computer controlled fabrication to be used, which also gives minimum cost. The result of these improvements, coupled with a relative increase in the cost of concrete, form-work and site labour, now means that the cost of a steel frame and floors is broadly similar to that for an insitu R.C. frame and floors with a slight edge in favour of steel. This now effectively eliminates one of the main arguments against the use of steel frames which had been used in the past, namely - that if there were delays in supplying and erecting the steel frame, then theadvantages of fast erection could be lost and the client would be penalised. The current history of fabrication, supply and erection of steel frame and floors is that the performance by fabricators has been extremely good, and very often erection of steel frames has been completed ahead of programme.

7.2 The erection sequence for a steel frame and composite floor design is shown in figure 7. The laying of the deck and the insitu stud welding follow the erection of the frame, such that the deck is laid as quickly as possible to provide protection for the following operations; thus the concrete topping is carried out whilst erection proceeds, allowing the following trades to be tightly sequenced to ensure continuity of construction.

Fig. 7 Erection sequence.



7.3 Three years ago CONSTRADO published their Report on the Cost Comparison between steel frames with steel deck composite floors, steel frames with precast concrete floors and insitu R.C. frame and floor designs. This Report has now been updated and published [4].

7.4 An experienced construction management organisation, was again commissioned to provide construction programmes for the three construction systems noted above for 3, 7 and 10-storey buildings in four different U.K. locations including London. An extract from the Report for a 10-storey office block in London is shown in figure 8, which shows the comparison times for steel or concrete-framed buildings. It will be seen that, up to the commencement of the construction of the frame and floors, the construction programmes are identical but that, due to the necessity of extensive propping to the formwork for the insitu concrete design, there is a considerable delay before other trades can commence operations. For instance, there is a delay of some 25 weeks before the fixing of the external cladding panels can commence. These delays show that the construction time to complete the building would be 32 weeks longer for the insitu concrete design.

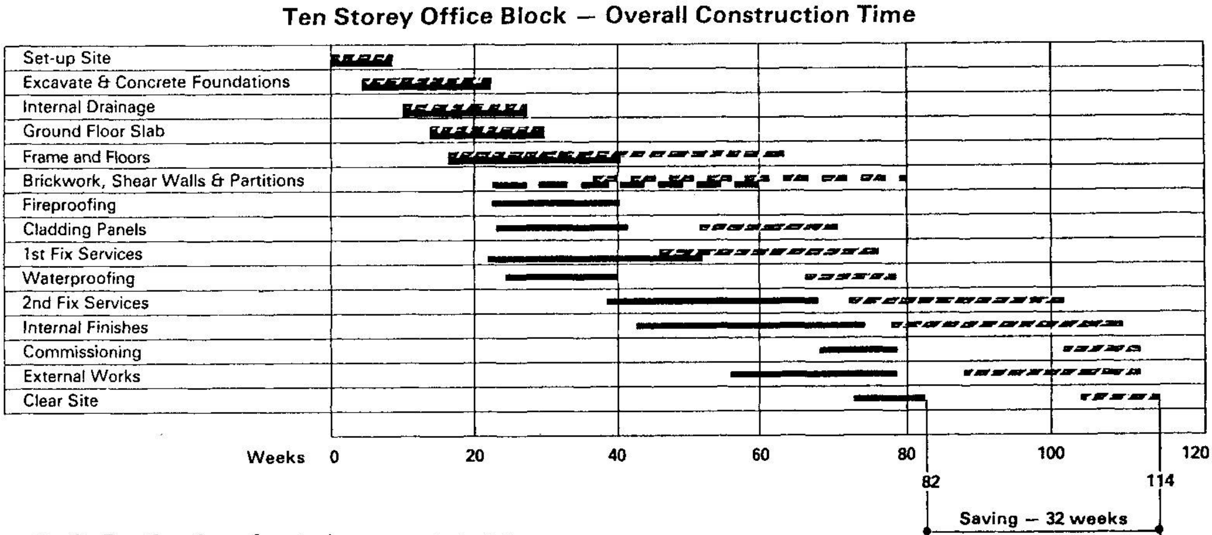


Fig. 8 Erection times for steel or concrete buildings.

7.5 One of the leading Cost Consultants, also again prepared comparative building costs for both the frame and floors, and for the complete building for the steel and concrete designs, and the result of the latter is shown in fig.9. It will be seen that the basic construction costs for the completed building, including the cost of land and professional fees for a building near the centre of London, are approximately the same, with the possibility that the steel design would be slightly less, largely due to reduced costs of hiring equipment for a shorter time and less effect from inflation. The interest charges for the capital involved in construction would be much greater for concrete, reflecting the longer period of time for which the capital is loaned

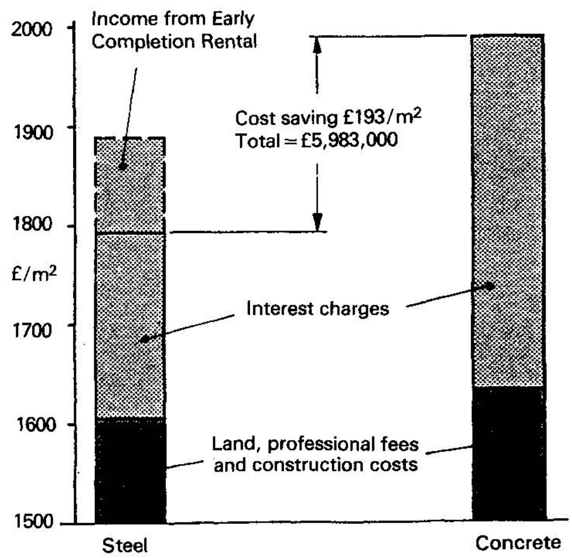


Fig. 9 Comparative building costs for 10 storey office block in London.

and, at current interest rates, this is a very considerable amount. If the time for construction in concrete is taken as the norm, then it can be assumed that the steel-framed building will be occupied by tenants at an earlier date, thus giving a return on the investment before the concrete design would have been completed. This income can also be included in the saving in cost to the client, and in the case under consideration the total cost saving amounts to some £6m. Savings of this order must be of considerable interest to clients.

7.6 The figures given in the Report are fully substantiated in practice, so much so that the principal office complex developments in London at the present time are now designed in steel, there being some half million square metres in thepipeline.

8. FUTURE DEVELOPMENTS

8.1 The increase in the amount of steel-framed construction has brought more construction, fabricating and component companies into this field, and prices are becoming more and more competitive. Construction management techniques are becoming widely used, and managers are moving higher up the learning curve, which will result in even faster construction times than are presently being achieved.

8.2 There is also a trend towards wider span construction to eliminate the number of columns in a building so that flexibility of the use of floor space can be extended. The column spacings of between 6 - 8m are largely based upon concrete practice to optimise construction depth and overall economy, but steel will perform much better as the span increases and its relative cost when compared with concrete will decrease even further. Research and development programmes are currently on hand to prepare recommendations for the design of stub girders for spans up to 15m, and methods which will make greater use of site welding are also being studied.

8.3 With the growth of computer designing and detailing, with automated steel fabrication processes, components will become even more economic and their greater accuracy, will ensure close fit and fast erection on site. Construction will become little more than assembling prefabricated components, which, coupled with tight control of the actual construction process, will produce low cost buildings that are efficient, pleasing to look at and very cost-effective.

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