# Fire Research Note No. 905

## A COST STUDY OF CONCRETE AND STEEL FRAMEWORKS

by

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## A SINGLE COLUMN

## SUMMARY

This exercise, which forms the second in a series, considers the costs of fire resistance requirements for concrete and steel frameworks when related to the column element.

Six categories of fire resistance are used - nil to four hours - and the methods of protecting the columns have been taken from the 'deemed-to-satisfy' provisions of Regulation E6, of the 1965 Building Regulations.

Besides indicating general economic assessments of fire protection to frameworks, this note also provides cost data for both steel and concrete columns and a brief cost analysis of the Regulations themselves.

The first part of this overall cost study - entitled 'Introductory Comments' - is included as Appendix C within this report.

KEYWORDS: Column, Economics, Concrete, Fire protection, Steel



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### INTRODUCTION

As the title indicates, this exercise deals with the column element of the framework and costs are based on the use of reinforced concrete forming one column, and structural steel as the other. Basic costs alone have been considered, although in estimating, allowances have been made for some of the more important overheads. (More detail is given in a later section).

Using just the column obviously limits the scope of the report and its conclusions, but the report will, nevertheless, furnish some trends as to the economics of fire protection to frameworks. This could then be used as a suitable basis for further research work on general framework economics, with the established patterns and guide lines of the priced forms of construction providing a useful basis for future estimating analysis. Indeed, the cost data from both the concrete and steel techniques may also be useful in further work connecting with fire resistance and its relationship to the costs of construction.

Although essentially not an objective, this report does provide a brief appraisal of part of the 1965 Building Regulations. In calculating the cost data, a breakdown has been carried out on a number of the 'deemed-to-satisfy' provisions of Schedule 8. Various factors have emerged and these have been discussed in the report and referred to in the conclusions. This work might therefore form the basis of a more thorough cost-benefit analysis of the Building Regulations, at a later date.

### METHOD

Using Schedule 8 to Regulation E6 of the Building Regulations, a list has been produced of the various means of protecting reinforced concrete columns and structural steel stanchions, to achieve particular degrees of fire resistance. Part II of the Schedule deals with the concrete columns and Part VA deals with the steel stanchions.

Each of these techniques has been priced, and the resulting figures related to the various types of buildings as defined in the table to Regulation E2, and Table A - Parts 1 and 2 to Regulation E5. The broad classification of heights of buildings, as outlined in the first part of this study (Appendix C), has been adopted.

GENERAL CONSIDERATIONS

1. Common element: The reason for adopting the column member of the framework is that of providing a common element of both materials. Eventually, it is intended to base the work on a structure rather than an element, but in the meanwhile a column provides a fairly well-defined, reasonably consistent basis in both materials. With similar heights and effective length factors and ignoring the foundations and beam conditions for the moment (see following consideration), concrete columns can be designed to correspond to steel stanchions based on the axial load bearing capacities of both members.

   Thus, a universal column - size 200 mm (8 in) x 200 mm (8 in) x 47.5 kg/m (32 lb/ft) has been adopted for the structural steel work and, using a length (or height) of 3.66 m (12 ft) - (effective length 2.56 m), then the permitted axial load bearing capacity of the column is 79 tonnes (77.5 tons).

   From these dimensions, ie effective length 2.56 m and axial load of 70 tonnes, and using the conventional stress value of $1.38 \times 10^8$ N/m$^2$ (20,000 lb/in$^2$) for mild steel and $6.55 \times 10^6$ N/m$^2$ (950 lb/in$^2$) for concrete, a reinforced concrete column equivalent to the steel stanchion can be adopted, the size of which is 250 mm (10 in) x 250 mm (10 in) with about 4 per cent steel reinforcement, (ie 4 per cent of the cross-sectional area of the column).

   Using these two columns - for steel 200 mm x 200 mm x 47.5 kg/m and for concrete 250 mm x 250 mm - the methods of protecting them to achieve various degrees of fire resistance have been estimated. The whole process has been carried out for this one pair of columns but other sizes have been calculated and, using the cheapest techniques of protection, costs have been worked out to assess any possible trends resulting from the change in size.

2. Other factors: It is appreciated that, besides the need for fire resistance, there are other considerations which might affect the choice of material for a framework; such as:

   (i) the required flexibility, rigidity or adaptability of the framework

   (ii) the type and standard of finish required within the design and its consequent maintenance cost

   (iii) the likely weather influence due to the time of year and general climatic conditions

   (iv) the height of the building and the consequent handling costs.

   (v) the desirability for larger spans, uninterrupted floor area, shallow beams or an integrated floor and column construction

(vi) the size of columns and the possible reduction in available floor space

(vii) the speed of erection, and shorter construction periods, coupled with the reduction in attendant trades

(viii) the storage and stacking facilities of the site and its general access and communication

(ix) the desirability of a lighter construction and the consequent lower foundation costs, the limitations of poor loadbearing ground and the integrated frame and foundation design.

In order to simplify this exercise, these other factors have been assumed to be compensating, their inclusions would only serve to confuse what is already a somewhat complex problem, rather than contributing to the results.

3. <u>Estimating:</u> Much of this exercise hinges on the results of estimated prices and although estimating is a personal operation it can be reasonably claimed that the idiosyncrasies of the estimator has affected all the costs in like manner. Also since we are dealing with comparisons rather than actual costs, the results will not be affected by the method or style of estimating. Additional comments regarding the estimated work are included elsewhere in the report and accompanying the tables themselves.

THE EXERCISE

The first stage involves the use of Schedule 8 of the Regulations, and in particular Part II and VA. A list has been compiled of most of the various techniques of protection which meet the required periods of fire resistance Appendix A tables 1-5. Those which have been ignored have been for the following reasons:

(i) The difference between the technique omitted and a similar technique is small or is obviously uneconomic. For example, solid block casing is identical to the hollow block casing except for the additional requirement of the filling.

(ii) Other factors are involved which have not been considered in the exercise, such as the use of loadbearing concrete

(iii) On investigation it appears that the form of construction is no longer current practice.

For convenience, the compiled list has been set out in categories depending on the fire resistance of the particular technique. These forms of construction which meet more than one period of fire resistance appear in each respective category.

As regards the requirement of no fire resistance the cheapest form of construction that meets this will naturally be the uncased stanchion for structural steel and the basic 250 mm x 250 mm reinforced concrete column. With the latter, it has to be remembered that there exists a load-carrying criterion to provide the common element in both materials. Thus, this concrete column is the smallest size that will correspond to the steel stanchion based on this criterion, and this therefore eliminates the use of a smaller column although permitted in Part II of Schedule 8.

The second stage comprises the estimating content of the exercise - that of pricing each of the methods of protecting the columns. Generally speaking the estimated prices are based on existing work reinforced with built-up rates where they are likely to exert the most influence. However, the following sources of information have been used in this exercise in order to ensure the maximum accuracy and consistency:

(a) Standard pricing books and estimating text books

(b) Rates supplied by material manufacturers

(c) Prices supplied by contractors for executing the work

Appendix A, Tables 1 to 5 shows the techniques, complete with estimated prices. Certain assumptions have, of necessity, been made in order to proceed with the estimating and these are stated at the foot of each table of the Schedule. Such variables as overheads, profit margin and the general preliminary items, have been included on a nominal but consistent basis but it cannot be claimed, particularly in view of the existing inflationary situation, that these prices would be today's charges for executing the work.

The third stage relates the estimated figures to particular types of buildings, and involves the use of Regulation E2 and its accompanying Table. This provides eight types of buildings, viz:-

(1) Small residential

(2) Institutional

(3) Other residential

(4) Offices

(5) Shops

(6) Factories

(7) Other places of assembly

(8) Storage and general

Table A, Parts 1 and 2 to Regulation E5, provides a further sub-division and allocates the various degrees of fire resistance required. However, to rationalise the building types the broader height classification (as described in Part 1 of this study) has been adopted. Several building types have been omitted either because a framework is unlikely to be used or the type of building at the present moment, is uncommon, eg high rise shops.

With these factors in mind, a new list has been compiled - see Appendix B, Table 1 - which shows the types of buildings likely to use a framework construction, and their corresponding fire resistance requirements.

Since, as one must assume, only the most economic solutions, ie the cheapest, would be expected to exert any influence on the decision, the final operation of this third stage has been the combination of the cheapest techniques for both materials in each fire resistance category, as obtained from Appendix A, Tables 1 to 5, with the list of building types found in Appendix B, Table 1.

The results and suggested economic solutions are recorded in the form of Appendix B, Table 2.

The final stage has been the costing of columns of other sizes to test whether the results of Appendix B and Table 2 hold firm for such columns. Again they have been used in pairs with reinforced concrete matched to structural steel based on the same loadbearing criteria.

Thus, following the procedure of the first stage, three universal columns were selected:

(i) 150 mm (6 in) x 150 mm (6 in) x *23.4 kg/m (15.7 lb/ft)

(ii) 250 mm (10 in) x 250 mm (10 in) x *73 kg/m (49 lb/ft)

(iii) 300 mm (12 in) x 300 mm (12 in) x *97 kg/m (65 lb/ft)

and using the same stress values, effective lengths and corresponding axial loadbearing capacities, three reinforced concrete columns were calculated to be the most economic equivalent to the steel. They are:

(i) 200 mm (8 in) x 200 mm (8 in) with ⨍3 per cent steel reinforcement

(ii) 330 mm (13 in) x 330 mm (13 in) with 4 per cent steel reinforcement

(iii) 380 mm (15 in) x 380 mm (15 in) with 4 per cent steel reinforcement

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*These dimensions are the direct metric equivalents to the imperial sizes and it should be noted that there may take place some rationalisation of the metric sizes at a later date. This will not affect the work but may make referencing to particular columns rather confusing.

⨍Alternative sizes of concrete columns with different areas of steel reinforcement were considered for the smaller columns in order to select the most economic solution.

With the smallest steel stanchion, the weight per length of steelwork is below the limit imposed by Schedule 8 Part VA. This means in effect that more protection would be required to meet the particular degree of fire resistance than that stated in the table. Therefore, although this stanchion has been compared with its equivalent concrete column an allowance would need to be added to the cost of fire protection to compensate for this factor.

With the largest stanchion, the steel tables do not provide axial loadbearing capacities for the effective lengths so far used in the exercise and thus, for this pair the effective length of column has been increased to about 3 metres (10 feet). However, with this sort of comparison the effect of an increase in height such as this, would be negligible.

Since generally speaking, an increase in the size of the steel stanchion will simply mean a pro rata increase in the size of the casing and therefore its cost, it is sufficient for comparison purposes, to consider only the cheapest casing in each category.

Thus, the re-estimated prices for the cheapest methods of protecting the columns of various sizes, are compared and the results are shown in Appendix B Table 3.

DISCUSSION OF THE RESULTS

1. Schedule 8 Parts II and VA: The breakdown of these parts of the schedule reveal certain aspects:
   (i) Several of the forms of construction are impractical from an economic standpoint. The 2 inch bricks specified would probably be more expensive than 3 inch common bricks, whilst the use of the brick infil, for the solid coring, achieves very little in respect of the extra costs that it would incur.
   (ii) Some of these methods are no longer current practice, probably the result of the time-lag between drafting these Regulations and their becoming mandatory.
2. The priced techniques (Appendix A Parts 1 to 5): Several features can be seen from the figures container in the tables:
   (i) The lightweight casings are generally cheaper than the solid casings with plaster and boarding tending to be the more economic.
   (ii) Very little separates the bulk of the techniques in the middle order particularly for the lower fire resistance periods.
   (iii) The cost of casing steelwork in concrete is one of the most uneconomic methods of fire protection, amounting to nearly 40 per cent more than the cheapest technique. The use of loadbearing concrete, although requiring a greater thickness of cover, would produce some economies.

(iv) With the exception of one or two extremes, the range of costs, over all the fire resistance periods, is reasonably small suggesting that it is the need to provide fire protection to the structure, rather than any particular requirement, that is the major factor.

3. In determining costs, the use of the common element - the column - means that the size of concrete column, calculated to correspond to the steel stanchion, is considerably higher than the smallest sizes contained in Part II of Schedule 8 of the 1965 Building Regulations. Hence the 250 mm x 250 mm concrete column adopted meets all the requirements up to and including 1½ hours. The use of larger steel stanchions further increases the size of the concrete equivalent such that even the maximum resistance periods are obtained without further protection to the concrete.

4. Appendix B, Table 1 indicates that there is a greater use of the lower and middle fire resistance periods. The 4 hour period rarely occurs and the 2 hour category is largely confined to the single storey structure.

5. The economic solution: It would be unwise to categorically state that a particular framework for a particular type of building was the most economic based simply on this exercise, but there are several distinct trends which can be observed, depending on the column sizes.

With the 200 mm x 200 mm x 47.5 kg/m stanchion and its equivalent concrete column the extreme periods of fire resistance - nil and 4 hours - show steel to have the advantage, but in the middle periods it is concrete which is more economic.

Using smaller columns the pattern remains the same with the extremities again favouring steel.

The pattern of large columns has a similar beginning but the advantage to concrete in the middle periods continues to increase as the period of required fire resistance rises.

CONCLUSIONS

(1) It is the need for fire protection around steel columns rather than the degree of fire resistance required which most influences the economics. The difference between the minimum requirement - ½ hour, and the usual maximum - 2 hours, is small compared to the difference between nil fire resistance and ½ hour.

(2) Again for steel, cost differences between periods of fire resistance are quite small if the extremes - nil and 4 hours - are ignored. The smallest stanchion - ie that of 23.4 kg/m (15.7 lbs/ft), which is below the minimum stated in Part VA of Schedule 8, would require additional protection, so the figures for this example, are not realistic.

(3) Generally speaking, as the fire resistance requirement increases so does the margin in favour of concrete. However, there are certain characteristics:

(i) The rate of increase is small

(ii) As the size of the steel stanchion increases, so the margin in favour of concrete diminishes. Thus, although the same curve would be obtained for the $\frac{1}{2}$ hour to 4 hour periods of fire resistance, the margin favouring concrete would be smaller in each case.

(iii) There is a minimum size of steel stanchion for which this trend applies. The 200 mm x 200 mm x 47.5 kg/m indicates an economic advantage towards steel in the higher categories, particularly 4 hours. The smaller stanchion would seem to repeat this trend.

(4) For the minimum fire resistance requirement - $\frac{1}{2}$ hour - the cost difference between steel and concrete would seem to be negligible. However, it would be interesting to see if this particular pattern is repeated with the inclusion of the beam element.

(5) Lightweight casings are cheaper than the solid casings. Their use, however, is somewhat dictated by the other factors and although concrete as a casing appears very uneconomic, its durability and repairability, in the event of a fire, often overrides its expense.

(6) From a general point-of-view, the cost breakdown of Parts II and VA reveals two problems - the economic impracticality of some of the technique and the lack of current practice of several of the others. Perhaps more work is needed in assessing the economic considerations of such methods of construction which are deemed to satisfy the requirements, and, either more general forms of construction are adopted, which are less likely to become dated or, more speed is required in the drafting and execution of such regulations and their amendments.

(7) The earlier paragraphs of this final heading apply only to a part of a framework, and it would be necessary in order to be more positive, to consider, not only the entire framework, but the other considerations affecting framework construction as well. However, it is hoped that future exercises will be carried out based upon the principles established within this note. Indeed work is currently in hand using some of the enclosed data in assessing the relationship between fire resistance and costs of construction.

# APPENDICES

APPENDIX A, TABLE 1.

**PRICED TECHNIQUES** - ½ hour

| | Technique | Regulations ref. no. | Cost (pounds) |
|---|---|---|---|
| **Encased stanchion** | | | |
| 7 mm (¼ in) | Vermiculite-gypsum plaster on 9.5 mm (⅜ in) plasterboard, including binding wire. | B 6a | 23.22 |
| 13 mm (½ in) | Gypsum plaster on 9.5 mm (⅜ in) plasterboard including binding wire. | B 5a | 23.78 |
| 50 mm (2 in) | Blocks (thermalite) reinforced every horizontal joint. | B 2 | 24.32 |
| 13 mm (½ in) | Gypsum plaster on metal lath. | B 3 | 24.35 |
| 7 mm (¼ in) | Gypsum plaster on 19 mm (¾ in) plasterboard including binding wire. | B 5b | 24.37 |
| 7 mm (¼ in) | Vermiculite-gypsum plaster on 19 mm (¾ in) plasterboard, including binding wire. | B 6b | 24.46 |
| 13 mm (½ in) | Vermiculite-gypsum plaster on metal lath. | B 4a | 24.78 |
| 10 mm (⅜ in) | Sprayed asbestos on metal lath. | B 7 | 24.95 |
| 10 mm (⅜ in) | Sprayed asbestos 140-240 $kg/m^3$ (9-15 $lb/ft^3$). | A 4 | 24.98 |
| 50 mm (2 in) | Solid casing of clay bricks. | A 2 | 26.72 |
| 50 mm (2 in) | Hollow casing of clay bricks (as A2) reinforced every horizontal joint. | B 1 | 27.60 |
| 25 mm (1 in) | Thick non-loadbearing concrete, reinforced with a light mesh reinforcement. | A 1a | 33.82 |

| Reinforced concrete | | Technique | Regulations ref. no. | Cost (pounds) |
|---|---|---|---|---|
| 250 mm (10 in) x 250 mm (10 in) | x | Column | 1a | 22.13 |
| 250 mm (10 in) x 250 mm (10 in) | x | Column, with a light mesh in concrete cover to maintain reinforcement | 1d | 23.40 |
| 250 mm (10 in) | x | Column, with a 13 mm (½ in) Vermiculite-gypsum plaster cover | 1c | 25.11 |
| 250 mm (10 in) | x | Column, with a 13 mm (½ in) Gypsum plaster cover on mesh reinforcement fixed around column | 1b | 25.91 |

Notes:

(1) The cost of using special 50 mm (2 in) bricks or of cutting 75 mm (3 in) bricks to size would exceed the cost of using normal 75 mm (3 in) x 115 mm (4½ in) bricks. Hence, even though 50 mm (2 in) bricks are stated the normal 75 mm (3 in) bricks were used in the estimating.

(2) 13 mm (½ in) plaster work has been measured as render and set. If metal lathing is used, then the render includes a pricking-up coat.

(3) 7 mm (¼ in) plaster work has been measured as one coat of board plaster.

(4) The Regulations reference number refers to Schedule 8 - Notional periods of Fire Resistance (to regulation E6), with the prefix letter indicating whether solid (A) or hollow protection (B) and the number and following letter refering to the order in which the technique is listed in Schedule 8.

APPENDIX A, TABLE 2.

PRICED TECHNIQUES - 1 hour

| | Technique | Regulations ref. no. | Cost (pounds) |
|---|---|---|---|
| Encased stanchion | | | |
| 10 mm ($\frac{3}{8}$ in) | Vermiculite-gypsum plaster, on 9.5 mm ($\frac{3}{8}$ in) plasterboard including binding wire. | B 6a | 23.76 |
| 13 mm ($\frac{1}{2}$ in) | Gypsum plaster on 9.5 mm ($\frac{3}{8}$ in) plasterboard (as Part 1). | B 5a | 23.77 |
| 50 mm (2 in) | Blocks (as Part 1). | B 2 | 24.32 |
| 7 mm ($\frac{1}{4}$ in) | Gypsum plaster, on 19 mm ($\frac{3}{4}$ in) plasterboard (as Part 1). | B 5b | 24.37 |
| 7 mm ($\frac{1}{4}$ in) | Vermiculite-gypsum plaster, on 19 mm ($\frac{3}{4}$ in) plasterboard (as Part 1). | B 6b | 24.46 |
| 13 mm ($\frac{1}{2}$ in) | Vermiculite-gypsum plaster on metal lath (as Part 1). | B 4a | 24.78 |
| 19 mm ($\frac{3}{4}$ in) | Gypsum plaster on metal lath. | B 3 | 24.88 |
| 10 mm ($\frac{3}{8}$ in) | Sprayed asbestos on metal lath (as Part 1). | B 7 | 24.95 |
| 10 mm ($\frac{3}{8}$ in) | Sprayed asbestos (as Part 1) | A 4 | 24.98 |
| 50 mm (2 in) | Solid casing of bricks (as Part 1). | A 2 | 26.72 |
| 50 mm (2 in) | Hollow casing of bricks (as Part 1) | B 1 | 27.60 |
| 25 mm (1 in) | Thick concrete (as Part 1) | A 1a | 33.82 |

| | Technique | Regulations ref. no. | Cost (pounds) |
|---|---|---|---|
| **Reinforced concrete** | | | |
| 250 mm (10 in) x 250 mm (10 in) | Column (as Part 1) | 1a | 22.13 |
| 250 mm (10 in) x 250 mm (10 in) | Column, with light mesh in concrete cover (as Part 1) | 1d | 23.40 |
| 250 mm (10 in) x 250 mm (10 in) | Column, with 13 mm ($\frac{1}{2}$ in) Vermiculite-gypsum plaster cover (as Part 1) | 1c | 25.11 |
| 250 mm (10 in) x | Column, with 13 mm ($\frac{1}{2}$ in) Gypsum plaster cover (as Part 1) | 1b | 25.91 |

Notes:

(1) As Part 1

(2) 19 mm ($\frac{3}{4}$ in) plaster work has been measured as render and set. If on metal lath, then the render includes a pricking-up coat.

(3) 10 mm ($\frac{3}{8}$ in) plaster work has been measured as render and set.

APPENDIX A, TABLE 3.

## PRICED TECHNIQUES - 1½ hour

| | Technique | Regulations ref. no. | Cost (pounds) |
|---|---|---|---|
| **Encased stanchion** | | | |
| 13 mm (½ in) | Vermiculite-gypsum plaster, on 9.5 mm (⅜ in) plasterboard, including binding wire | B 6a | 24.01 |
| 50 mm (2 in) | Blocks (as Part 2) | B 2 | 24.32 |
| 10 mm (⅜ in) | Gypsum plaster, on 19 mm (¾ in) plasterboard, including binding wire | B 5b | 24.86 |
| 10 mm (⅜ in) | Vermiculite-gypsum plaster, on 19 mm (¾ in) plasterboard, including binding wire | B 6b | 25.05 |
| 16 mm (⅝ in) | Vermiculite-gypsum plaster on metal lath | B 4a | 25.19 |
| 25 mm (1 in) | Gypsum plaster on metal lath | B 3 | 26.07 |
| 16 mm (⅝ in) | Sprayed asbestos on metal lath | B 7 | 26.35 |
| 50 mm (2 in) | Solid casing of bricks (as Part 2) | A 2 | 26.72 |
| 16 mm (⅝ in) | Sprayed asbestos | A 4 | 26.93 |
| 50 mm (2 in) | Hollow casing of bricks (as Part 2) | B 1 | 27.60 |
| 25 mm (1 in) | Thick concrete (as Part 2) | A 1a | 33.82 |

| | | Technique | Regulations ref. no. | Cost (pounds) |
|---|---|---|---|---|
| **Reinforced concrete** | | | | |
| 250 mm (10 in) 250 mm (10 in) | x | Column | 1a | 22.13 |
| 250 mm (10 in) 250 mm (10 in) | x | Column, with light mesh in concrete cover (as Part 2) | 1d | 23.40 |
| 250 mm (10 in) 250 mm (10 in) | x | Column, with 13 mm ($\frac{1}{2}$ in) Vermiculite-gypsum plaster cover (as Part 2) | 1c | 25.11 |
| 250 mm (10 in) | x | Column, with 13 mm ($\frac{1}{2}$ in) Gypsum plaster cover (as Part 2) | 1b | 25.91 |

Notes:

(1) As Part 2.

(2) 25 mm (1 in) plasterwork has been measured as render, float and set. If on metal lathing, then the render includes a pricking-up coat.

(3) 16 mm ($\frac{5}{8}$ in) plasterwork has been measured as render and set. If on metal lathing, then the render includes a pricking-up coat.

APPENDIX A, TABLE 4.

PRICED TECHNIQUES - 2 hours

| | Technique | Regulations ref. no. | Cost (pounds) |
|---|---|---|---|
| Encased stanchion | | | |
| 16 mm ($\frac{5}{8}$ in) | Vermiculite-gypsum plaster, on 9.5 mm ($\frac{3}{8}$ in) plasterboard, including binding wire | B 6a | 24.26 |
| 50 mm (2 in) | Blocks (as Part 3) | B 2 | 24.32 |
| 10 mm ($\frac{3}{8}$ in) | Vermiculite-gypsum plaster, on 19 mm ($\frac{3}{4}$ in) plasterboard including binding wire (As Part 3) | B 6b | 25.05 |
| 13 mm ($\frac{1}{2}$ in) | Gypsum plaster, on 19 mm ($\frac{3}{4}$ in) plasterboard, including binding wire | B 5b | 25.05 |
| 19 mm ($\frac{3}{4}$ in) | Vermiculite-gypsum plaster on metal lath | B 4a | 25.60 |
| 50 mm (2 in) | Solid casing of bricks (as Part 3) | A 2 | 26.72 |
| 19 mm ($\frac{3}{4}$ in) | Sprayed asbestos on metal lath | B 7 | 26.91 |
| 50 mm (2 in) | Hollow casing of bricks (as Part 3) | B 1 | 27.60 |
| 19 mm ($\frac{3}{4}$ in) | Sprayed asbestos | A 4 | 27.68 |
| 38 mm ($1\frac{1}{2}$ in) | Gypsum plaster on metal lath, including a light mesh reinforcement | B 3 | 28.58 |
| 25 mm (1 in) | Thick concrete (as Part 3) | A 1a | 33.82 |

| | | Technique | Regulations ref. no. | Cost (pounds) |
|---|---|---|---|---|
| **Reinforced concrete** | | | | |
| 250 mm (10 in) 250 mm (10 in) | x | Column, with light mesh in concrete cover to main reinforcement | 1d | 23.40 |
| 250 mm (10 in) 250 mm (10 in) | x | Column, with 13 mm ($\frac{1}{2}$ in) Vermiculite-gypsum plaster cover | 1c | 25.11 |
| 300 mm (12 in) 300 mm (12 in) | x | Column | 1a | 27.26 |
| 280 mm (11 in) 280 mm (11 in) | x | Column, with 13 mm ($\frac{1}{2}$ in) Gypsum plaster cover on mesh reinforcement fixed around the column | 1b | 28.07 |

Notes:

(1) As Part 3

(2) 38 mm (1$\frac{1}{2}$ in) plaster work measured as 3 coats render and 1 coat set. If on metal lathing then 1st render coat includes a pricking-up coat.

APPENDIX A, TABLE 5.

PRICED TECHNIQUES - 4 hours

| | Technique | Regulations ref. no. | Cost (pounds) |
|---|---|---|---|
| Encased stanchion | | | |
| 75 mm (3 in) | Solid casing of clay bricks (see Note to part 1) | A 2 | 26.72 |
| 75 mm (3 in) | Blocks (thermalite) reinforced every horizontal joint | B 2 | 26.90 |
| 32 mm (1¼ in) | Vermiculite-gypsum plaster, on 19 mm (¾ in) plasterboard, including binding wire and light mesh reinforcement | B 6b | 28.49 |
| 45 mm (1¾ in) | Sprayed asbestos on metal lath | B 7 | 32.09 |
| 50 mm (2 in) | Vermiculite-gypsum plaster on metal lath including a light mesh reinforcement | B 4a | 33.06 |
| 115 mm (4½ in) | Hollow casing of clay bricks reinforced as before | B 1 | 33.25 |
| 45 mm (1¾ in) | Sprayed asbestos 140-240 $Kg/m^3$ (9-15 $lb/ft^3$) | A 4 | 34.60 |
| 45 mm (1¾ in) | Vermiculite-gypsum plaster on metal lath but spaced 25 mm (1 in) from flanges | B 4b | 35.15 |
| 50 mm (2 in) | Thick non-loadbearing concrete reinforced with a light mesh reinforcement | A 1a | 37.63 |

| | Technique | Regulations ref. no. | Cost (pounds) |
|---|---|---|---|
| **Reinforced concrete** | | | |
| 300 mm (12 in) x 300 mm (12 in) | Column, with wire fabric in concrete cover to main reinforcement | 1d | 28.73 |
| 300 mm (12 in) x 300 mm (12 in) | Column, with 13 mm (½ in) Vermiculite-gypsum plaster cover | 1c | 30.80 |
| 460 mm (18 in) x 460 mm (18 in) | Column | 1a | 42.33 |
| 430 mm (17 in) x 430 mm (17 in) | Column, with a 13 mm (½ in) Gypsum plaster cover on mesh reinforcement around the column | 1b | 47.89 |

Notes:

(1) As Part 4.

(2) 50 mm (2 in) plaster work has been measured as 4 coats render and 1 coat set, with the 1st coat of render including a pricking-up coat on lath.

(3) 45 mm (1¾ in) plaster work has been measured as 3 coats render and 1 coat set, with the 1st coat of render including a pricking-up coat on lath.

(4) 32 mm (1¼ in) plasterwork has been measured as 2 coats render and 1 coat set.

APPENDIX B, TABLE 1.

## PERIODS OF FIRE RESISTANCE

| Category of building | | Purpose group | Part 1 Fire resistance period (hours) | Part 2 Fire resistance period (hours) |
|---|---|---|---|---|
| Institutional | low rise | 2 | | $\frac{1}{2}$ |
| | medium rise | | 1 | |
| | high rise | | $1\frac{1}{2}$ | |
| Other residential (flats) | medium rise | 3 | 1 | |
| | high rise | | $1\frac{1}{2}$ | |
| Offices | low rise | 4 | 0, $\frac{1}{2}$ | $\frac{1}{2}$, 1 |
| | medium rise | | 1 | |
| | high rise | | $1\frac{1}{2}$ | |
| Shops | low rise | 5 | 0, $\frac{1}{2}$ | $\frac{1}{2}$, 1, 2 |
| | medium rise | | 1 | |
| Factories | low rise | 6 | 0, $\frac{1}{2}$ | $\frac{1}{2}$, 1, 2 |
| | medium rise | | 1, 2 | |
| Places of assembly | low rise | 7 | 0, $\frac{1}{2}$ | $\frac{1}{2}$, 1 |
| | medium rise | | 1 | |
| | high rise | | $1\frac{1}{2}$ | |
| Storage & General | low rise | 8 | 0, $\frac{1}{2}$ | $\frac{1}{2}$, 1, 2, 4 |
| | medium rise | | 1, 2, 4 | |

APPENDIX B, TABLE 2.

## SUGGESTED ECONOMIC SOLUTIONS FOR VARIOUS CATEGORIES OF BUILDINGS

(based on 200 mm x 200 mm x 47.5 Kg/m steel stanchion & 250 mm x 250 mm reinforced concrete column)

| Category of building | | Period of fire resistance (hours) | Cheapest concrete (£) | Cheapest steel (£) | Difference (£) | Difference % | Economic solution |
|---|---|---|---|---|---|---|---|
| Institutional | low rise ) medium rise) | 1 | 22.13 | 23.76 | 1.63 | 7½ | concrete |
| | high rise ) | 1½ | 22.13 | 24.01 | 1.88 | 8½ | concrete |
| Other residential (i.e. flats etc.) | medium rise | 1 | 22.13 | 23.76 | 1.63 | 7½ | concrete |
| | high rise | 1½ | 22.13 | 24.01 | 1.88 | 8½ | concrete |
| Offices | low rise | 0 | 22.13 | 18.70 | -3.43 | -18½ | steel |
| | low rise | ½ | 22.13 | 23.22 | 1.09 | 5 | either |
| | medium rise | 1 | 22.13 | 23.76 | 1.63 | 7½ | concrete |
| | high rise | 1½ | 22.13 | 24.01 | 1.88 | 8½ | concrete |
| Shops | low rise | 0 | 22.13 | 18.70 | -3.43 | -18½ | steel |
| | low rise | ½ | 22.13 | 23.22 | 1.09 | 5 | either |
| | medium rise | 1 | 22.13 | 23.76 | 1.63 | 7½ | concrete |
| Factories | low rise | 0 | 22.13 | 18.70 | -3.43 | -18½ | steel |
| | low rise | ½ | 22.13 | 23.22 | 1.09 | 5 | either |
| | medium rise | 1 | 22.13 | 23.76 | 1.63 | 7½ | concrete |
| | medium rise | 2 | 23.40 | 24.26 | 0.87 | 3½ | either |
| Places of assembly | low rise | 0 | 22.13 | 18.70 | -3.43 | -18½ | steel |
| | low rise | ½ | 22.13 | 23.22 | 1.09 | 5 | either |
| | medium rise | 1 | 22.13 | 23.76 | 1.63 | 7½ | concrete |
| | high rise | 1½ | 22.13 | 24.01 | 1.88 | 8½ | concrete |
| Storage & General | low rise | 0 | 22.13 | 18.70 | -3.43 | -18½ | steel |
| | low rise | ½ | 22.13 | 23.22 | 1.09 | 5 | either |
| | medium rise | 1 | 22.13 | 23.76 | 1.63 | 7½ | concrete |
| | medium rise | 2 | 23.40 | 24.26 | 0.87 | 3½ | either |
| | medium rise | 4 | 28.73 | 26.72 | -2.01 | -7½ | steel |

Note: The ½ hour and 2 hour periods are less than 5 per cent and one could consider such a difference negligible.

APPENDIX B, TABLE 3.

## ECONOMIC SOLUTIONS WITH VARYING SIZES OF COLUMNS

| | | Period of fire resistance | Cheapest concrete (£) | Cheapest steel (£) | Difference (£) | Difference % | Economic solution |
|---|---|---|---|---|---|---|---|
| A | 150 mm x 150 mm x 23.4 Kg/m stanchion | Nil | 13.13 | 10.05 | -3.08 | -31 | - |
| | 200 mm x 200 mm reinforced concrete column | ½ | 13.13 | 13.73 | 0.60 | 4½ | - |
| | | 1 | 15.57 | 14.09 | -1.48 | -10½ | - |
| | | 1½ | 16.65 | 14.33 | -2.32 | -16 | - |
| | | 2 | 18.55 | 14.52 | -4.03 | -27½ | - |
| | | 4 | 28.73 | 16.20 | -12.53 | -78 | - |
| B | 200 mm x 200 mm x 47.5 Kg/m stanchion | Nil | 22.13 | 18.70 | -3.43 | -18½ | Steel |
| | 250 mm x 250 mm reinforced concrete column | ½ | 22.13 | 23.22 | 1.09 | 5 | Either |
| | | 1 | 22.13 | 23.76 | 1.63 | 7½ | Concrete |
| | | 1½ | 22.13 | 24.01 | 1.88 | 8½ | Concrete |
| | | 2 | 23.40 | 24.26 | 0.87 | 3½ | Either |
| | | 4 | 28.73 | 26.72 | -2.01 | -7½ | Steel |
| C | 250 mm x 250 mm x 73 Kg/m stanchion | Nil | 32.25 | 28.10 | -4.15 | -15 | Steel |
| | 330 mm x 330 mm reinforced concrete column | ½ | 32.25 | 33.46 | 1.21 | 4 | Either |
| | | 1 | 32.25 | 34.13 | 1.88 | 6 | Concrete |
| | | 1½ | 32.25 | 34.45 | 2.20 | 7 | Concrete |
| | | 2 | 32.25 | 34.78 | 2.53 | 8 | Concrete |
| | | 4 | 34.00 | 37.75 | 3.75 | 11 | Concrete |
| D | 300 mm x 300 mm x 97 Kg/m stanchion | Nil | 50.65 | 44.75 | -5.90 | -13 | Steel |
| | 380 mm x 380 mm reinforced concrete column | ½ | 50.65 | 52.49 | 1.84 | 3½ | Either |
| | | 1 | 50.65 | 53.52 | 2.87 | 5½ | Concrete |
| | | 1½ | 50.65 | 54.00 | 3.35 | 6½ | Concrete |
| | | 2 | 50.65 | 54.46 | 3.81 | 7½ | Concrete |
| | | 4 | 53.15 | 58.13 | 5.02 | 9½ | Concrete |

Note: No solution has been quoted for the smallest columns since additional protection would be required to the steel and the cheapest technique quoted might be considerably higher. The figures have only been included to indicate the trend - see results section for further comments, and Page 5.

APPENDIX C

## Introductory Comments

### INTRODUCTION

If the design of a building lends itself to a framed structure, then a decision has to be made whether to use concrete or structural steel for the framework. Certain types of buildings may use other materials e.g. timber, but their use at the moment is limited and in any case outside the scope of this report.

Over the years, circumstances and fashion have tended to favour the use of one or other of these materials and it seems to be considered that present-day conditions favour concrete, largely because of the cost differential caused by fire protection, and to a lesser extent, the additional maintenance requirements for steel and the uncertain supply, caused by the pressures placed on the steel manufacturers by industry as a whole. Also, concrete technology has advanced with the design mix and the improved mixing and handling facilities and the better finishing techniques.

However, to be fair to the steel industry, they too have progressed with the introduction of high yield and weathering steels, improved welding techniques and the use of high strength friction grip bolts. This progress, coupled with an improving supply, help to make steel a much more attractive proposition than at first would seem.

The main disadvantage therefore in using this material appears to be the additional cost of fire protection, and any cost differential caused by this will be clearly indicated in the study.

The study will take the form of several exercises, each considering the problem confined to certain parameters. The ultimate stage will be that of comparing frameworks of both concrete and structural steel, taking into consideration all the cost factors - both basic and inter-relating. By working in stages it is hoped to carry out the successive exercises based upon the knowledge gained and the principles thus formulated in the previous step.

### OBJECTIVE

This is to determine the most economic solution between concrete and steel frameworks for different types of buildings requiring specific degrees of fire resistance. The ultimate goal might therefore be, to assess the merits of the statement that conditions to-day favour the use of a concrete frame, and to evaluate the findings.

Each step, however, will have its secondary objectives and its consequent results which may well indicate some other trend or reveal some other facet of the problem. These will be discussed together with the various limitations or parameters to which they have followed, within each exercise.

METHOD

The basis of this cost study is Part E of the 1965 Building Regulations and the subsequent Amendments, and in particular, sections:-

E2 - Designation of purpose groups

E5 - Fire Resistance

E6 - Tests of Fire Resistance

The various means of protecting reinforced concrete and structural steel are obtained from Schedule 8 (to Regulation E6) titled "Notional Periods of Fire Resistance." This Schedule contains, in fact, the deemed to satisfy provisions of the Regulation (E6). Those which are no longer in use have been ignored whilst a few, which are not in the Schedule, have been added for comparison.

The types of buildings which may make use of a framework structure, have been taken from the table to Regulation E2, viz:

(1) Small residential
(2) Institutional
(3) Other residential
(4) Offices
(5) Shops
(6) Factories
(7) Other places of assembly
(8) Storage and general

The size of building, and the period of fire resistance that it may have, has been taken from Table A Parts 1 and 2 to Regulation E5 which concerns periods of fire resistance. To rationalise the height factor, a broader classification has been adopted in the form of the following:

(i) Low rise - up to 15 m (50 feet) high
(ii) Medium rise - 15 m (50 feet) to 27 m (90 feet)
(iii) High rise - over 27 m (90 feet) high

The first exercise of this study will be the comparison of the frameworks when related to the fire resistance requirements of a single column. It considers the simple choice between concrete and steel using only the first costs. The other factors which might affect the choice of material have been ignored, but the exercise itself will explain its own limitations and its own particular objectives.

Further exercises will consider a frame or bay of a framework system, and evaluate the other factors likely to affect the choice which have been ignored by the previous exercises, and the final exercise will be to compare more complex frameworks taking into consideration all the factors in order to keep the fire resistance aspect into perspective.

From the results of these exercises, conclusions will be drawn as to the economics of the choice and the current validity of the initial statement regarding present-day conditions.