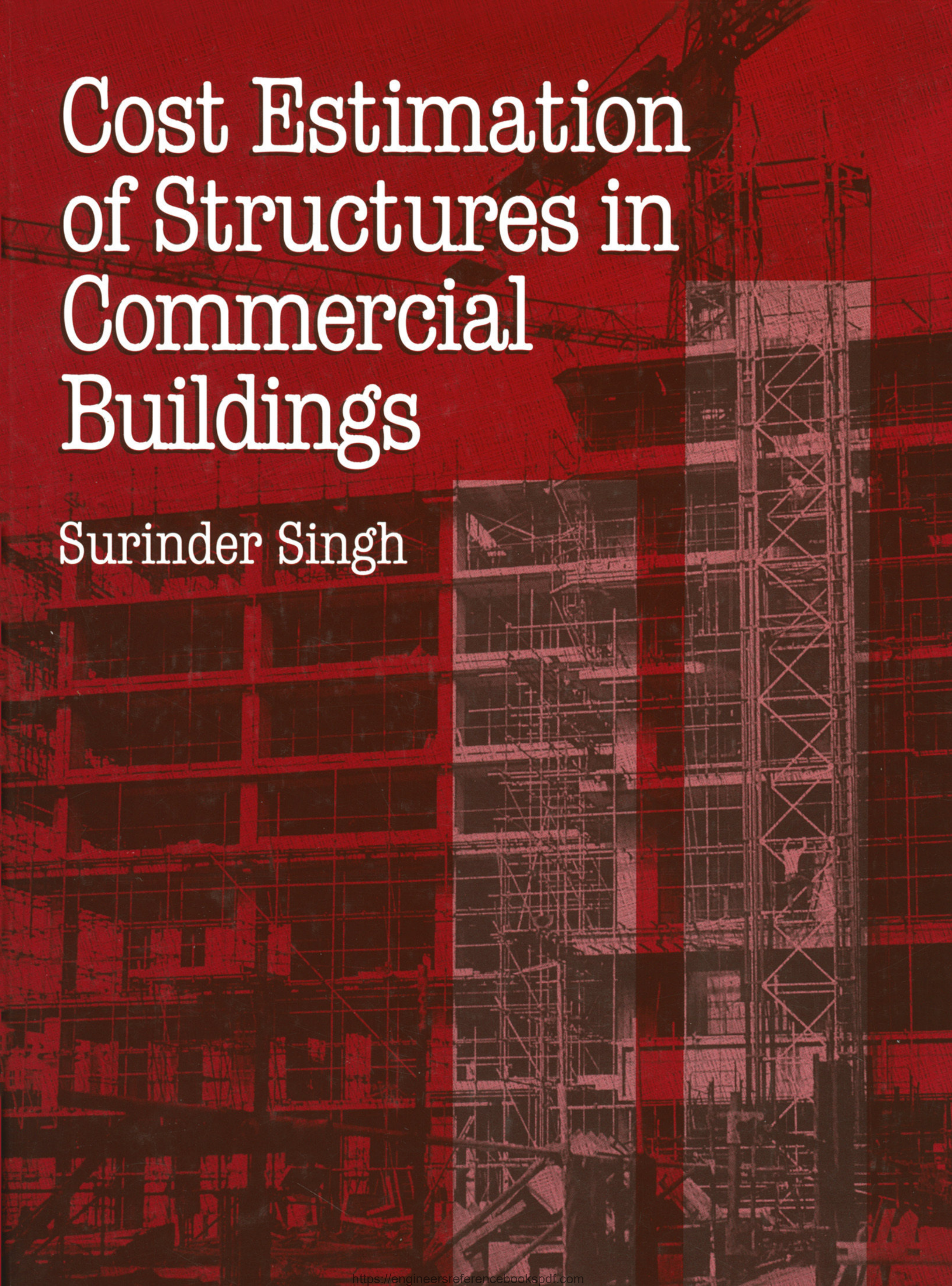
Cost Estimation of Structures in Commercial Buildings

Surinder Singh



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To my wife Manjit

my children
Rajwinder, Anjli, Sonia, Harmeen

and my grandchildren
Navreen and Gurmukh

Contents

Preface

Approximate cost estimates for structural works are always needed for one reason or another at the initial design stage in the building construction industry, and the techniques generally used for their preparation are the percentage estimate method, the superficial or floor area method (also known as the square metre method) and the approximate quantities method. A proper application of the first two methods requires an in-depth knowledge of historical cost information of completed buildings and of the effect of design parameters on the construction cost.

Information on constituent quantities of completed buildings is not readily available. Realistic estimates may thus require the engineer to work out different schemes so that the most economical one may be selected. It is time consuming and unsystematic if this has to be done for every project. With these drawbacks in mind, the author has supplied the basic data and discussed, in relation to commercial buildings ranging from 5 to 50 storeys, the effect of different design parameters on quantities of constituents for common structural systems, namely the reinforced concrete beam and slab system, the flat slab and waffle slab systems, and the prestressed concrete beam and reinforced concrete slab system. This approach to constituent quantities will enable both students and professionals to develop estimates with ease, speed and accuracy.

A critical review of the previous work relating to structural design economics has indicated that the investigations were either based on records of past completed projects or on first principles by analysis, design and computation of quantities. The former approach has a number of drawbacks and, in view of this, the author decided to follow the more scientific approach of analysis, design and computation of quantities for structures of varying heights and structural systems based on the latest British Standards and Codes.

The information on constituent quantities is presented in the form of charts and the effects of design parameters such as column grid size, number of storeys, location of structural components, arrangement of beams, grades of concrete, etc. on the quantities of various constituents of concrete construction for different structural systems have been discussed.

Using the charts presented, applications for comparative cost estimation to assess the effect of various design parameters, for approximate structural cost estimation of an overall project given its design features, for checking the estimates for structural works, for calculation of quantity index for structural works, and for various other building economics studies have been illustrated.

Singapore, 1994 SURINDER SINGH

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Last but by no means least, the moral support and the acceptance of divided attention over the years by the author's family are recognised with warm appreciation.

List of Symbols

The symbols used in this book are as follows:

f_{cu}	Characteristic concrete cube strength
f_y	Characteristic strength of reinforcement
f_{pu}	Characteristic strength of prestressing tendons or strands
G_k	Characteristic dead load
Q_k	Characteristic imposed load
W_k	Characteristic wind load
N/mm^2 or N/sq mm	Newtons per square millimetre
kN/m^2 or kN/sq m	Kilonewtons per square metre

1 Introduction

1.1 Background

In a framed building, four major areas which consume a substantial portion of the total project cost are the structural frame, architectural construction, foundations, and mechanical and electrical services. It is essential to explore all possibilities to achieve economy in each of these areas at the design stage, since investigations have indicated that about 80 per cent of the project cost is committed by the time 20 per cent of the design (sketch design stage) has been completed [1]. Further, in the present age of ever-increasing costs, the majority of the clients of building projects are insisting on projects being designed and executed to give maximum value for money. Hence professionals are employed to work as a team to an increasing extent during the design stage. As buildings become more complex and building clients more exacting in their requirements, so it becomes necessary to improve and refine the cost control tools.

Cost planning and cost control are complementary. During cost planning, the commonly adopted approximate estimating methods for computing the cost of structures are the percentage estimate method, the superficial or floor area method (also known as the square metre method) and the approximate quantities method. A proper application of the first two methods in practice requires, on the one hand, an in-depth knowledge of past historical cost information of completed projects and, on the other hand, a knowledge of the effect of design parameters on the construction cost. The latter, though not emphasised in practice is very important, since buildings are not generally alike and rates have to be adjusted for changes in design features. Besides, past historical cost information needs to be adjusted by the application of the cost index which is rarely available in the desired form, especially in developing countries.

In the approximate quantities method, cost estimates for new building works are often made by assuming approximate quantities of concrete, reinforcement and formwork. In the absence of realistic information relating to variations in the quantities of materials with changes in sizes of column grids, structural scheme, number of storeys and other design parameters, the quantities assumed tend to be very approximate and the percentage errors could be large. Where more realistic estimates are required, the engineer works out alternative structural schemes, and the most economical scheme consistent with the requirements is selected after the quantity surveyor has calculated the quantities and costs for the various schemes. It is extremely unsystematic and wasteful if structural schemes have to be worked out and costs estimated every time a new building project comes up. However, in recent years, the emphasis on research relating to building cost techniques, especially through mathematical modelling and the availability of microcomputers at the cost of electric typewriters, have provided openings to overcome these problems.

Trimble and Jupp [2] at Loughborough University of Technology developed cost models using regression techniques for various facets of building work. Gould [3] produced a cost model which deals with the capital cost of heating, ventilating and air conditioning installations for various building types. Badby [4], Wood [5], Baker [6], McCaffer [7], Newton [8] and Schofield *et al.* [9] also produced cost models related to the various aspects of building.

1.2 Aim

The aim of this book is to illustrate in the form of charts, in relation to high-rise commercial buildings ranging from 5 to 50 storeys, the effect of different design parameters on quantities of constituents using traditional structural systems, namely the solid slab and beam system, the flat slab/waffle slab system, and the prestressed beam and slab system.

Using the charts relationships, the user should be able to compute approximate quantities and hence the cost of the structure, given the structural scheme and other design parameters.

The effect of design variables such as grid size, structural system/scheme, grid location, grade of concrete, number of storeys, continuity of structure, shear core size, etc. has been investigated by the author and is presented in this book. The above parameters, in addition, facilitate a study of the effect of plan shape and size on the building structure.

The charts presented are useful for analysing the effect of the following on structural cost:

- Variation in cost of alternative structural systems.

- Variation in cost of alternative structural schemes within a specific structural system.
- Variation in cost due to difference in number of storeys.
- Plan shape and plan size.
- Beam and column spacings for optimum cost.
- Cost variation due to continuity of a structure (number of spans).
- Reduction in area of columns to increase letting space by either increasing grid size or by using high strength concrete in columns.
- Varying frame grid to minimise column disruption to working areas.
- Computation of additional cost involved for reducing beam depths to improve aesthetics.
- Additional cost involved, if any, to provide flat slab so as to permit services to run in both directions.

The crux of the contents of this book is therefore to establish cost-generating data to help students to study the effect of design variables on structural cost and for professionals to achieve speed, reliability and productivity in their cost advisory performance at the architectural design stage.

Table 1.1 Estimating accuracy.

Estimating method	*Mean deviation of estimates from tenders (%)*	*Coefficient of variation of errors (%)*
1. Cost per square metre taken from one previous project	18	22.5
2. Cost per square metre derived by averaging rates from a number of previous projects	15.5	19
3. Elemental estimating based on rates taken from one previous project	10	13
4. Elemental estimating based on rates derived by averaging the rates taken from a number of previous projects	9	11
5. Elemental estimating based on statistical analysis of all relevant data in the database	6	7.5
6. Resource use and costs based on contractors' estimating methods	5.5	6.5

Source: Bennett, J. Cost planning and computers. In *Building Cost Techniques: New Directions*, edited by Brandon, P.S., Spon, London, 1982, pp. 17–26.

1.3 Approach or Choice of Methods

The quantities of materials for any structural system can either be computed based on the past records of completed buildings, or derived from first principles by analysis, design and computation of quantities. The accuracy in the case of the first method depends on whether the various structural components of completed buildings were designed using the methods being adopted at present. Murthy (10) investigated results based on this approach and found substantial differences in quantities when considering similar buildings, structural schemes and design parameters. Further, a comparison of the cost estimating accuracy of different estimation methods has indicated (Table 1.1) that the percentage mean deviation of estimates from tenders and the percentage coefficient of variation of errors are lowest in estimates that are based on resource use as compared to those based on historical cost information [11]. In order to overcome the above limitations it was decided to compute and illustrate the constituent quantities of different structural systems, considering various design parameters for commercial buildings ranging from 5 to 50 storeys, in denominations of 5 storeys, based on first principles. The study of the effects of various parameters on quantities of materials is presented in Chapter 3 for beam and slab construction, in Chapter 4 for flat slab/waffle slab construction and in Chapter 5 for prestressed beam and slab construction.

Examples of applications of the charts generating the quantities/cost data for decision making are given in Chapter 6. Chapter 7 discusses the observations, trends and variations in quantities/cost, while Chapter 8 illustrates the computer-based cost model for the reinforced concrete beam and slab system. The accuracy of charts developed is discussed in Chapter 9 after having compared the theoretical quantities (based on charts) with the actual quantities for some local buildings. Some additional useful data for preliminary estimation is presented in Chapter 10.

It has been stated earlier that the quantities of materials may vary considerably for the same spans and loading, depending on the engineer who designed the structure. However, the relevance of the charts developed and presented in this book can be utilised by an engineer for assessing his own design and by a project manager for assessing whether a structure designed is too heavy or too light. This would help to check and detect if any errors have been made in the choice of the structural system or design calculations. It must be emphasised here that the maximum benefit can be derived by using the charts at the very beginning in decision making, so that an appropriate choice of the structure can be made before proceeding to analyse and design the structure.

1.4 Scope of Study

Requirements in different building types are different and hence the results of any investigation relevant to any particular type of building may not be universally applicable to all types of buildings. Thus it was decided to restrict the contents to commercial high-rise buildings. Pure shear wall structures, although they are suitable for the building-heights (5 to 50 storeys) considered in this book, require exhaustive study of their own and are not included in the studies presented here. Tube structures, tube-in-tube structures and other special structures not only require exhaustive investigations, but are also considered suitable for building-heights outside the range covered in the book. The discussion is confined to interacting frames and shear walls incorporating beam and slab, flat slab and waffle slab, and prestressed beam and slab floor systems, and these account for the great majority of the structural systems used for commercial buildings in almost all countries. Further, generally commercial buildings are built to accommodate offices, thus the charts have been developed to cover such buildings. However, in certain countries, especially those in South East Asia, the first five floors of many commercial buildings are built for shopping and the remainder for office blocks. Likewise, in the UK shopping use is normally confined to the ground floor or possibly the bottom two floors. To cover such constructions, necessary guidelines have been given in the appropriate chapters on how to compute the quantities of constituents.

Foundations consume about 8–15 per cent of the project cost. The foundation cost varies with the nature of soil, foundation type and dead weight of the superstructure. However, since an investigation of foundations is an exhaustive study in itself, the topic is considered to lie outside the scope of this book.

In many countries, the use of British standards and codes is quite common, hence for the design and analysis of reinforced and prestressed concrete structures, British Standard BS 8110: 1985 has been used for the structural calculations needed to develop charts in this book.

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2 Review of Previous Work

Research relating to structural design economics either uses records of past completed projects or is based on first principles by analysis, design and computation of quantities. Studies carried out using the former approach indicate that, in similar structural schemes and with specific values of design variables substantial variation in the quantities of constituents exists and thus a rational comparison of structural costs cannot be made. In contrast, the results of studies based on first principles indicate more scientific trends. Further, limited research work has been carried out in the past, both nationally and internationally, on aspects of structural design economics; the scientific investigations described in Chapters 3 to 5 of this book have never previously been reported.

2.1 General

Limited research work has been carried out in the past, both nationally and internationally, on aspects of structural design economics even though there is a Working Group W 55 in the International Council of Building Research Studies and Documentation (CIB) with specific interest in all areas of Building Economics. Research relating to structural design economics either uses records of past completed projects or is based on first principles by analysis, design and computation of quantities. The work carried out in the past is therefore being reviewed under the above headings in the sections which follow in this chapter.

2.2 Research based on Past Completed Projects

Buchanan [1] attempted to develop a cost model for the reinforced concrete frame based on the 38 cases of reinforced concrete frame structures constructed by the Ministry of Public Building and Works (UK) between 1960 and 1968. The buildings comprised a selection of postal sorting offices, telephone exchanges and other general office type buildings. Data were extracted as necessary from cost analysis and from the drawings.

Buchanan emphasised it was unlikely that a close description of cost could be found using only the set of 'basic' variables and that some manipulation of these was necessary. He thus considered that the structural part of the model could be represented by six basic factors – namely slabs, beams, columns, stairways, lift shafts and structural walls – and each of these could be subdivided into three cost sources: concrete, formwork and reinforcement. Expressions were thus derived for each component of the structural model in terms of design variables and were called 'derived' structural variables. Considering the basic and derived variables, the theoretical model was thus taken as the cost of:

> slab concrete + beam concrete + column concrete + slab formwork + beam formwork + columns formwork + slab reinforcement + beam reinforcement + column reinforcement + perimeter conditions + craft operative's wage rate + labourer's wage rate + NHI + SET + steel cost + cement cost + location + bank rate

The precision of the seven-variable Buchanan's model as a predictor can be gauged from Figure 2.1 which plots predicted against actual values. It can be seen that an accuracy of +5 per cent has been achieved when predicting high values, but at the lower end of the scale the accuracy of +40 per cent is not good enough.

Buchanan made a good attempt at developing derived variables for different structural components of a frame and tried to simplify the postulated model. However, his efforts are open to the following criticisms:

- Quantities of reinforced concrete constituents for the frame were based on bills of completed buildings, and as such the strictness with which the individual designer followed the required design codes is questionable. The present author, when dealing with historical data of completed buildings, has experienced substantial differences in quantities of constituents under similar cases of design. The results of Murthy's [2] investigation on this aspect reinforce the views of the author and are discussed later.
- Buchanan's model does not reflect the variation in cost due to differences in the arrangement of struc-

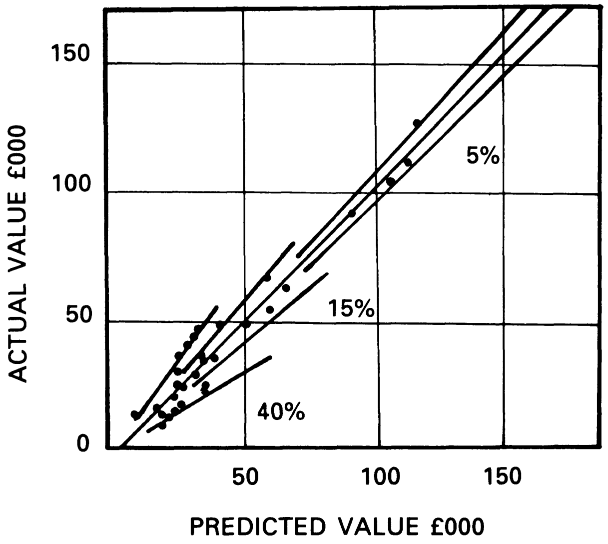

Figure 2.1 Plot of actual value versus predicted value showing limits of accuracy. (*Source*: Buchanan, J.A. *Development of a cost model for the reinforced concrete frame of a building*. MSc Thesis, Loughborough University of Technology, UK.)

tural members for a given column grid size. Singh and Murthy [3] have shown the wide variation in quantities that can occur owing to changes in the number and spacing of secondary beams in a beam and slab floor system.

- As reported, limited tests using new and independent data have been made and the results have indicated a substantial variation (about 40 per cent) between the theoretical and actual values. This shows that the developed model needs to be modified.
- There are a number of design variables for which decisions are generally needed at the design stage and which have not been considered in the model developed. Some of these design variables are the effect of different beam sections, the effect of different grid sizes in a specific structural scheme, the number of storeys, the concrete grade, etc.
- A wide range of buildings have been considered in the same sample of population selected for study, namely postal sorting offices, telephone exchanges and other general office type buildings.
- In the absence of proper cost index, especially as in many developing countries, the approach adopted needs to be modified.

Murthy [2] made a comparison of structural costs and structural systems for some commercial buildings in Singapore based on their final quantities of constituents of reinforced concrete. To avoid the variations in tendered rates for these buildings, he preferred to use prevailing rates for different materials in all the buildings. This was a better approach than using the tendered rates and then applying a cost index to change to a certain base year for comparison, since the projects considered were executed in different years. The information on quantities and cost for the typical internal panels of multi-bay buildings for the structural floor are shown in Table 2.1 in order of increasing spans (average of column spacings in two directions). The values in this table indicate that there is a wide variation in the structural cost per square metre of typical office floors of buildings. Further, considering similar flooring schemes, no regular trend exists between spans and costs. From this it can be concluded that, in similar structural schemes and with specific values of design variables, substantial variation in the quantities of constituents can be expected; in other words, using the above methodology of basing the comparison on historical information, it is not possible to give a rational comparison of structural costs. The only rational approach for true comparison appears to be one based on first principles of analysis, design and computation of quantities, since this allows consideration of the design variables, which affect the quantities of constituents.

Murthy made a comparison of different structural floor systems but did not consider the effect of each of these systems on columns. Because this effect was excluded from the comparison, the latter cannot be regarded as complete since various flooring systems considered affect the constituents of columns differently.

Khan and Iyengar [4] have contributed substantially by giving guidelines for the suitability of different structural systems for various number of storeys (Figure 2.2) in office buildings. They have further considered different structural systems for up to 70 storeys (Figure 2.3). The results presented appear to be very useful visually since limits are provided within which a particular structural system is economical. However, if the quantity curves (Figure 2.3) for concrete and reinforcement for various systems are projected backwards, it is seen that the curves do not intersect even for single storey construction. This indicates that the framed tube (type IV), the tube-in-tube (type V) and the modular tube (type VI) systems are most economical even for low-rise construction, and further that the shear wall (type II) construction is cheaper than the frame (type I) system even in a single storey office building. This does not appear

Table 2.1 Quantities and structural cost per sq m of structural floor for various buildings in Singapore.

Code name of building and description	*Concrete*		*Reinforcement*		*Formwork*		*Total cost per sq m of structural floor ($)*
	Quantity per sq m (cu m)	*Cost per sq m ($)*	*Quantity per sq m (kg)*	*Cost per sq m ($)*	*Quantity per sq m (sq m)*	*Cost per sq m ($)*	
Building E: multi-bay, typical panel 5.26 m × 7.92 m, reinforced concrete (RC) beam and slab, average of span in two directions = 6.5 m	0.184	19.50	38.42	38.42	1.15	12.62	70.54
Building G: multi-bay, typical panel 8.53 m × 6.7 m, RC beam and slab, average of span in two directions = 7.62 M	0.225	23.80	61.00	61.00	1.85	20.40	105.20
Building D: multi-bay, typical panel 10.36 m × 8.23 m, RC beam and slab, average of span in two directions = 9.30 m	0.170	18.03	30.28	30.28	1.5	16.65	64.95
Building I: multi-bay, typical panel 10.21 m × 10.59 m, RC beam and slab, average of span in two directions = 10.40 m	0.355	37.67	61.60	61.60	1.31	14.45	113.70

Source: Murthy, C.K. Comparison of structural costs and structural systems for some commercial buildings in Singapore. *Proceedings of the Seminar on Our World in Concrete*, 25 August 1976, pp. 31–50.

to be realistic. Further, it has been shown that formwork and labour costs are the same in different structural systems, and this is again not convincing.

In structural system type II, it has been assumed that this system derives all its lateral stiffness and strength from only shear walls. This is not a good assumption from economy considerations. It is recommended by the ACI committee that the contribution of the frame be considered in the analysis [5]. In addition, the premiums for wind load resistance depend on the plan shape of the building, basic wind speeds and topography of the region, the structural system used and the number of spans. In the text and the results presented, mention has not been made of such factors. Murthy and Tharmaratnam [6] have investigated this problem and have provided guidelines in this respect, in quantitative terms.

The results presented cannot be used for studying the effect of design variables within an individual system, since neither the salient structural details adopted for any structural system are given nor are the effects of any change in values of design variables presented.

Khan and Iyengar have selected a non-variable base for providing quantities of concrete and reinforcement for different structural systems, and for formwork and labour, in lieu of quantities, cost in absolute currency units per unit area is presented (converted by the au-

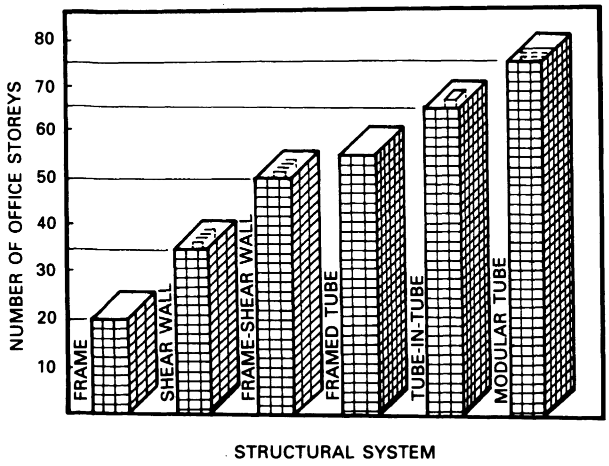

Figure 2.2 Concrete structural systems for office buildings. (*Source*: Khan, F.R. and Iyengar, H.S. Optimisation approach for concrete high-rise structures. In *Response of Multistorey High-rise Concrete Structures to Lateral Forces.* ACI Publication SP-36, Detroit, Michigan, pp. 61–74.)

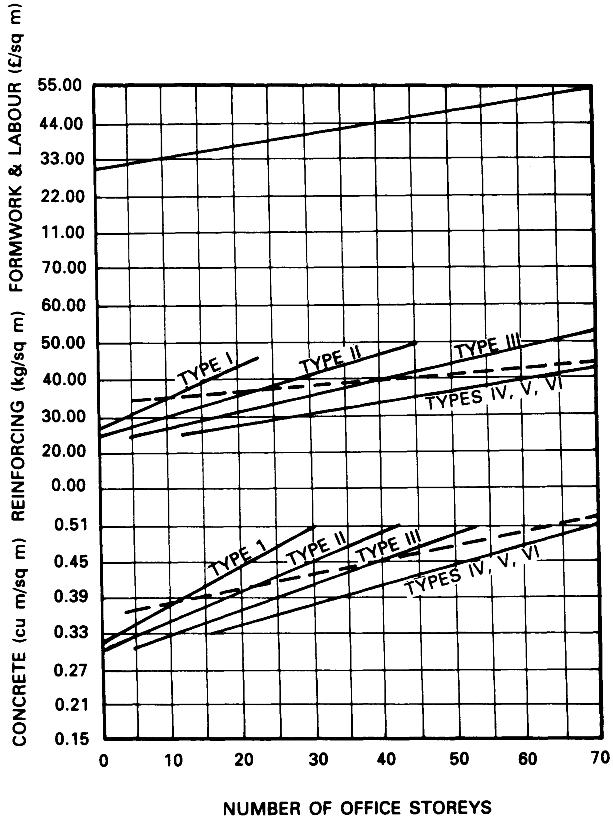

Figure 2.3 Quantity curves for systems. (*Source*: Khan, F.R. and Iyengar, H.S. Optimisation approach for concrete high-rise structures. In *Response of Multistorey High-rise Concrete Structures to Lateral Forces.* ACI Publication SP-36, Detroit, Michigan, pp. 61–74. Converted to metric units.)

thor into £ per unit area, Figure 2.3). This latter information is not a great deal of use since it changes over time.

Singh [7] and Singh and Sofat [8] attempted to establish regression equations for different materials in framed residential structures based on completed buildings, and these in turn were recommended for approximate cost estimation, preparation of building cost indices and for materials budgeting. The mathematical equations were related to the floor area of the individual tenements. Then, based on the equations, nomograms were established to show the required quantities directly. This investigation was made for residential buildings but the methodology adopted could well be used for other types of buildings, both for overall building as well as for individual building component/elements.

It was a good idea to relate the floor area to the quantities of individual materials/labour. For any given floor area, overall quantities of constituents could be calculated using the regression equations and the former in turn could be used to compute the building cost by applying the prevailing market rates. However, the equations established in the quoted works were based on a typical construction using a specific set of specifications in different building elements, and thus it is not possible to use them for studying the effect of any change in the design variables. Further, the relationships arrived at were for the whole building and no attempt was made to base them on different aspects of construction such as structural system, architectural work, etc. Lastly, the basic source of information used was quantities in the final bills for respective completed buildings, and the effect of various design variables in different sizes of dwellings was not catered for separately.

Cost analysis of completed buildings is another important source of cost information for approximate cost estimation. At present, in UK, elemental cost analyses are being published regularly for completed buildings based on lists of standard elements developed by the Building Cost Information Service of the Royal Institution of Chartered Surveyors. Previously, this information had been prepared on a number of different forms and on the basis of a variety of approaches and element lists, which detracted from their value for cost comparison purposes [9].

Based on a cost analysis, quantity surveyors can usually prepare estimates for proposed buildings by employing the interpolation method since buildings are generally not alike. This appears to be logical except for structural elements such as frames, upper floors, roofs, stairs and shear walls, since with simple interpolation the effect of design variables on quantities is not automatically taken care of. Hence there is a need to use means other than interpolation to prepare estimates for structural elements using cost analysis. A rational solution for the above appears to be the result of research investigations into the effect of design parameters on quantities of structural elements.

2.3 Research based on First Principles

The Wilderness Study Group [10] investigated the design cost relationships of a large number of hypothetical steel-framed buildings of equal total floor area and similar specification, but with the accommodation arranged on one or more storeys in buildings of varying shapes with varying bay sizes, column spacings, storey heights and superimposed floor loadings. The Study Group confined its investigations on the functional components of roofs, floor slabs, columns, beams, ties and column foundations, collectively termed 'the core'. The Group produced a set of charts designed to indicate cost relationships under varying conditions of numbers of storeys (one to eight), storey heights (mainly 3 to 4.5 m), loadings (2 to 10 kN/m^2) and column spacings (3 to 12 m), but all were limited to steel-framed buildings of simple design with solid *in situ* reinforced concrete floor and roof slabs.

An examination of these charts shows increasing costs with the increase in grid size of columns. Adopting a storey height of 3 m and floor loadings of 5 kN/m^2, a comparison is made of the effect of increase in cost due to the increase in grid size of 4.5 m × 4.5 m to 12 m × 12 m. The increased cost of the structure resulting from the above increased grid size in single-storey buildings is shown as 67 per cent, rising to over 100 per cent for eight-storey blocks. If the storey height is increased to 4.5 m, the increases in cost are less spectacular as they are partially offset by the extra material in the extended columns. The extra structural cost due to the more widely spaced columns in blocks with 4.5 m storey heights rises from about 60 per cent in single-storey buildings to 90 per cent in eight-storey blocks. It is interesting to note that the variations in the costs of structures due to different storey heights reduces as grid size increases, although the extra structural costs arising from increases in storey heights are relatively small compared with those stemming from increase in grid sizes. For example, increasing storey heights from 3 m to 4.5 m produces a 6 per cent addition to structural costs for single-storey buildings, rising to 16 per cent for eight-storey blocks.

As far as different floor loadings are concerned, the Wilderness Group has shown that variations in design of floor loadings can have an appreciable effect on structural costs. Adopting a grid size of 7.5 m × 7.5 m and a 3 m storey height, a comparison of structural costs for buildings with floor loadings of 2 and 10 kN/m^2, respectively, shows an increase in cost of about 20 per cent for two-storey buildings, rising to about 40 per cent for eight-storey buildings for the higher floor loadings. Further increases of 2 to 4 per cent occur if the storey height is increased to 4.5 m.

The Wilderness Study Group investigations provided useful guidelines in assessing the probable cost relationships of different structural designs for a project, however the study made was limited to certain specific design parameters of steel-framed buildings of simple design with solid *in situ* reinforced concrete floor and roof slabs.

Singh and Murthy [11] established statistical relationships between the quantities of constituents of reinforced concrete structures and floor areas for various number of storeys and sizes of flats in Housing and Development Board flats, Singapore. Based on this investigation it was reported that when the number of storeys is increased from 5 to 20, the increase in the quantities of both the concrete and formwork is about 19 per cent, while the increase in steel is substantially higher at 33 per cent. The variation in the constituents due to the change in the sizes of flats is much smaller. The charts developed were found useful in making decisions about the number of storeys at the planning stage, preparing approximate cost estimates, cost indices, budgeting of materials and for checking of estimates. Although the investigation was made for residential buildings, the methodology is equally applicable to other types of buildings.

The quantities of constituents of reinforced concrete structures were based on first principles by analysis, design and computation of quantities.

The adopted approach was considered superior to the one based on past records of completed buildings, since it allows one design variable to be varied at a time while keeping the others the same in a structural system.

Bathurst and Butler [12] made a good attempt to investigate the cost of an industrialised structural frame based on quantities of materials consumed and prevailing market rates. They preferred this approach since they believed it was useless to base cost on 'live' projects since the continual changes in the relative costs of materials and labour quickly invalidate any conclusions drawn from an actual design.

A formula (not presented in their book) was devised to calculate the cost of an industrialised structural frame in relation to the floor area for various modules specified by length and breadth. The gross floor areas of the buildings ranged from 960 m^2 to 1200 m^2 and scatter of costs per square metre of floor area within this range of floor area was found to be very erratic, making it impossible to establish a regular cost trend on the basis of gross floor area of building. However, a more useful yardstick was found to be cost related to 'density of columns' expressed as the average number of square metres of floor area served per column. A statistical relationship was then established between cost and column density.

The approach followed above is reasonable for industrialized frames where components are of standard size and there are only limited variations. However, in the case of a traditional *in situ* concrete frame there can be a number of variations in each component; in beams, for example, the size of beam, grade of concrete, beam category (main or secondary), number of spans, etc. are some of the parameters to be considered. Hence the approach needs to be modified to account for these variations. Further, in the case of the traditional *in situ* concrete frame, statistical relationships should be established with quantities in lieu of cost, since the latter changes with time while no significant change is likely, in the former.

Cheema and Sood [13] carried out a cost investigation of a reinforced concrete grid beam construction both for square and rectangular plans based on the first principles of analysis, design and computation of quantities. Grid intervals of 1.5 m, 2 m, 2.5 m and 3 m were adopted for square plans, while a uniform grid interval of 2 m was maintained in rectangular plans. The grid floors had spans varying between 4 m and 24 m and were assumed to be simply supported all along the boundaries. The design was based on the Indian Standard IS:456–1978 code and the cost was computed on prevailing market rates.

For square plans it was shown that the quantities of constituents and cost were higher for smaller grid intervals (1.5 m and 2 m) owing to the large number of ribs and their steel requirement on the basis of a minimal distribution of steel. In the case of rectangular plans, the authors concluded that the cost was controlled by the length of the short span, the longer span not affecting the cost much.

The authors followed a rational approach for the investigation and have provided useful information for cost comparison, but the study has a limited scope since it was carried out for simply supported conditions and is applicable only to roof slabs.

A number of handbooks on building design and construction provide design information for different structural components. Merritt [14] included charts and tables which provide quantities of reinforced concrete constituents given such design parameters as clear span of slab, permissible stress values of concrete/reinforcement and live load.

The material supplied in such handbooks has the following limitations:

- The information supplied is for illustrative purposes only and for a limited range of values.
- The time taken to compute the effects of various design parameters is substantial and impractical at the initial decision-making stage.
- Often, using the information supplied in handbooks it is not possible to consider the effects of all the variables, and computations based on first principles have to be resorted to.

The setting up of a computer database for quantities and costs of structural components for different building configurations, structural systems, structural schemes and structural materials based on analysis and design from first principles would provide professionals with quick access to information and a rational approach to the selection of structural systems/materials and the estimation of quantities/costs. The work presented in this book is a first step in this direction and the results can be updated as required and enlarged to include other building configurations, structural systems and materials.

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3 Reinforced Concrete Beam and Slab System

The effects of column grid size, number of storeys, location of structural components, grade of concrete, number of continuous spans and arrangement of beams in structural systems on the quantities of various constituents of reinforced concrete construction have been studied and presented in the form of charts for the reinforced concrete beam and slab structural system. The charts give the relationships between the quantities of each of the constituents of reinforced concrete construction, namely concrete, reinforcement and formwork, and each of the various parameters of the structure.

3.1 Introduction

The solid slab, beam and column system (RC frame) is an age-old structural system for reinforced concrete for buildings, and even at the present time is still being extensively used for both low- and high-rise building structures in its original or modified form. Depending upon the length–width ratio, slabs span either in one of the panel directions or in two directions at right angles. The column grid size varies in practice and, unless there are special reasons to the contrary, columns are arranged at regular intervals on a square or rectangular grid.

For the low wind-speeds prevailing in London and similar locations, framed structures can be constructed to considerable heights without any interacting shear walls. However, reinforced concrete shear cores are generally used in multi-storey buildings to enclose lifts and other services.

The quantities of constituents of concrete are affected by a number of parameters such as column grid size, number of storeys, slab system, strength of concrete, number of continuous spans and dimensional constraints of member components. To investigate the effects of the above parameters three square grids with sides of 6, 8 and 10 metres and having structural arrangements as shown in Figure 3.1 were analysed for 5 to 50 storeys using the STRUDL [1] package on an IBM 3081 mainframe computer system. Based on the analysis the various structural members of the building were designed using computer programs developed by the author, and quantities of their constituents as obtained from the computer print-out were used to establish statistical relationships. Loadings adopted and procedures for the analysis of frames and the design of structural members are explained below, followed by presentation of the quantities of constituents of reinforced concrete for different structural components.

3.2 Loading and Analysis of Frames

3.2.1 Vertical Loading

A dead load comprising 1.2 kN/m^2 for finishes, 0.25 kN/m^2 for ceiling and 1.0 kN/m^2 for light-weight partitions was considered in the analysis and the service loads were taken from the British Code of Practice CP3, Chapter V, Part 1 [2]. Sometimes, the first 2 to 5 floors of commercial buildings are built for shopping (live load 4.0 kN/m^2) and the remaining for office blocks (live load 2.5 kN/m^2). This trend was not taken into account in the various structures of different number of storeys. However, for analysis purposes, only structures with office blocks were considered. For structures with shopping floors, it is proposed that the necessary multiplying factors be computed so that the constituent quantities can be calculated for any number of shopping floors in a building (Section 3.6). A floor-to-floor height of 3.5 m was assumed.

3.2.2 Lateral Loading

The assessment of wind loads followed the recommendations of British Code of Practice CP3, Chapter V, Part 2 [3] based on a basic wind speed of 38 m/s in the context of London (UK). As an alternative, a second case of ultimate horizontal load equivalent to 1.5 per cent of the total characteristic dead load was also considered for stability considerations (Section 3.1.4.2 of BS 8110) [4]. The statistical factors S1 and S3 were taken to be 1.0 and the ground roughness factor S2 at different heights was taken as that for a country with many windbreaks. Loads due to earthquakes were not considered since London is free from such hazards.

3.2.3 Method of Analysis

The method used for the analysis of a building structure depends on the complexity of the structure. This complexity may be in the floor systems or in the lateral load resisting systems. It is generally more economical to carry out the analysis separately for the gravity loads and the wind loads (lateral loads).

The forces on structural members also vary with the number of continuous spans. It was therefore decided to analyse, design and compute quantities for five continuous spans initially and to correlate later the effect of other numbers of spans with the former.

The effect of torsion in unsymmetrical buildings will not be considered in this book.

3.2.4 Gravity Load Analysis of Building Frames

One-way slab – ultimate bending moments and shear forces given for over three or more spans (Table 3.13, Section 3.5.2.4 of BS 8110) were used to design continuous one-way slabs, since the characteristic imposed load did not exceed the characteristic dead load and the five equal continuous spans were considered.

Two-way slab – bending moment coefficients for slab panels supported on four sides with provision for torsion reinforcement at corners (Table 3.15 of BS 8110) were adopted for the design of two-way slabs.

Main beams and columns – for structural schemes with one-way slabs (Figure 3.1), the elastic analysis for the gravity loads was carried out by considering a series of sub-frames, each consisting of the beam at a typical level together with the columns above and below assumed to be fixed at their remote ends from these beams (Figure 3.2). The following arrangements of loads were considered:

- Alternate spans loaded with total ultimate load ($1.4G_k + 1.6Q_k$) and all other spans loaded with minimum dead load ($1.0G_k$).
- Any two adjacent spans loaded with total ultimate load ($1.4G_k + 1.6Q_k$) and all other spans loaded with minimum dead load ($1.0G_k$).
- All spans loaded with ultimate load of ($1.2G_k + 1.2Q_k$) for combining later with results of wind load analysis ($1.2W_k$).

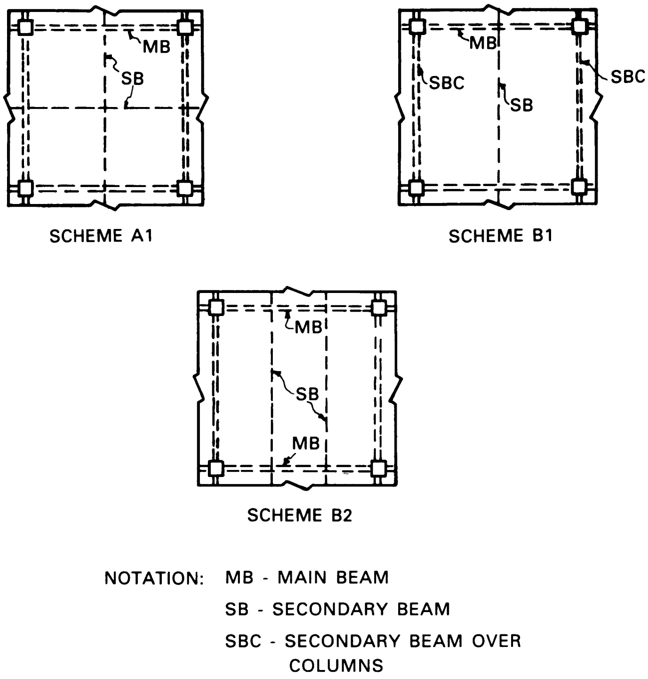


Figure 3.1 Designation of structural schemes and components (reinforced concrete slab and beam construction).

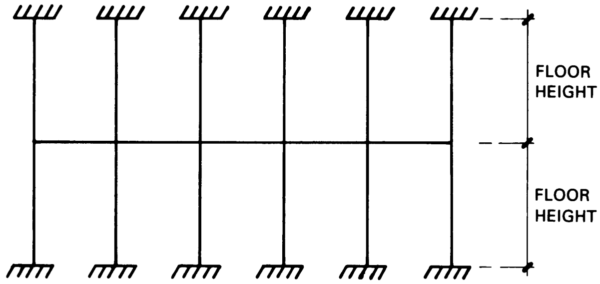


Figure 3.2 Sub-frame analysis for structural schemes involving one-way slabs.

In the case of structural schemes involving grid beams and two-way slabs (Figure 3.1), plane grid analysis (Figure 3.3) was carried out for the vertical loading but retaining the pattern loading as described above.

Secondary beams over columns (Figure 3.1) – similar analysis as for main beams (but with appropriate loading) was carried out to determine the ultimate moment and shear force values in secondary beams over columns.

Secondary beams (Figure 3.1) – for structural schemes involving one-way slabs, ultimate bending moments and shear forces obtained from coefficients given in BS 8110 for over three or more spans (Table 3.13, Section 3.5.2.4 of BS 8110) were used to design continuous secondary beams. However, in the case of

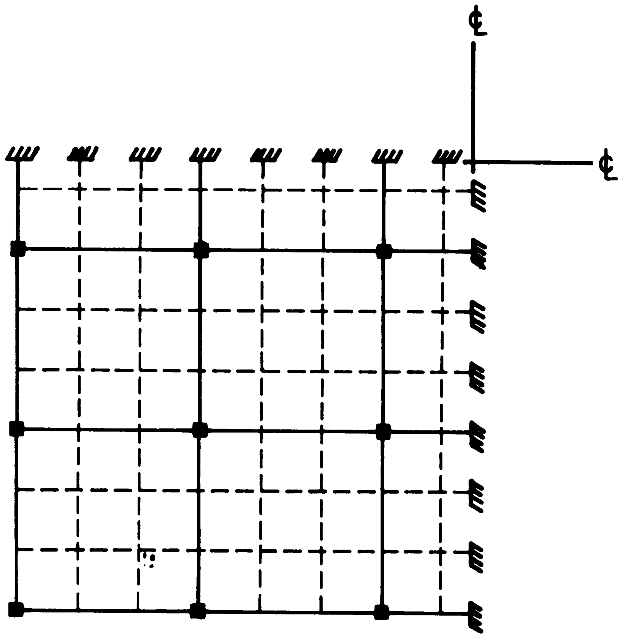


Figure 3.3 Plane grid analysis for structural schemes involving two-way slabs (1/4 panel only).

structural schemes involving slabs spanning in two directions, plane grid analysis (Figure 3.3) was carried out with pattern loading for arriving at the ultimate bending moments and shear forces.

Shear walls – axial load was computed at different levels considering the floor area to be supported by shear walls.

3.2.5 Lateral Load Analysis of Interacting Building Frames and Shear Walls

In practice, a common assumption is to neglect the frame for resistance of lateral loads and assume that all the lateral load is taken by the shear walls. This may not always be an acceptable procedure with regard to frames and it is recommended [5–7] that the contribution of the frames be considered in the analysis. Structural frames were therefore assumed to provide lateral stability to the structure in conjunction with shear walls, and thus analysis of the frames having 5 equal continuous bays was carried out for both vertical and lateral loads.

The elastic analysis for lateral loads must be carried out on the complete frame, because approximate methods are far from being accurate and the effect of differential shortening of columns is too important to be ignored in tall buildings.

In buildings composed of interacting plane frames and shear walls, groups of similar frames were combined together into a single frame of equivalent properties. These equivalent frames were placed one behind the other, connected together by links (Figures 3.4 and 3.5). The links force all the frames to deflect equally in the horizontal direction, thus simulating the diaphragm action of the floor slab. As shown in Figure 3.4, Frame 2 is represented by external columns, interior columns and a central column which has the properties of the shear wall. The beam connecting the interior columns and the central columns (shear walls) was made infinitely stiff over the length of the wall. The infinite stiffness for the beams was modelled by specifying a moment of inertia which was 1000 times higher than that of the other beams.

The following two cases of horizontal loads on the structure were considered:

- Wind load as calculated from CP3 Chapter V, Part 2 for a basic wind speed of 38 m/s.
- Horizontal loads corresponding to 1.5 per cent of the total characteristic dead load applied at each floor level as given in Section 3.1.4.2 of BS 8110.

Critical values obtained as a result of different loading combinations were considered for the design of individual members (Section 3.3).

In the absence of any specific stipulation in BS 8110 regarding limits on lateral deflection, a value of height/500 was adopted for the storey drift as well as the lateral deflection at the top of the building in accordance with the recommendations of the American Concrete Institute (ACI) Committee 435 [8].

3.2.6 Shear Core Size

Generally, services such as lifts and plenum ducts require extensive space in tall buildings, and in addition there are electrical conduits and water pipes to be accommodated. It thus becomes economical to group services together in one or more vertical shafts which can act as shear cores for structural purposes. In addition, service shafts accommodating stairs and toilets can be used to resist vertical and lateral loads in conjunction with frames. For analysis purposes the first requirement was therefore to fix the sizes and location of shafts accommodating the above services.

A survey of existing buildings was carried out with the object of relating the lift core area with the floor area and the number of storeys. Based on this investigation the required relationship was established (Figure 3.6) by considering the average lift core area as a percentage of the floor area and the number of storeys. With this it was possible to deduce the area

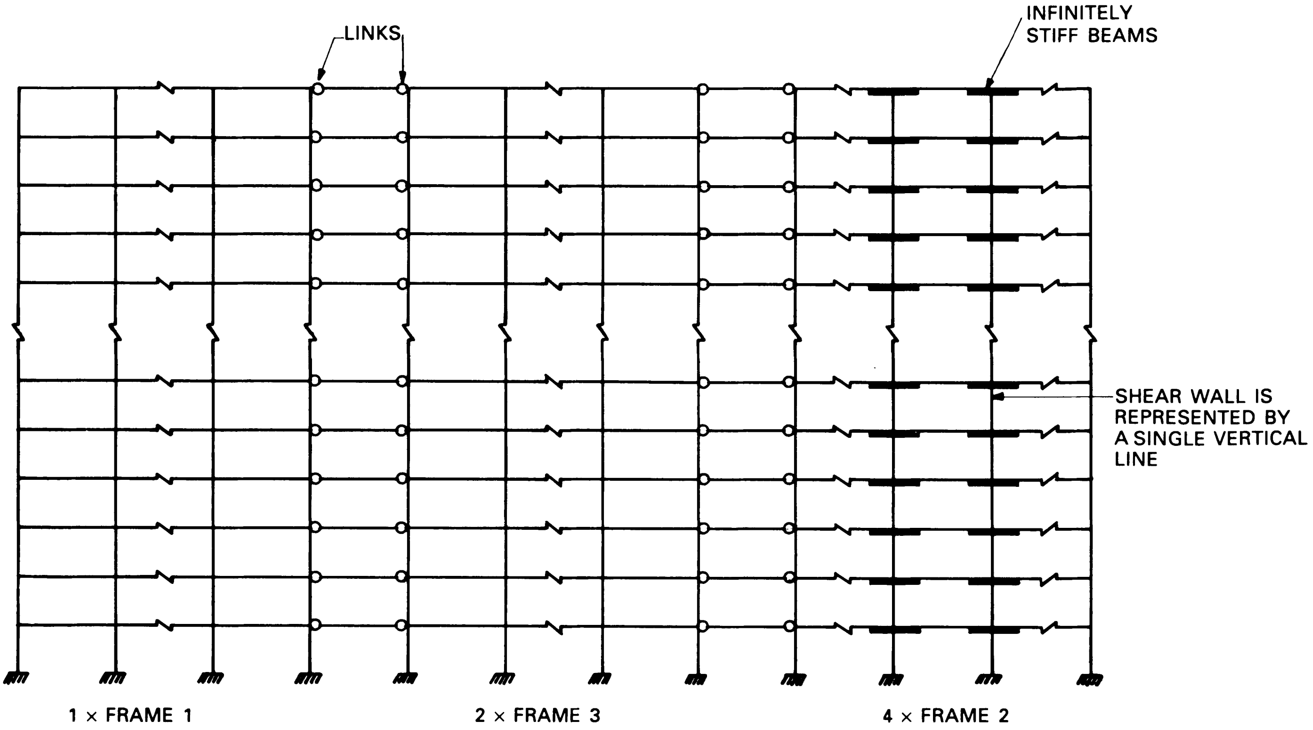


Figure 3.4 Link-frame model for frame–shear wall interaction.

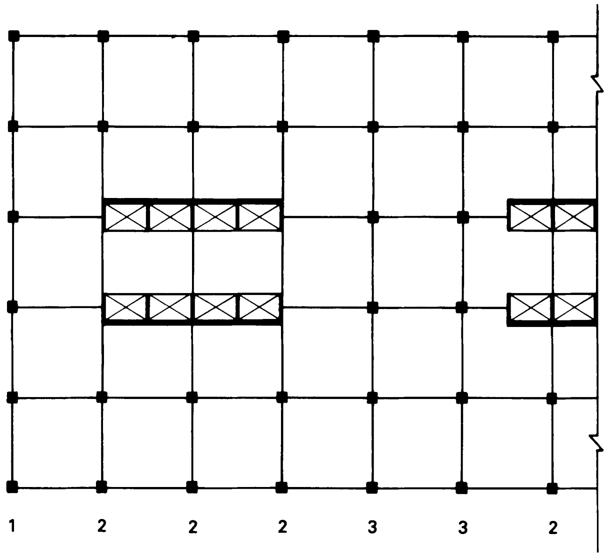


Figure 3.5 Typical symmetrical floor plan (shown half) indicating building frames and shear walls.

of core for any building floor area and number of storeys. Based on the above relationship, shear core size was computed for the required plan sizes and the number of storeys of construction and, this in turn was considered in the lateral load analysis of interacting building frames and shear walls.

3.2.7 Plan Shape and Size

Force coefficient of wind (C_f) required to convert the dynamic pressure to equivalent static loads depends on the plan size and overall height of the building. Having decided upon the storey height (3.5 m) and the number of storeys of construction (5 to 50) it was necessary to decide on the plan sizes of buildings to be analysed. These were fixed according to the sizes of the existing and the proposed buildings and varied from 30 m x 30 m to 50 m x 50 m for square plans, while for rectangular plans the maximum dimensions varied from 30 m x 78 m to 50 m x 80 m depending upon the column grid size.

3.3 Design of Structural Members

Computer programs were developed to design reinforced concrete slabs, beams and columns to conform strictly to the requirements of British Standard BS 8110: 1985 with the additional capability of computing the quantities of concrete, reinforcement and formwork. The above was considered essential considering the repetitions needed for designing structural components and computing these quantities. The development of computer programs was necessary because of their non-availability locally at that time.

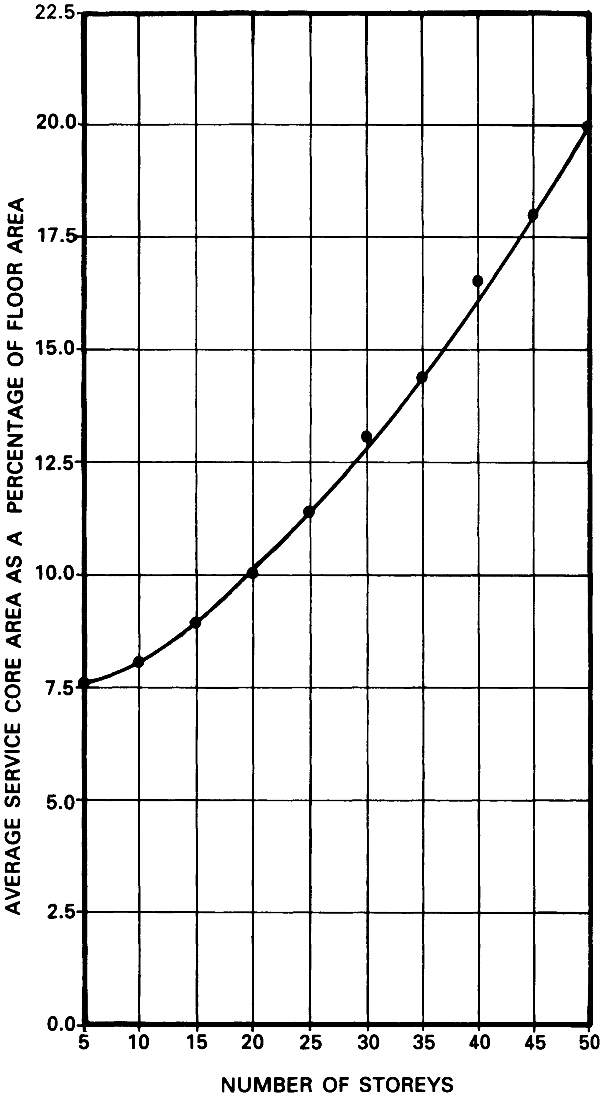


Figure 3.6 Relationship between average service core areas and number of storeys.

3.3.1 Solid Slabs

The program developed provided for slabs spanning in both one direction and two directions at right angles. The coefficients given in BS 8110 for one-way continuous slabs and two-way restrained slabs were used in the program. A minimum slab thickness of 100 mm was assumed.

Requirements of minimum and maximum areas of reinforcement and checks for shear, deflection and bond were incorporated into the program as codified. In addition, reinforcement spacing rules to control cracking were also considered. The overall depth of the slab and the spacing of the reinforcement were adjusted so as to be in modules of 5 mm. This was considered necessary since in practice odd dimensions in these respects are avoided.

3.3.2 Beams

In framed buildings, the depth of a beam is generally governed by architectural considerations provided it is structurally adequate, and it is the width and requirement of reinforcement which are to be decided according to the design forces. The program for beams was therefore developed with this in mind and the width and depth of each beam were to be fed as input. The program has a number of subroutines relating to different aspects of design in accordance with BS 8110. For main beams, a minimum width and a minimum depth based on span–width and span–depth ratios of 22 and 16.5 respectively were adopted. A number of other beam sections were also considered in each grid by keeping the value of bd^2, as obtained from above ratios, the same. For secondary beams the width was fixed at $\frac{3}{4}$ of that of main beams, while the depth was varied from $\frac{3}{4}$ to 1 of the latter. The above variations were considered for structural schemes involving slabs spanning in one direction only, while for other schemes that are seldom used in practice a span–depth ratio of 15 was maintained for both main and secondary beams.

3.3.3 Columns

A comprehensive computer program was developed to design both short and slender columns, and also axially loaded columns with and without bending (both uniaxial and biaxial) based on the design formulae given in BS 8110. Given the section and design forces the program checked the section and increased the size, if necessary. Square column sections were considered for interior columns in denominations of 75 mm and the elevation of exposed columns was kept the same by varying the thickness for aesthetic considerations. Further, after every 5-storey interval, the sections of columns were reduced where possible for economy and within the same section the reinforcement was varied for each storey depending upon the values of forces. The maximum percentage of longitudinal reinforcement was limited to 4.5.

3.3.4 Shear Walls

A minimum thickness of 150 mm was considered from practical considerations and the forces obtained from the analysis formed the basis of the design. Further, the thickness as obtained in the design for the ground level was adopted uniformly from ground to the top in all storeys except in the case of 50-storey construction. This matched the usual practice in the industry since slip form construction is commonly used for shear walls. The amount of reinforcement was however varied at each storey depending upon the forces at that level keeping a minimum area of I per cent from fire resistance considerations (Section 3.12.5.3 of BS 8110). In the case of 50-storey construction a change in thickness at the 25th storey level was made for economic considerations.

3.4 Quantities of Constituents

In computing the quantities of concrete for beams, the portion of the beam common with the slab has been included with the latter in accordance with the Standard Method of Measurement [9]. Similarly, in slabs, the formwork has been reduced to the extent of the plan area of the beam webs, and the common portion of slabs, beams and columns has been accounted for in columns. For computing the quantities of reinforcement in beams and slabs, simplified rules for curtailment of bars as given in BS 8110: 1985 were followed.

3.4.1 Solid Slabs

The quantities of concrete and reinforcement per square metre of floor area for solid slabs spanning in one direction are shown in Figures 3.7 to 3.9 for different live loads. Further, the quantities of reinforcement for different spans are plotted for various locations of slab panels, namely for interior panels, first interior panels and for edge panels, so that depending upon the configuration of the given building and the plan size the overall quantities can be computed. Similar information is shown in Figures 3.10 to 3.12 for slab panels of different sizes spanning in two directions.

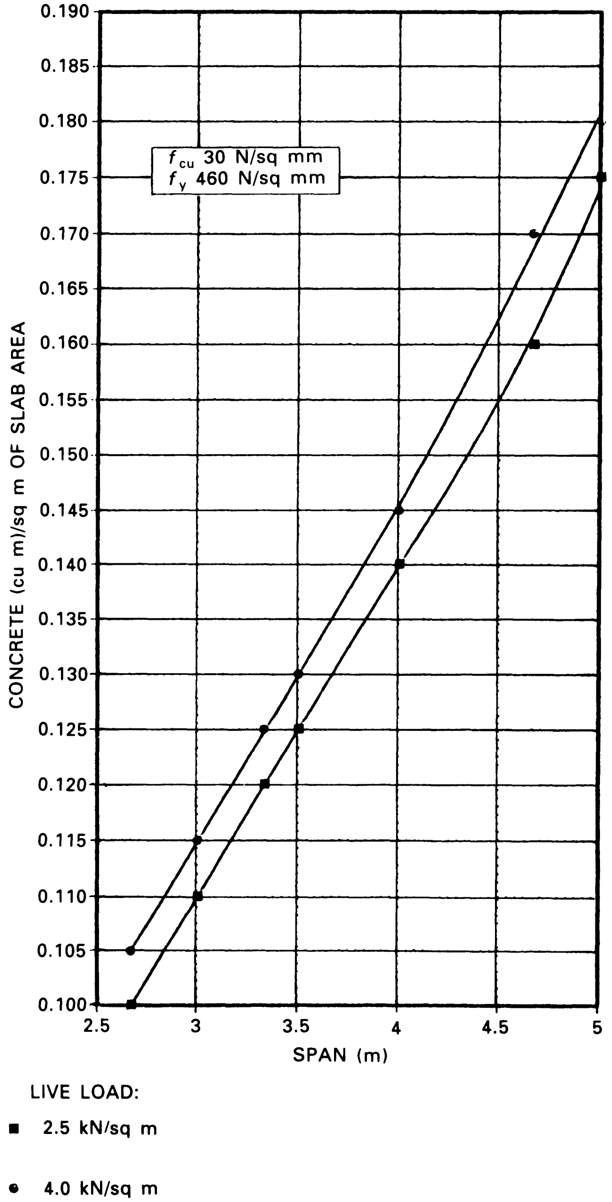


Figure 3.7 Quantities of concrete for slabs spanning in one direction.

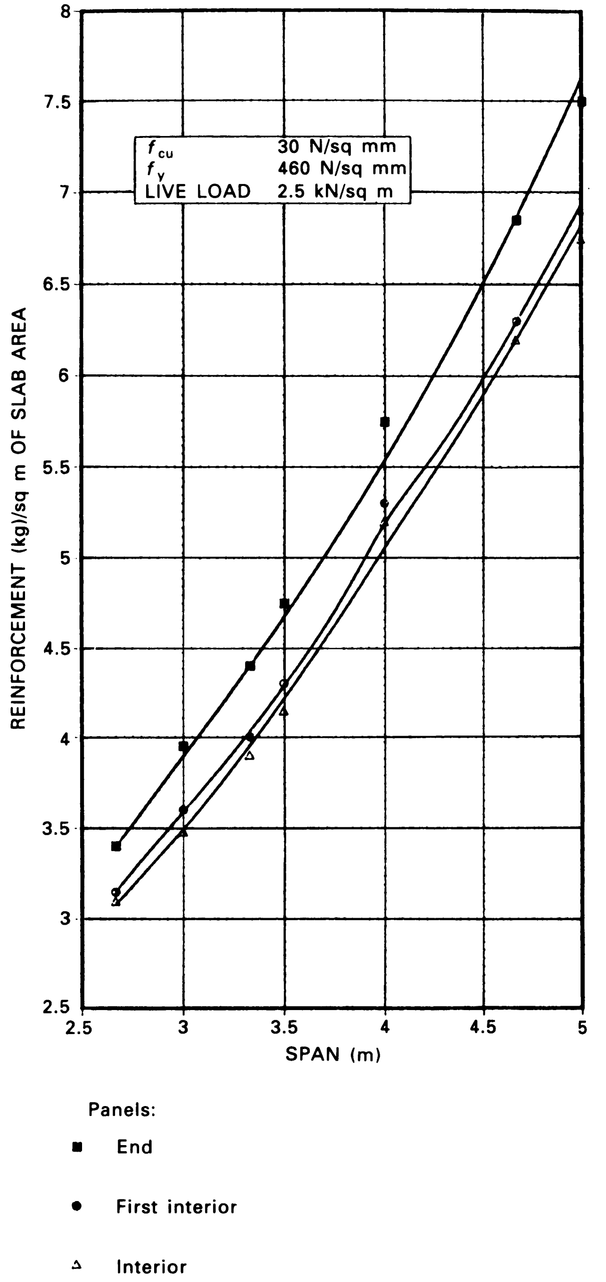


Figure 3.8 Quantities of reinforcement for slabs spanning in one direction: 2.5 kN/sq m.

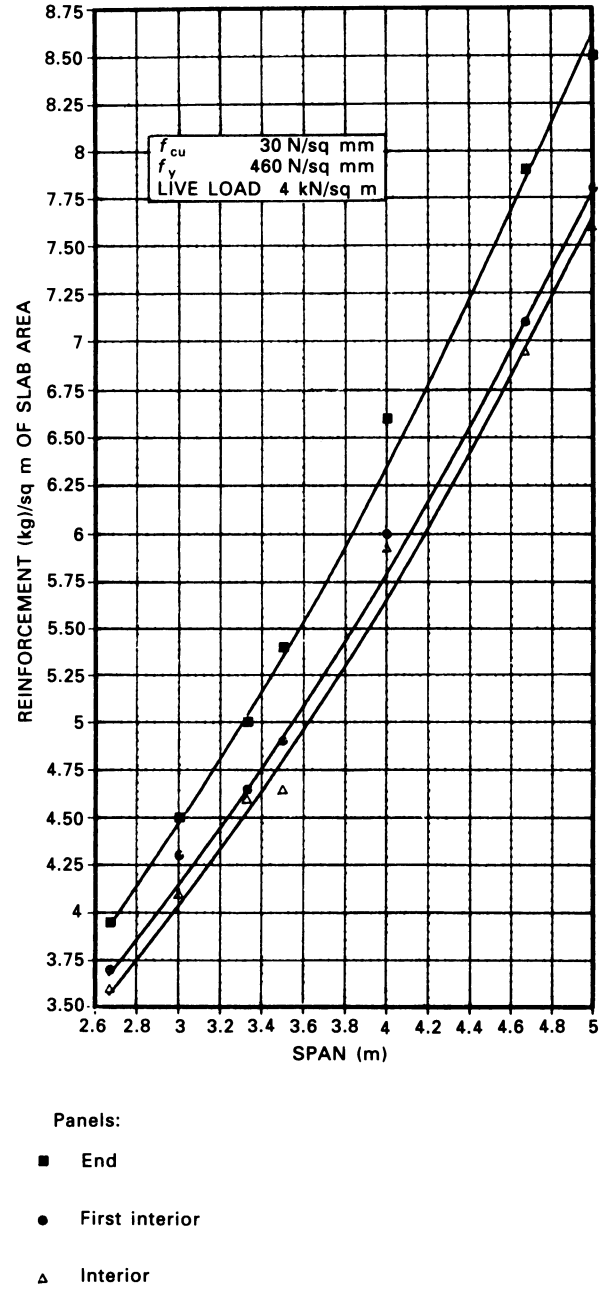


Figure 3.9 Quantities of reinforcement for slabs spanning in one direction: 4.0 kN sq. m.

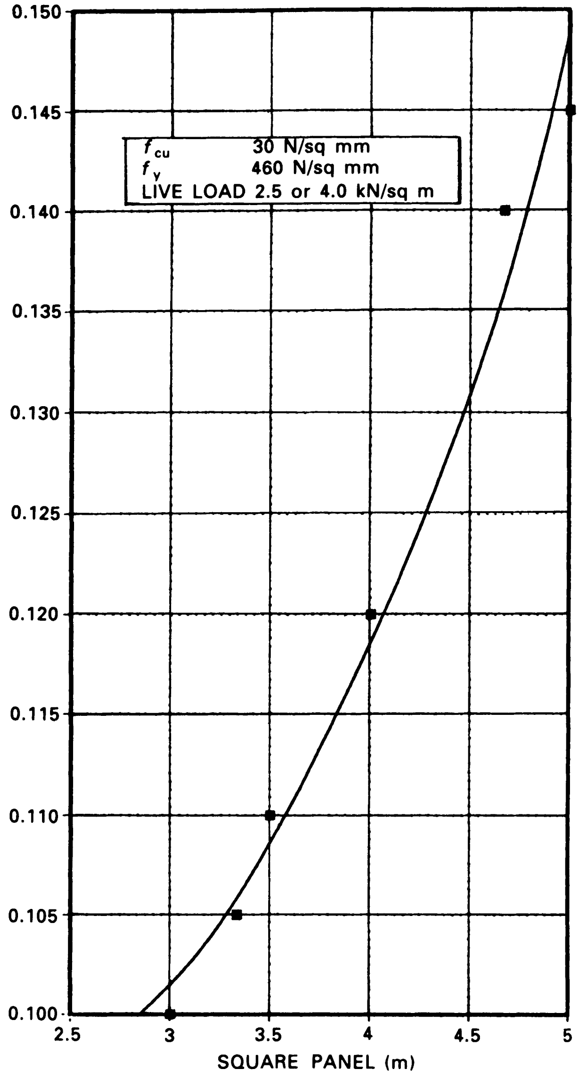


Figure 3.10 Quantities of concrete for slabs spanning in two directions.

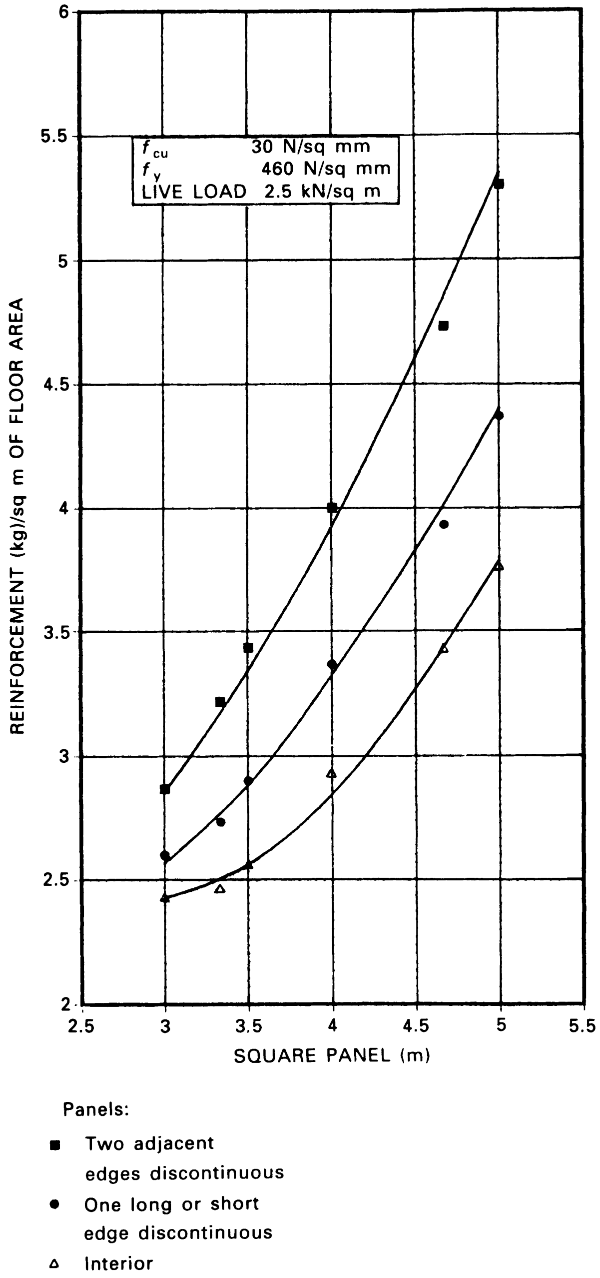


Figure 3.11 Quantities of reinforcement for slabs spanning in two directions: 2.5 kN/sq m.

Based on the above basic quantities, relationships were developed for framed commercial buildings ranging from 5 to 50 storeys in denomination of 5 storeys and the results are shown in Figures 3.13 and 3.14 for concrete and formwork respectively. Further, in accordance with Standard Measurement practice [9], the reinforcement needed for beam flanges is to be measured along with the slab. The flange reinforcement was determined according to the requirements of BS 8110: 1985. The overall requirement of reinforcement incorporating the above quantities of flange reinforcement is shown in Figures 3.15 to 3.17 for different panel locations.

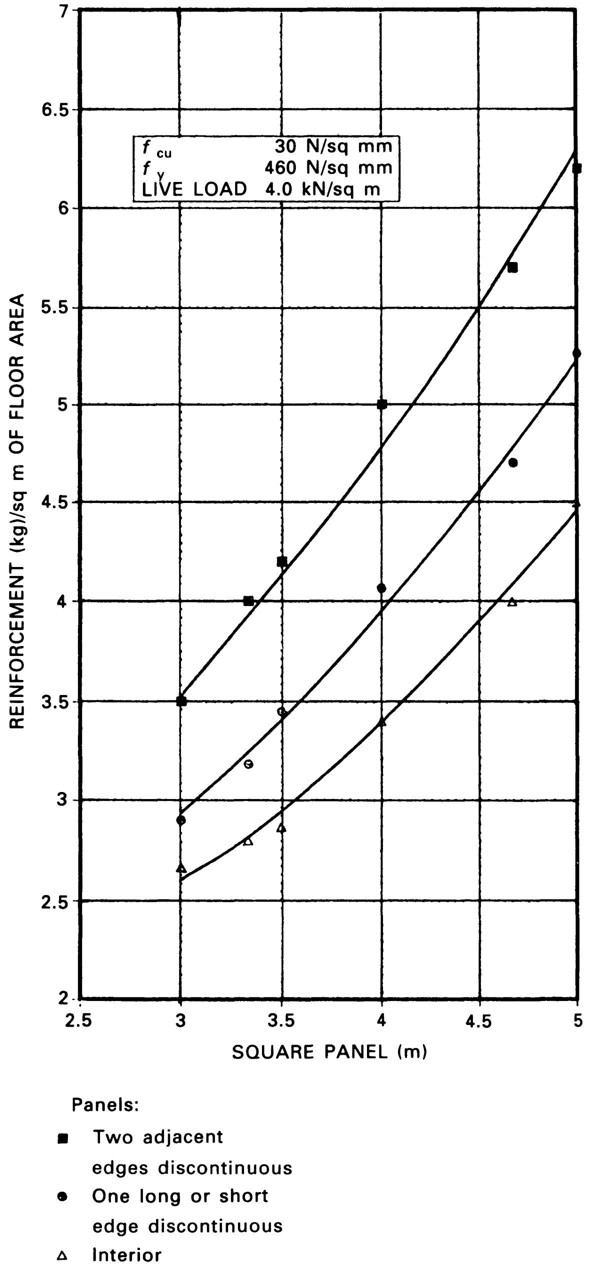


Figure 3.12 Quantities of reinforcement for slabs spanning in two direction: 4.0 kN/sq m.

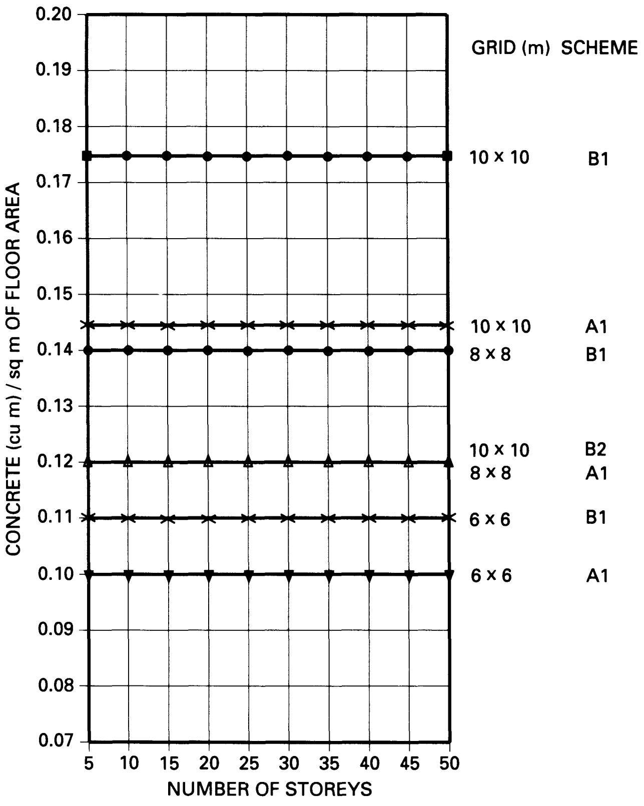


Figure 3.13 Quantities of concrete for slabs.

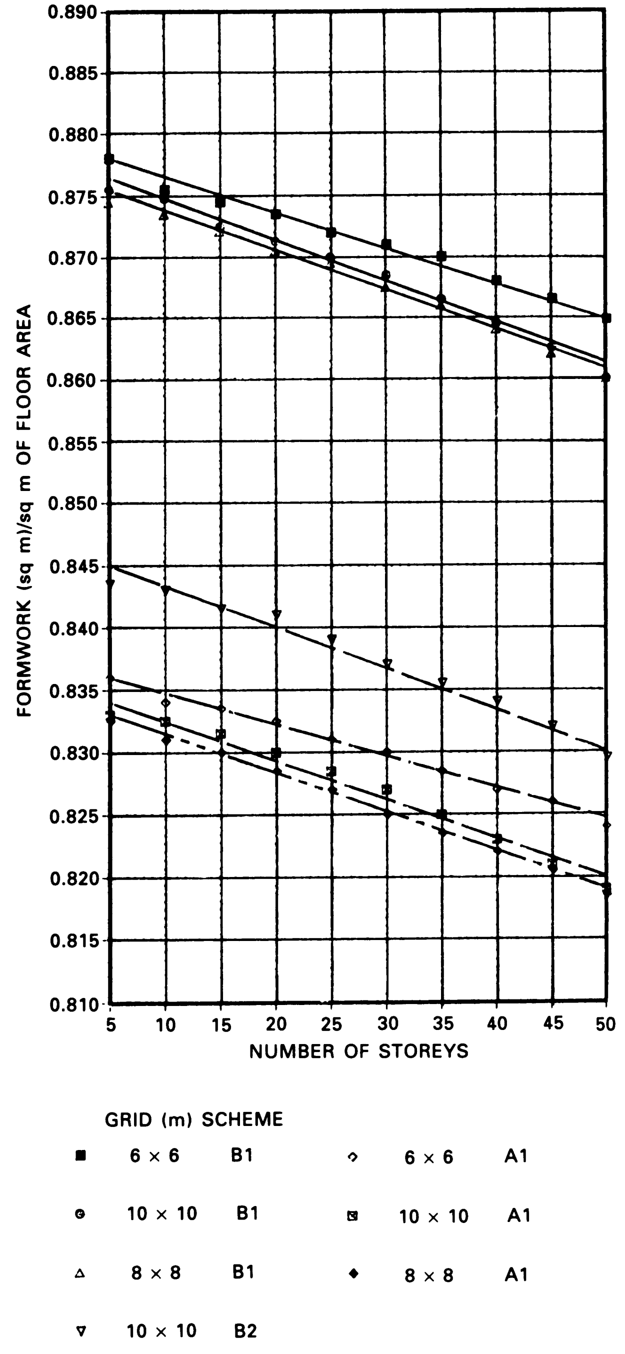


Figure 3.14 Quantities of formwork for slabs.

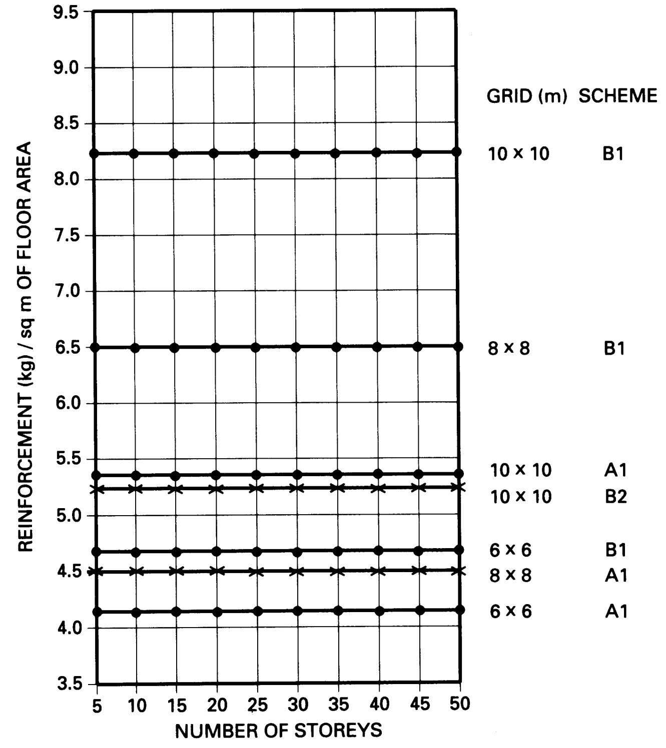


Figure 3.15 Quantities of reinforcement in slabs for interior panels.

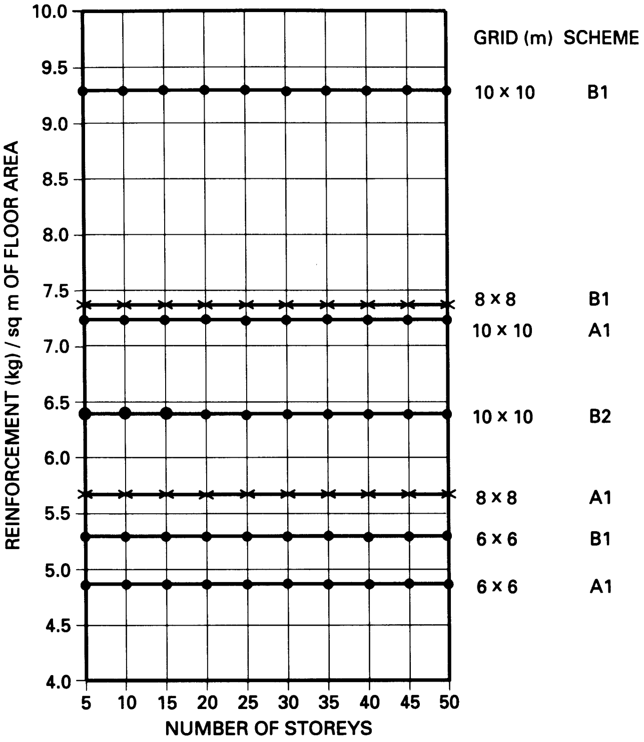


Figure 3.16 Quantities of reinforcement in slabs for end panels (spanning in one direction) and two-way slabs (two edges discontinuous).

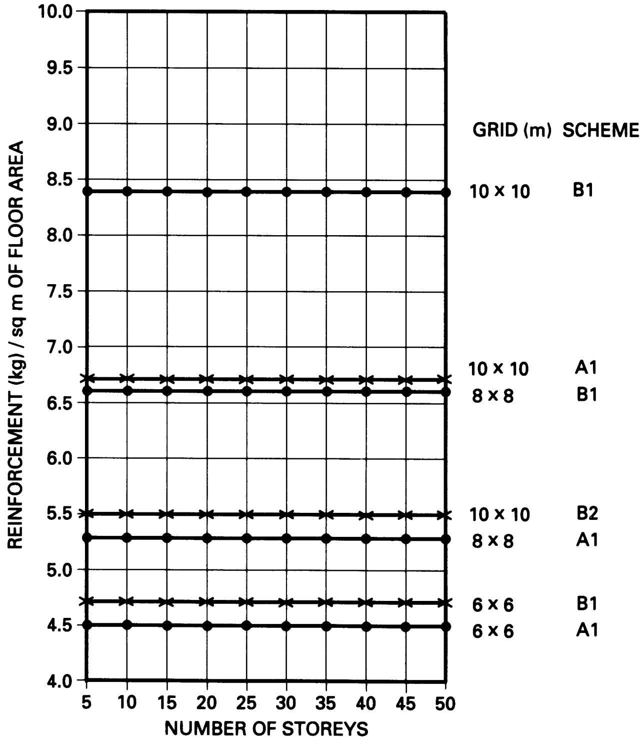


Figure 3.17 Quantities of reinforcement in slabs for first interior panel (spanning in one direction) and two-way slabs (one edge discontinuous).

3.4.2 Beams

In different structural schemes (Figure 3.1) the beams can be classified as main and secondary beams. In the case of secondary beams, further classification is to be made depending upon whether or not the beams are running over columns. This is considered necessary since the design forces and hence quantities of constituents depend on this parameter.

The quantities of concrete and formwork for main beams and for various storeys of construction, grid sizes and structural schemes are shown in Figures 3.18 and 3.19 respectively. The quantities of reinforcement for combinations of vertical and lateral loadings are shown in Figures 3.20 to 3.22 for different locations of the main beam. The basic wind speed considered in calculating these constituents is 38 m/s. Alternative quantities of reinforcement for horizontal load equivalent to 1.5 per cent of the total characteristic dead load (Section 3.1.4.2 of BS 8110) in conjunction with the dead and imposed loads are shown in Figures 3.22 and 3.23. It was considered worthwhile to show the results of the above two loadings separately since in local practice many engineers ignore the consideration of second loading. However for other structural systems in this book it is proposed to consider the more severe of the two loadings and design the structural components accordingly. Further results are shown in Figures 3.24 to 3.31.

The size of the building affects the magnitude of the lateral load which in turn affects the forces on structural members and thus the quantities of reinforcement needed. The variation in reinforcement for such an effect is shown in Figures 3.32 and 3.33 for a grid size of 6 m × 6 m and for different building plan sizes.

The quantities of concrete, formwork and reinforcement for secondary beams running over columns are shown in Figures 3.34 to 3.38 for different grid sizes, number of storeys of construction and structural schemes, while the constituent quantities for secondary beams running over main beams for these respective parameters are given in Figures 3.39 to 3.43.

The effect of different beam sections on the quantities of constituents of main beams is shown in Figures 3.44 to 3.49 for different grid sizes and structural schemes. Similar effects for secondary beams running over columns are shown in Figures 3.50 to 3.52 and for the secondary beams running over main beams in Figures 3.53 to 3.55.

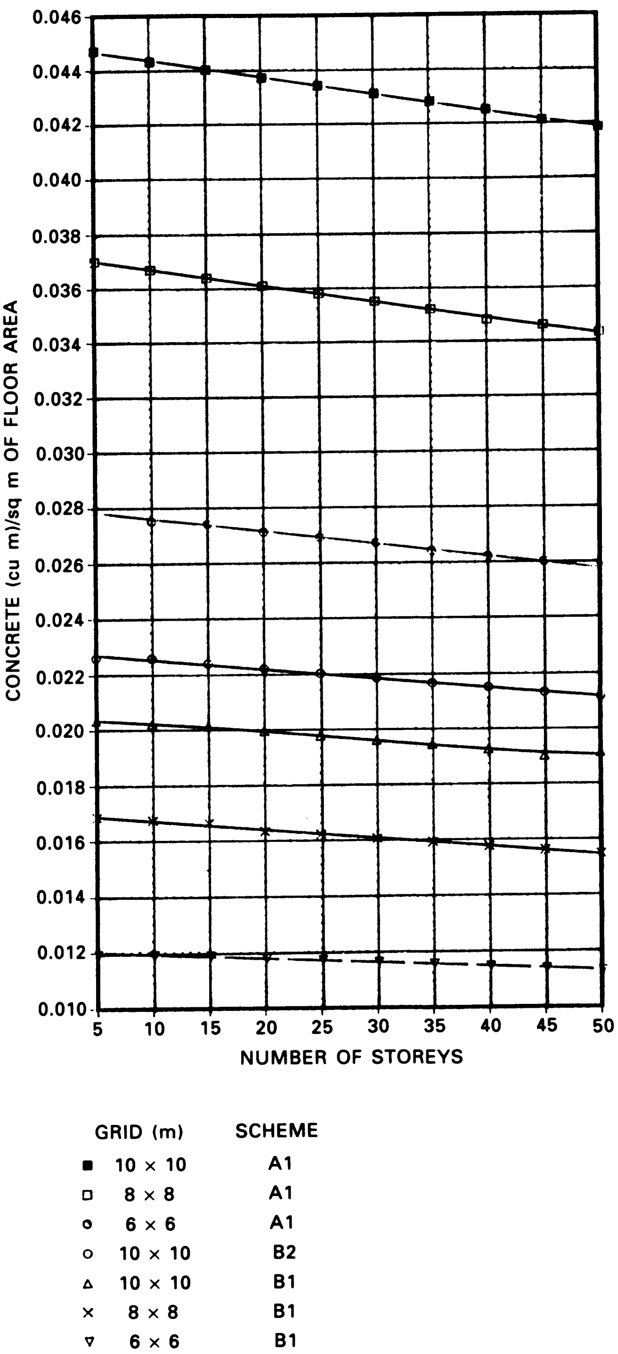


Figure 3.18 Effect of number of storeys and grid size on quantities of concrete for main beams.

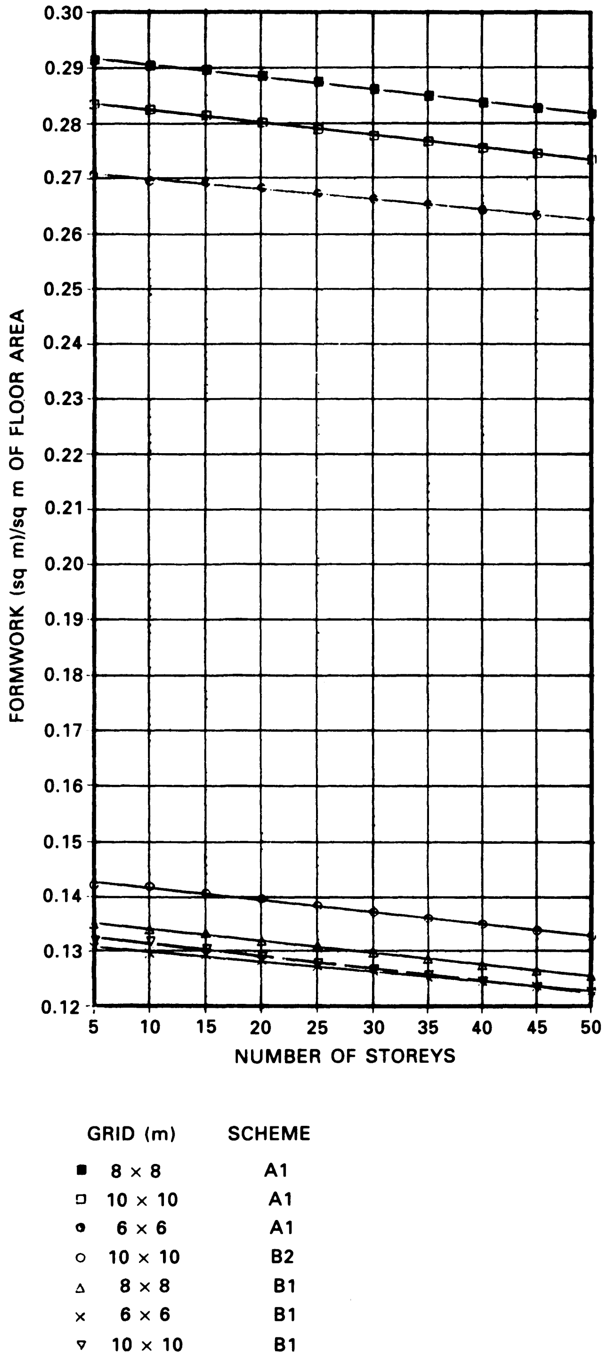


Figure 3.19 Effect of number of storeys and grid size on quantities of formwork for main beams.

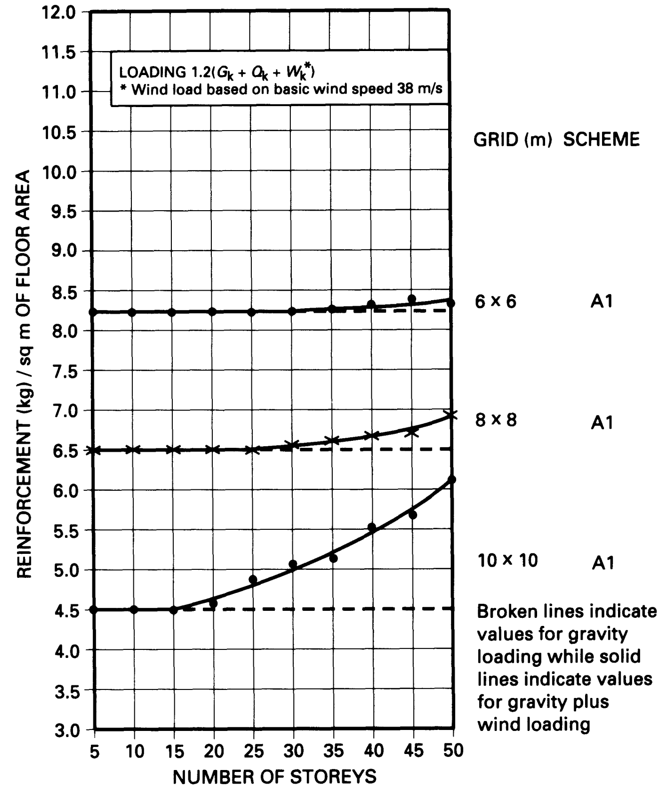


Figure 3.20 Quantities of reinforcement for main first interior beams for different numbers of storeys and grid sizes: loading = 1.2(G_k + Q_k + W_k^*).

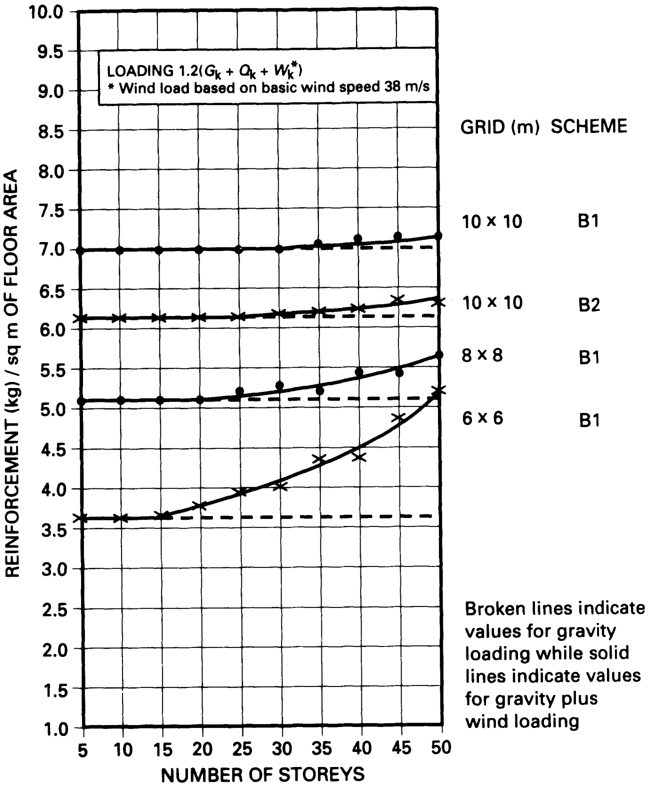


Figure 3.21 Quantities of reinforcement for main first interior beams for different numbers of storeys and grid sizes: loading = 1.2(G_k + Q_k + W_k^*) (*continued*).

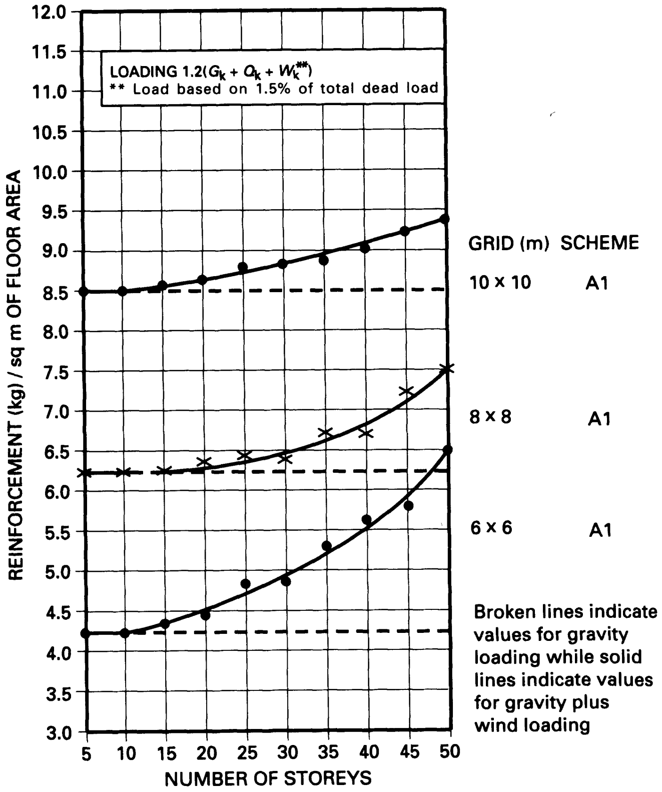


Figure 3.22 Quantities of reinforcement for main first interior beams for different numbers of storeys and grid sizes: loading = 1.2(G_k + Q_k + W_k^{**}) (*continued*).

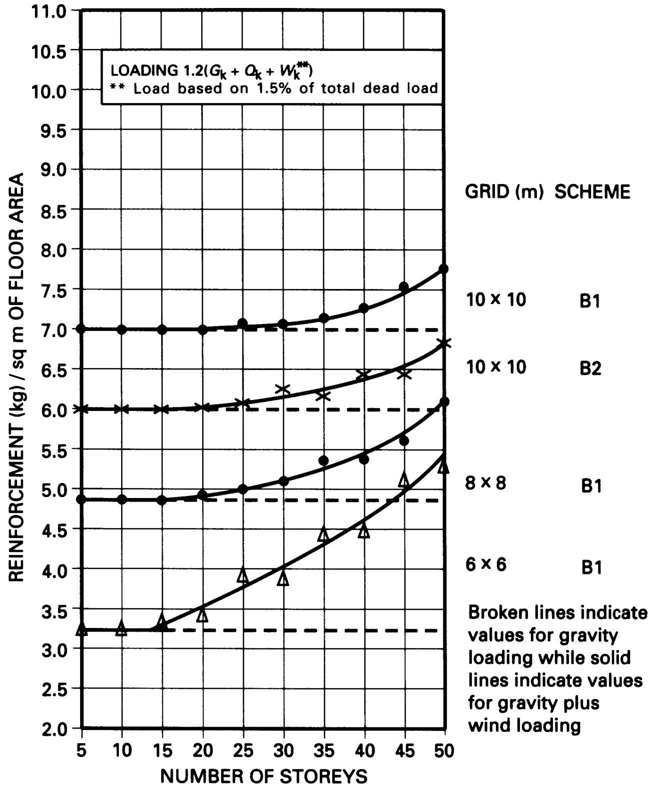


Figure 3.23 Quantities of reinforcement for main first interior beams for different numbers of storeys and grid sizes: loading = 1.2(G_k + Q_k + W_k^{**}) (*continued*).

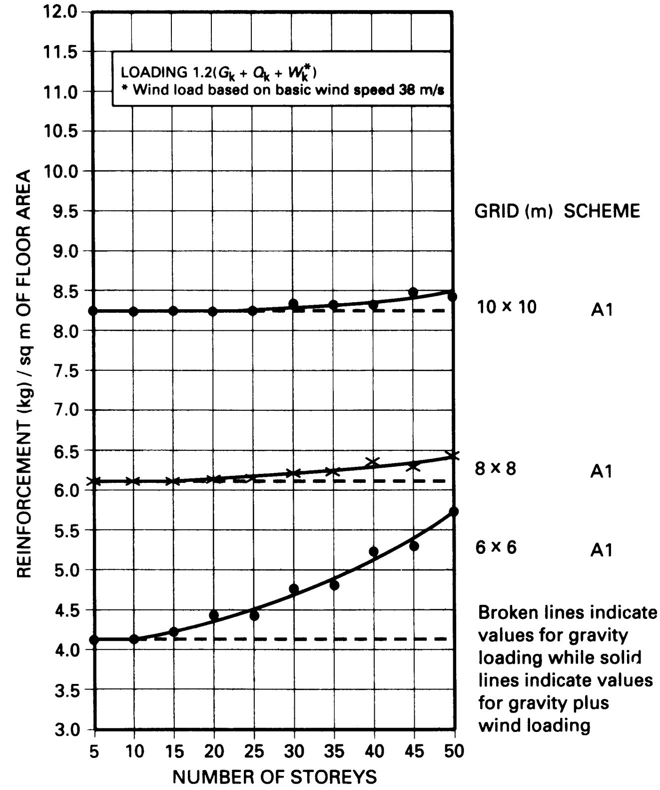


Figure 3.24 Quantities of reinforcement for main end beams for different numbers of storeys and grid sizes: loading = 1.2 (G_k + Q_k + W_k^*).

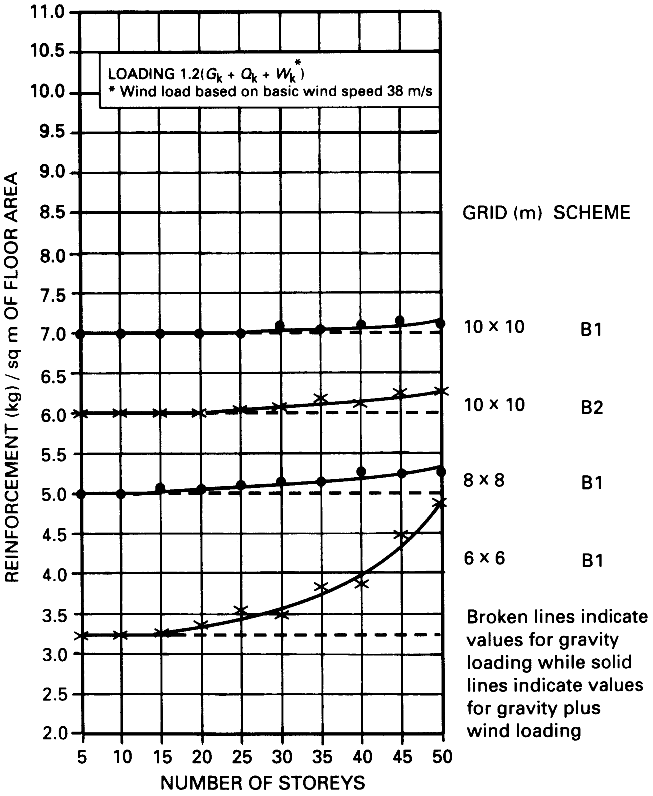


Figure 3.25 Quantities of reinforcement for main end beams for different numbers of storeys and grid sizes: loading = 1.2 (G_k + Q_k + W_k^*) (*continued*).

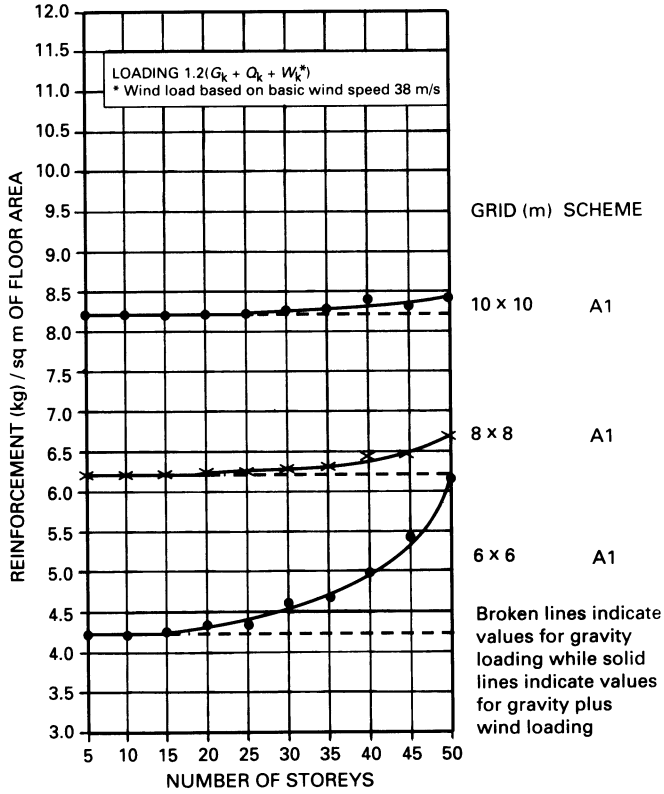


Figure 3.26 Quantities of reinforcement for main first interior beams for different numbers of storeys and grid sizes: loading = 1.2(G_k + Q_k + W_k^*).

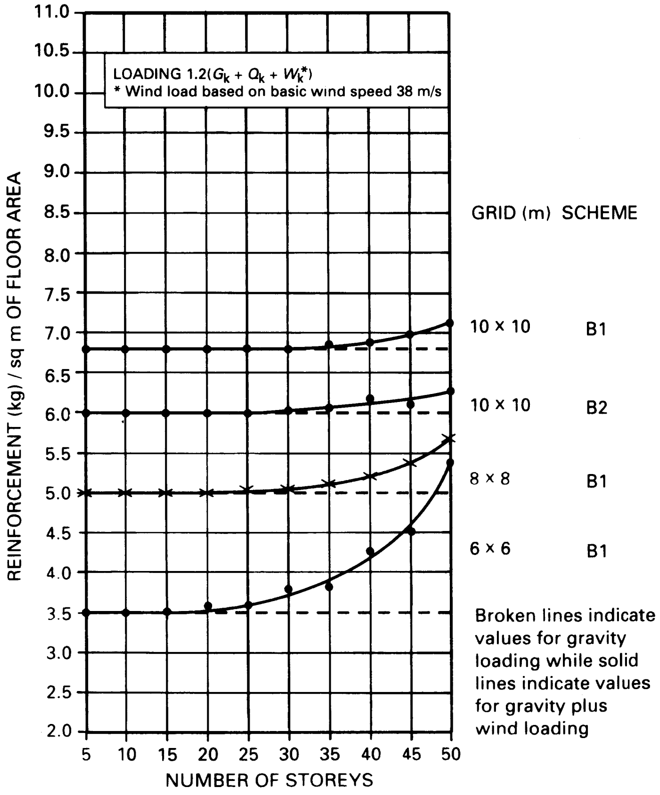


Figure 3.27 Quantities of reinforcement for main interior beams for different numbers of storeys and grid sizes: loading = $1.2(G_k + Q_k + W_k^*)$ (*continued*).

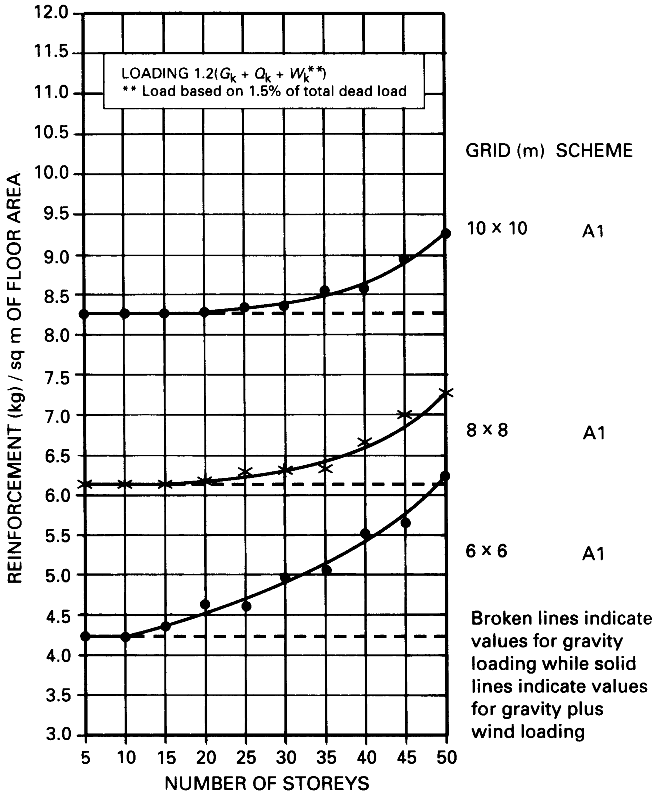


Figure 3.28 Quantities of reinforcement for main first interior beams for different numbers of storeys and grid sizes: loading = $1.2(G_k + Q_k + W_k^{**})$ (*continued*).

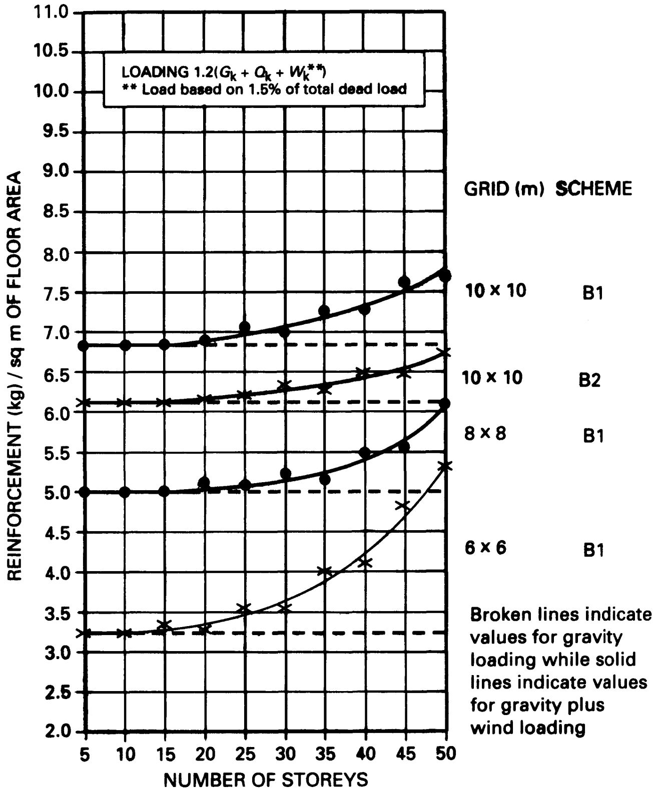


Figure 3.29 Quantities of reinforcement for main first interior beams for different numbers of storeys and grid sizes: loading = $1.2(G_k + Q_k + W_k^{**})$ (*continued*).

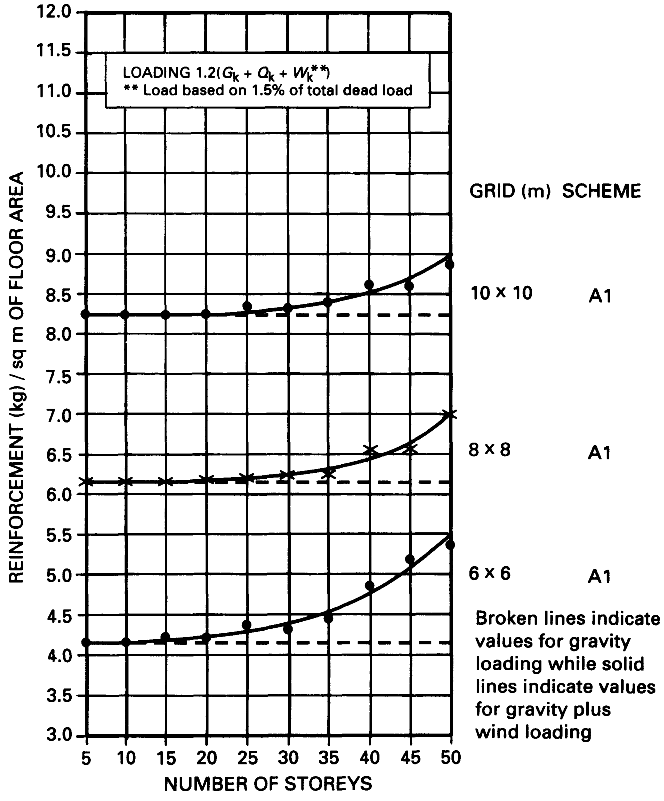


Figure 3.30 Quantities of reinforcement for main end beams for different numbers of storeys and grid sizes: loading = $1.2(G_k + Q_k + W_k^{**})$.

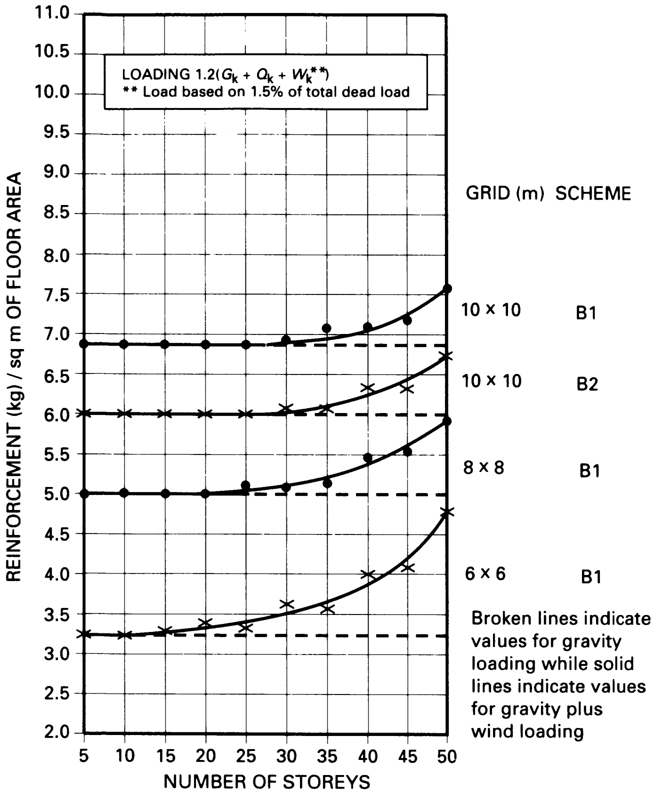


Figure 3.31 Quantities of reinforcement for main end beams for different numbers of storeys and grid sizes: loading = 1.2 (G_k + Q_k + W_k^{**}) (*continued*).

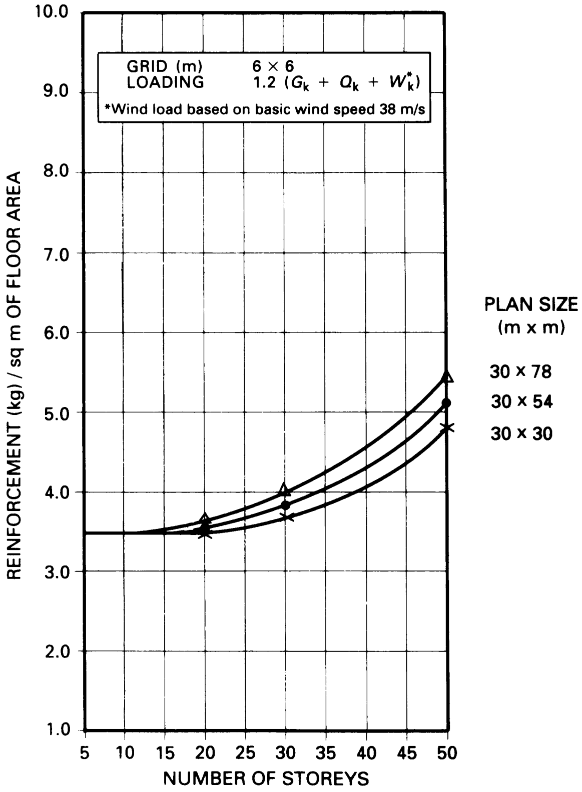


Figure 3.32 Effect of plan size on reinforcement of main interior beams: loading = 1.2 (G_k + Q_k + W_k^*).

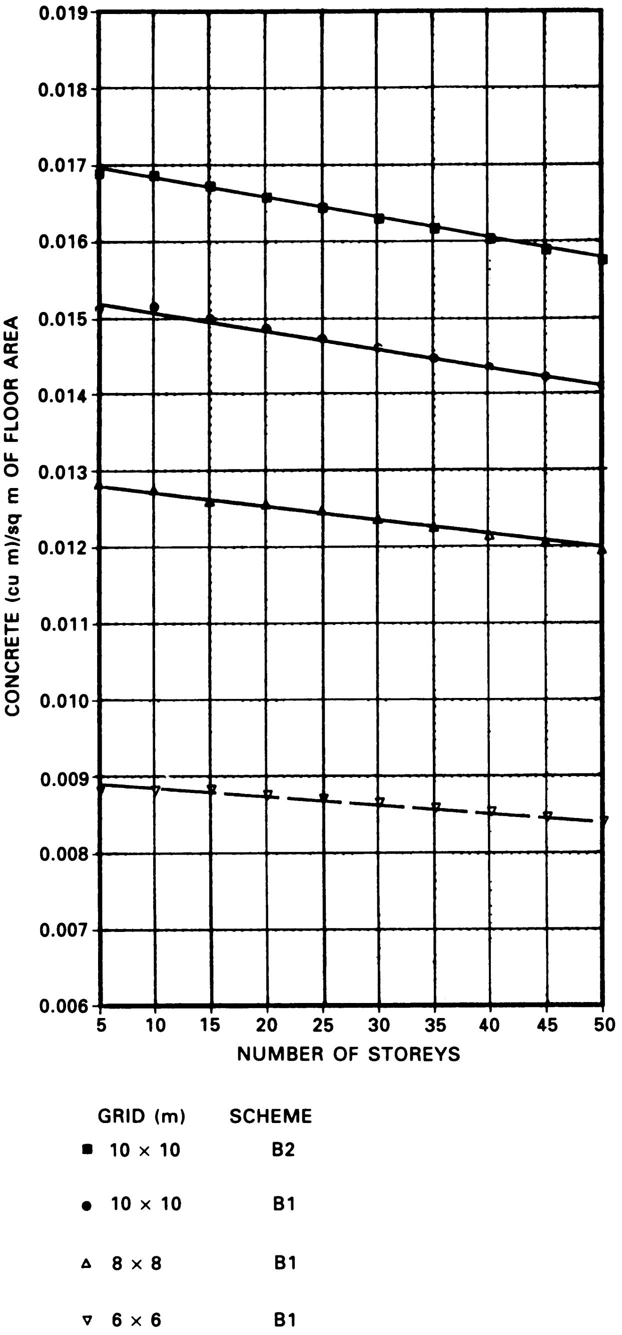


Figure 3.34 Quantities of concrete for secondary beams over columns.

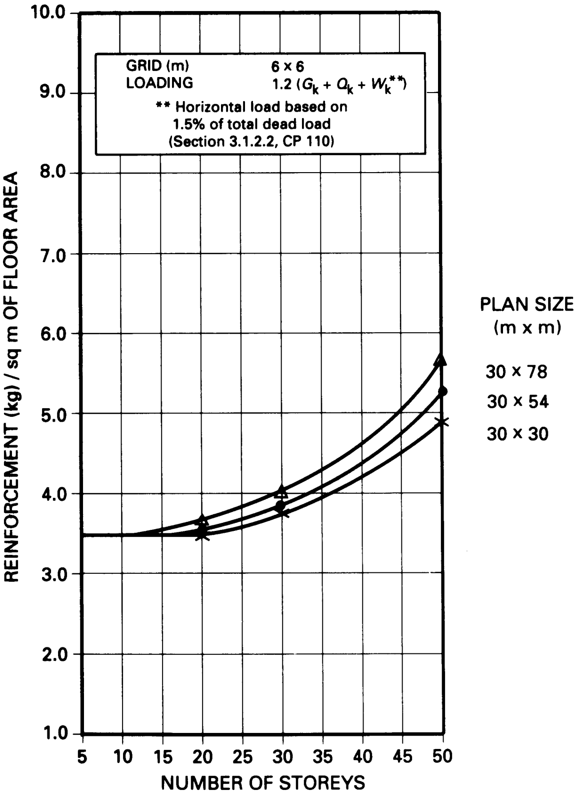


Figure 3.33 Effect of plan size on reinforcement of main interior beams: loading = 1.2 ($G_k + Q_k + W_k^{**}$).

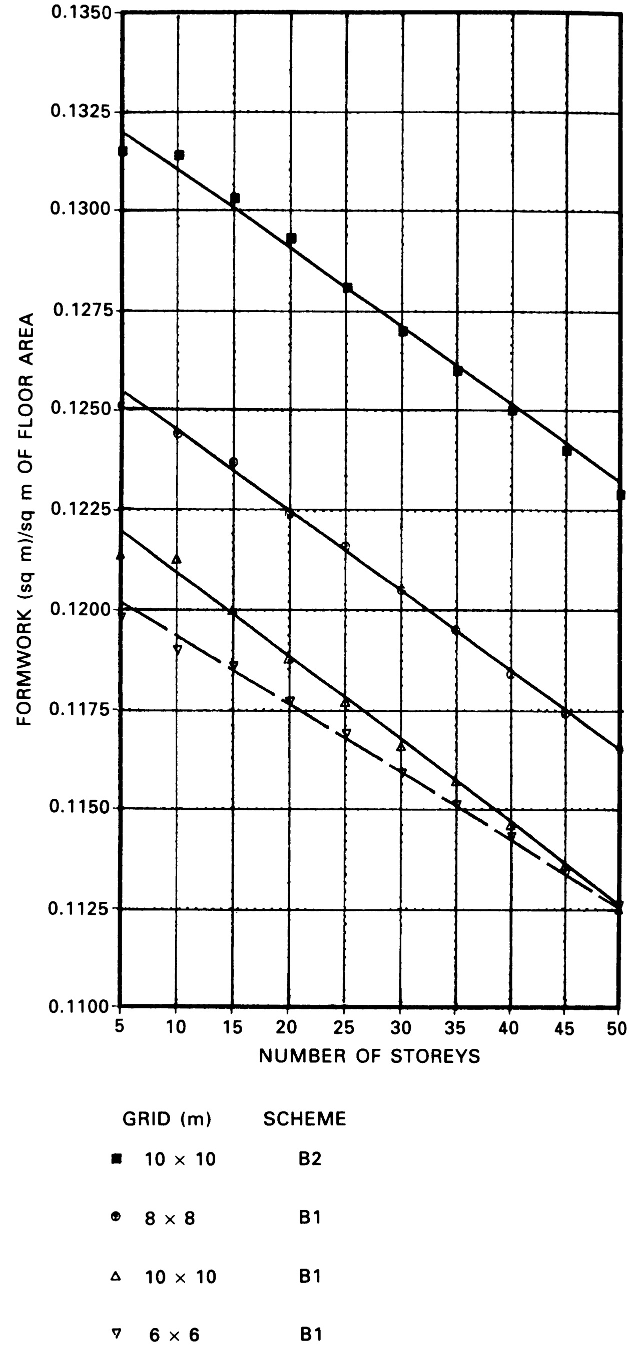


Figure 3.35 Quantities of formwork for secondary beams over columns.

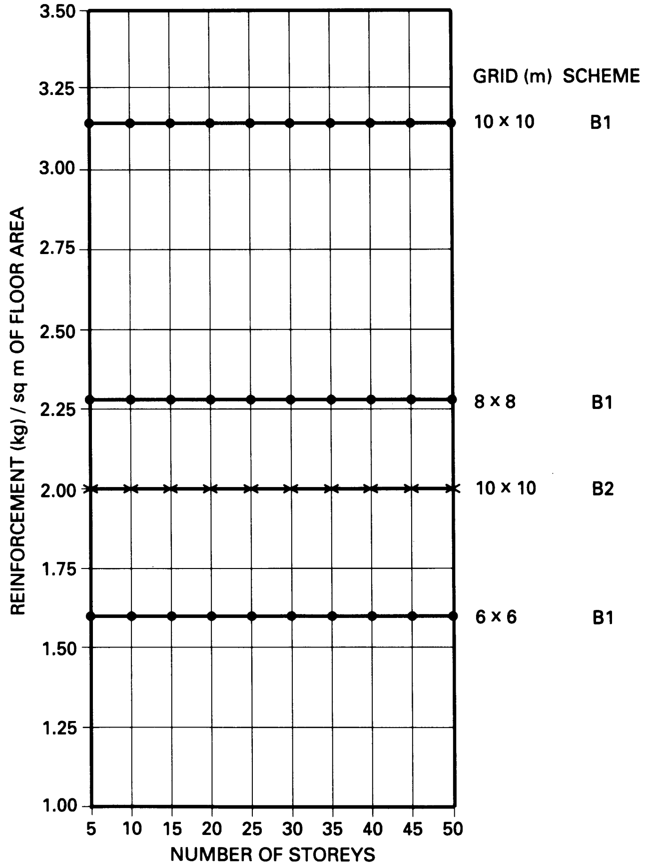


Figure 3.36 Quantities of reinforcement secondary beams over columns – interior beams.

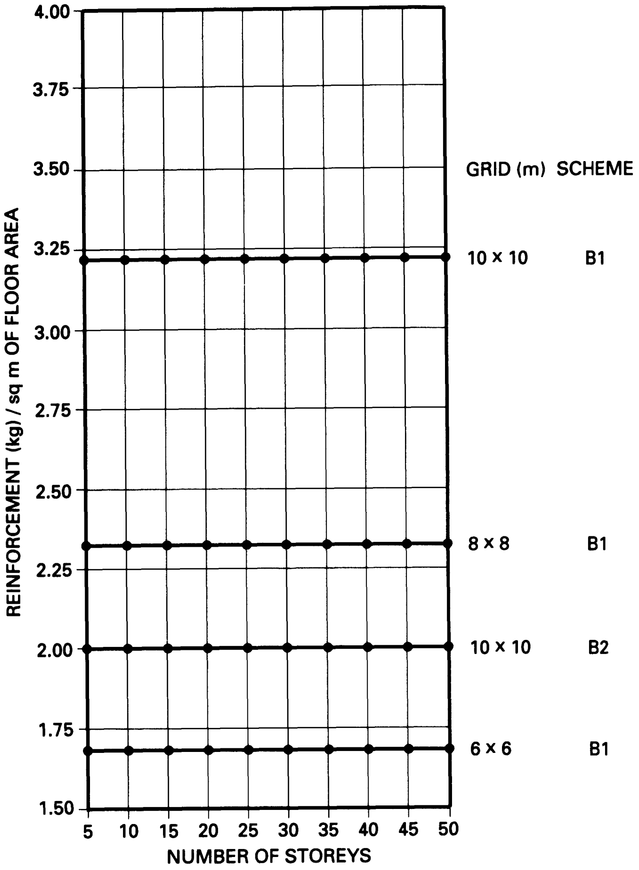


Figure 3.37 Quantities of reinforcement for secondary beams over columns – first interior beams.

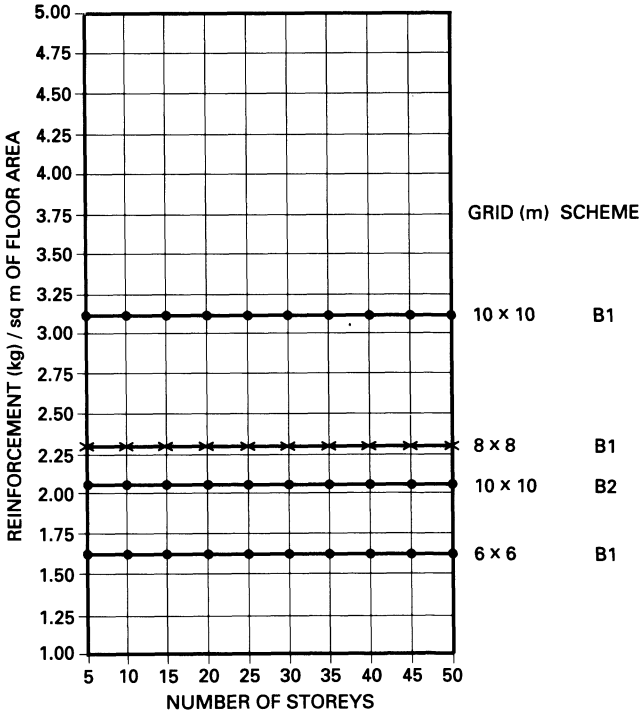


Figure 3.38 Quantities of reinforcement for secondary beams over columns – end beams.

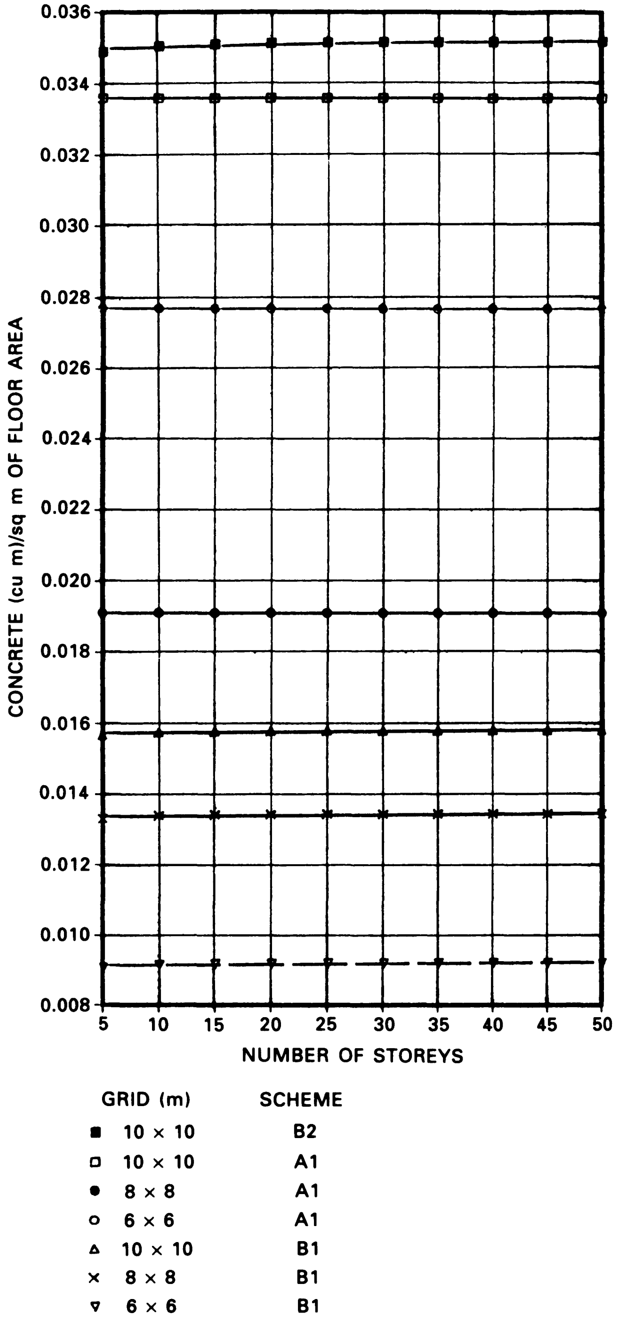


Figure 3.39 Quantities of concrete for secondary beams running over main beams for different numbers of storey and grid sizes.

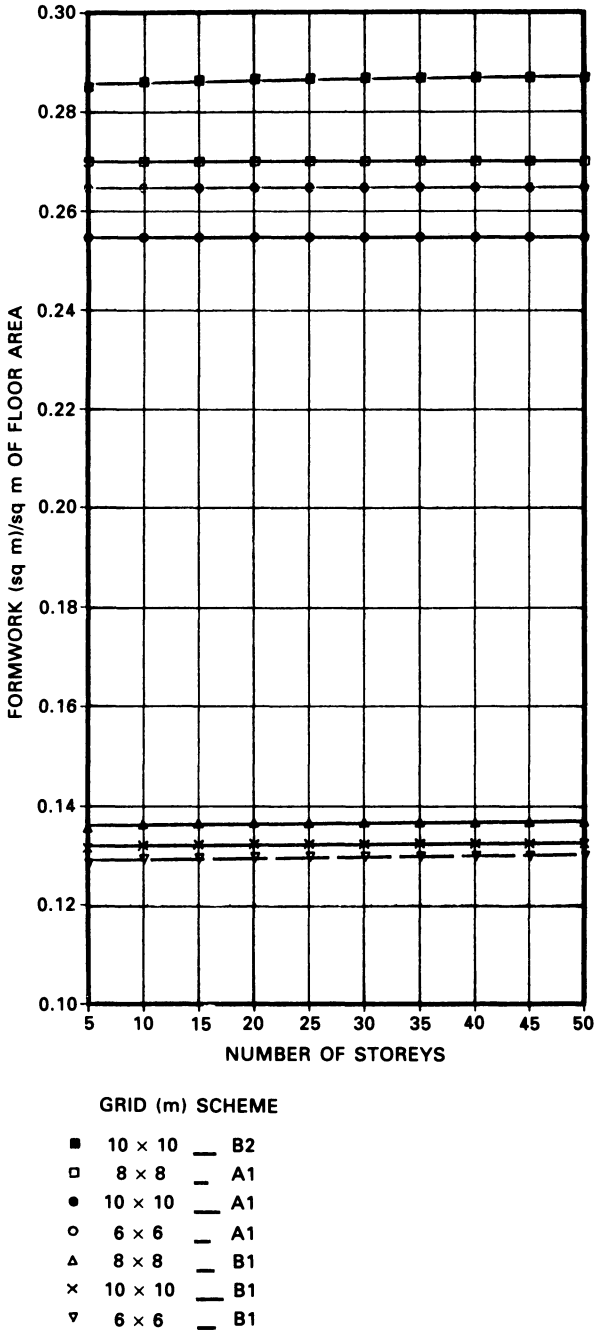


Figure 3.40 Quantities of formwork for secondary beams running over main beams for different numbers of storey and grid sizes.

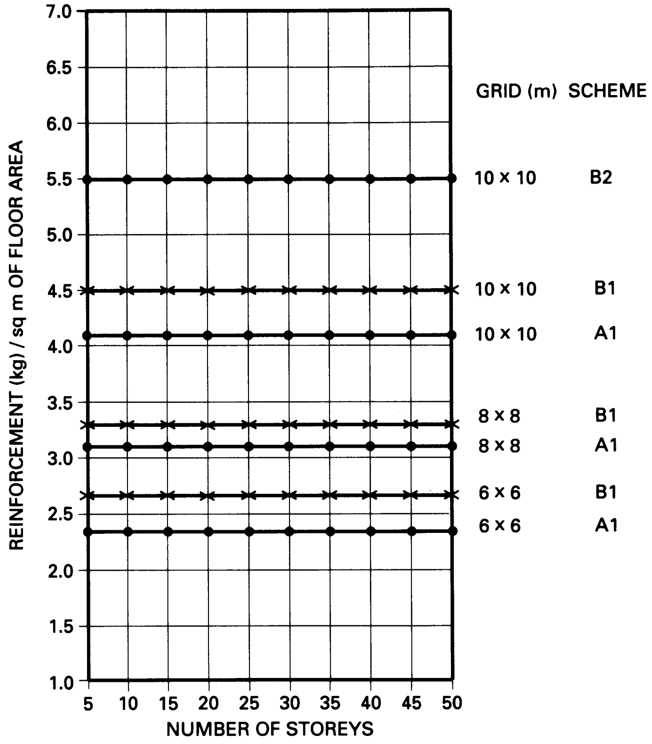


Figure 3.42 Quantities of reinforcement in first interior secondary beams.

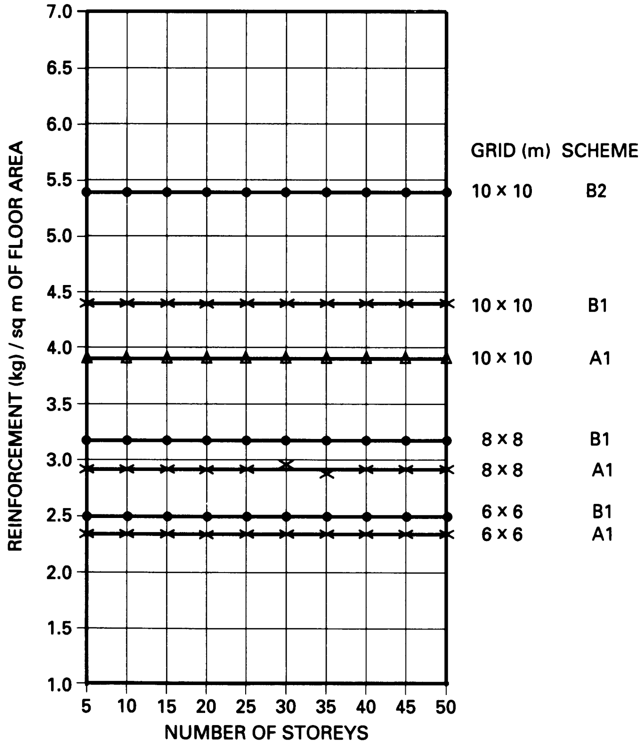
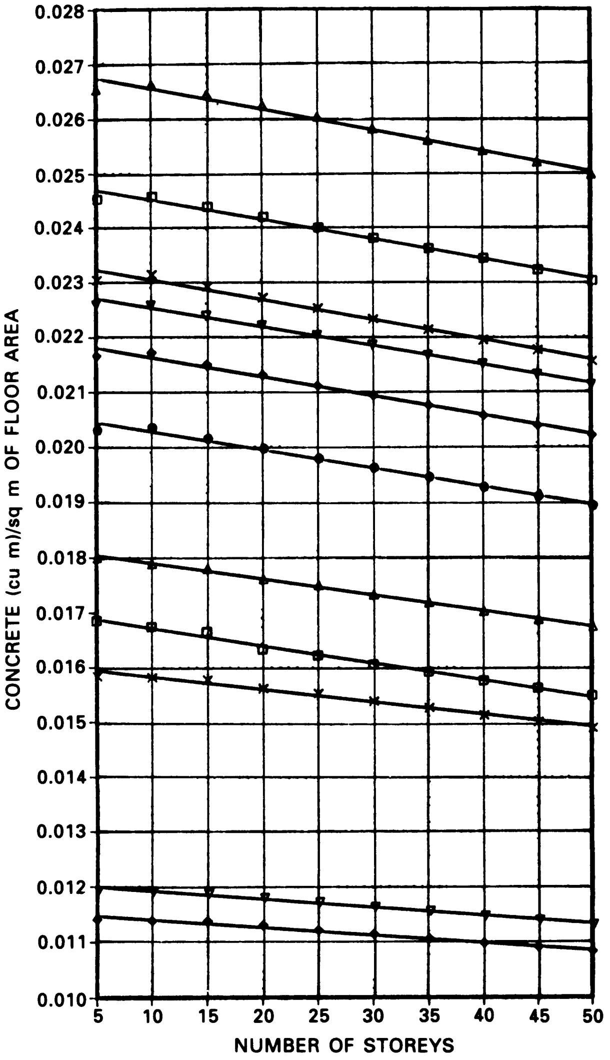


Figure 3.41 Quantities of reinforcement in interior secondary beams for different numbers of storey and grid sizes.



	GRID (m)/ SCHEME	BEAM SECTION (mm)			
			●	10 × 10 B1	450 × 670
△	10 × 10 B2	695 × 540	▲	8 × 8 B1	445 × 495
□	10 × 10 B2	560 × 600	□	8 × 8 B1	360 × 550
×	10 × 10 B1	695 × 540	×	8 × 8 B1	300 × 605
▽	10 × 10 B2	450 × 670	▽	6 × 6 B1	270 × 400
◆	10 × 10 B1	560 × 600	◆	6 × 6 B1	225 × 440

Figure 3.44 Effect of beam section on quantities of concrete for main beams.

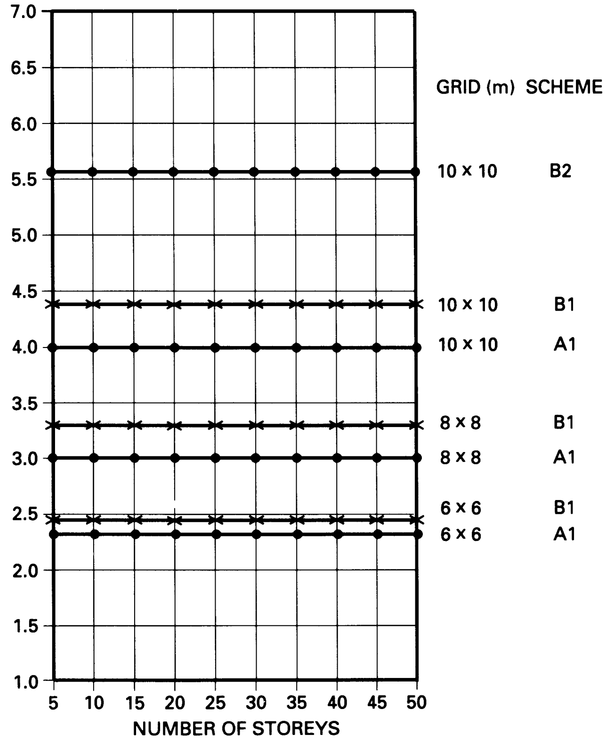


Figure 3.43 Quantities of reinforcement for secondary end beams for different numbers of storey and grid sizes.

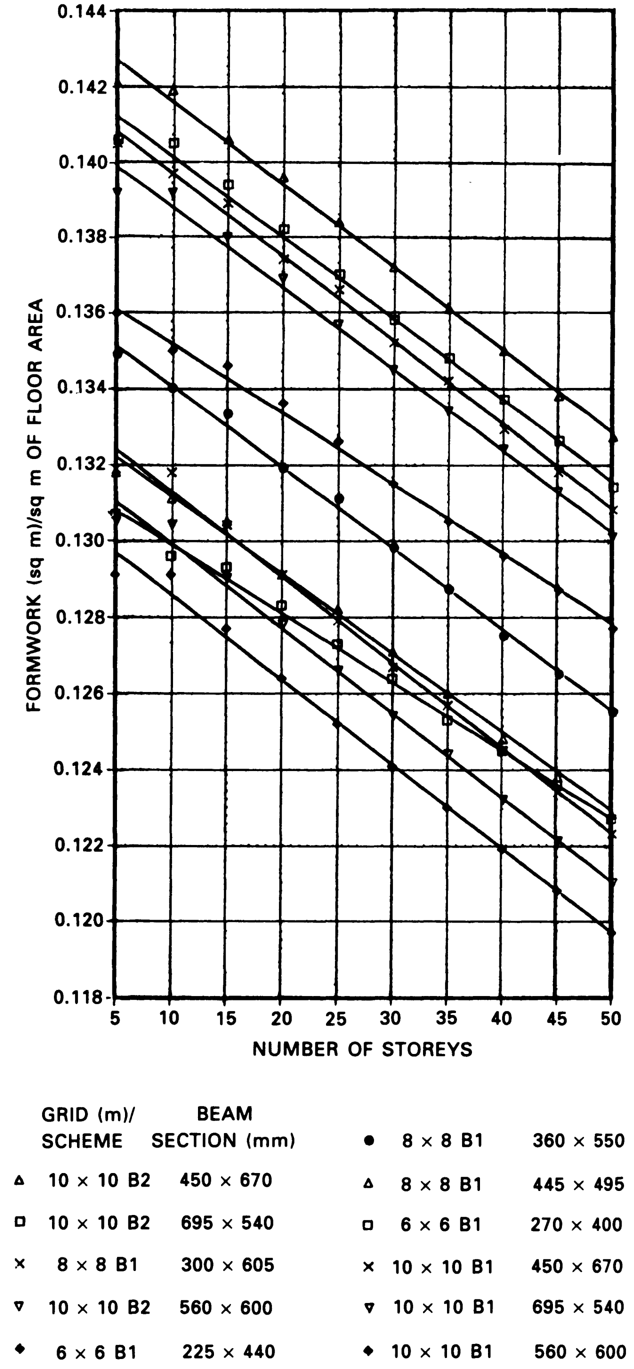


Figure 3.45 Effect of beam section on quantities of formwork for interior/first interior main beams.

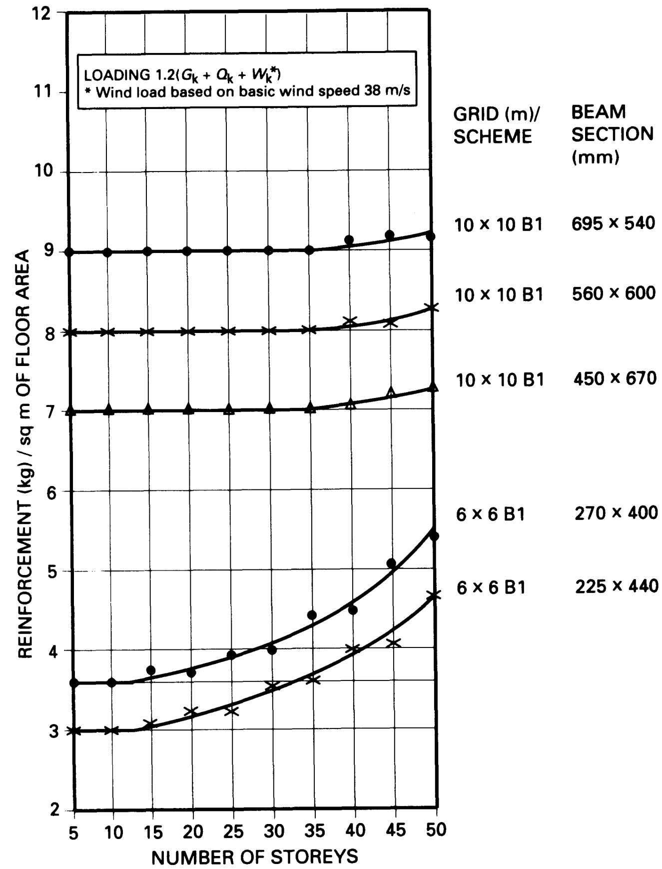


Figure 3.46 Effect of different beam sections on quantities of reinforcement for main interior beams: loading = 1.2(G_k + Q_k + W_k^*); 6 × 6 B1; 10 × 10 B1.

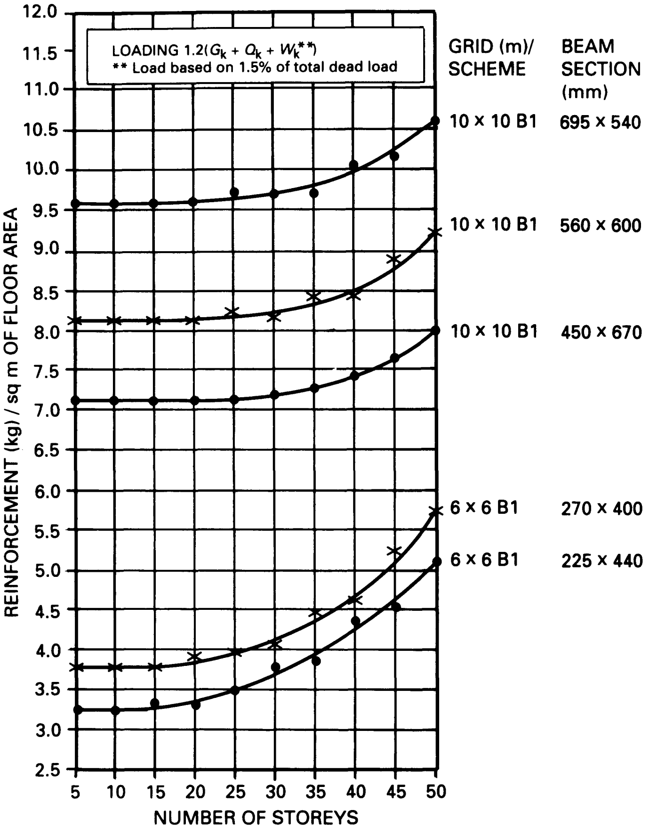


Figure 3.48 Effect of different beam sections on quantities of reinforcement for main interior beams: loading = 1.2(G_k + Q_k + W_k^{**}); 6 × 6 B1; 10 × 10 B1.

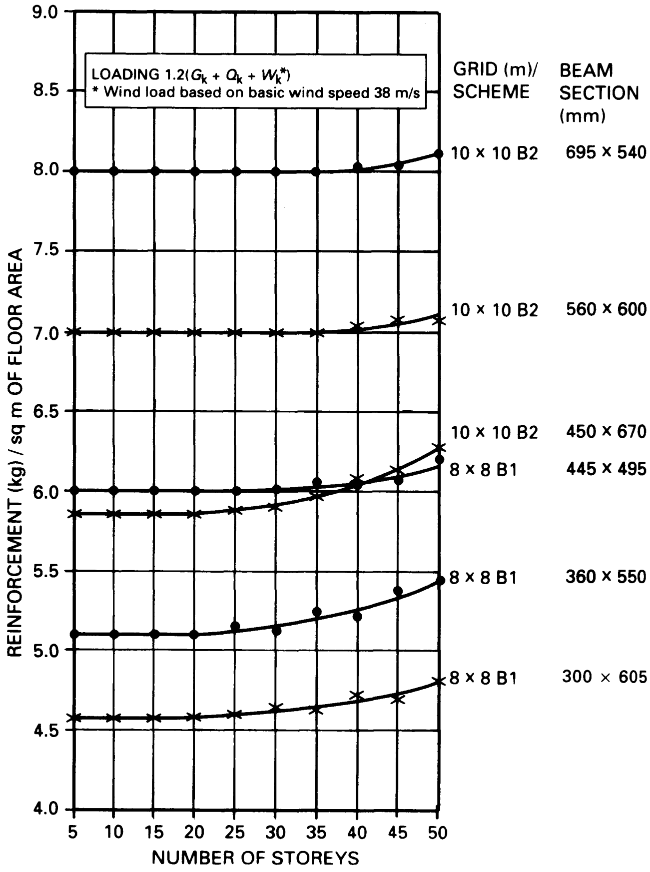


Figure 3.47 Effect of different beam sections on quantities of reinforcement for main interior beams: loading = 1.2(G_k + Q_k + W_k^{*}); 8 × 8 B1; 10 × 10 B2.

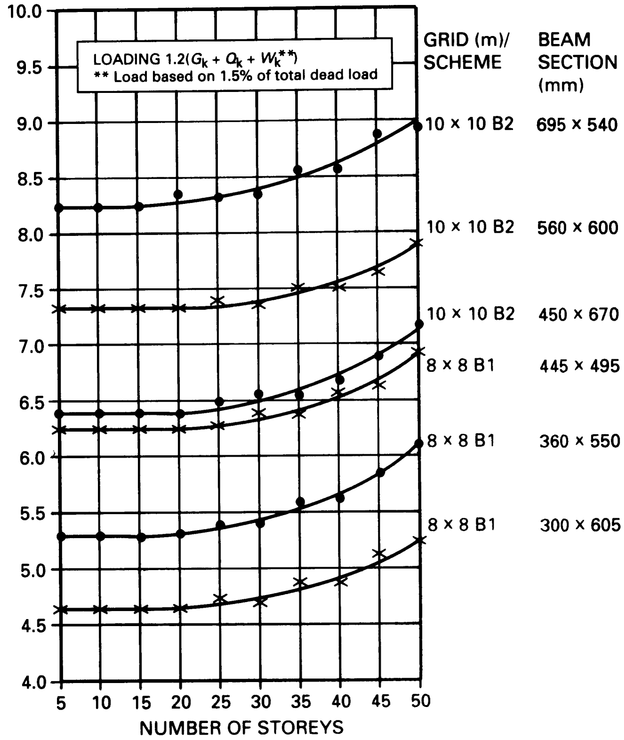


Figure 3.49 Effect of different beam sections on quantities of reinforcement for main interior beams: loading = $1.2(G_k + Q_k + W_k^{**})$; 8 × 8 B1; 10 × 10 B2.

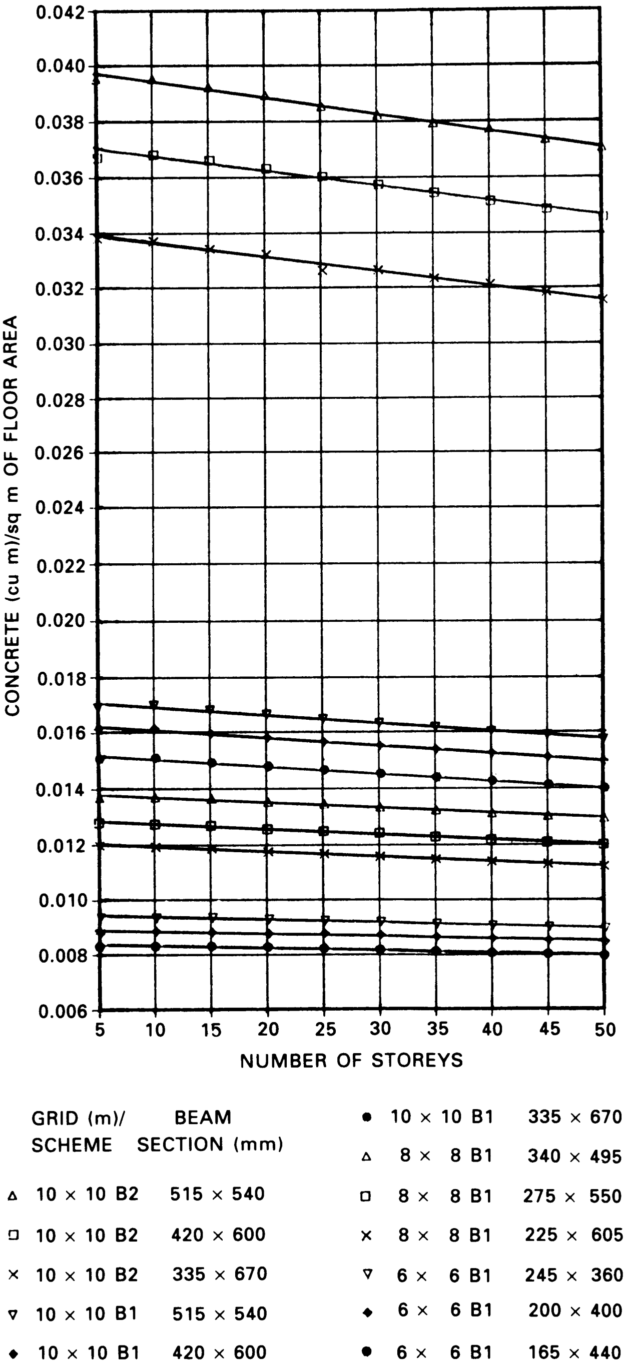


Figure 3.50 Effect of different beam sections on quantities of concrete for main interior/first interior beams over columns.

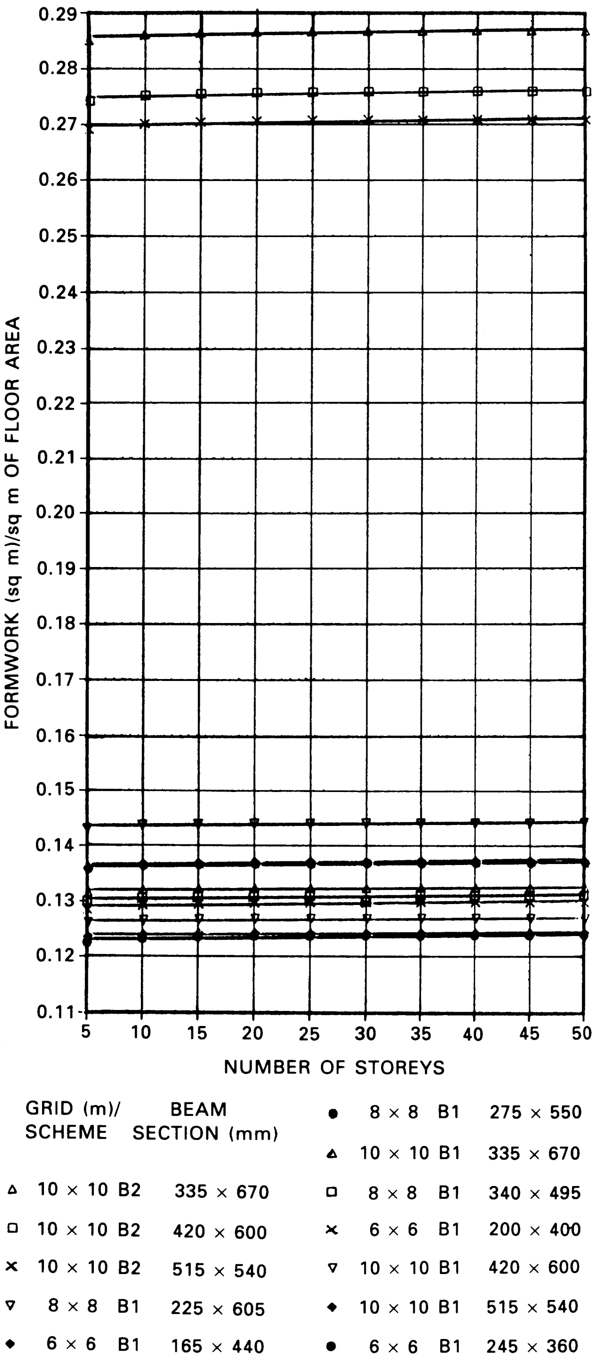


Figure 3.51 Effect of different beam sections on quantities of formwork for interior/first interior secondary beams over columns.

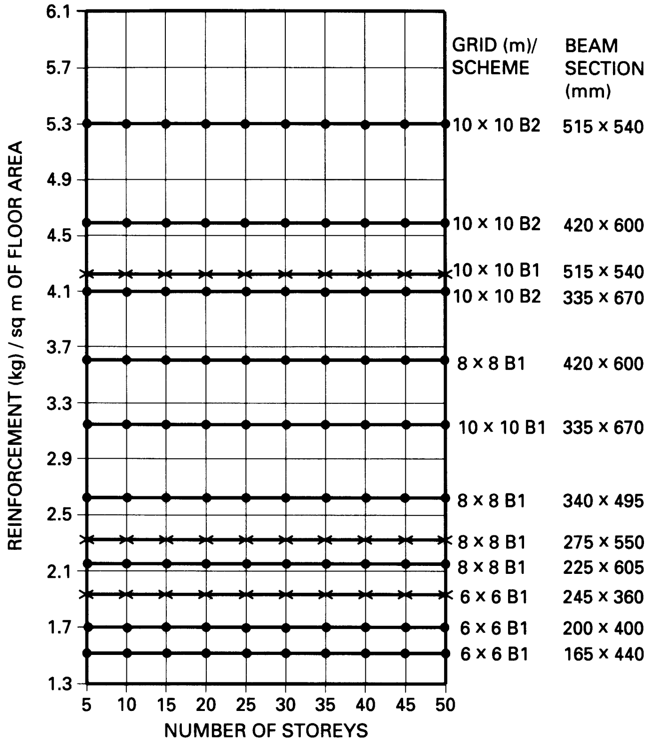


Figure 3.52 Effect of different beam sections on quantities of reinforcement for interior secondary beams over columns: 6 × 6 B1; 8 × 8 B1; 10 × 10 B1; 10 × 10 B2.

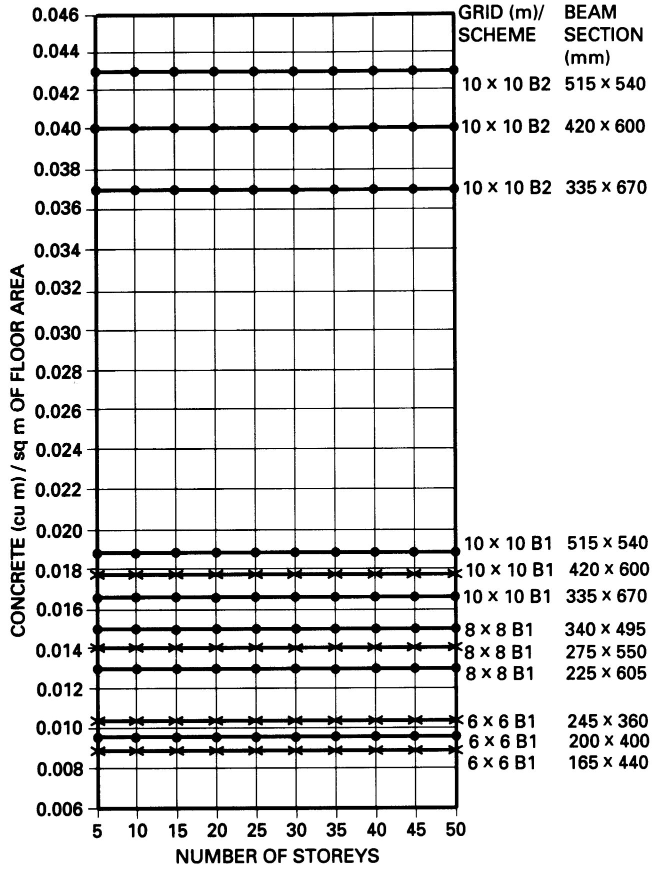


Figure 3.53 Effect of different beam sections on quantities of concrete for interior and first interior secondary beams.

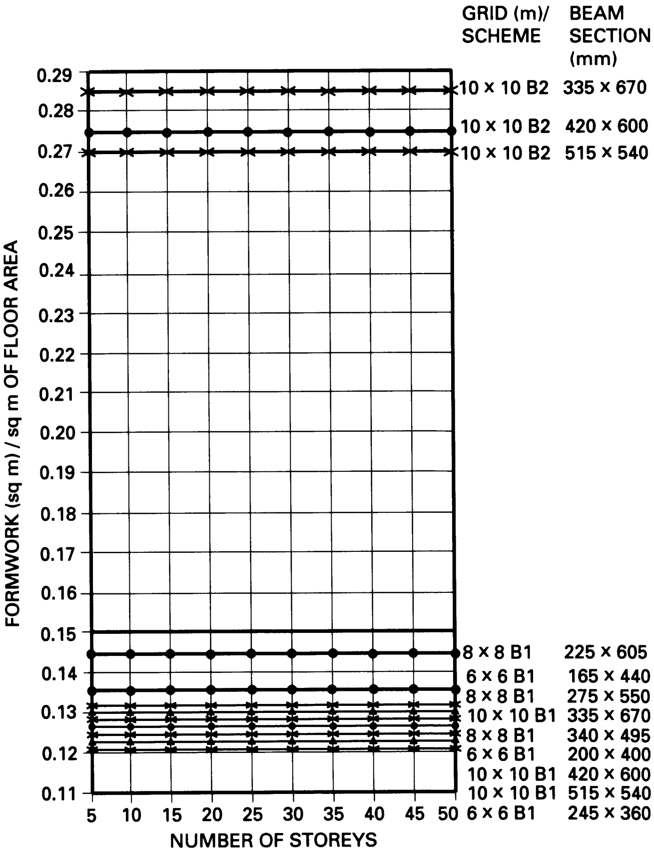


Figure 3.54 Effect of different beam sections on quantities of formwork for interior and first interior secondary beams.

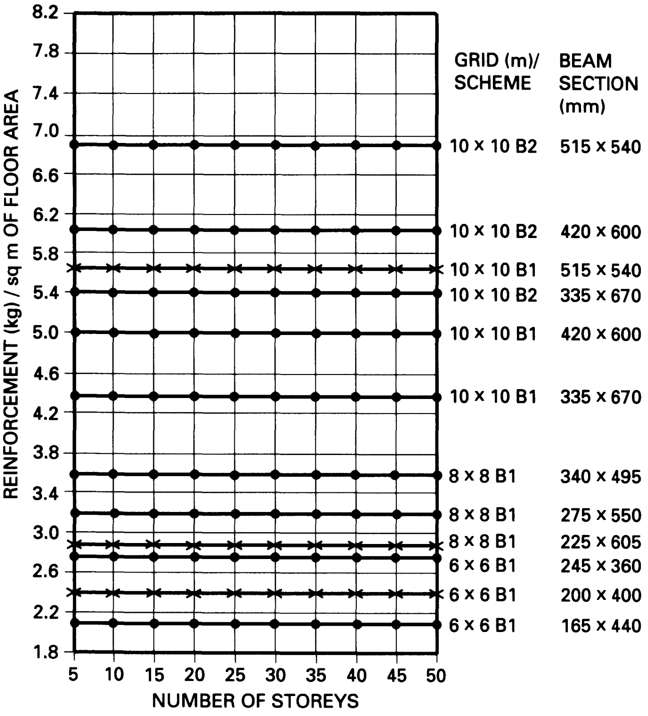


Figure 3.55 Effect of different beam sections on quantities of reinforcement for secondary interior beams.

3.4.3 *Columns*

The quantities of constituents for the interior column of different grid sizes and structural schemes in terms of concrete, formwork and reinforcement are shown in Figures 3.56 to 3.58, while for the exterior and corner columns the same parameters are shown in Figures 3.59 to 3.61 and Figures 3.62 to 3.64 respectively.

The use of higher grades of concrete helps in reducing the section of the column and this in turn yields more usable space. This effect was studied for different grid sizes and structural schemes and the results in terms of concrete, formwork and reinforcement are shown in Figures 3.65 to 3.67, Figures 3.68 to 3.70, Figures 3.71 to 3.73 and Figures 3.74 to 3.76 for grid sizes of 6 m × 6 m, 8 m × 8 m, 10 m × 10 m (Scheme B1) and 10 m × 10 m (Scheme B2) respectively. Similar results for exterior and corner columns are shown in Figures 3.77 to 3.79 and 3.80 to 3.82 respectively.

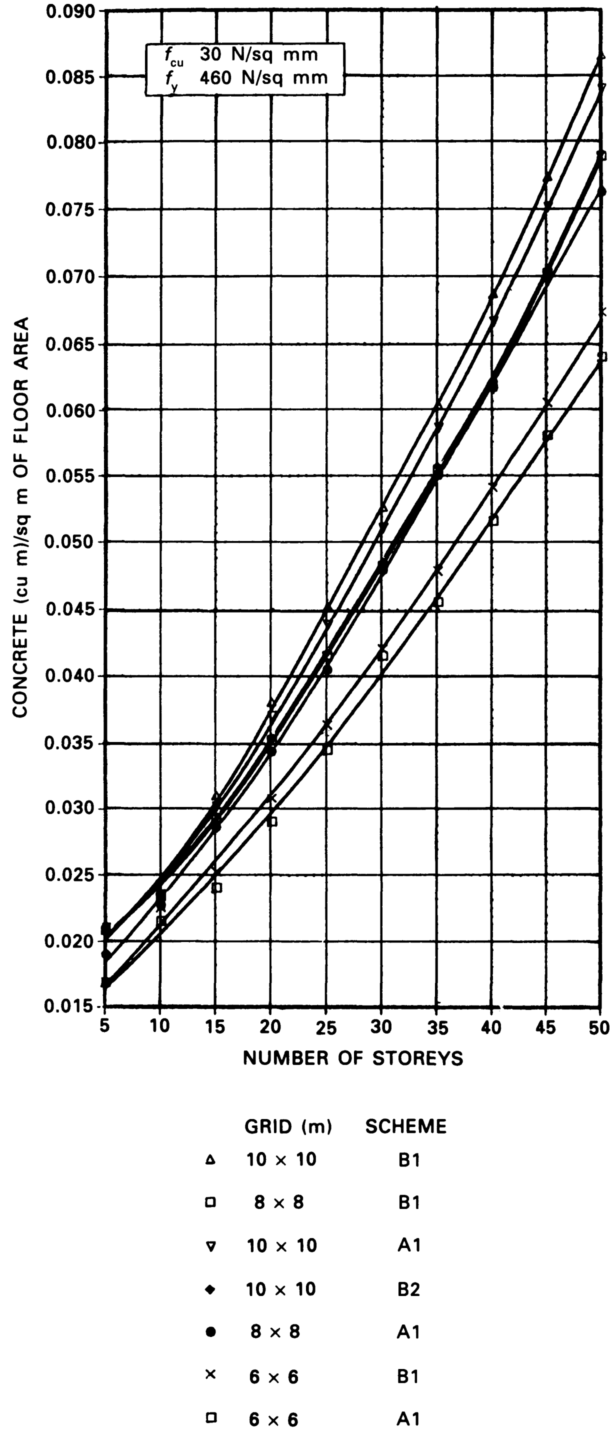


Figure 3.56 Quantities of concrete for interior columns: f_{cu} = 30 N/sq mm².

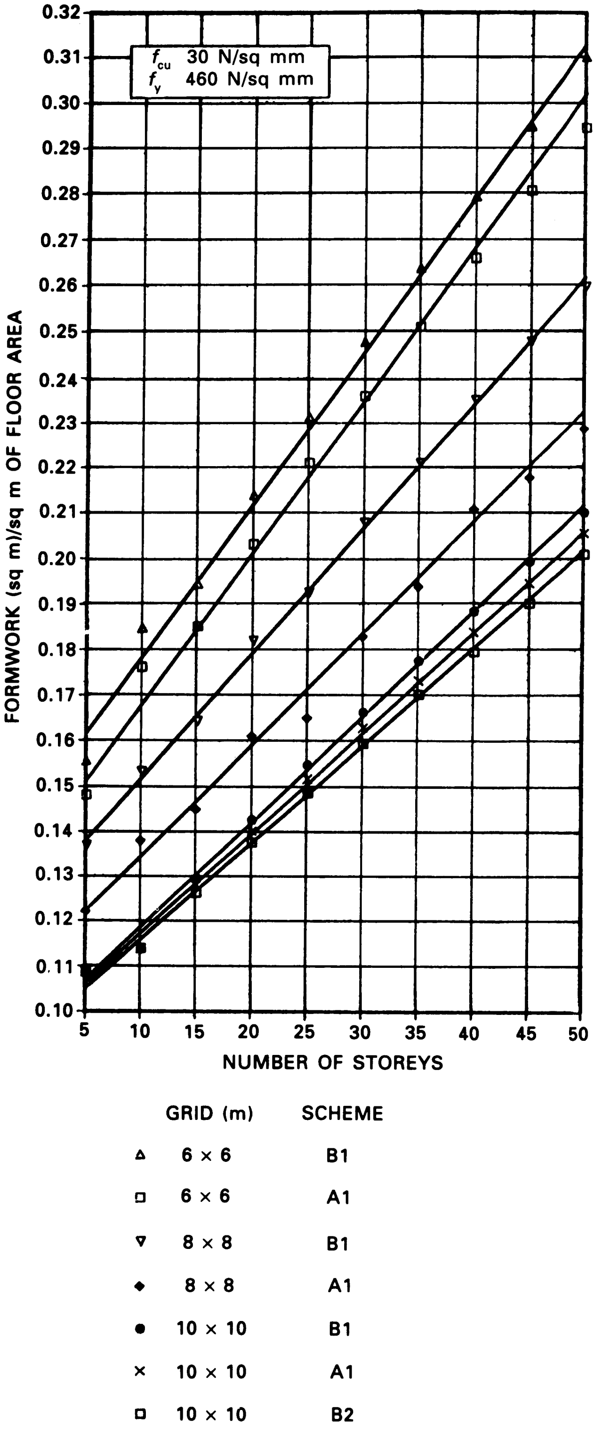


Figure 3.57 Quantities of formwork for interior columns: $f_{cu} = 30$ N/sq mm^2.

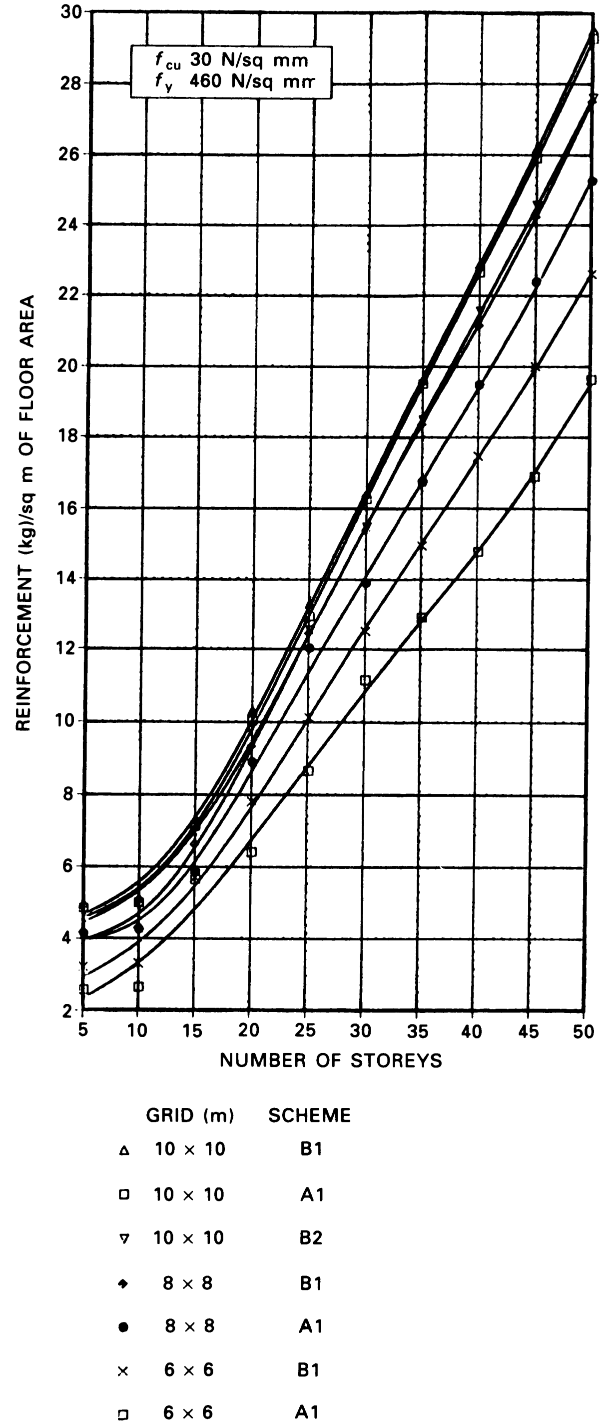


Figure 3.58 Quantities of reinforcement for interior columns: $f_{cu} = 30$ N/sq mm^2.

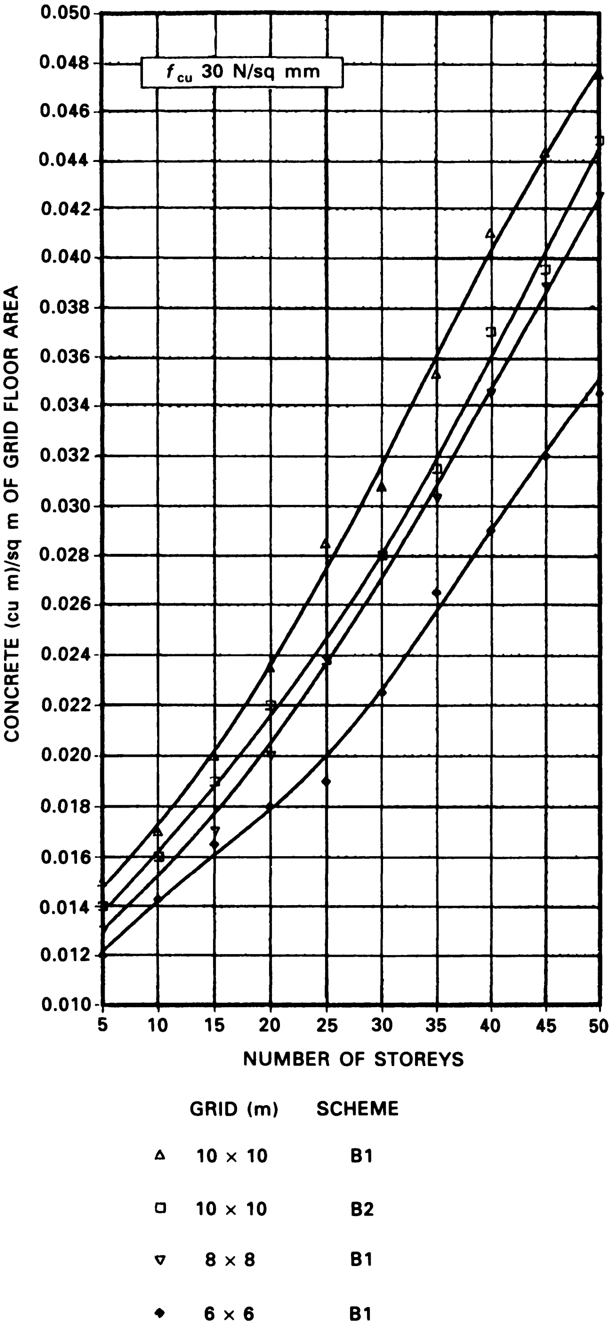


Figure 3.59 Quantities of concrete for exterior columns: f_{cu} = 30 N sq mm^2.

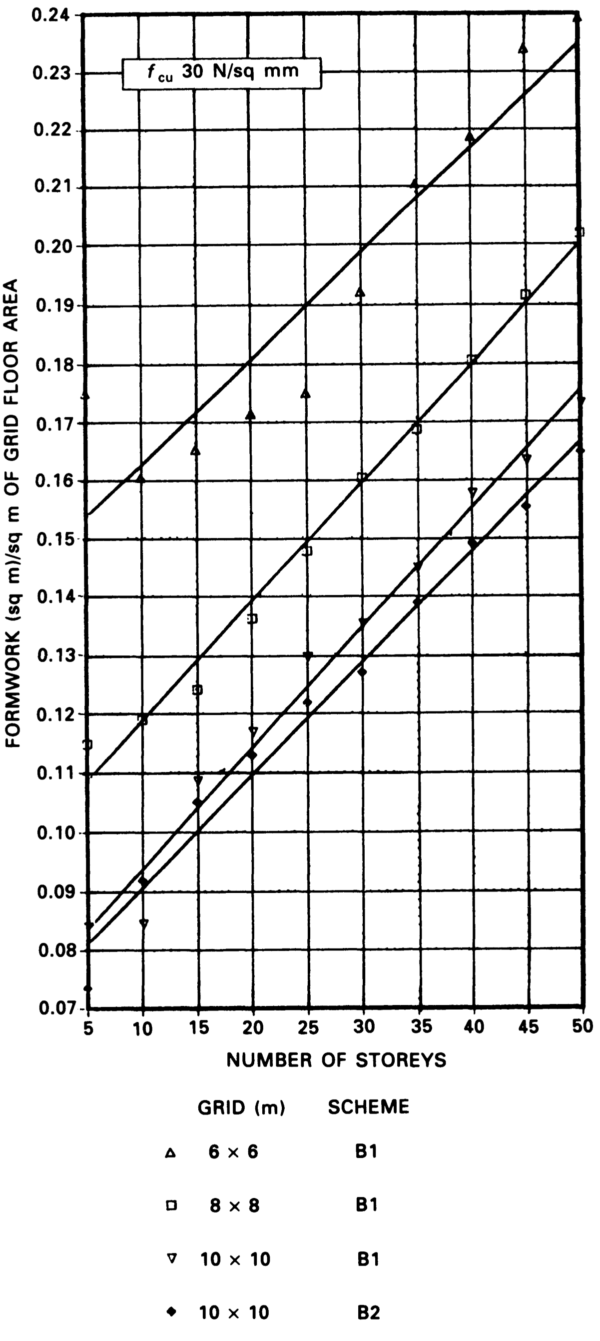


Figure 3.60 Quantities of formwork for exterior columns: f_{cu} = 30 N sq mm^2.

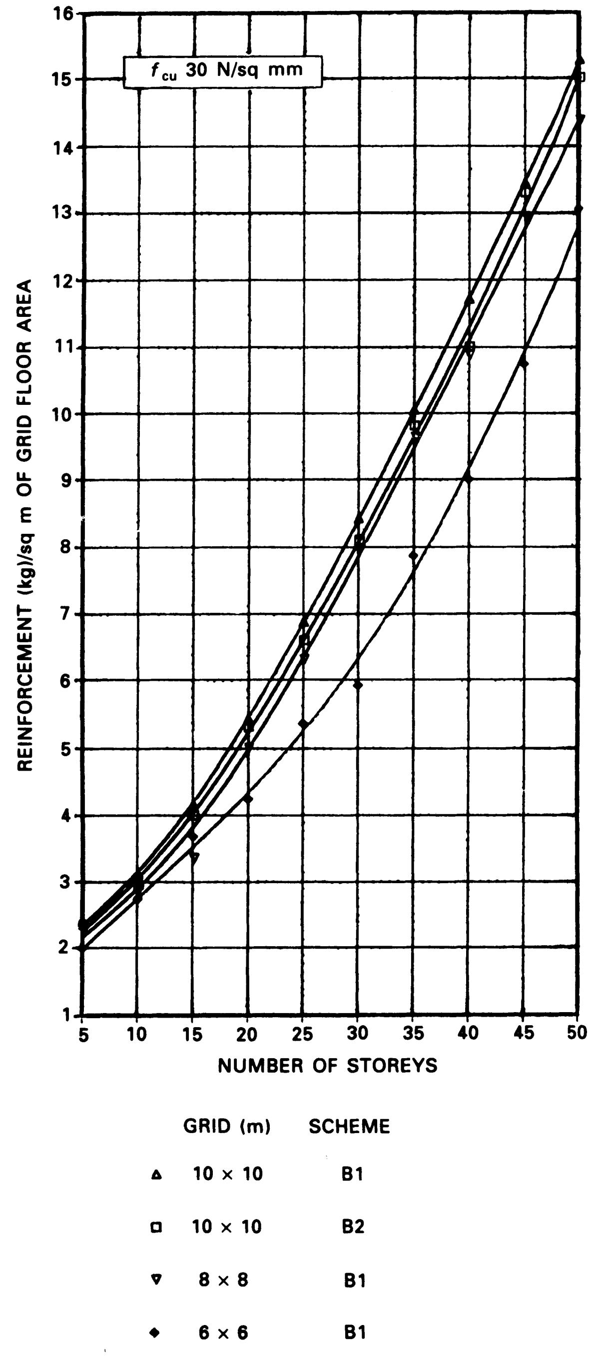


Figure 3.61 Quantities of reinforcement for exterior columns: f_{cu} = 30 N/mm^2.

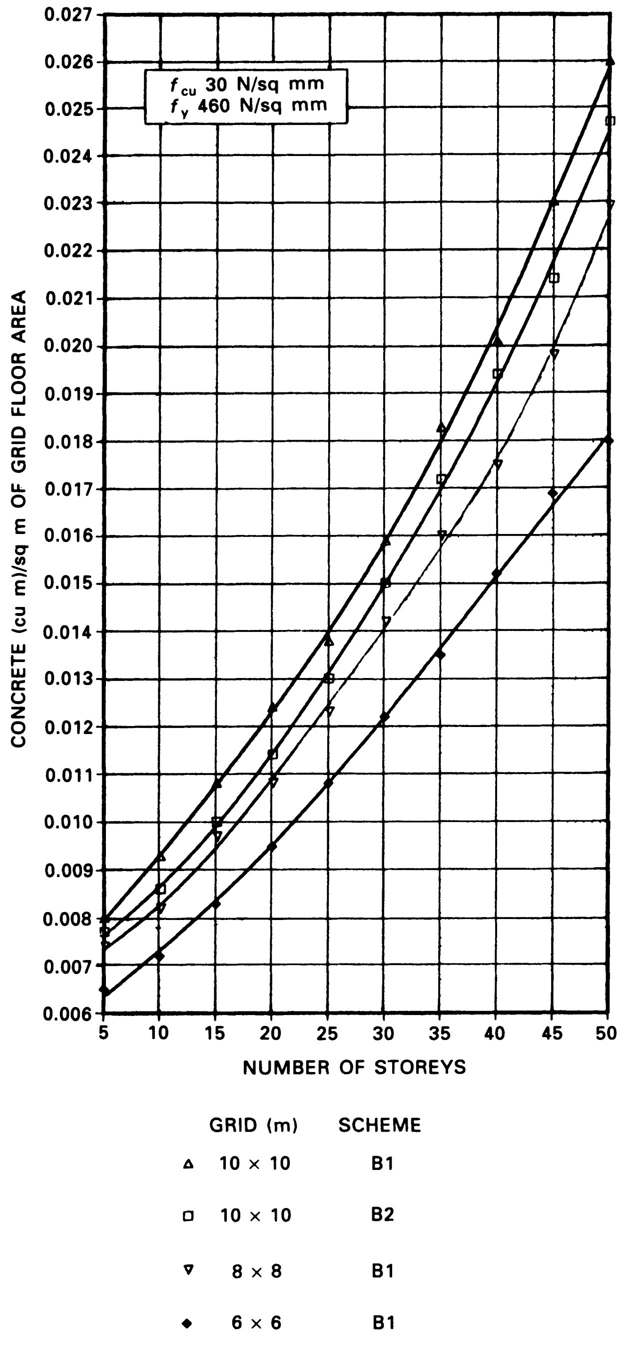


Figure 3.62 Quantities of concrete for corner columns: f_{cu} = 30 N/mm^2.

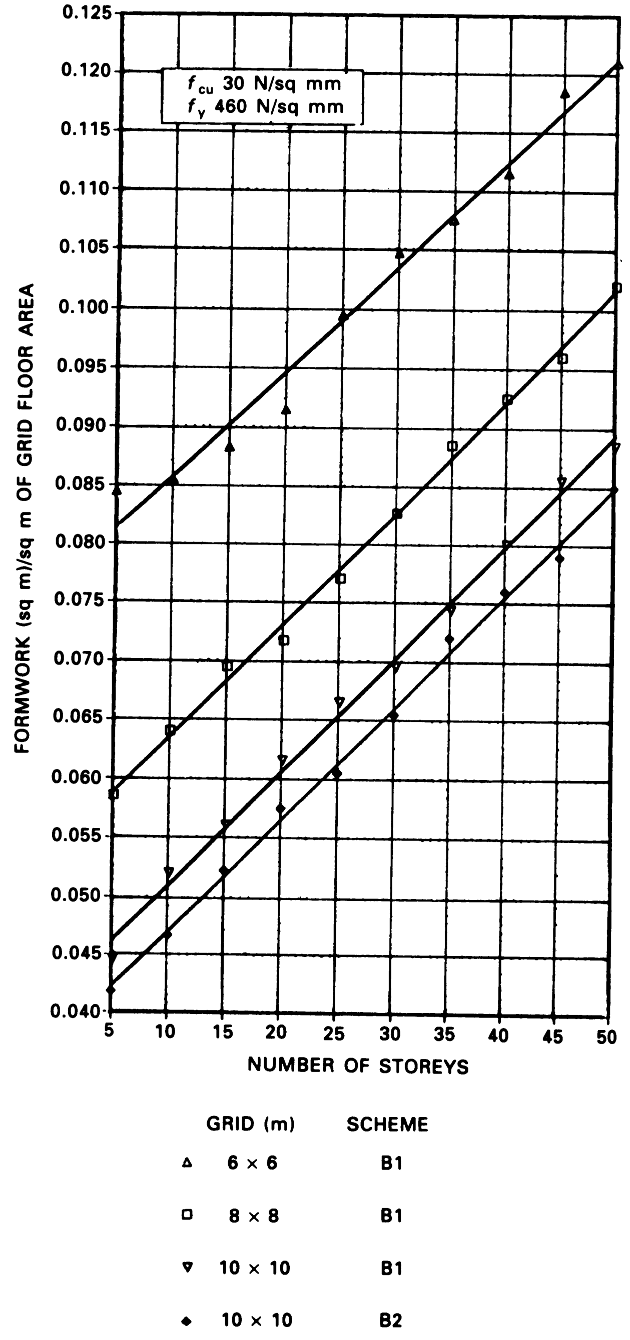


Figure 3.63 Quantities of formwork for corner columns: $f_{cu} = 30$ N/mm^2.

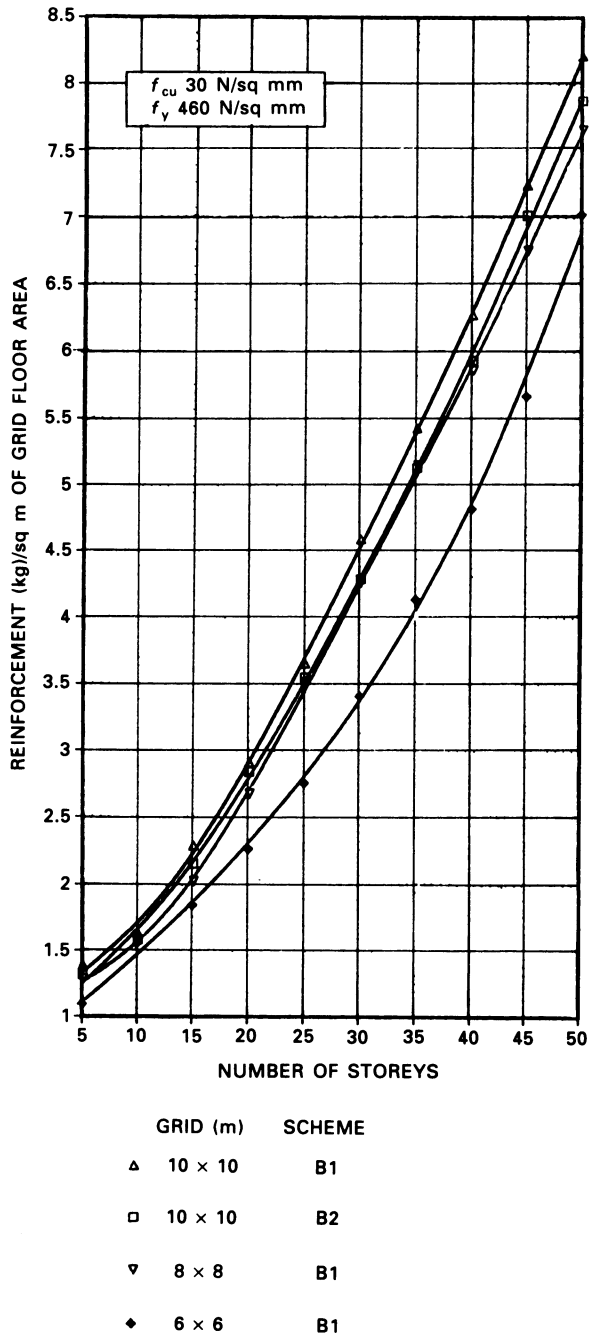


Figure 3.64 Quantities of reinforcement for corner columns: $f_{cu} = 30$ N/mm^2.

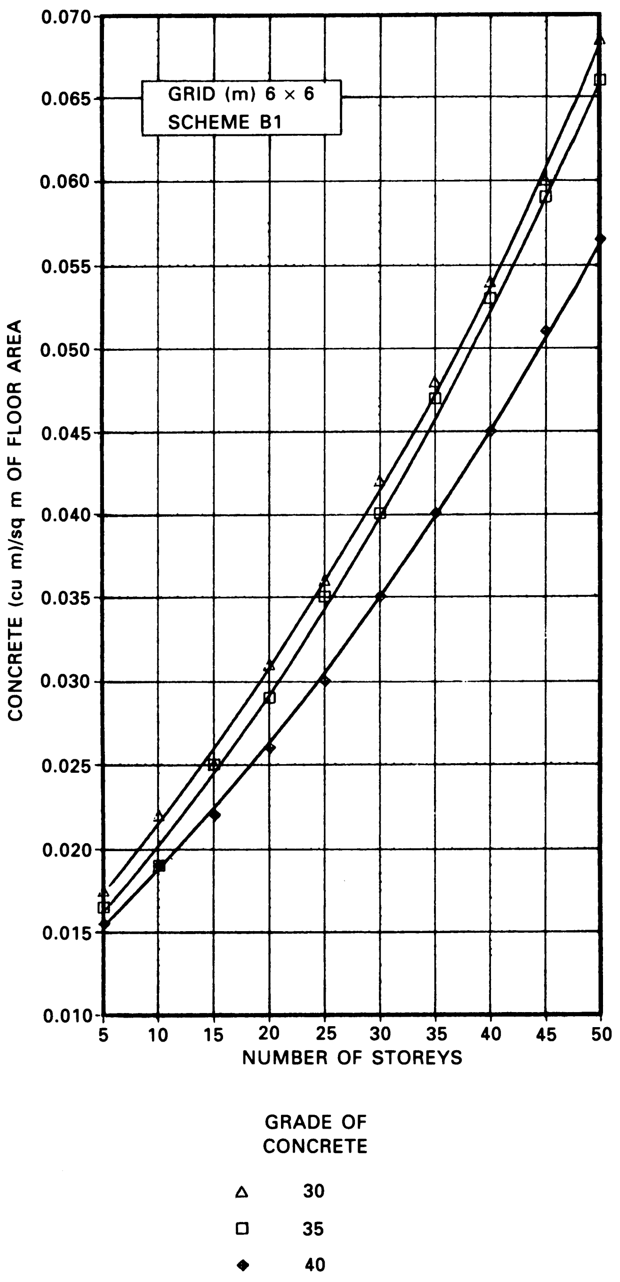


Figure 3.65 Effect of grade of concrete on quantities of concrete for interior columns: 6 m × 6 m; Scheme B1.

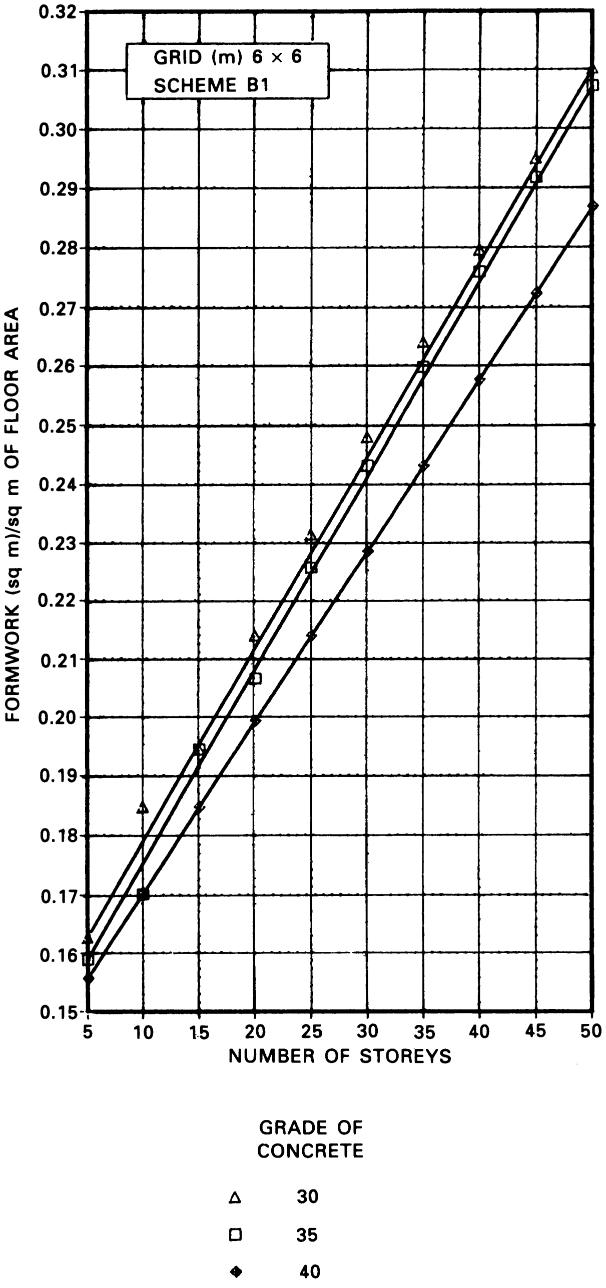


Figure 3.66 Effect of grade of concrete on quantities of formwork for interior columns: 6 m × 6 m; Scheme B1.

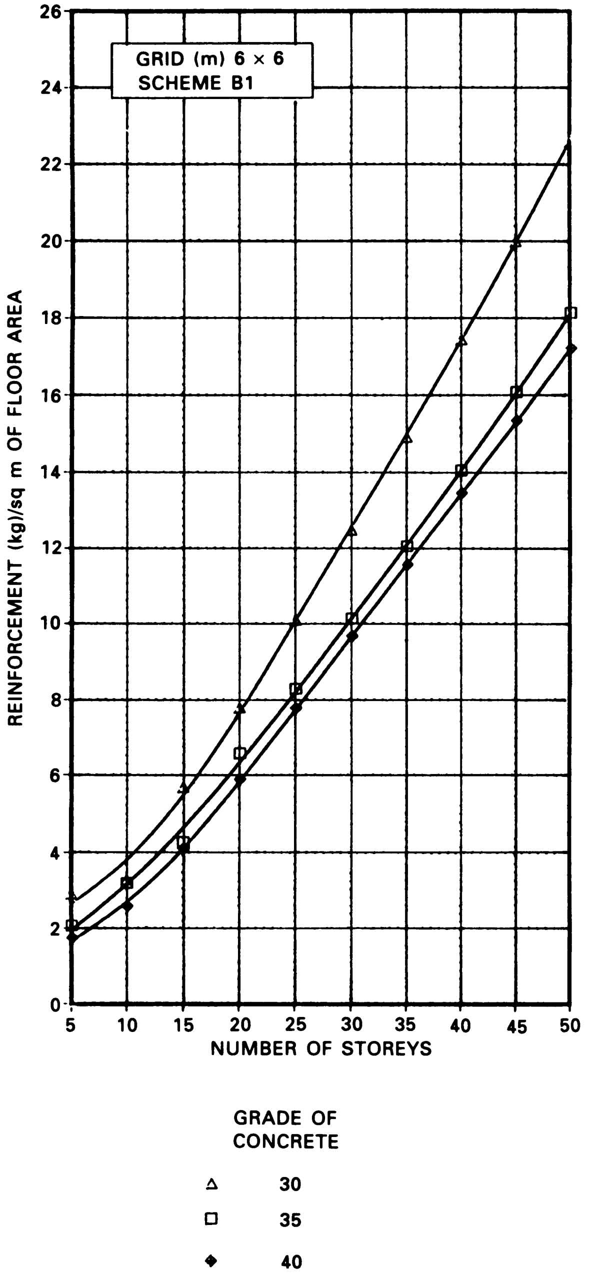


Figure 3.67 Effect of grade of concrete on quantities of reinforcement for interior columns: 6 m × 6 m; Scheme B1.

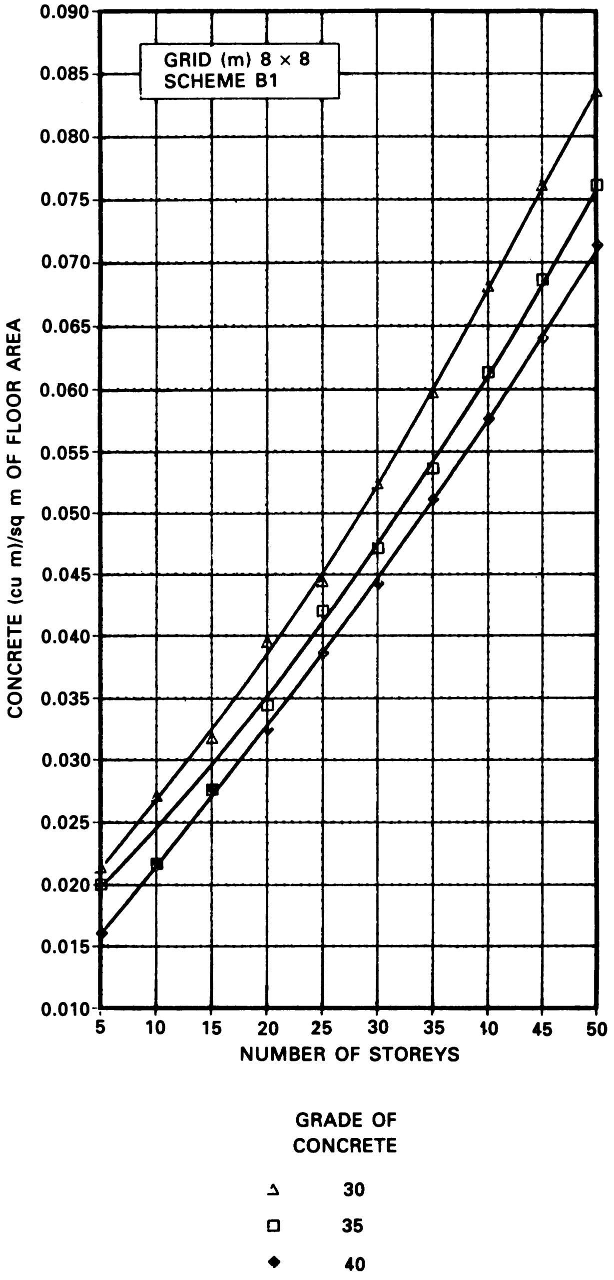


Figure 3.68 Effect of grade of concrete on quantities of concrete for interior columns: 8 m × 8 m; Scheme B1.

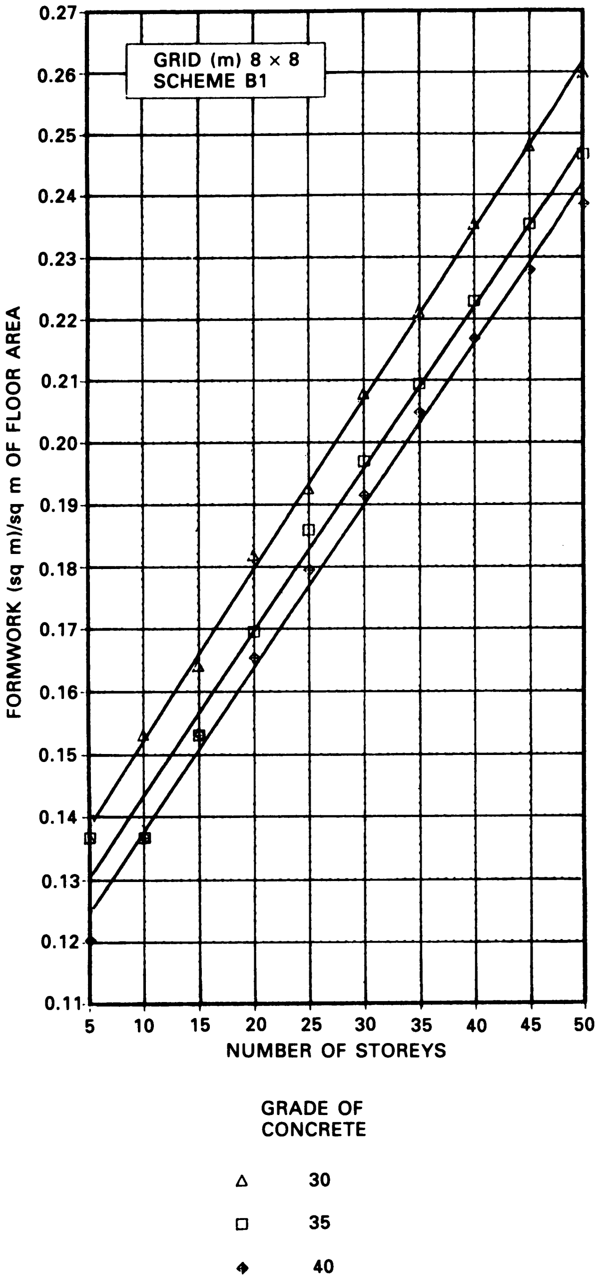


Figure 3.69 Effect of grade of concrete on quantities of formwork for interior columns: 8 m × 8 m; Scheme B1.

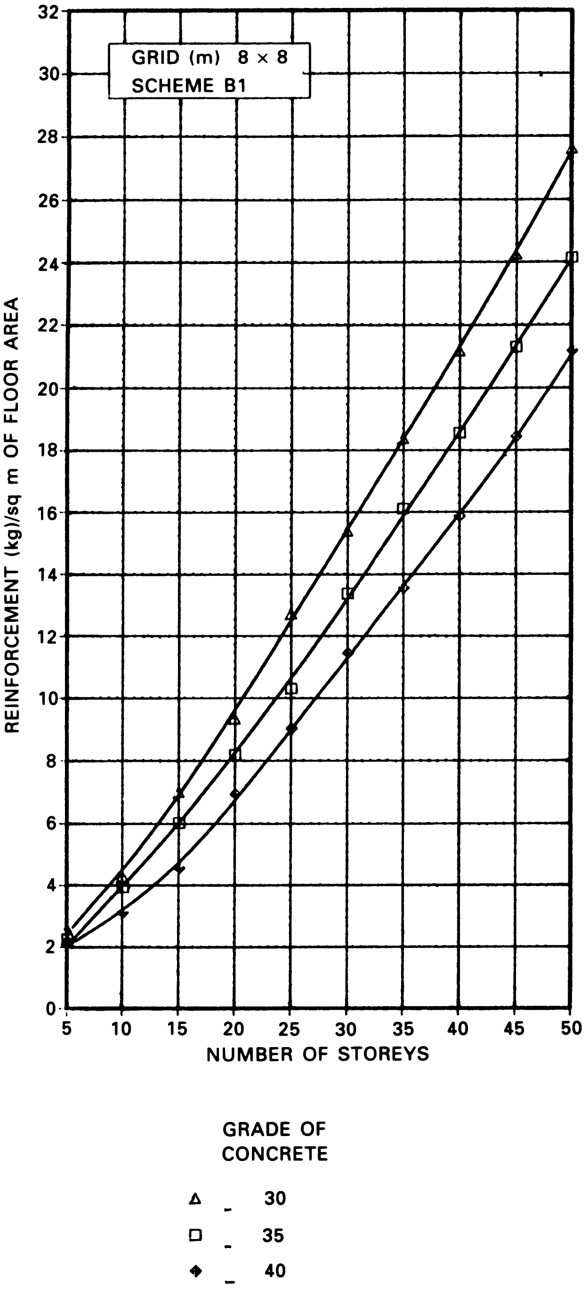


Figure 3.70 Effect of grade of concrete on quantities of reinforcement for interior columns: 8 m × 8 m; Scheme B1.

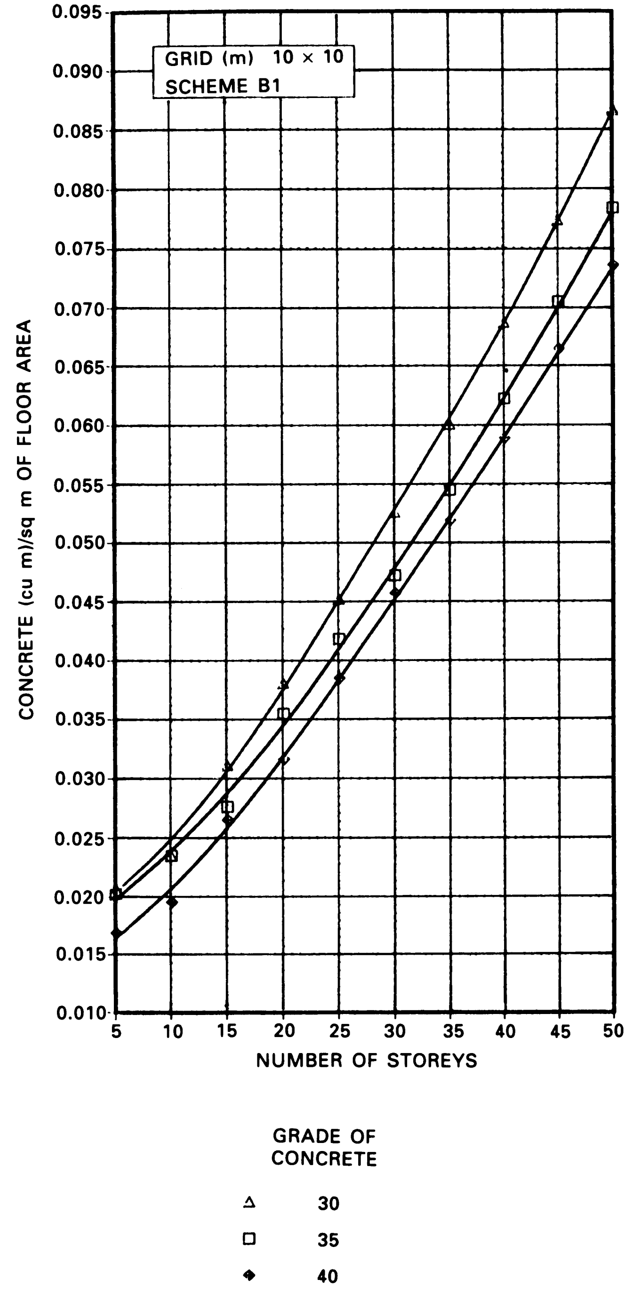


Figure 3.71 Effect of grade of concrete on quantities of concrete for interior columns: 10 m × 10 m; Scheme B1.

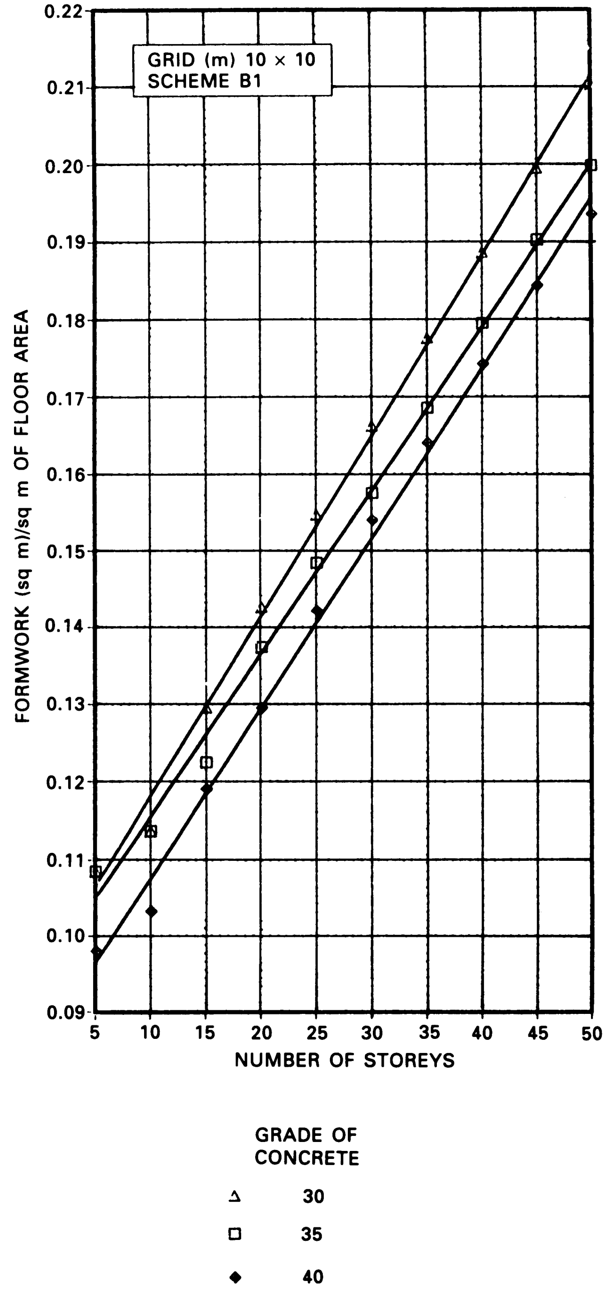


Figure 3.72 Effect of grade of concrete on quantities of formwork for interior columns: 10 m × 10 m; Scheme B1.

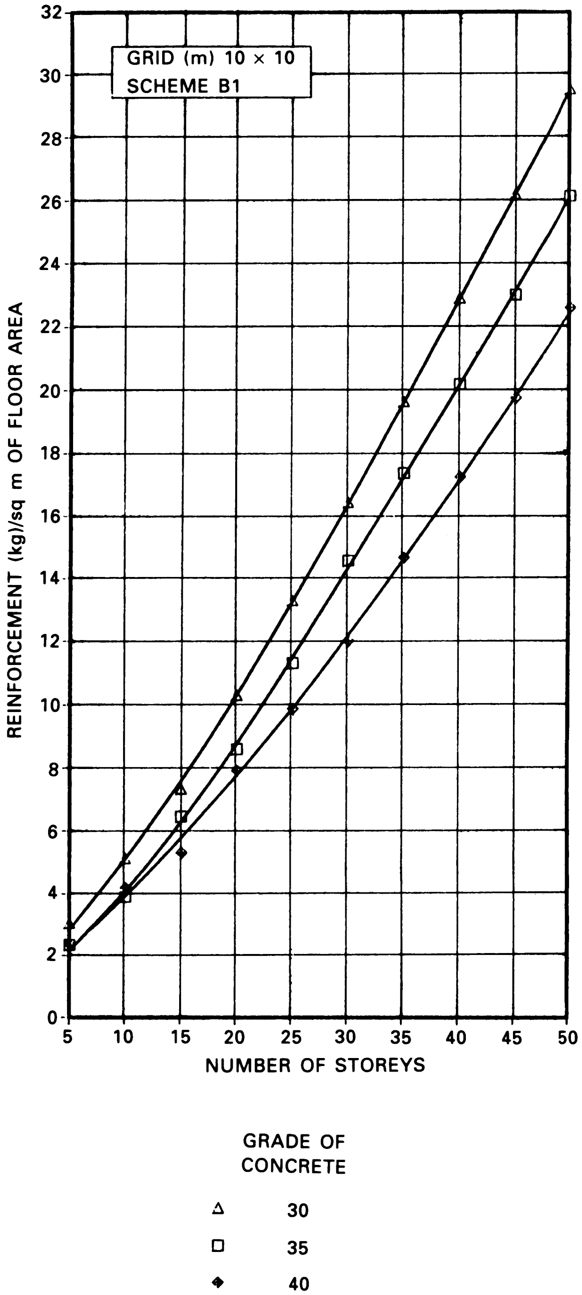


Figure 3.73 Effect of grade of concrete on quantities of reinforcement for interior columns: 10 m × 10 m; Scheme B1.

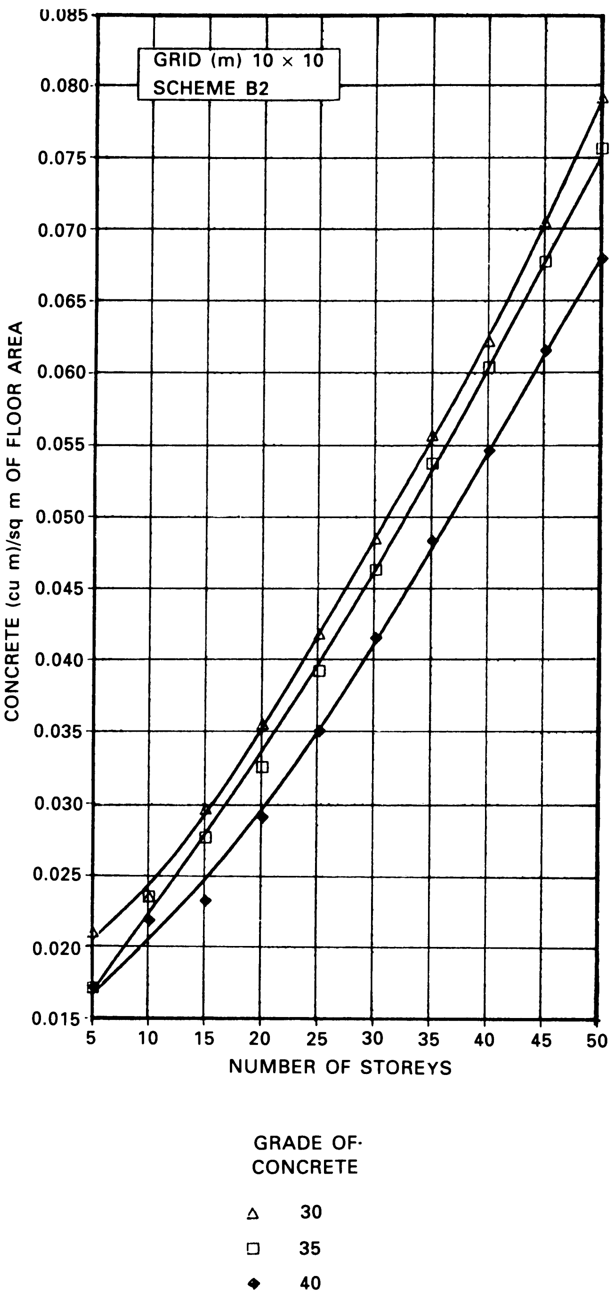


Figure 3.74 Effect of grade of concrete on quantities of concrete for interior columns: 10 m × 10 m; Scheme B2.

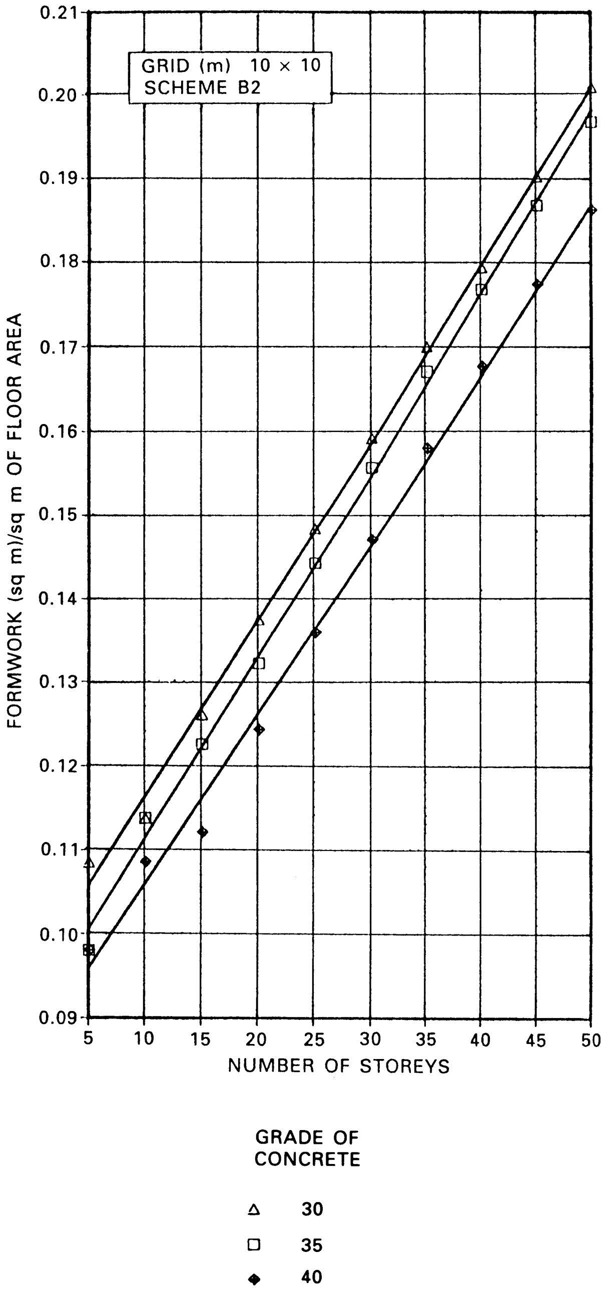


Figure 3.75 Effect of grade of concrete on quantities of formwork for interior columns: 10 m × 10 m; Scheme B2.

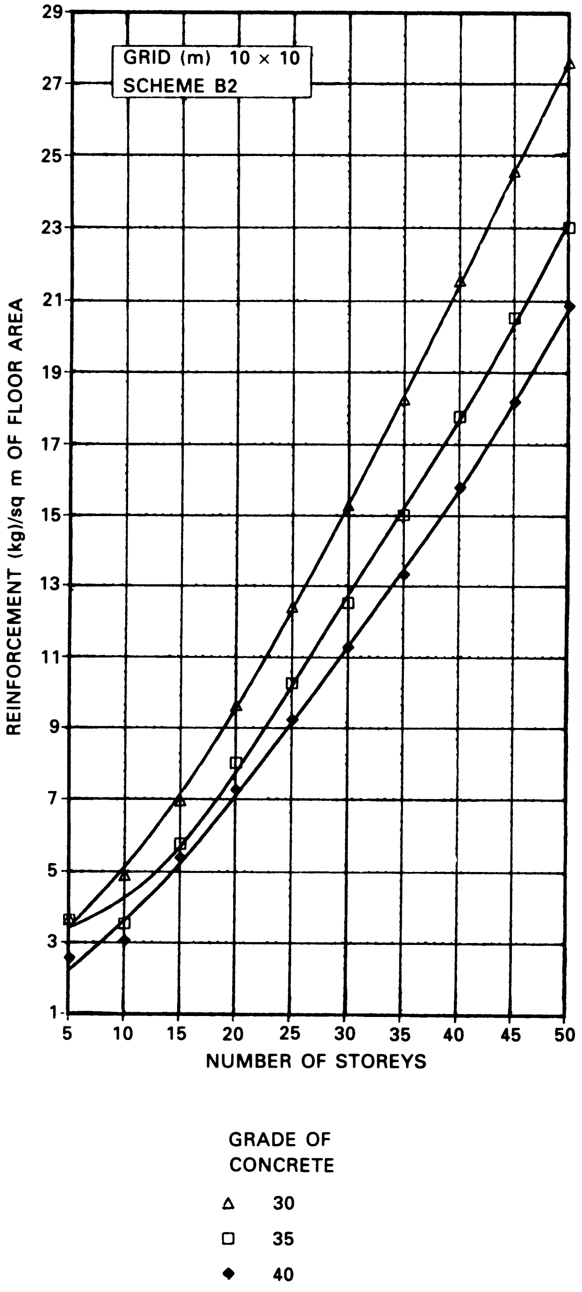


Figure 3.76 Effect of grade of concrete on quantities of reinforcement for interior columns: 10 m × 10 m; Scheme B2.

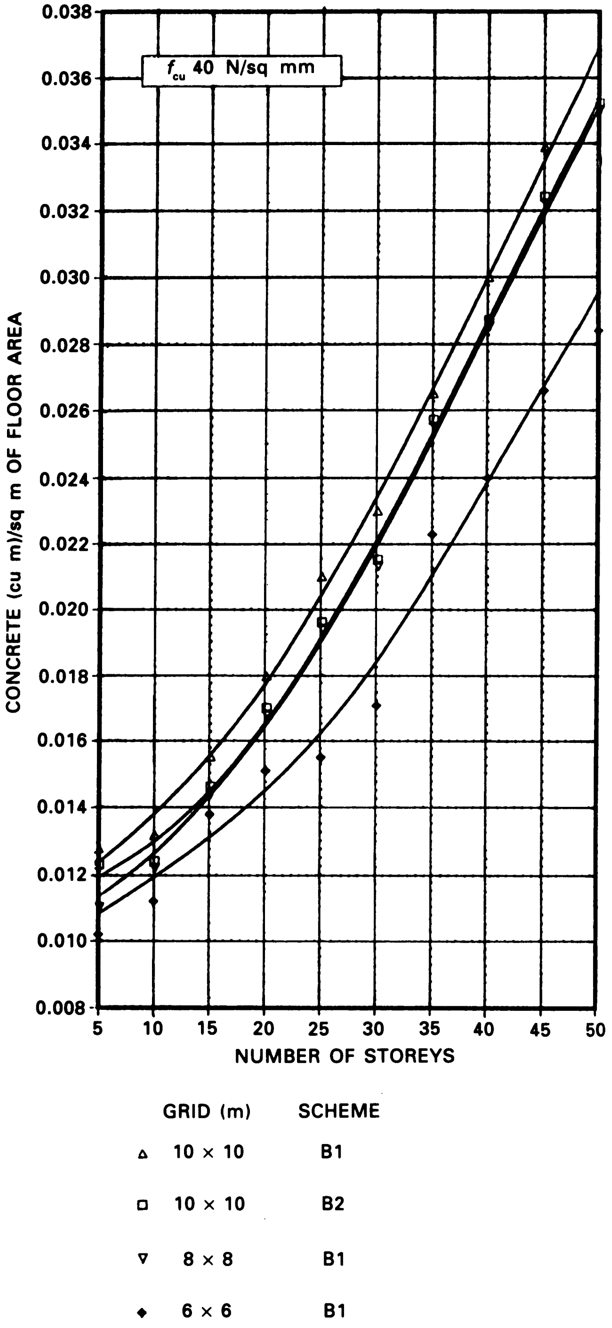


Figure 3.77 Quantities of concrete for exterior columns: $f_{cu} = 40\ \text{N/mm}^2$.

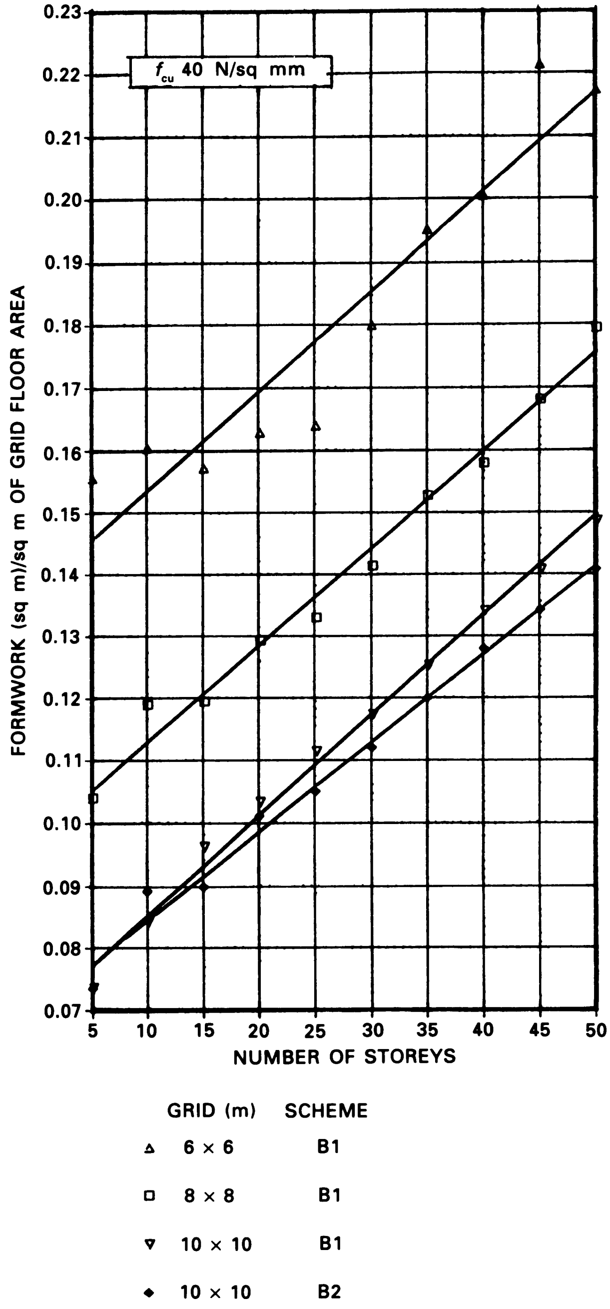


Figure 3.78 Quantities of formwork for exterior columns: $f_{cu} = 40\ \text{N/mm}^2$.

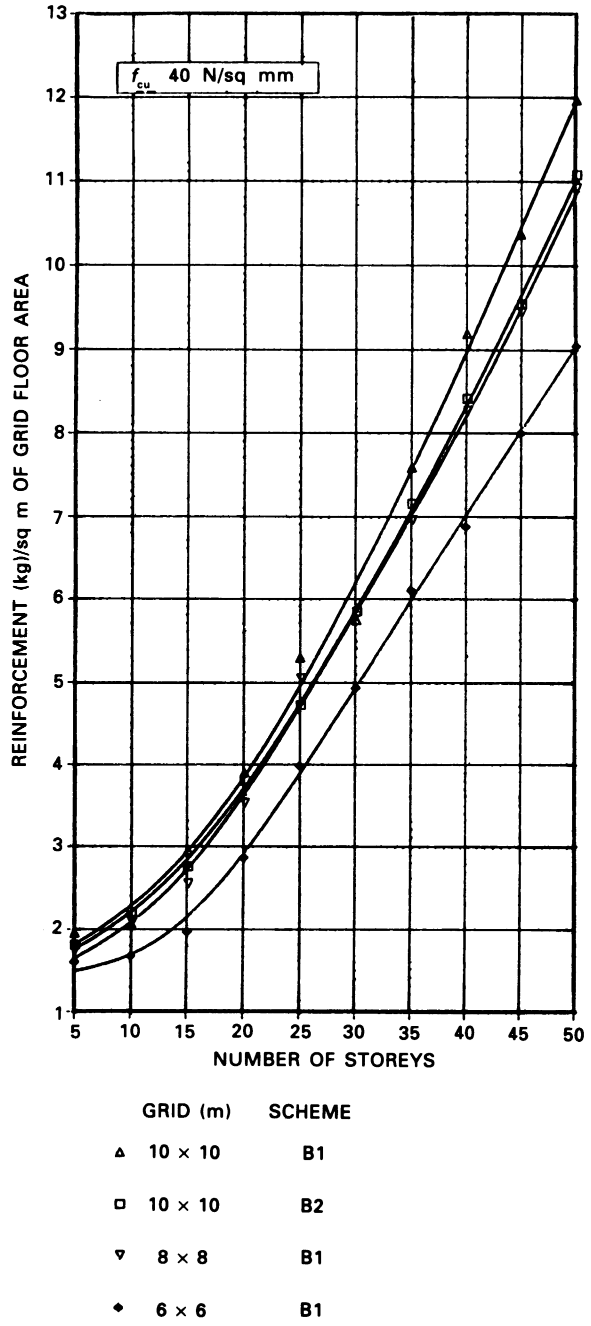


Figure 3.79 Quantities of reinforcement for exterior columns: f_{cu} = 40 N/mm^2.

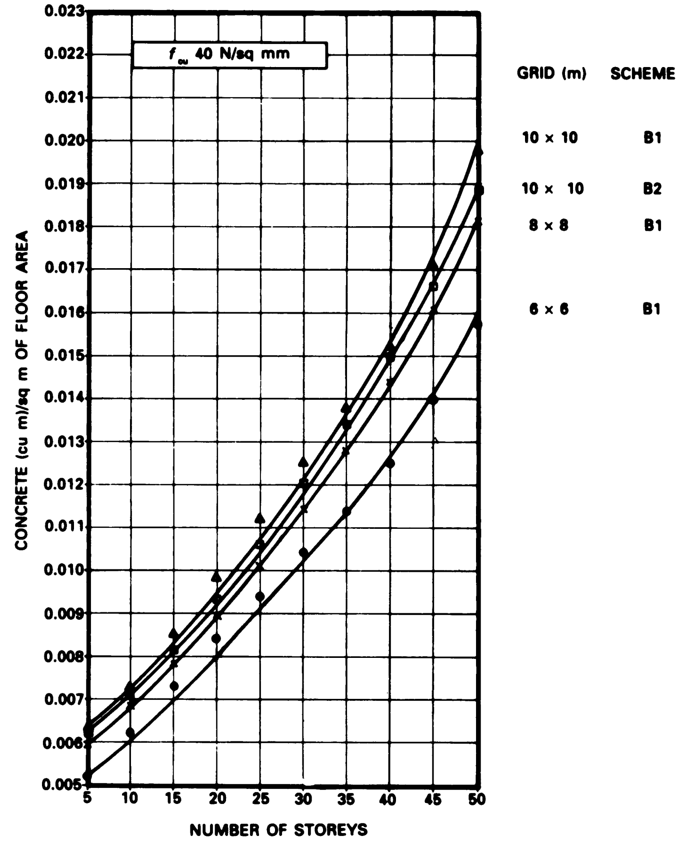


Figure 3.80 Quantities of concrete for corner columns: f_{cu} = 40 N/mm^2.

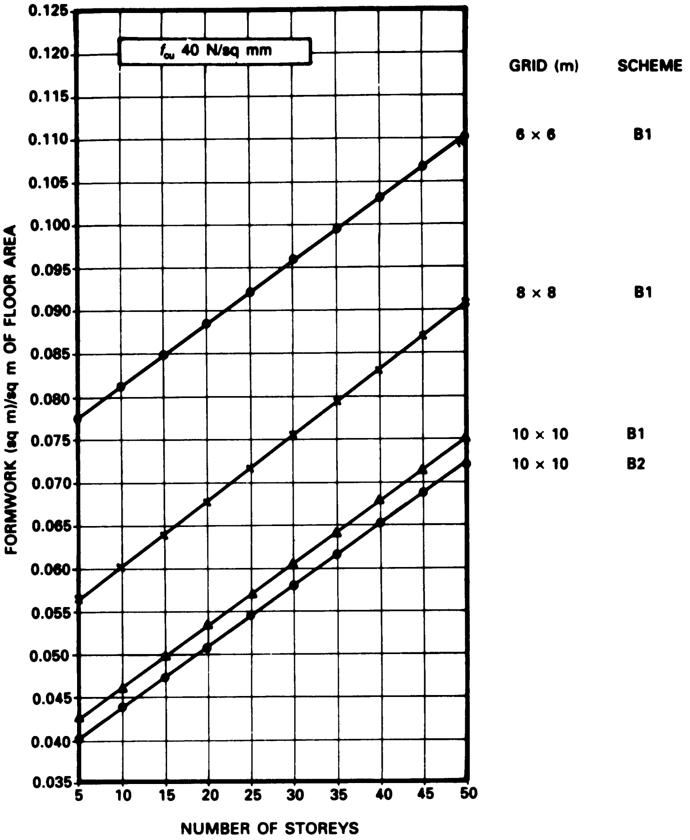


Figure 3.81 Quantities of formwork for corner columns: f_{cu} = 40 N/mm^2.

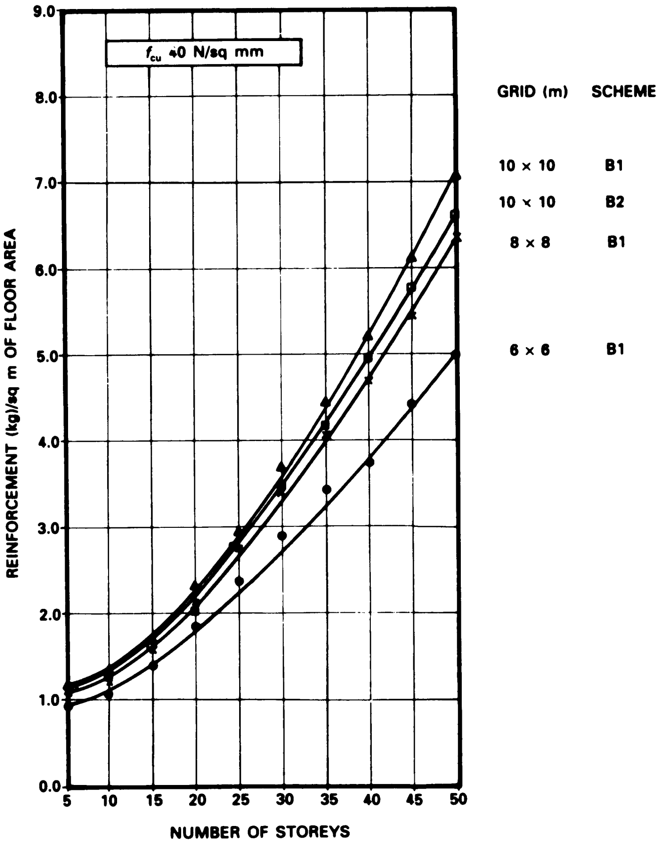


Figure 3.82 Quantities of reinforcement for corner columns: f_{cu} = 40 N/mm^2.

3.4.4 *Shear Walls*

Based on the mean percentage of lift core area for different number of storeys (Figure 3.6) and the designed thickness of shear walls, the quantities of their constituents were calculated using grade 30 concrete. The results are shown in Figures 3.83 to 3.86 for concrete, formwork and reinforcement.

3.4.5 *Total Structure*

Various combinations specifically arising from the use of different possible beam sections and structural schemes will result in changed quantities of constituents for the total structure. However, charts developed for total quantities for an interior grid using main beams with span–width and span–depth ratios of 22 and 16.5 respectively (Section 3.3.2) are discussed in Chapter 7.

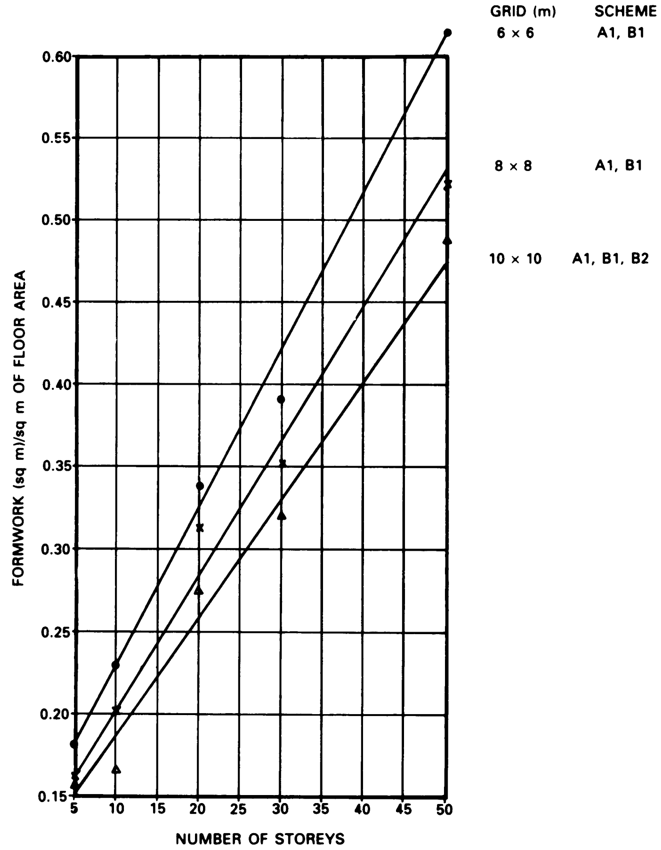


Figure 3.84 Quantities of formwork in shear walls: f_{cu} = 30 N/mm^2.

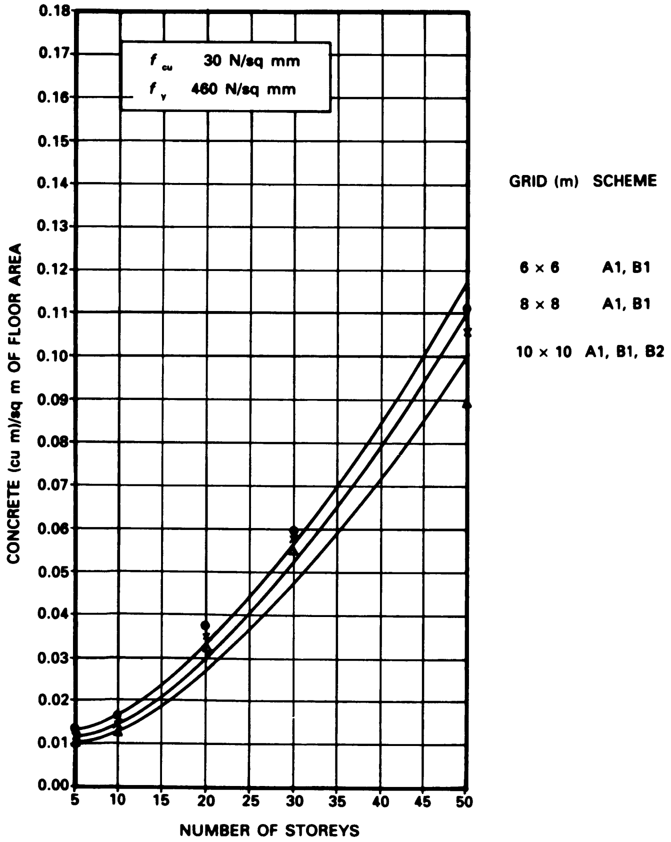


Figure 3.83 Quantities of concrete in shear walls: f_{cu} = 30 N/mm^2.

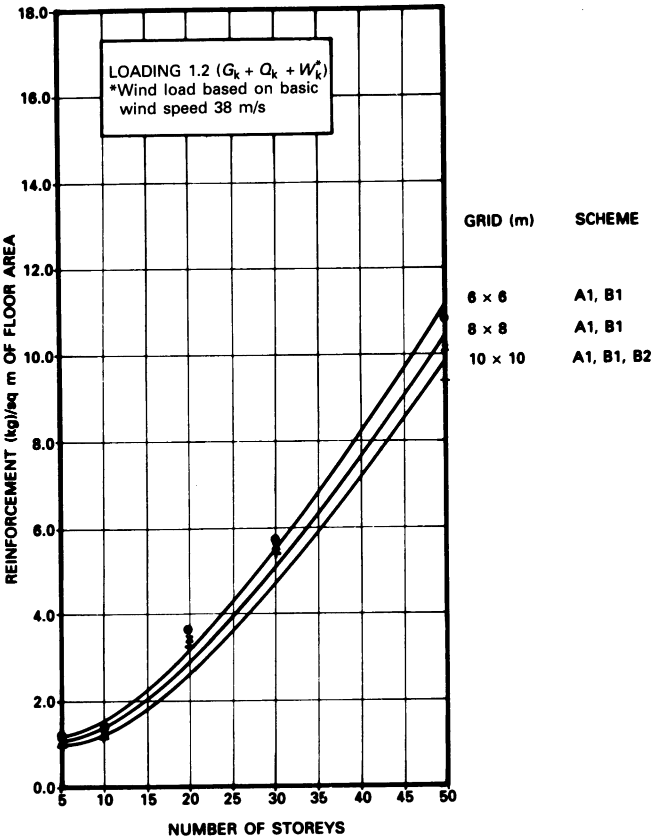


Figure 3.85 Quantities of reinforcement in shear walls: f_{cu} = 30 N/mm^2. Loading = 1.2(G_k + Q_k + W_k^*).

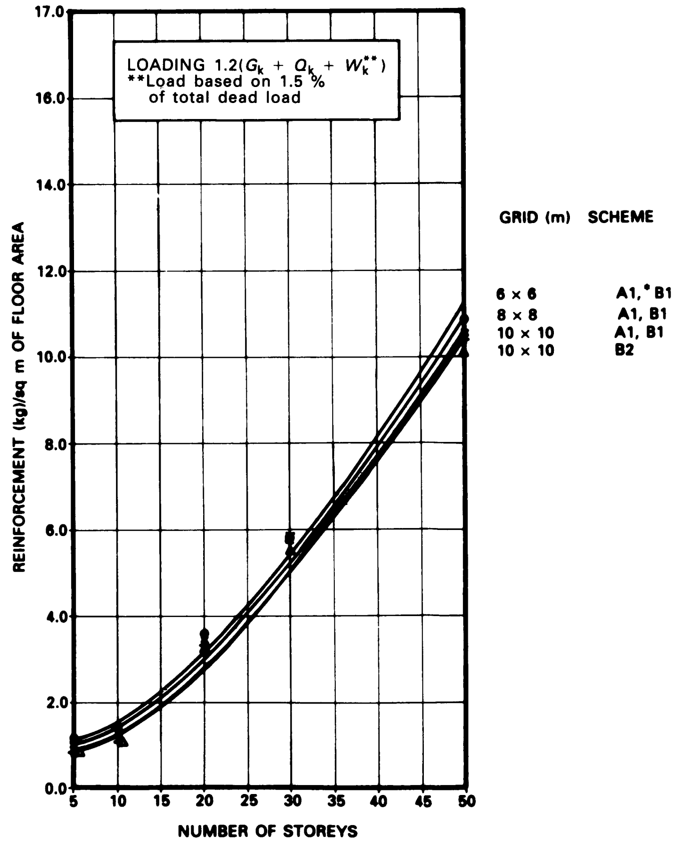


Figure 3.86 Quantities of reinforcement in shear walls: f_{cu} = 30 N/mm^2. Loading = 1.2(G_k + Q_k + W_k^{**}).

3.5 Effect of Number of Spans on Constituent Quantities

In building projects, the number of continuous spans varies from project to project. Analyses were therefore made, both with gravity and lateral loads and with different numbers of continuous spans varying from 2 to 4 (Section 3.2.3). The structural components were designed and constituent quantities were computed. The comparative effect for different numbers of spans is shown in Figures 3.87 to 3.89 for beams, in Figures 3.90 to 3.92 for columns and in Figure 3.93 for shear walls. The effect for different grid sizes was similar. Using the above results multiplying factors for different numbers of spans, considering respective constituents quantities as 1 for 5 spans, were computed and multiplying factors were established (Tables 3.1 to 3.3). Using these factors it is possible to compute quantities for any continuity, i.e. number of spans (2 to 4) based on the quantities for 5 spans for which various figures have been developed in this chapter.

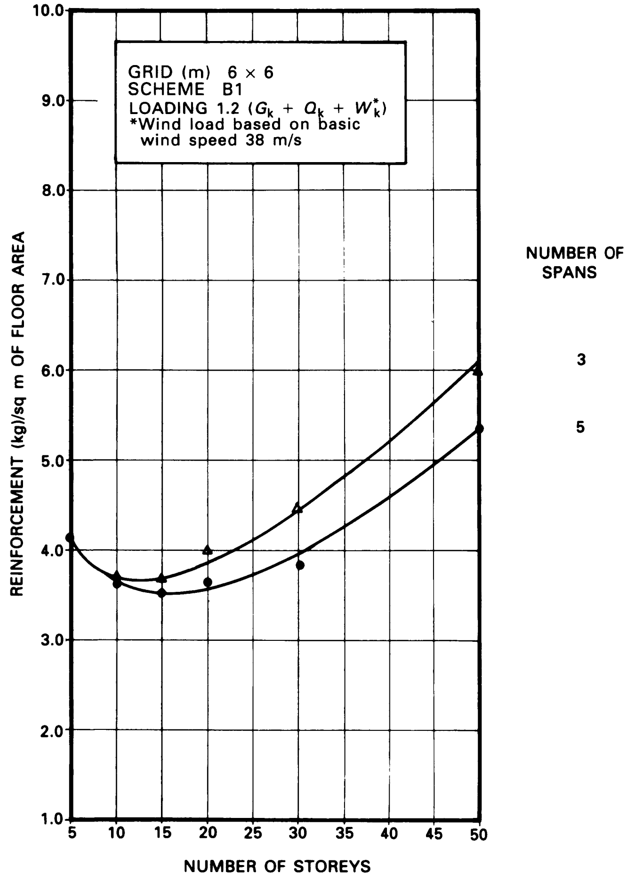


Figure 3.87 Effect of number of continuous spans on quantities of reinforcement for main interior beams: Grid (m) 6 × 6; Scheme B1. Loading = 1.2(G_k + Q_k+ W_k^*).

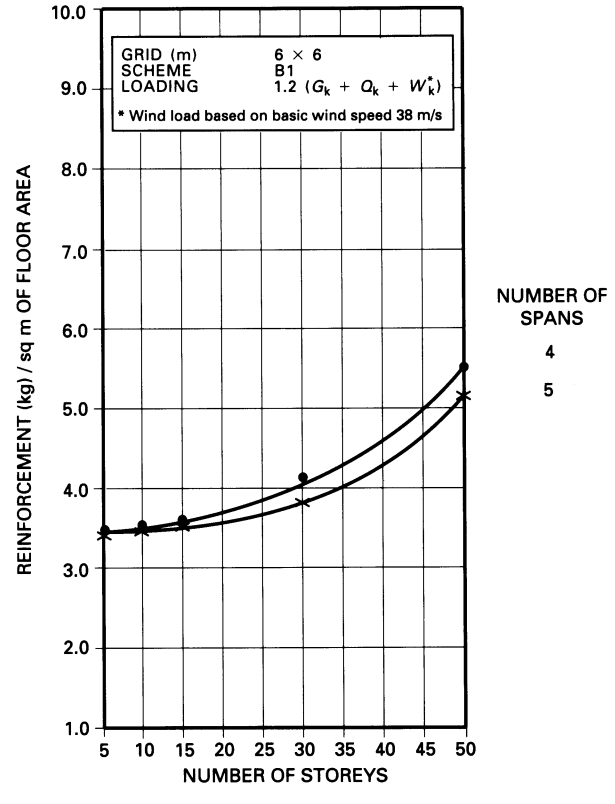


Figure 3.88 Effect of number of continuous spans on quantities of reinforcement for main first interior beams: Grid (m) 6 × 6; Scheme B1. Loading = 1.2(G_k + Q_k + W_k^*).

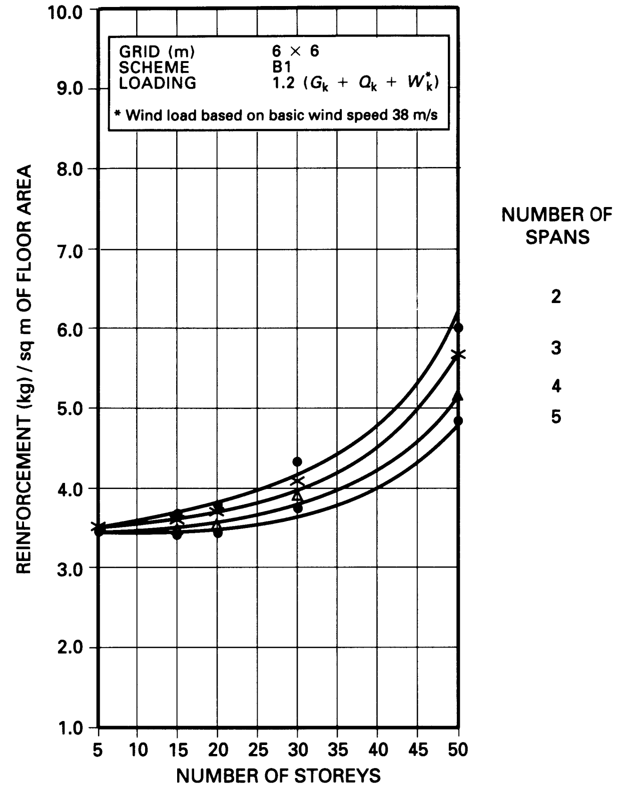


Figure 3.89 Effect of number of continuous spans on quantities of reinforcement for main end beams: Grid (m) 6 × 6; Scheme B1. Loading = 1.2(G_k + Q_k + W_k^*).

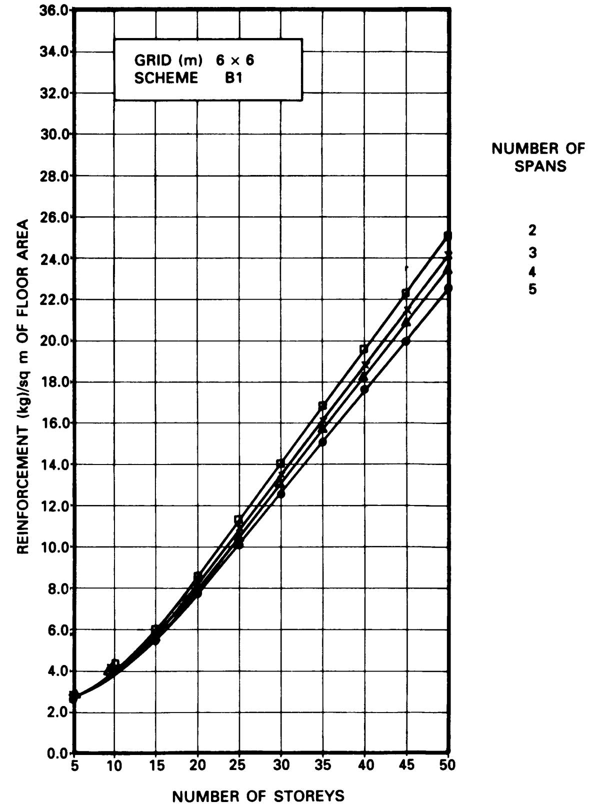


Figure 3.90 Effect of number of continuous spans on quantities of reinforcement for main interior columns: Grid (m) 6 × 6; Scheme B1. Loading = 1.2(G_k + Q_k + W_k^*).

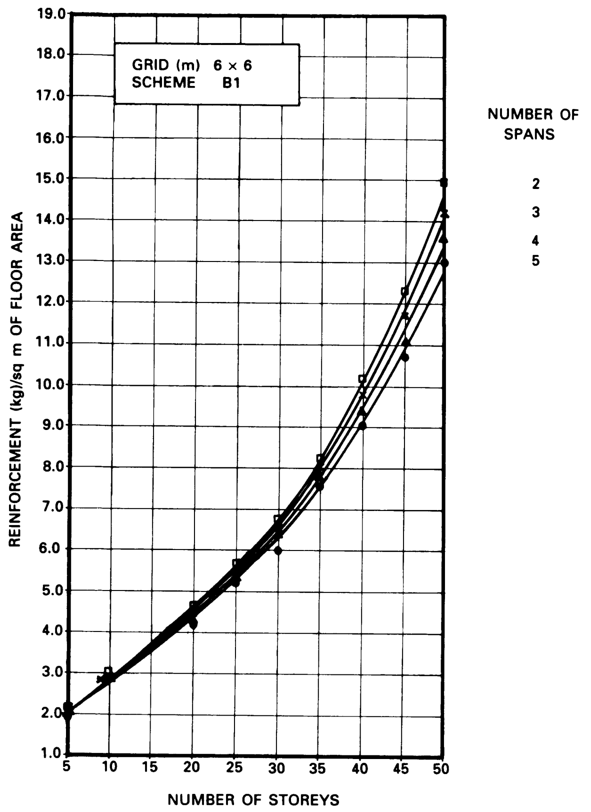


Figure 3.91 Effect of number of continuous spans on quantities of reinforcement for exterior columns: Grid (m) 6 × 6; Scheme B1.

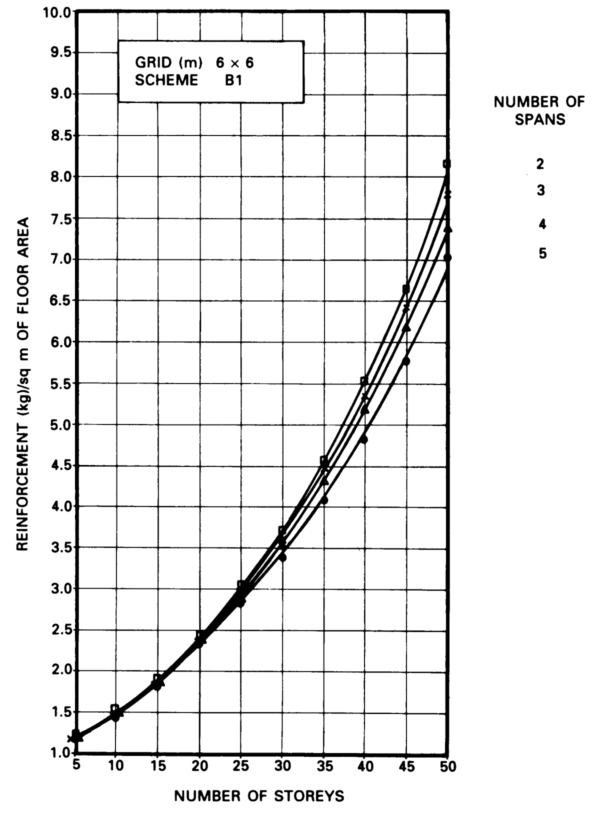


Figure 3.92 Effect of number of continuous spans on quantities of reinforcement for corner columns: Grid (m) 6 × 6; Scheme B1.

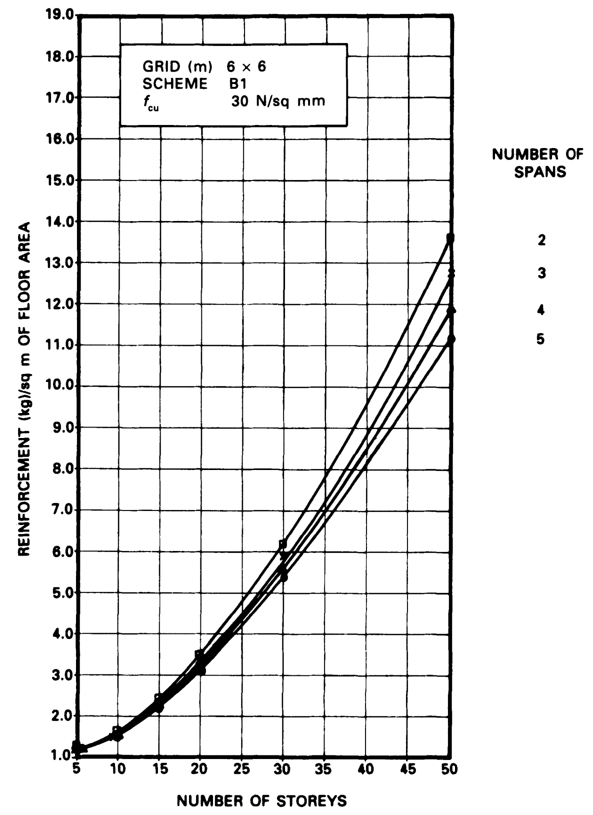


Figure 3.93 Effect of number of continuous spans on quantities of reinforcement for shear walls: Grid (m) 6 × 6; Scheme B1; f_{cu} = 30N/sq mm^2.

Table 3.1 Multiplying factors for effect of different numbers of continuous spans on quantities of reinforcement in main beams (compared with 5 continuous spans taken as 1).

Continuity/ No. of storeys	*Multiplying factors for*		
	Interior beams	*First interior beams*	*End beams*
Two continuous spans			
Storeys 5			1.00
10			1.03
15			1.05
20			1.07
25			1.10
30			1.14
35			1.16
40			1.19
45			1.21
50			1.23
Three continuous spans			
Storeys 5	1.00		1.00
10	1.01		1.02
15	1.04		1.03
20	1.07		1.04
25	1.10		1.06
30	1.12		1.09
35	1.13		1.10
40	1.13		1.14
45	1.14		1.16
50	1.14		1.17
Four continuous spans			
Storeys 5		1.00	1.00
10		1.01	1.02
15		1.01	1.02
20		1.02	1.03
25		1.02	1.03
30		1.03	1.04
35		1.03	1.04
40		1.04	1.05
45		1.04	1.06
50		1.05	1.07

3.6 Effect of Number of Shopping Floors

In the charts developed so far the number of shopping floors taken is nil (Section 3.2.1). However, to adjust the constituent quantities for any number of shopping floors, appropriate multiplying factors have been worked out (Table 3.4). The factors established are related constituent quantities for respective number of office floors taken as 1.

3.7 Computing Constituent Quantities for Structures

To compute constituent quantities for a specific grid, appropriate charts for slabs, beams and shear walls can be read directly. However for columns, these are to be built up based upon the location of the grid. For example, for an exterior grid, the constituent quantities for half interior column and one exterior column are to be added together. Likewise for a corner grid, the constituent quantities for a quarter interior column, one exterior column and one corner column are to be considered.

Table 3.2 Multiplying factors for effect of different numbers of continuous spans on quantities of reinforcement in columns (compared with 5 continuous spans taken as 1).

Continuity/ No. of storeys	*Modification factors for*		
	Interior columns	*Exterior columns*	*Corner columns*
Two continuous spans			
Storeys 5	1.00	1.00	1.01
10	1.01	1.01	1.02
15	1.02	1.03	1.04
20	1.03	1.05	1.06
25	1.04	1.07	1.08
30	1.05	1.09	1.10
35	1.06	1.11	1.12
40	1.07	1.13	1.14
45	1.11	1.15	1.16
50	1.13	1.17	1.19
Three continuous spans			
Storeys 5	1.00	1.00	1.01
10	1.01	1.01	1.02
25	1.02	1.02	1.03
30	1.03	1.04	1.05
35	1.04	1.06	1.07
40	1.06	1.08	1.09
45	1.08	1.10	1.11
50	1.10	1.12	1.13
Four continuous spans			
Storeys 5	1.00	1.00	1.00
10	1.00	1.01	1.01
15	1.01	1.02	1.02
20	1.02	1.03	1.03
25	1.03	1.04	1.04
30	1.04	1.05	1.05
35	1.05	1.06	1.07
40	1.06	1.07	1.09
45	1.07	1.08	1.10
50	1.08	1.09	1.11

Table 3.3 Multiplying factors for effect of numbers of continuous spans on quantities of reinforcement in shear walls (compared with 5 continuous spans taken as 1).

Continuity/ No. of storeys	*Multiplication factor*
Two continuous spans	
Storeys 5	1.06
10	1.07
15	1.08
20	1.09
25	1.10
30	1.12
35	1.14
40	1.16
45	1.18
50	1.21
Three continuous spans	
Storeys 5	1.05
10	1.06
15	1.07
20	1.08
25	1.09
30	1.10
35	1.11
40	1.12
45	1.13
50	1.15
Four continuous spans	
Storeys 5	1.01
10	1.02
15	1.02
20	1.03
25	1.03
30	1.04
35	1.04
40	1.05
45	1.06
50	1.08

Table 3.4 Multiplying factors for effect of varying numbers of floors for shopping in a building (compared with office block taken as 1).

Element/constituent/ shopping floors	*Multiplying factors for storeys*					
	5	*10*	*20*	*30*	*40*	*50*
Slabs						
Concrete						
5	1.046	1.023	1.012	1.008	1.006	1.005
4	1.037	1.018	1.009	1.006	1.005	1.004
3	1.027	1.014	1.007	1.005	1.004	1.003
2	1.018	1.009	1.005	1.003	1.002	1.002
1	1.009	1.005	1.002	1.002	1.001	1.001
Reinforcement						
5	1.134	1.067	1.034	1.022	1.017	1.014
4	1.107	1.054	1.027	1.018	1.014	1.011
3	1.081	1.040	1.020	1.013	1.010	1.008
2	1.054	1.027	1.014	1.009	1.007	1.005
1	1.027	1.014	1.007	1.005	1.004	1.003
Beams						
Concrete						
5	1.105	1.073	1.062	1.050	1.041	1.032
4	1.083	1.071	1.060	1.041	1.032	1.020
3	1.071	1.062	1.051	1.031	1.021	1.018
2	1.061	1.052	1.048	1.019	1.017	1.010
1	1.049	1.038	1.032	1.015	1.010	1.008
Reinforcement						
5	1.205	1.102	1.051	1.034	1.026	1.020
4	1.164	1.082	1.041	1.027	1.021	1.016
3	1.123	1.061	1.031	1.021	1.053	1.012
2	1.082	1.041	1.021	1.011	1.009	1.008
1	1.041	1.021	1.010	1.007	1.005	1.004
Formwork						
5	1.091	1.052	1.022	1.018	1.010	1.006
4	1.072	1.031	1.015	1.009	1.006	1.004
3	1.050	1.020	1.011	1.006	1.004	1.002
2	1.033	1.012	1.007	1.005	1.003	1.001
1	1.020	1.008	1.006	1.004	1.002	1.001
Columns						
Concrete						
5	1.057	1.041	1.031	1.020	1.014	1.009
4	1.039	1.035	1.024	1.017	1.010	1.006
3	1.029	1.026	1.020	1.013	1.007	1.004
2	1.021	1.019	1.014	1.008	1.005	1.001
1	1.019	1.014	1.009	1.006	1.004	1.001
Reinforcement						
5	1.601	1.032	1.152	1.101	1.075	1.062
4	1.482	1.241	1.121	1.082	1.061	1.048
3	1.360	1.180	1.091	1.062	1.045	1.036
2	1.241	1.123	1.062	1.041	1.032	1.024
1	1.121	1.062	1.031	1.023	1.015	1.012
Formwork						
5	1.093	1.074	1.055	1.038	1.020	1.017
4	1.071	1.058	1.039	1.025	1.017	1.012
3	1.057	1.040	1.022	1.018	1.013	1.009
2	1.039	1.024	1.019	1.013	1.009	1.006
1	1.024	1.019	1.014	1.010	1.007	1.003
Shear walls						
Concrete						
5	1.052	1.033	1.020	1.013	1.009	1.007
4	1.041	1.022	1.015	1.010	1.007	1.005
3	1.031	1.017	1.012	1.008	1.005	1.003
2	1.020	1.014	1.010	1.006	1.003	1.001
1	1.015	1.012	1.007	1.004	1.001	1.000
Reinforcement						
5	1.411	1.152	1.104	1.063	1.042	1.021
4	1.332	1.112	1.081	1.051	1.023	1.017
3	1.251	1.092	1.061	1.030	1.019	1.014
2	1.161	1.061	1.032	1.020	1.015	1.012
1	1.082	1.029	1.018	1.014	1.012	1.010

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4 Flat Slab and Waffle Slab Systems

The effects of column grid size, number of storeys, use of mild/high yield steel reinforcement, location of structural element, grade of concrete and provision of column heads in structural systems on the quantities of various constituents of reinforced concrete construction using flat slabs and waffle slabs have been studied and presented in the form of charts and mathematical equations. The charts give relationships between the quantities of each of the constituents of reinforced concrete construction, namely concrete, reinforcements and formwork, and each of the various parameters of the structure.

4.1 Introduction

A flat slab construction has many advantages over the traditional beam and slab floor. It permits much simpler formwork and helps to reduce storey heights. Windows can extend up to the underside of the slab and there are no beams to obstruct the light and the circulation of air. Further, unlike slab and beam construction, service ducts can run directly under the flat slab in either direction without obstruction from beams. It is also claimed that the absence of sharp corners gives greater fire resistance since there is less danger of the concrete spalling and exposing the reinforcement [1].

In flat slab construction (Figure 4.1), slabs without drops are not common since they are more expensive compared to those with drops.

Where standard forms are available, waffle slabs which are lighter may provide a suitable alternative to flat slabs. Though waffle slabs are about 40 per cent deeper than flat slabs, the reduction in concrete and steel quantities is considerable and where exposed, they are aesthetically appealing.

An important aspect in the design of flat and waffle slab floors is the calculation of punching shear at the head of the columns and at the change in depth of the slab, if drop panels are used. In this respect it can be economical to use mild steel in lieu of high yield steel reinforcement since the resulting higher percentages allow a correspondingly higher ultimate concrete shear stress (Table 3.9 of BS 8110). In view of this, at places where the difference in cost of high yield steel and mild steel is negligible, the use of the former can be considered by permitting lower values of stresses in the design. The effects of the column grid size, number of storeys, use of mild/high yield steel reinforcement, location of structural element, grade of concrete and provision of column heads on the quantities of various constituents of reinforced concrete construction using flat and waffle slabs have been studied in different grid sizes and number of storeys ranging from 5 to 50 in denominations of 5 storeys, and the results presented in the form of charts and statistical relationships.

4.2 Structures, Loading and Analysis of Frames

Three square grids, with sides of 6, 8 and 10 m for structural schemes with flat slabs (Figure 4.1a & b) and with sides of 6.4, 8 and 10.4 m for those with waffle slabs (Figure 4.2) were considered. The grid sizes in the latter case were varied so as to accommodate the standard moulds available in the UK [2].

The analysis and design were carried out in accordance with the limit state design proposed in British Standard BS 8110: Part I: 1985, the service loads being taken from British Code of Practice CP3, Chapter V, Parts 1 and 2: 1972. As in the previous chapter, all structures considered are for office floors. Dead loads of 1.2 kN/m^2 for finishes, 0.25 kN/m^2 for ceiling and 1.0 N/m^2 for light-weight partitions have been considered in the design. A floor-to-floor height of 3.5 m was assumed.

The assessment of wind load is in accordance with British Code of Practice CP3 incorporating a basic wind speed of 38 m/s in the context of London (UK). As an alternative, a second case of ultimate horizontal load equivalent to 1.5 per cent of the total characteristic dead load was also considered from stability considerations (Section 3.1.4.2 of BS 8110). However, for the design of structural components, most severe forces due to the above loadings were considered and the results presented in this book (Section 3.4.2). The statistical factors SI and S3 were taken to be 1.0 and the ground roughness factors S2 at different heights were taken as for a country with many windbreaks. Load due to earthquake was not considered since London is free from such hazards.

Shear core sizes and allied information to deter-

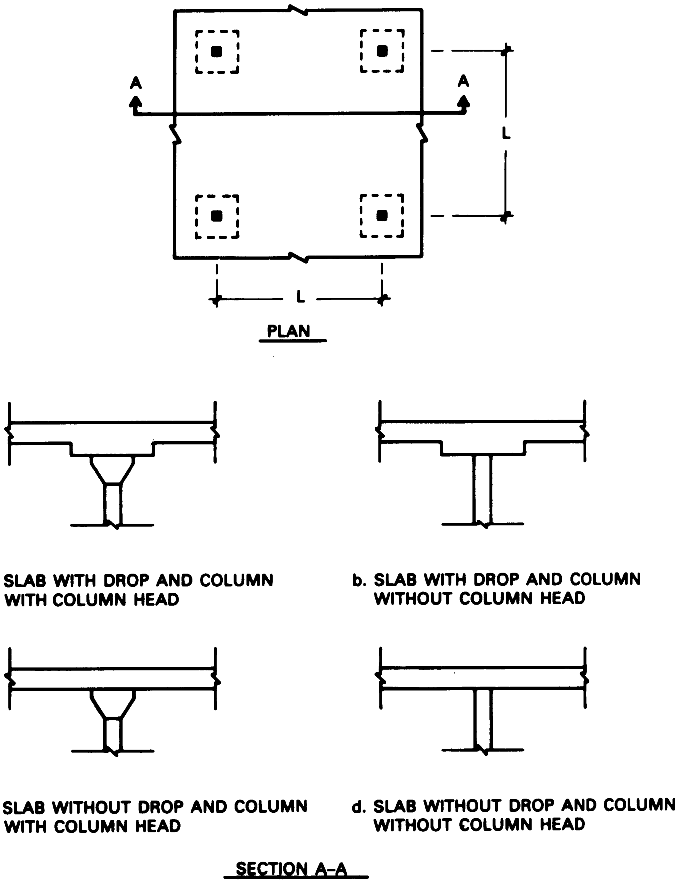


Figure 4.1 Flat slab construction.

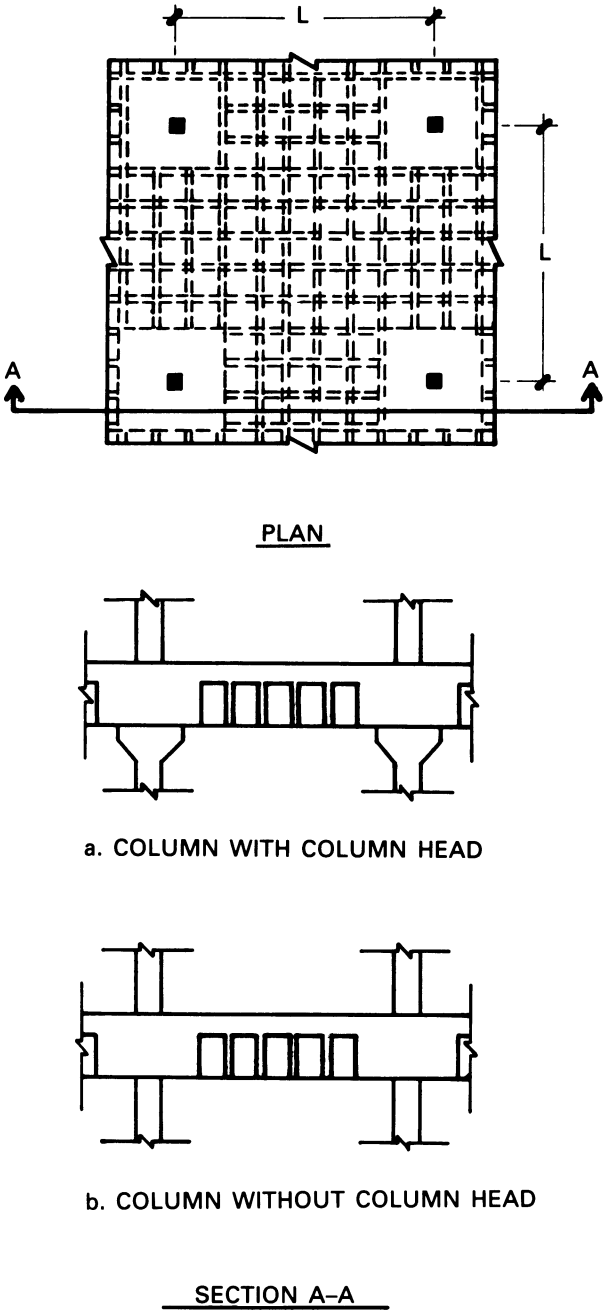


Figure 4.2 Waffle slab construction.

mine the lateral loads as explained in Sections 3.2.5 and 3.2.6, were adopted.

4.3 Design of Structural Members

Computer programs were developed to design reinforced concrete flat and waffle slabs and columns [3] with the additional capability of computing the quantities of concrete, reinforcement and formwork. Characteristic strengths of 30 N/mm^2, 250 N/mm^2 and 460 N/mm^2 were considered for concrete, hot rolled mild steel and high yield steel respectively.

4.3.1 Flat and Waffle Slabs

Flat slabs and waffle slabs were designed with and without column heads according to the empirical method codified in BS 8110: Part I: 1985 (Section 3.7). The effect of the use of mild steel in lieu of high yield steel in flat slabs was studied, maintaining the provision of high yield steel reinforcement in columns in both cases. The width and thickness of drop panels in flat slabs were kept as half of the corresponding dimensions of those of the slab panel.

4.3.2 Columns

Square column sections were considered in denominations of 75 mm keeping 400 × 400 mm as the minimum section. After every 5-storey intervals, the sections of columns were reduced where possible for economy, and within the same section the reinforcement was varied for each storey depending upon the values of the forces.

4.3.3 Shear Walls

The empirical method [4] for the design of flat and waffle slabs suggests that the stability of the structure be provided by shear walls designed to resist all the lateral forces, hence the latter were designed likewise. A minimum thickness of 150 mm was considered from practical considerations and the forces obtained from the analysis were taken for the design along with other parameters as discussed in Section 3.3.4.

4.4 Quantities of Constituents

In computing the quantities of concrete for slabs, the portion of the slab common with the column has been included with the latter in accordance with the Standard Method of Measurement [5].

4.4.1 Flat Slabs

The relationships between the number of storeys and quantities per square metre of floor area for an interior panel are shown in Figures 4.3 to 4.6 for concrete, formwork and reinforcement respectively in flat slab using mild steel and alternatively high yield steel reinforcement. The quantities of reinforcement are affected by the provision of column heads or flares, so these quantities were computed both with and without column heads but maintaining the same slab thickness.

The location of the slab panel affects the quantity of reinforcement in it. The quantities were therefore computed for exterior slab panels using both mild steel and high yield steel reinforcement and the results are shown in Figure 4.7 and 4.8 for flat slabs with and without column heads respectively.

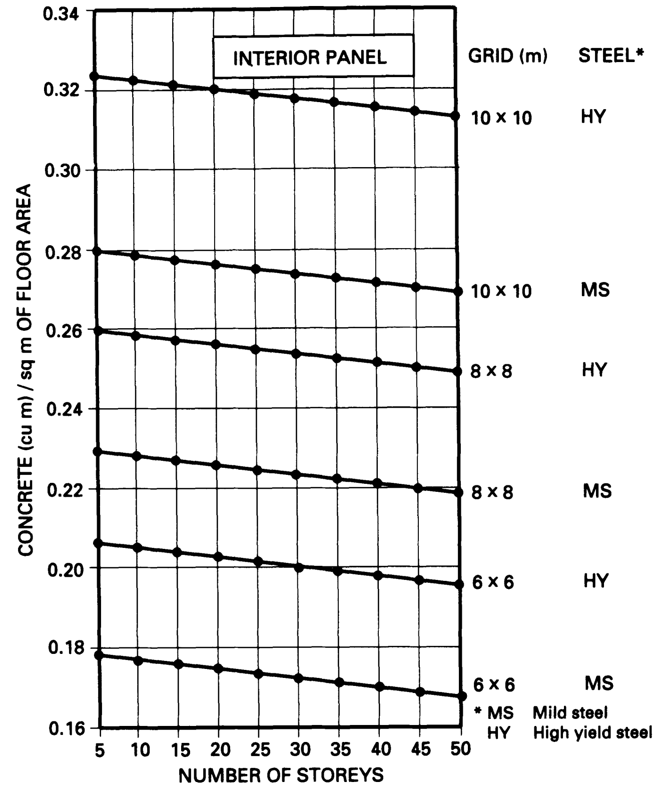


Figure 4.3 Quantities of concrete in slabs, for flat slab construction, using mild steel (MS)/high yield steel (HY) reinforcement (for schemes both with and without column heads).

4.4.2 Waffle Slabs

Having established the effect, on quantities, of the use of mild steel in lieu of high yield steel reinforcement in flat slabs (Section 4.4.1) it was not considered worthwhile to repeat the calculations for waffle slabs since similar differences were expected. Hence, the use of high yield steel reinforcement was considered for waffle slabs. The quantities per unit area for an interior panel, for concrete, formwork and reinforcement, are illustrated in Figures 4.9 to 4.11 respectively for different grid sizes and storeys of construction. The quantities of reinforcement were studied both with and without column heads while keeping the same slab thickness.

The quantities of reinforcement for an exterior panel using waffle slabs both with and without column heads are shown in Figure 4.12.

4.4.3 Columns

The relationships between the number of storeys and the quantities per square metre of floor area for different grid sizes in interior columns are shown in Figures 4.13 to 4.17 for flat slabs, and similar results are shown in Figures 4.18 to 4.21 for waffle slab construction.

The effects of the grade of concrete on quantities of constituents for different grid sizes and number of storeys in interior columns using flat slabs (without column heads) are shown in Figures 4.22 to 4.31. Similar results for exterior columns are shown in

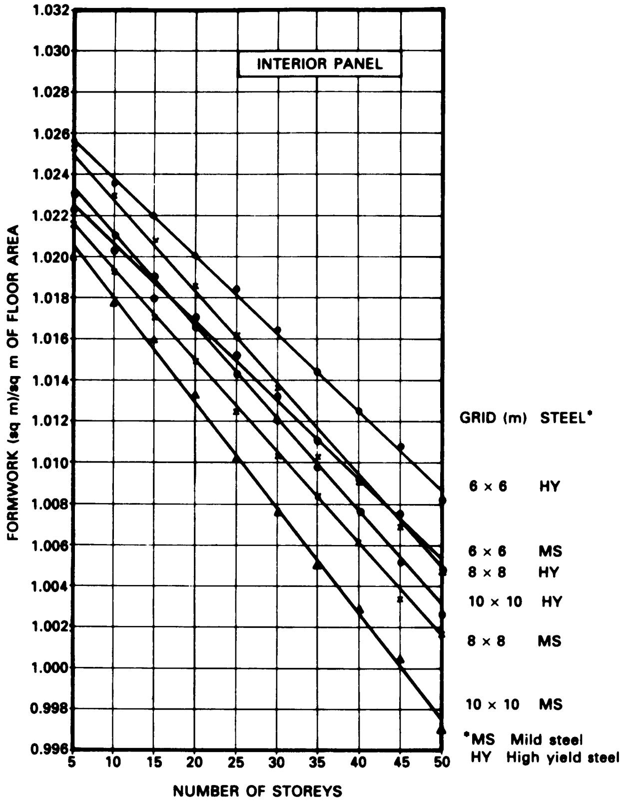


Figure 4.4 Quantities of formwork in slabs, for flat slab construction, using mild steel (MS)/high yield steel (HY) reinforcement (for schemes both with and without column heads).

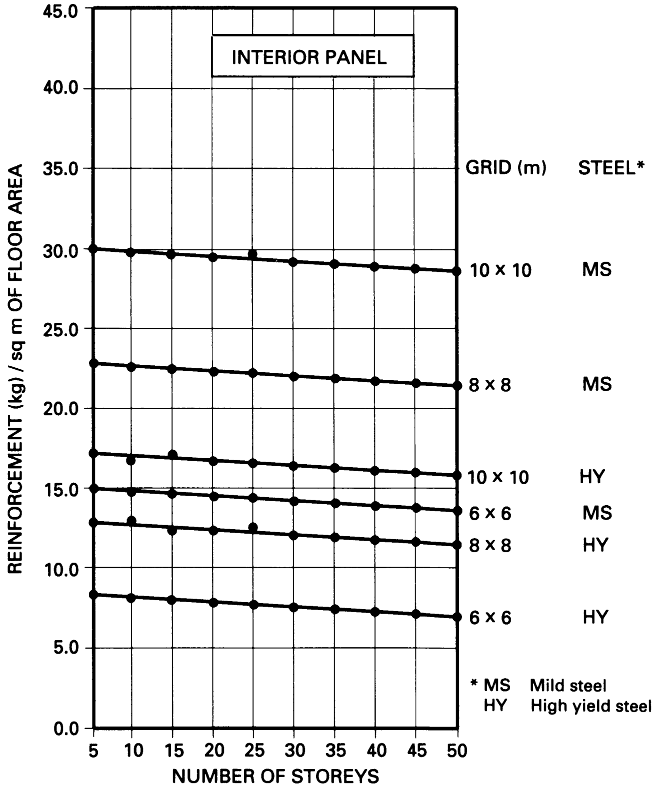


Figure 4.5 Quantities of reinforcement in slabs, for flat slab construction without column heads, using mild steel (MS)/ high yield steel (HY) reinforcement – interior panel.

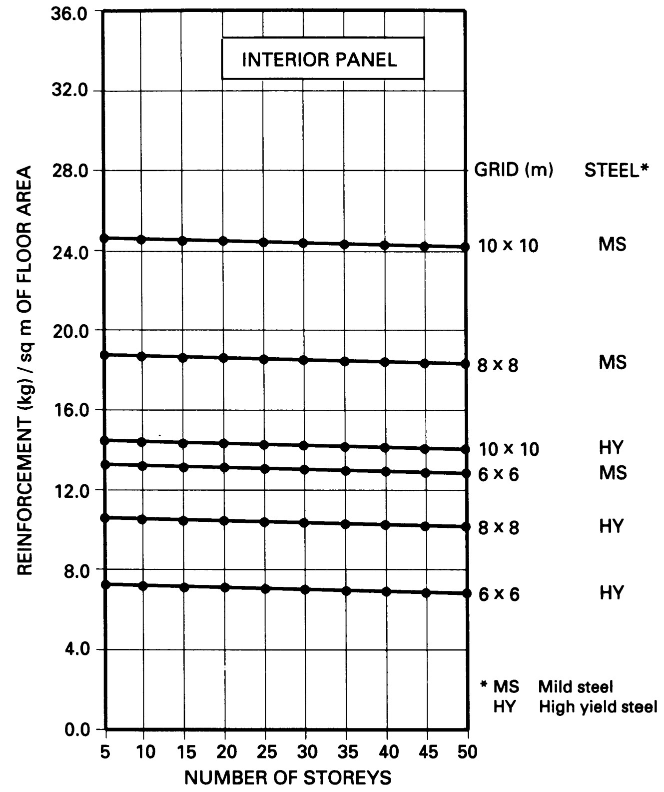


Figure 4.6 Quantities of reinforcement in slabs, for flat slab construction with column heads, using mild steel (MS)/high yield steel (HY) reinforcement – interior panel.

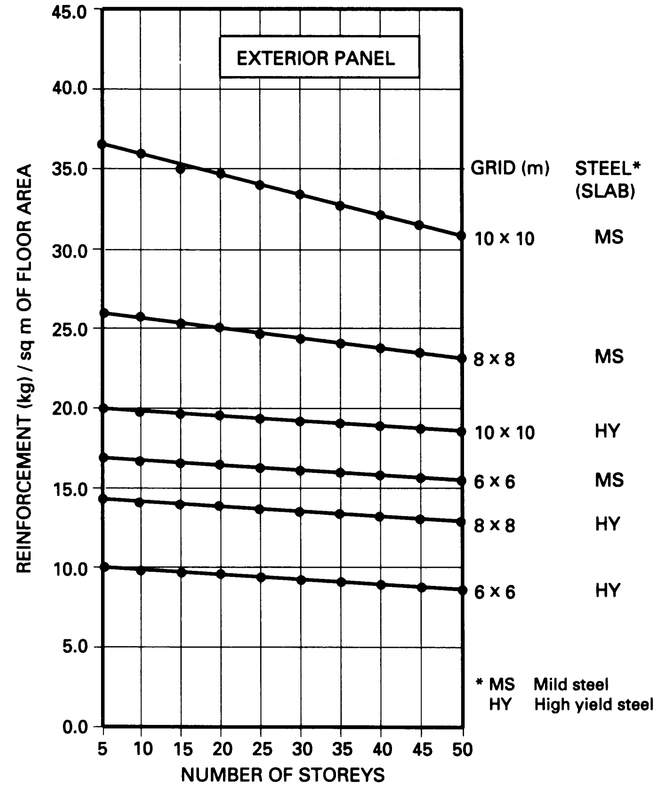


Figure 4.7 Quantities of reinforcement in slabs, for flat slab construction without column heads, using mild steel (MS)/ high yield steel (HY) reinforcement – exterior panel.

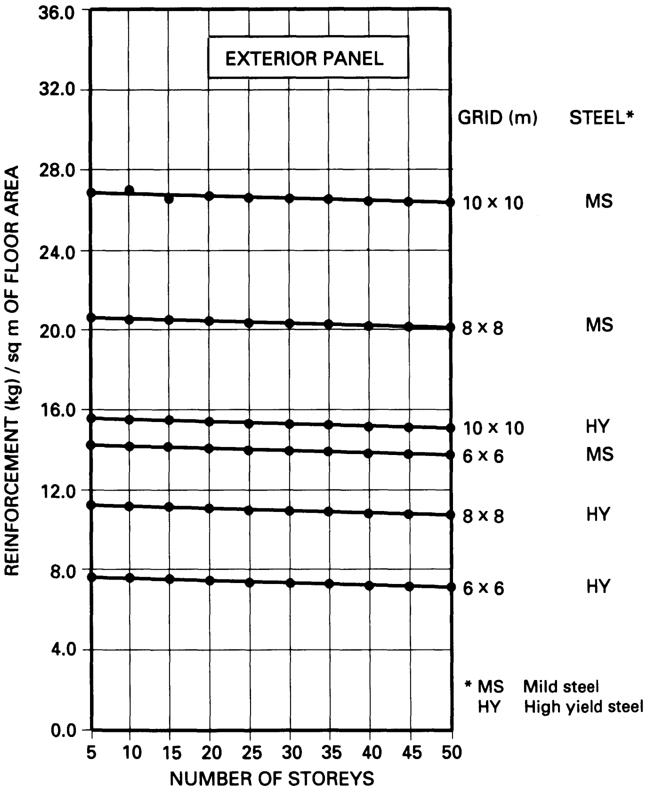


Figure 4.8 Quantities of reinforcement in slabs, for flat slab construction with column heads using mild steel (MS)/high yield steel (HY) reinforcement – exterior panel.

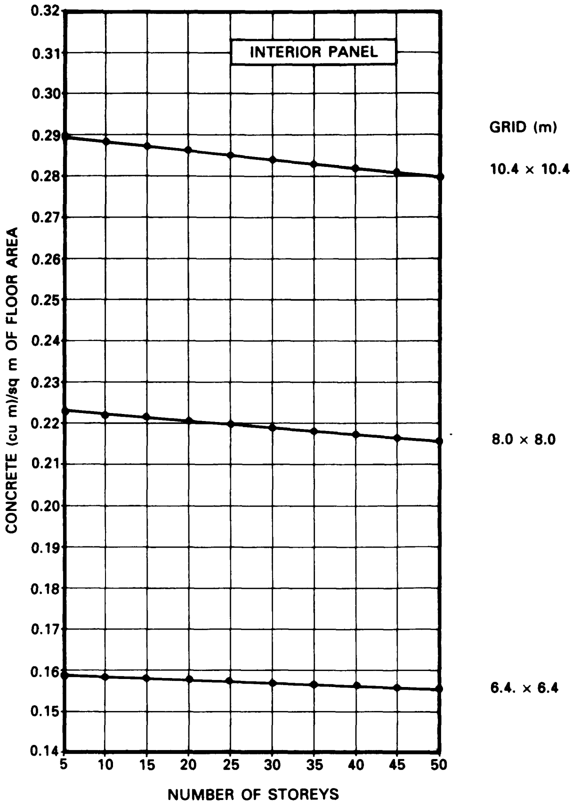


Figure 4.9 Quantities of concrete in slabs for waffle slab construction (for schemes without column heads).

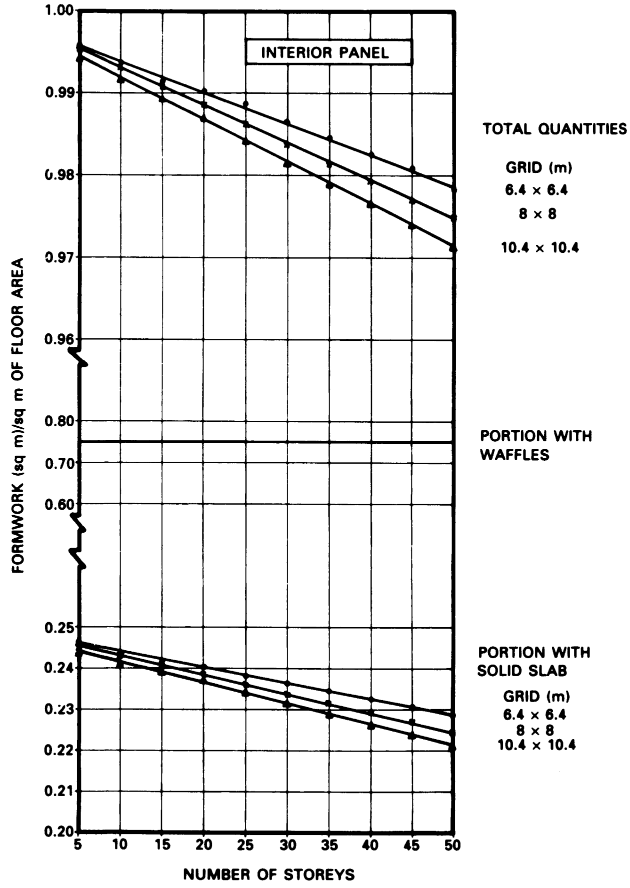


Figure 4.10 Quantities of formwork in slabs for waffle slab construction (for schemes both with and without column heads).

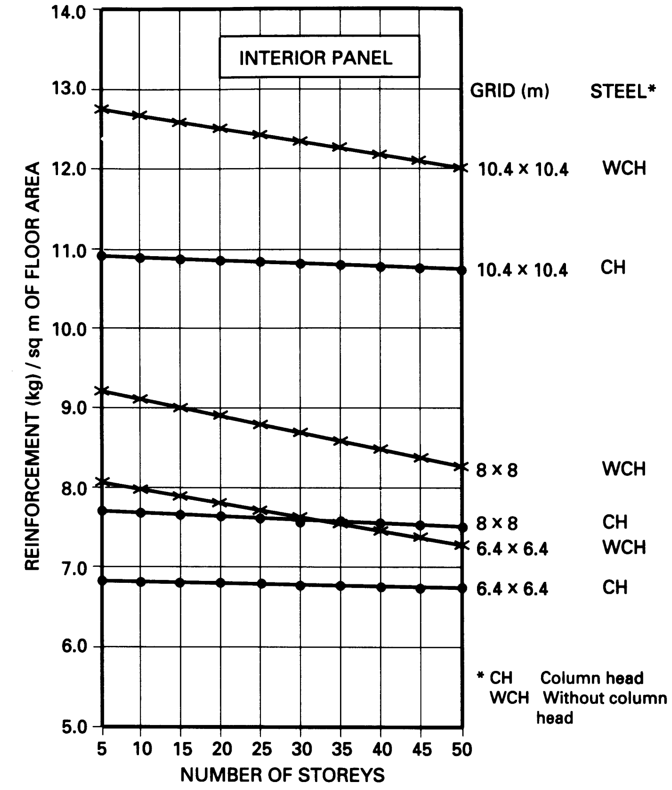


Figure 4.11 Quantities of reinforcement in slabs for waffle slab construction with (CH) and without (WCH) column heads – interior panel.

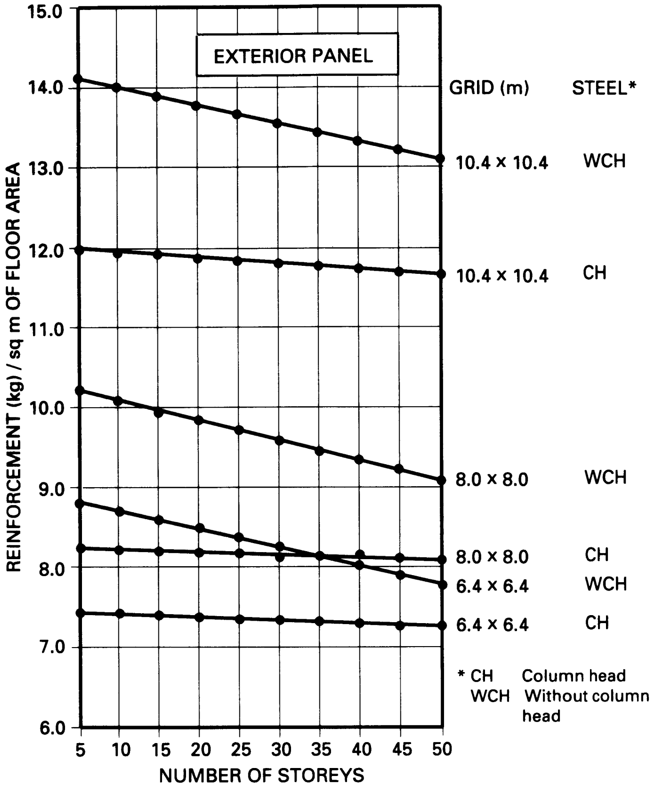


Figure 4.12 Quantities of reinforcement in slabs for waffle slab construction with (CH) and without (WCH) column heads – exterior panel.

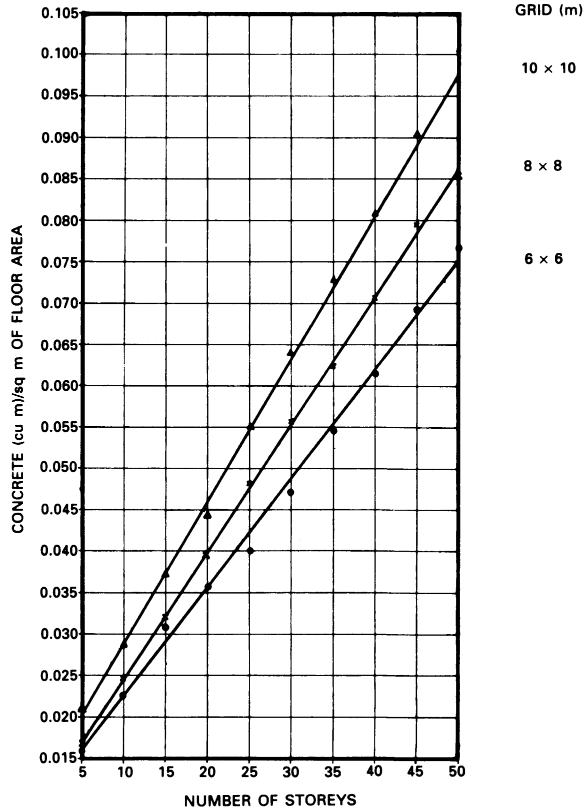


Figure 4.13 Quantities of concrete in interior columns for flat slab construction without column heads.

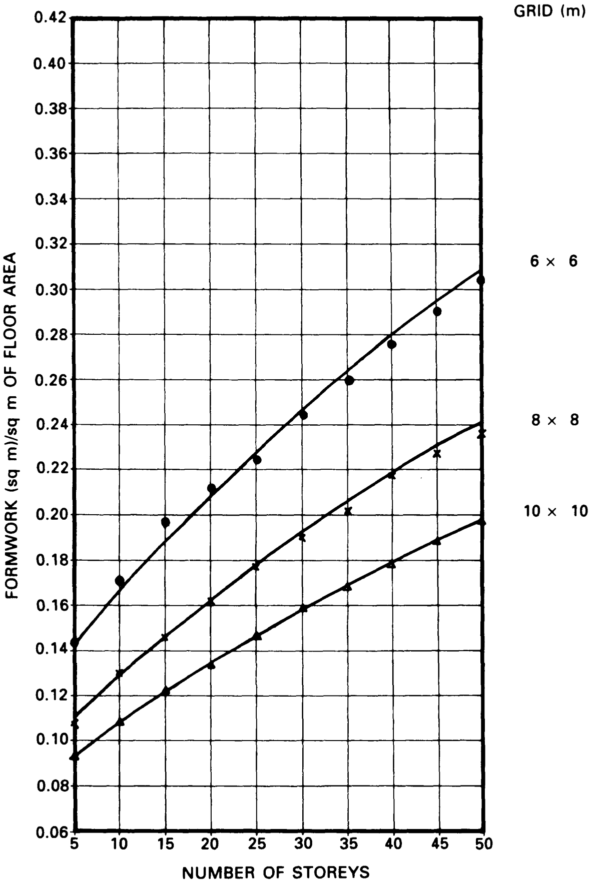


Figure 4.14 Quantities of formwork in interior columns for flat slab construction without column heads (with high yield steel reinforcement in slabs).

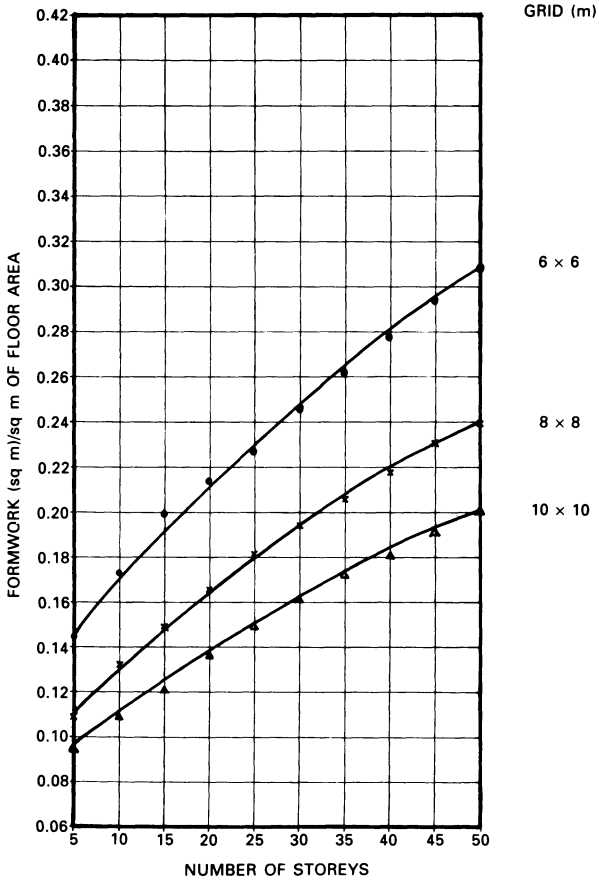


Figure 4.15 Quantities of formwork in interior columns for flat slab construction without column heads (with mild steel reinforcement in slabs).

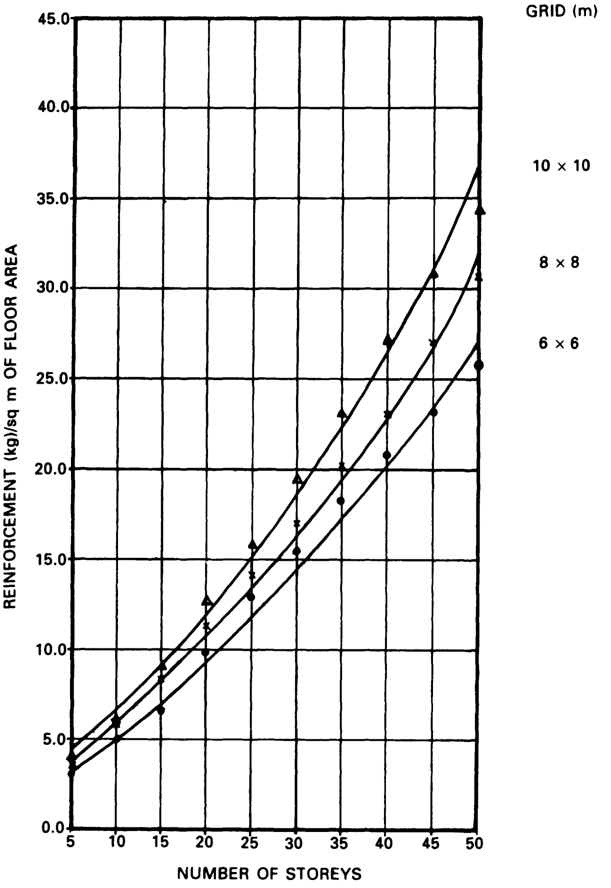


Figure 4.16 Quantities of reinforcement in interior columns for flat slab construction without column heads (with high yield reinforcement in slabs).

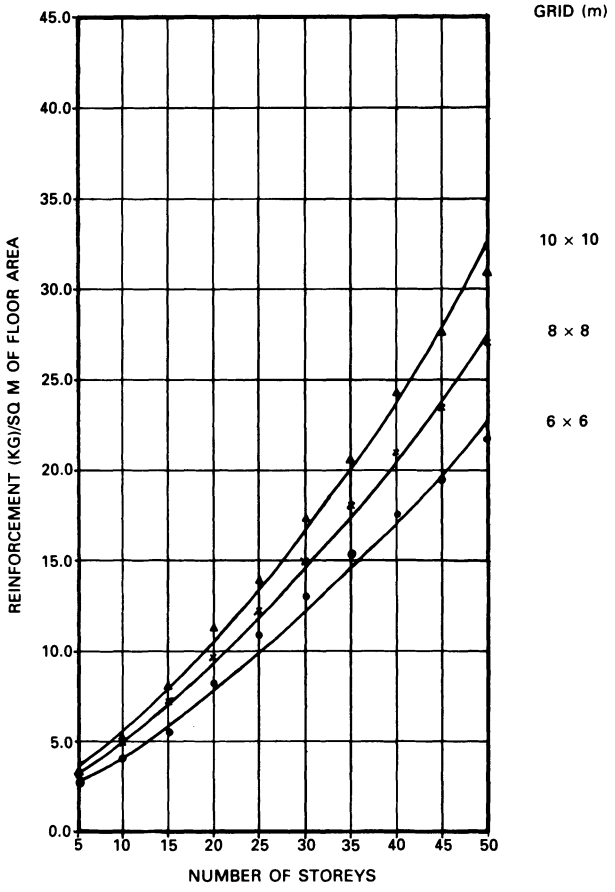


Figure 4.17 Quantities of reinforcement in interior columns for flat slab construction without column heads (with mild steel reinforcement in slabs).

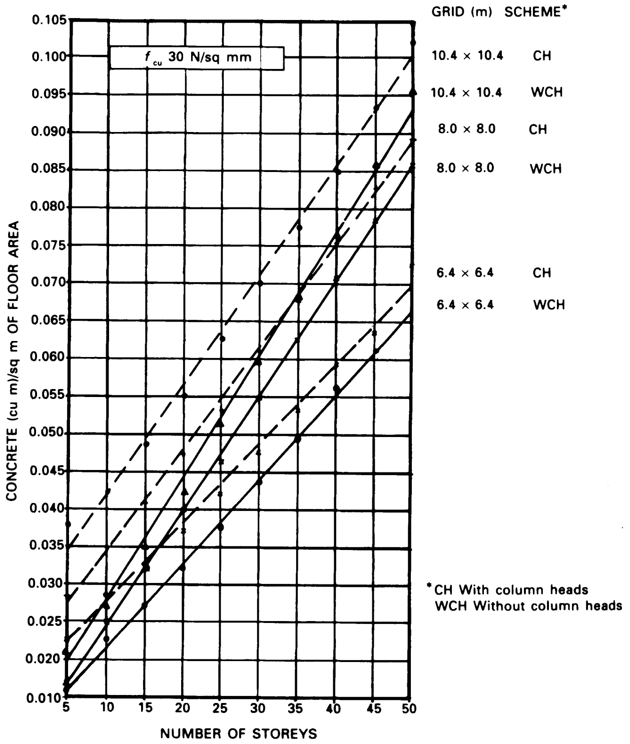


Figure 4.18 Quantities of concrete in interior columns for waffle slab construction (for schemes both with and without column heads).

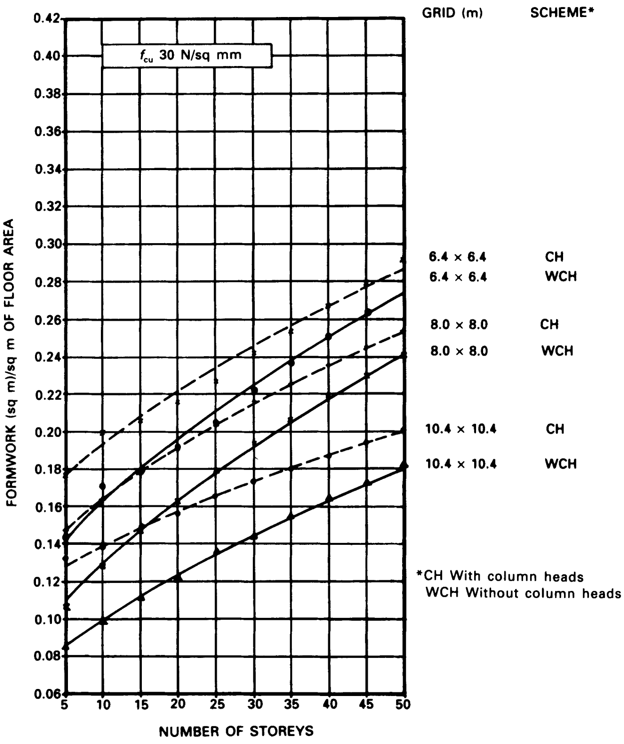


Figure 4.19 Quantities of formwork in interior columns for waffle slab construction (for schemes with (CH) and without (WCH) column heads.

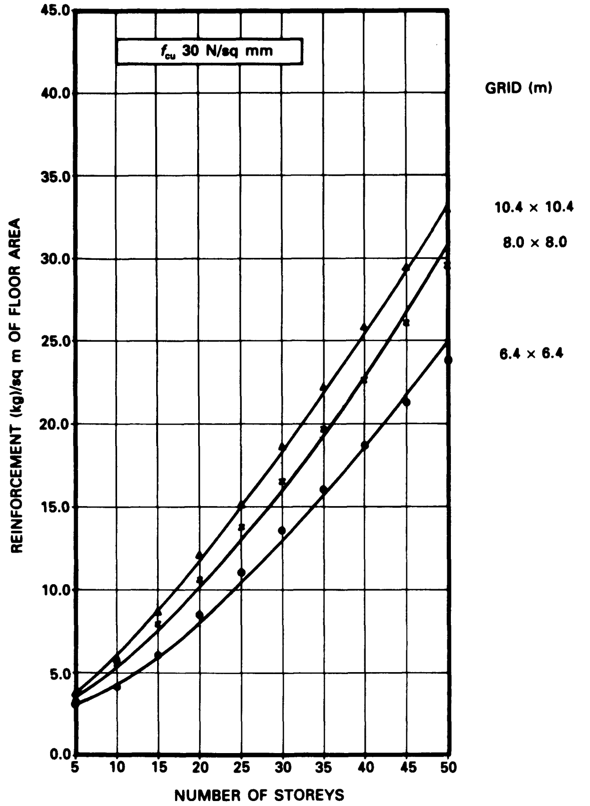


Figure 4.20 Quantities of reinforcement in interior columns for waffle slab construction without column heads.

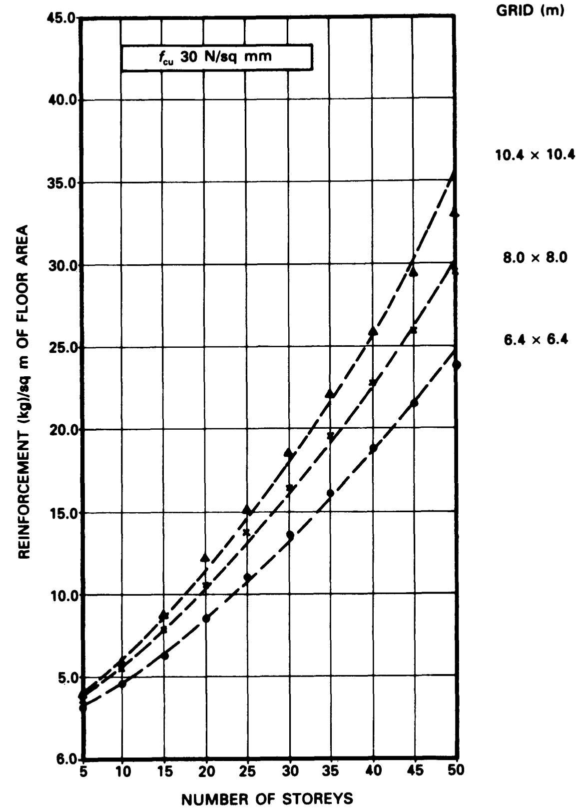


Figure 4.21 Quantities of reinforcement in interior columns for waffle slab construction with column heads.

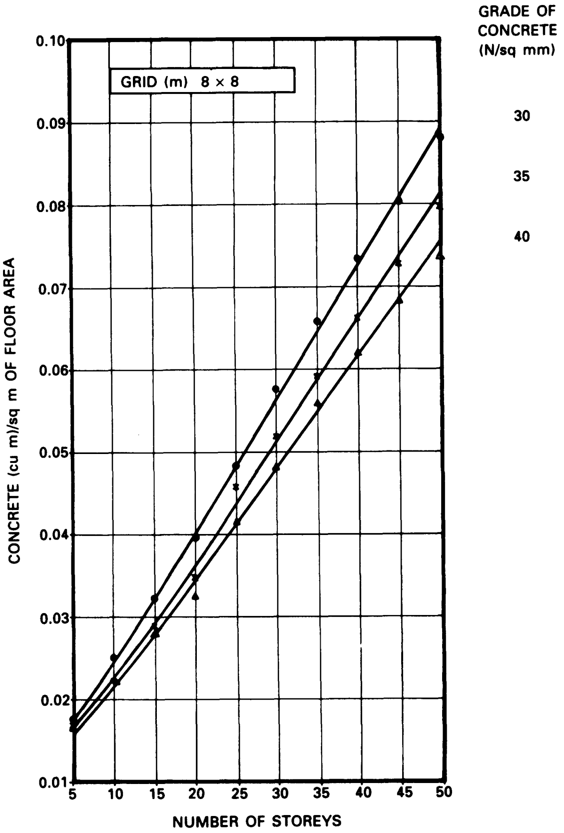


Figure 4.23 Effect of grade of concrete on quantities of concrete in interior columns for flat slab construction without column heads. Grid (m) 8 × 8.

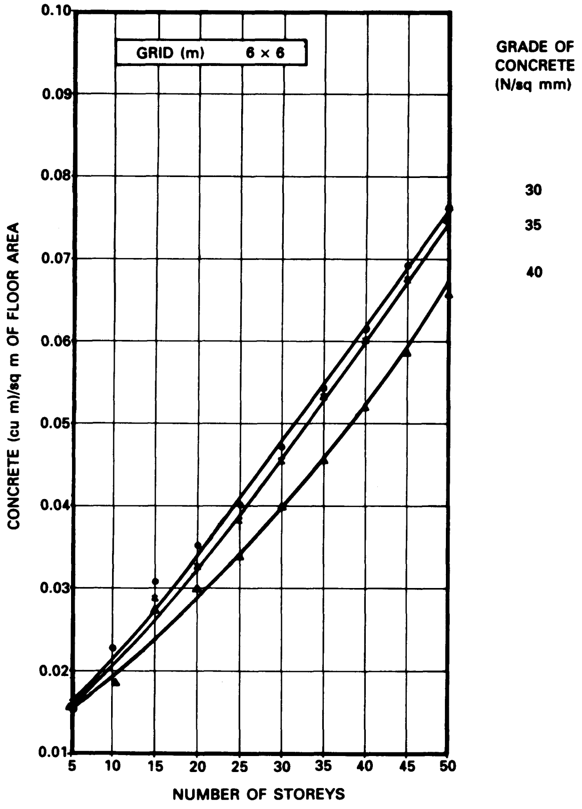


Figure 4.22 Effect of grade of concrete on quantities of concrete in interior columns for flat slab construction without column heads. Grid (m) 6 × 6.

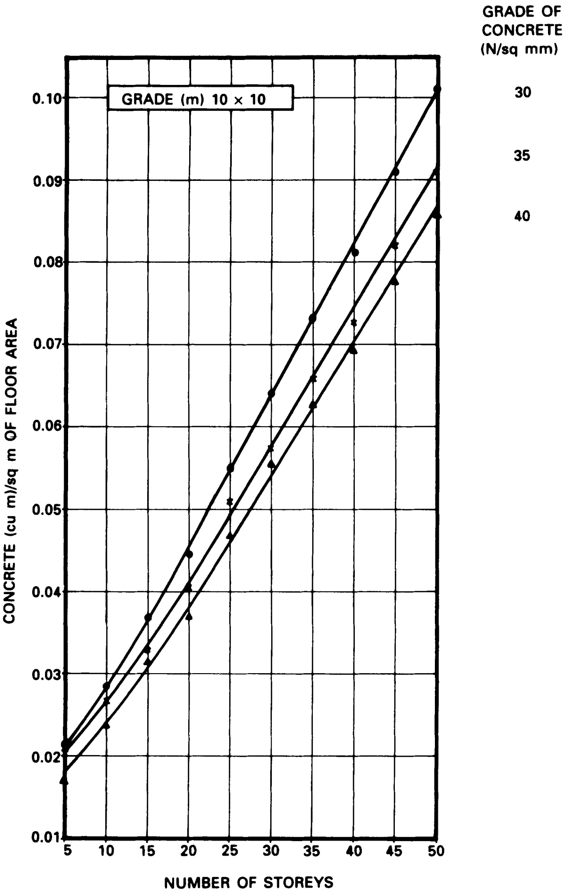


Figure 4.24 Effect of grade of concrete on quantities of concrete in interior columns for flat slab construction without column heads. Grid (m) 10 × 10.

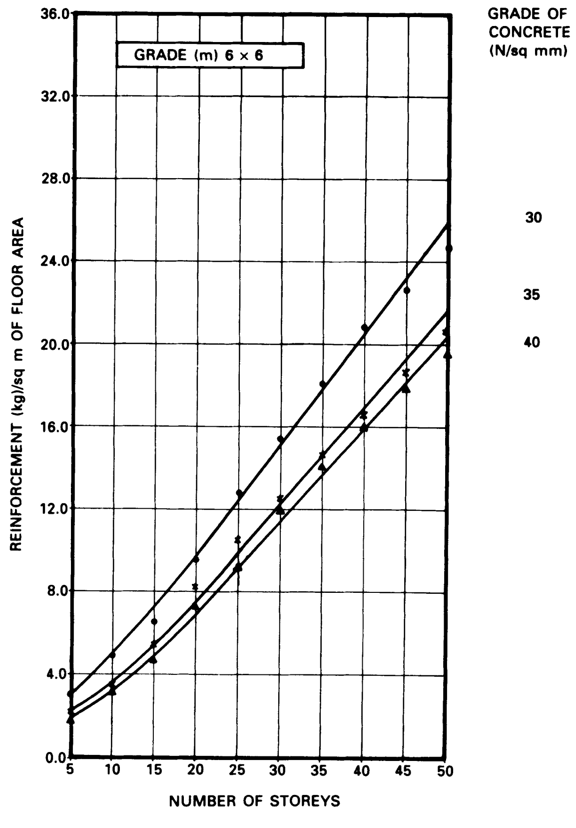


Figure 4.25 Effect of grade of concrete on quantities of reinforcement in interior columns for flat slab construction without column heads. Grid (m) 6 × 6.

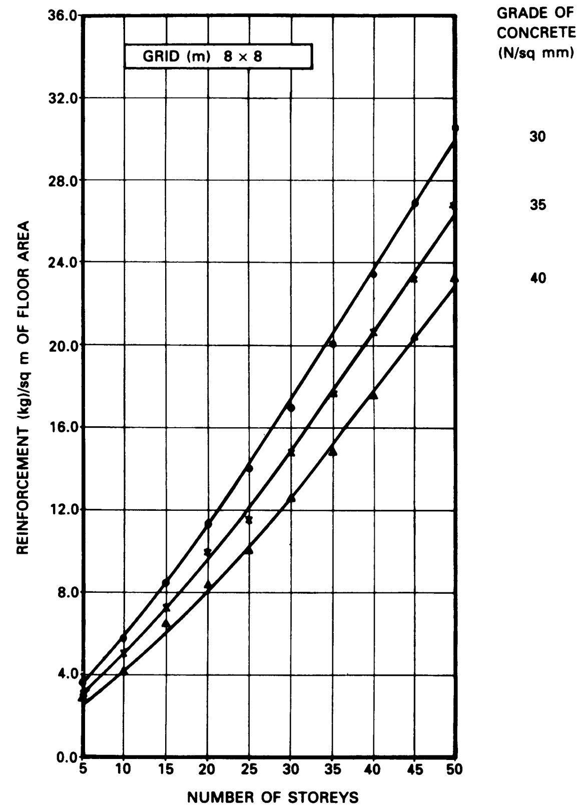


Figure 4.26 Effect of grade of concrete on quantities of reinforcement in interior columns for flat slab construction without column heads. Grid (m) 8 × 8.

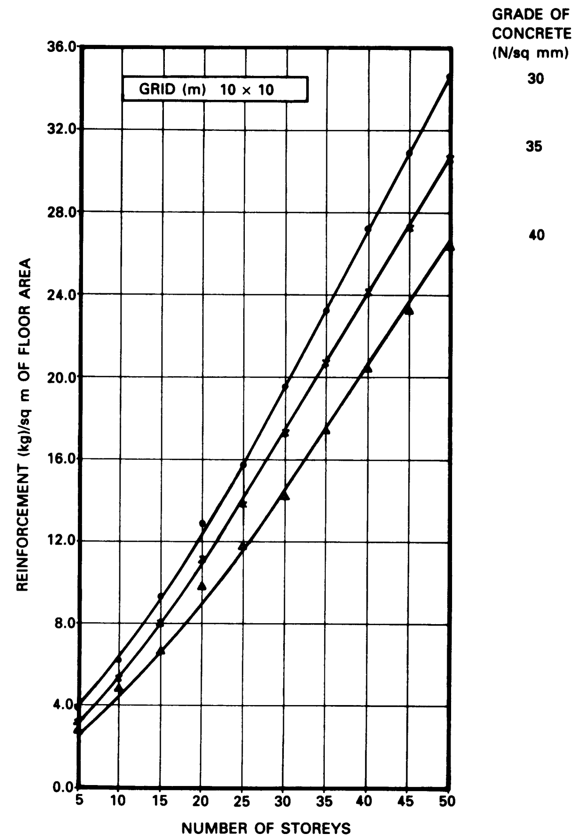


Figure 4.27 Effect of grade of concrete on quantities of reinforcement in interior columns for flat slab construction without column heads. Grid (m) 10 × 10.

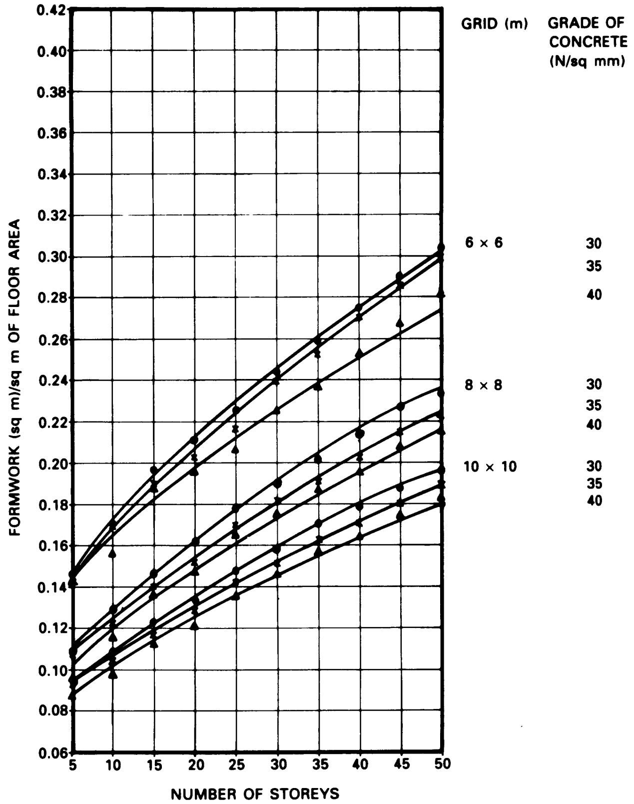


Figure 4.28 Effect of grade of concrete on quantities of formwork in interior columns for flat slab construction without column heads.

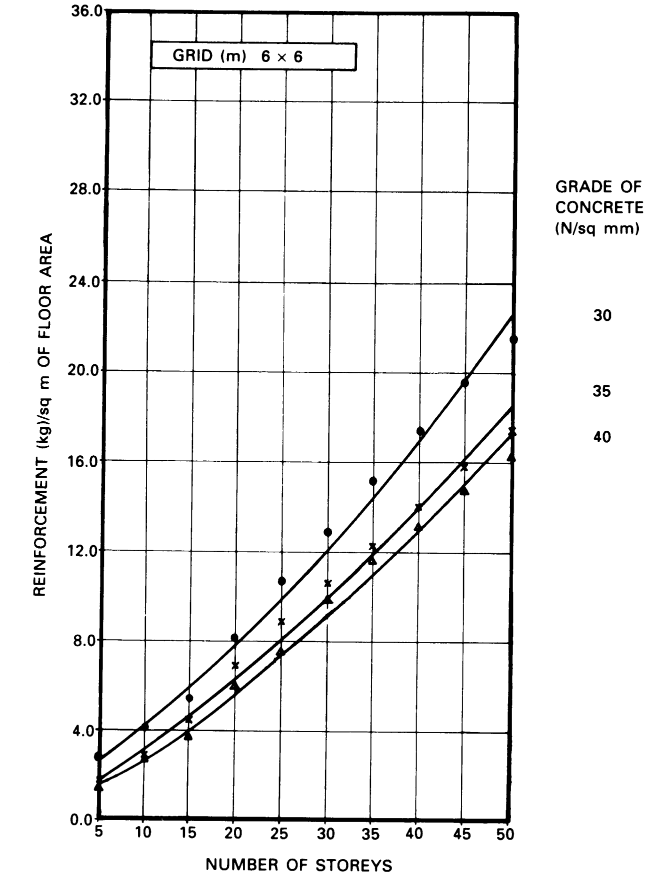


Figure 4.29 Effect of grade of concrete on quantities of reinforcement in interior columns for flat slab construction without column heads (using mild steel in flat slab). Grid (m) 6 × 6.

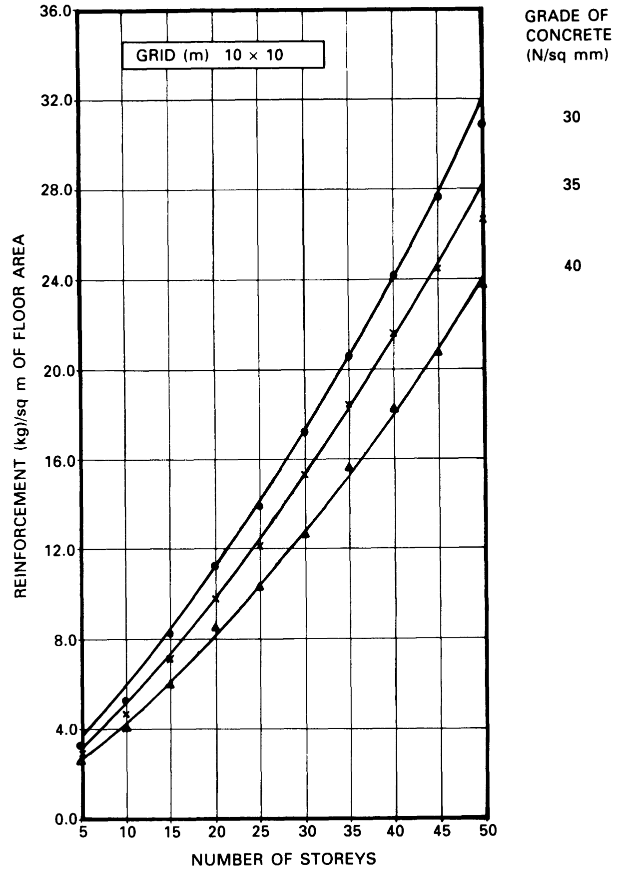


Figure 4.31 Effect of grade of concrete on quantities of reinforcement in interior columns for flat slab construction without column heads (using mild steel in flat slab). Grid (m) 10 × 10.

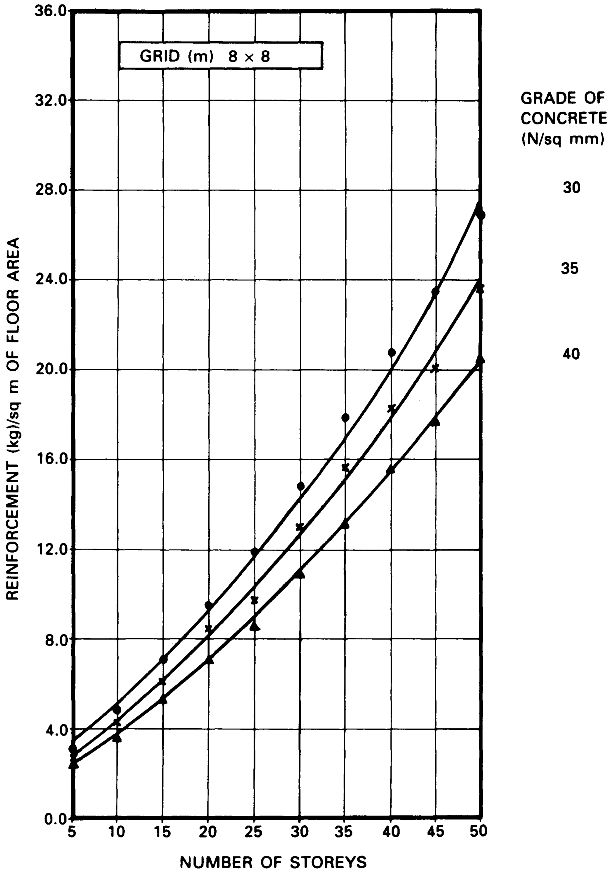


Figure 4.30 Effect of grade of concrete on quantities of reinforcement in interior columns for flat slab construction without column heads (using mild steel in flat slab). Grid (m) 8 × 8.

Figures 4.32 to 4.40 and for corner columns in Figures 4.41 to 4.49.

The effects of grade of concrete on quantities of constituents for interior columns without column heads and using waffle slabs are shown in Figures 4.50 to 4.56 and for interior columns with column heads in Figures 4.57 to 4.65. Similar results for exterior columns are shown in Figures 4.66 to 4.74 and for corner columns in Figures 4.75 to 4.83.

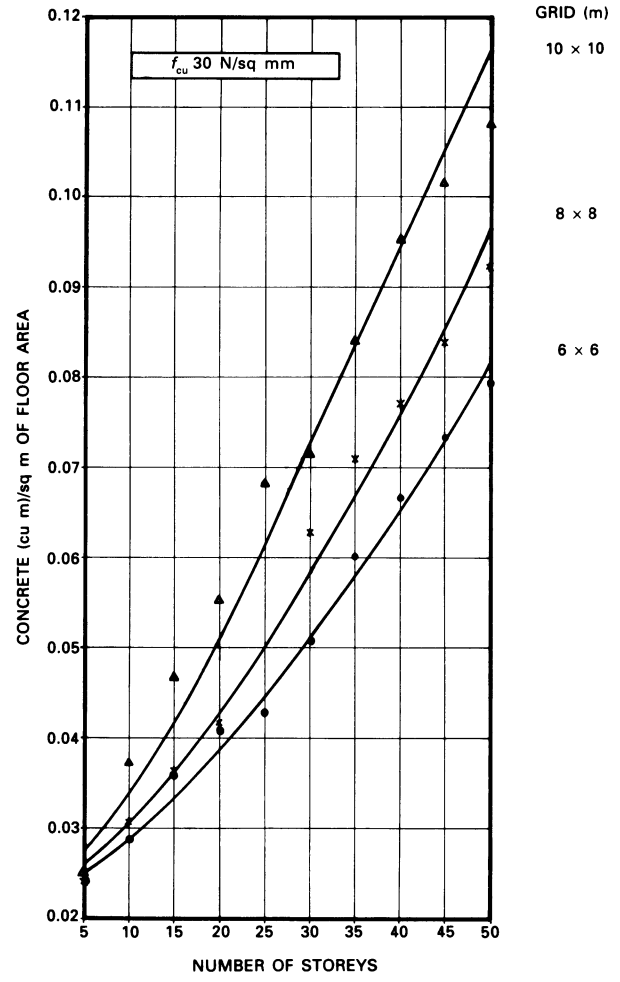


Figure 4.32 Quantities of concrete in exterior columns for flat slab construction without column heads: 30 N/mm^2.

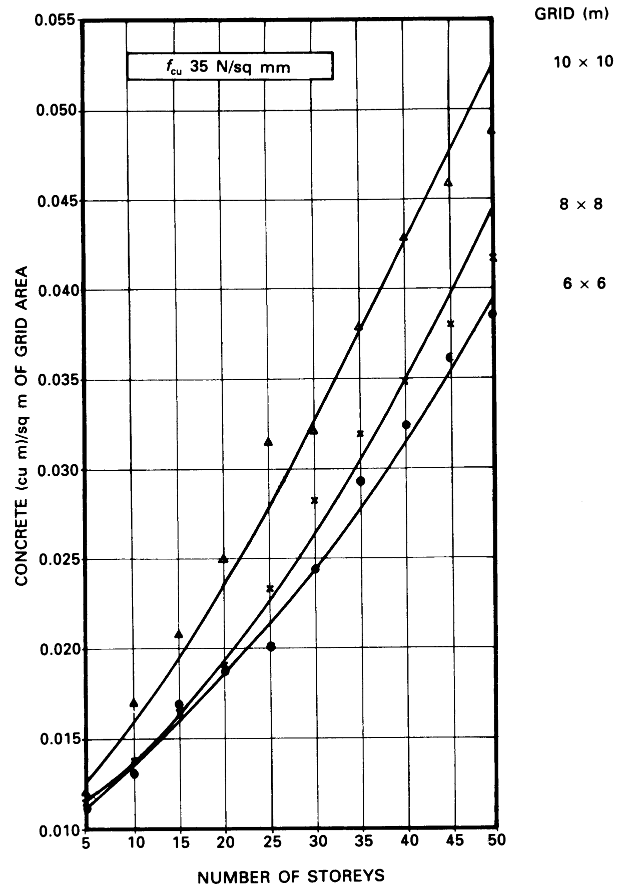


Figure 4.33 Quantities of concrete in exterior columns for flat slab construction without column heads: 35 N/mm^2.

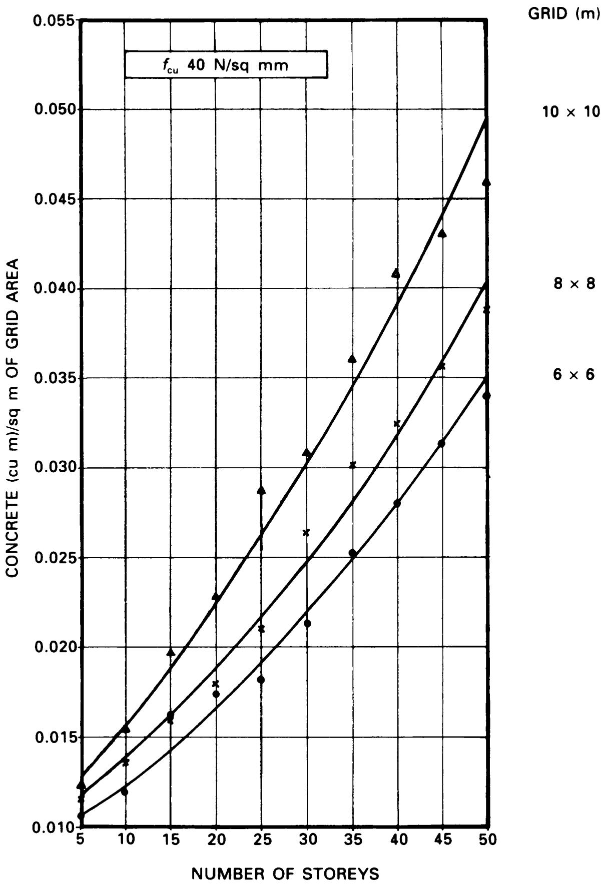


Figure 4.34 Quantities of concrete in exterior columns for flat slab construction without column heads: 40 N/mm^2.

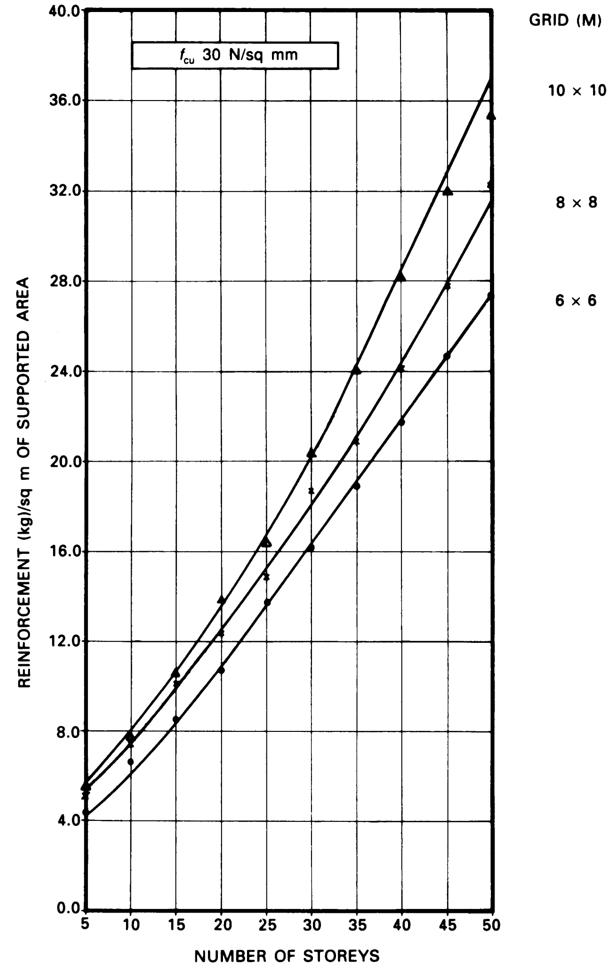


Figure 4.35 Quantities of reinforcement in exterior columns for flat slab construction without column heads: 30 N/mm^2.

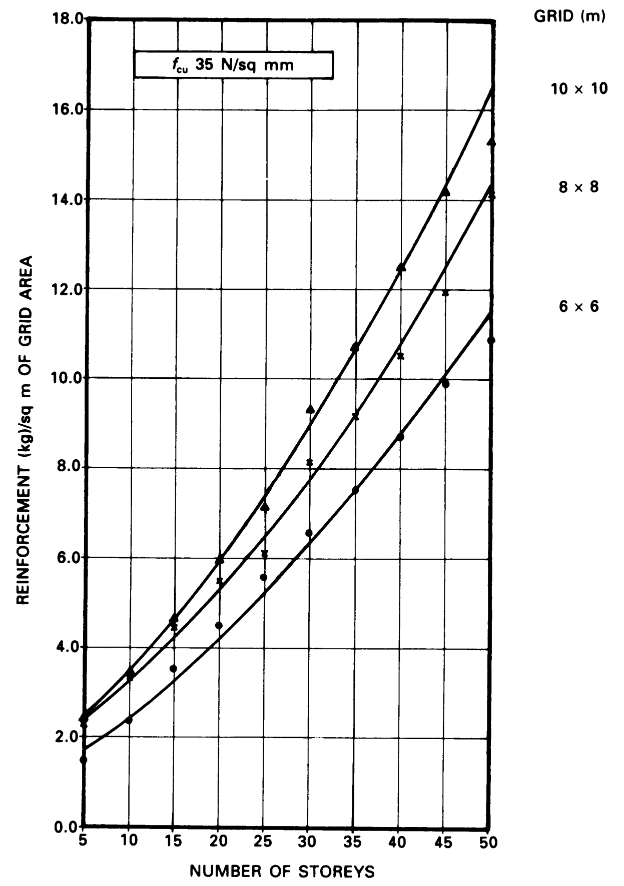


Figure 4.36 Quantities of reinforcement in exterior columns for flat slab construction without column heads: 35 N/mm^2.

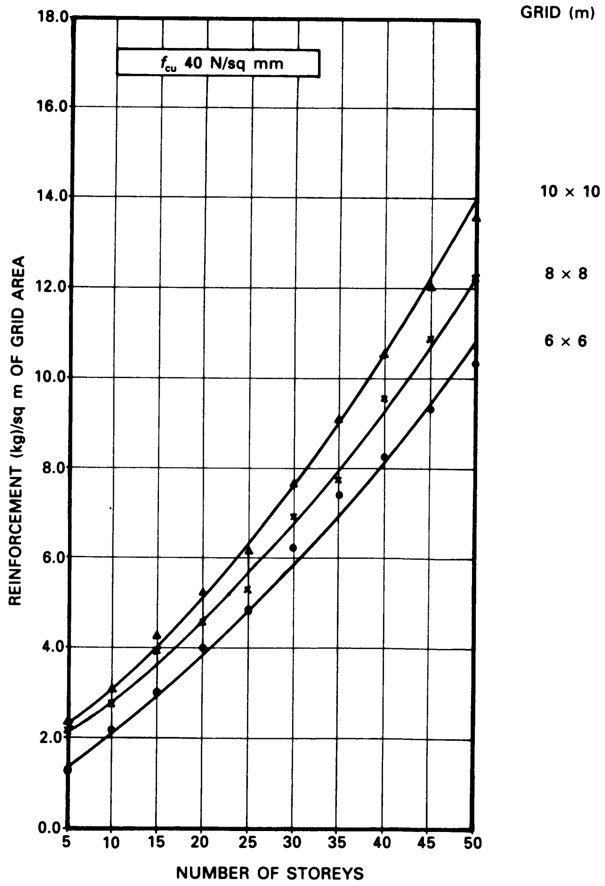


Figure 4.37 Quantities of reinforcement in exterior columns for flat slab construction without column heads: 40 N/mm^2.

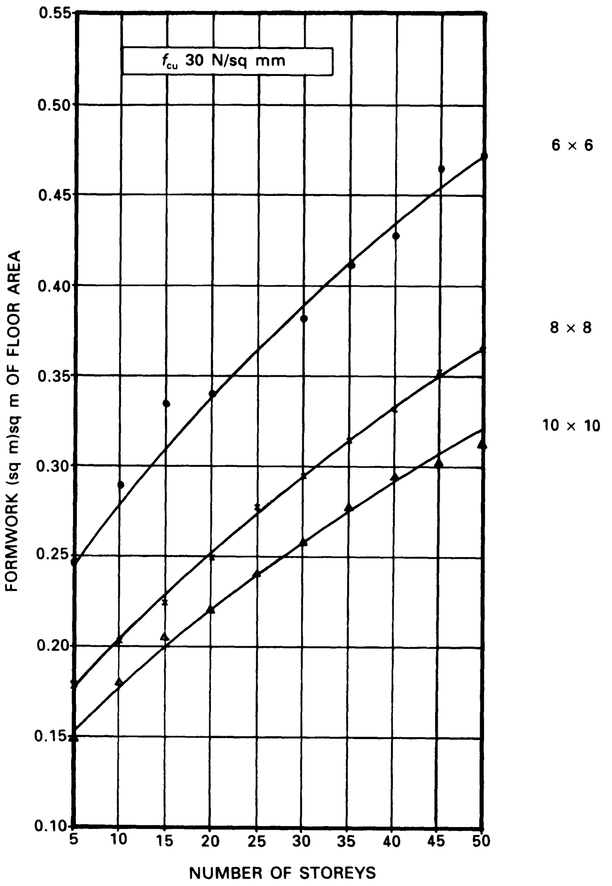


Figure 4.38 Quantities of formwork in exterior columns for flat slab construction without column heads: 30 N/mm^2.

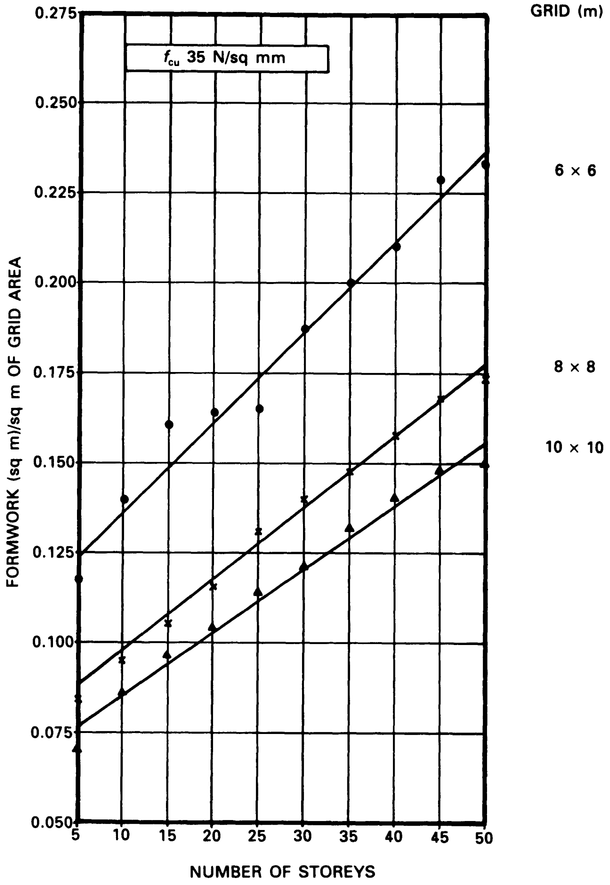


Figure 4.39 Quantities of formwork in exterior columns for flat slab construction without column heads: 35 N/mm^2.

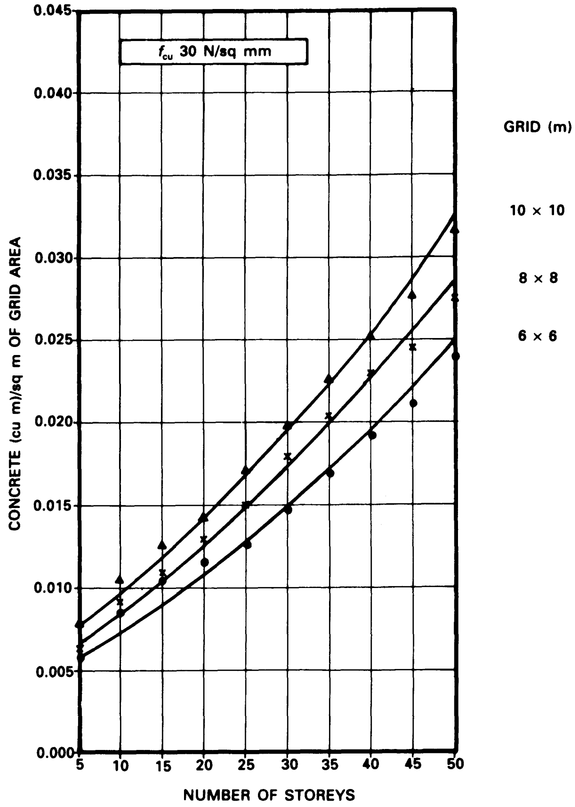


Figure 4.41 Quantities of concrete in corner columns for flat slab construction without column heads: 30 N/mm^2.

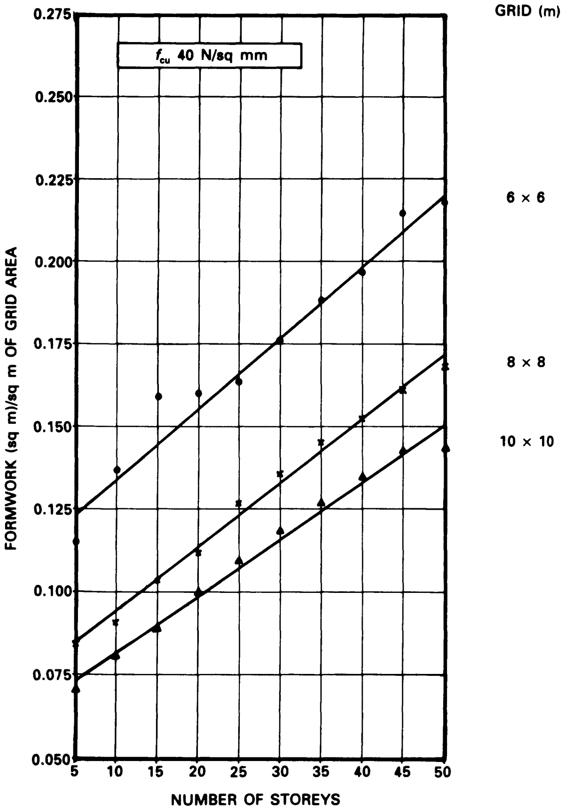


Figure 4.40 Quantities of formwork in exterior columns for flat slab construction without column heads: 40 N/mm^2.

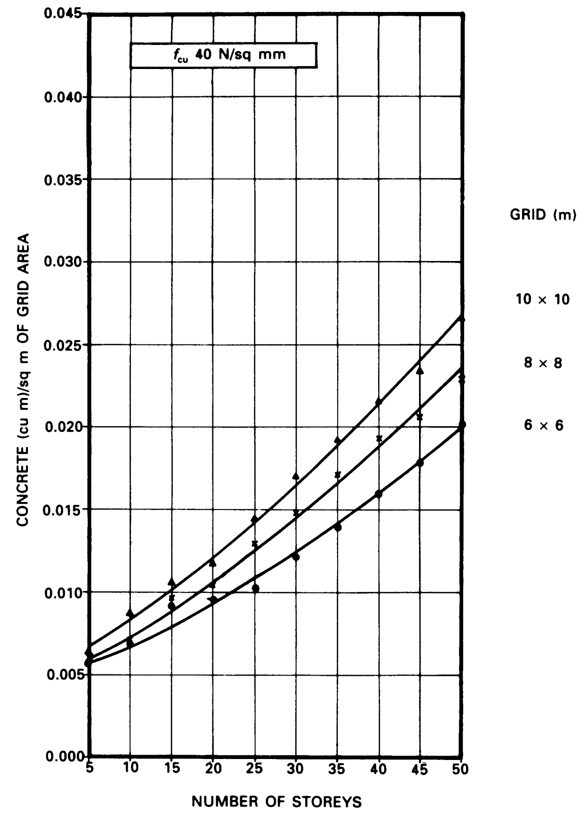


Figure 4.43 Quantities of concrete in corner columns for flat slab construction without column heads: 40 N/mm^2.

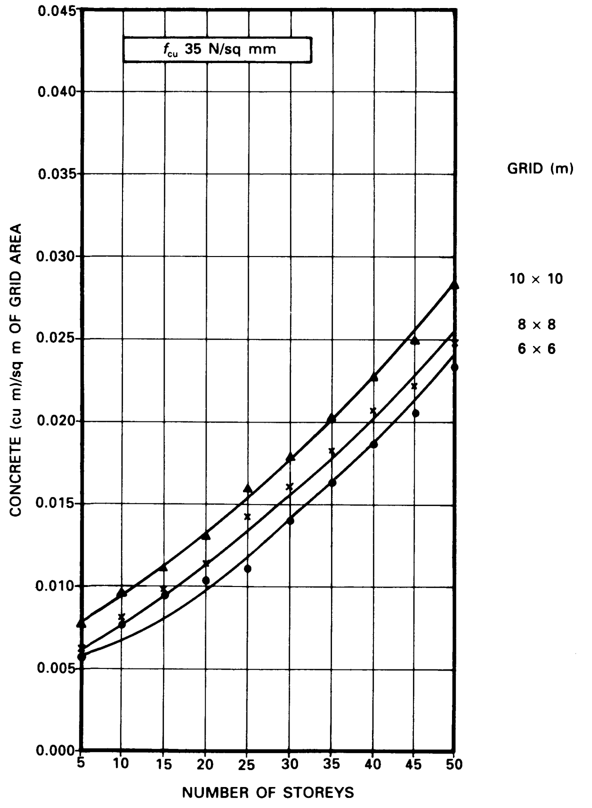


Figure 4.42 Quantities of concrete in corner columns for flat slab construction without column heads: 35 N/mm^2.

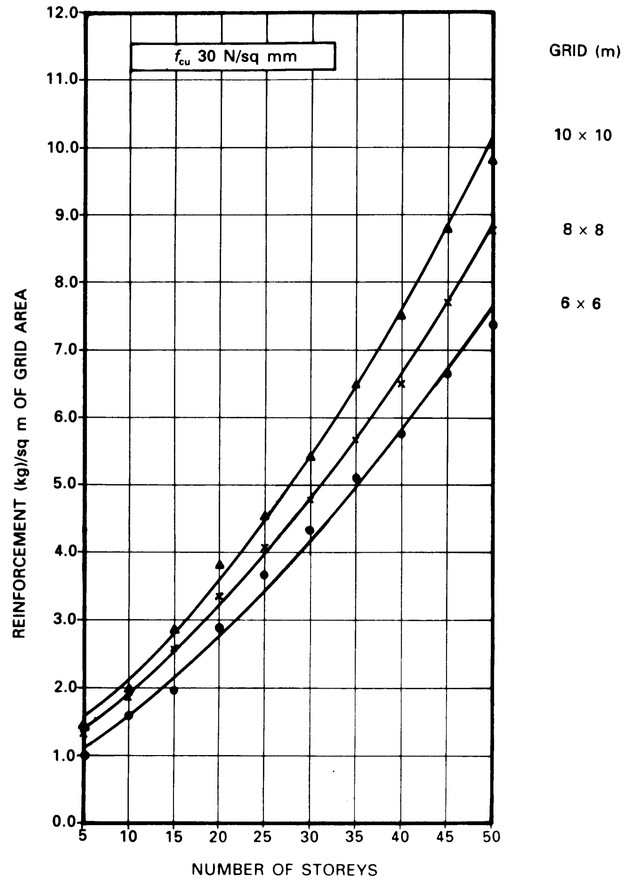


Figure 4.44 Quantities of reinforcement in corner columns for flat slab construction without column heads: 30 N/mm^2.

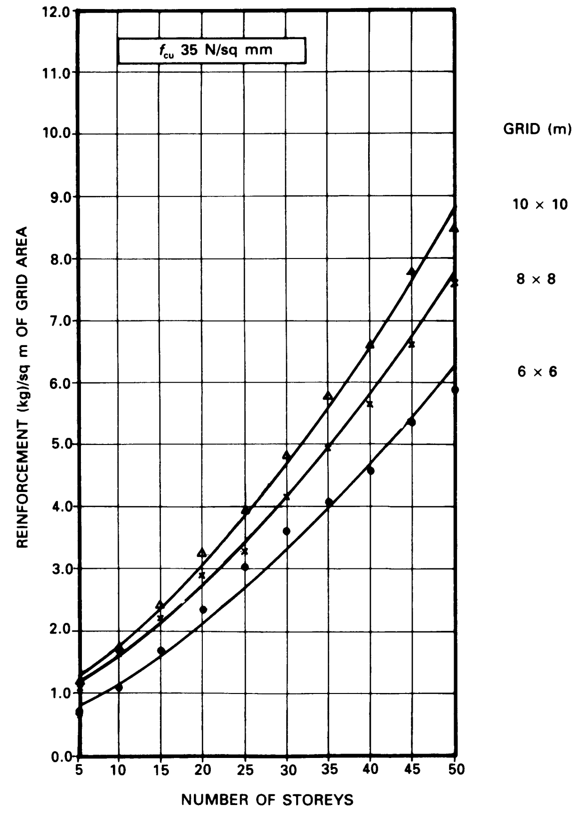


Figure 4.45 Quantities of reinforcement in corner columns for flat slab construction without column heads: 35 N/mm^2.

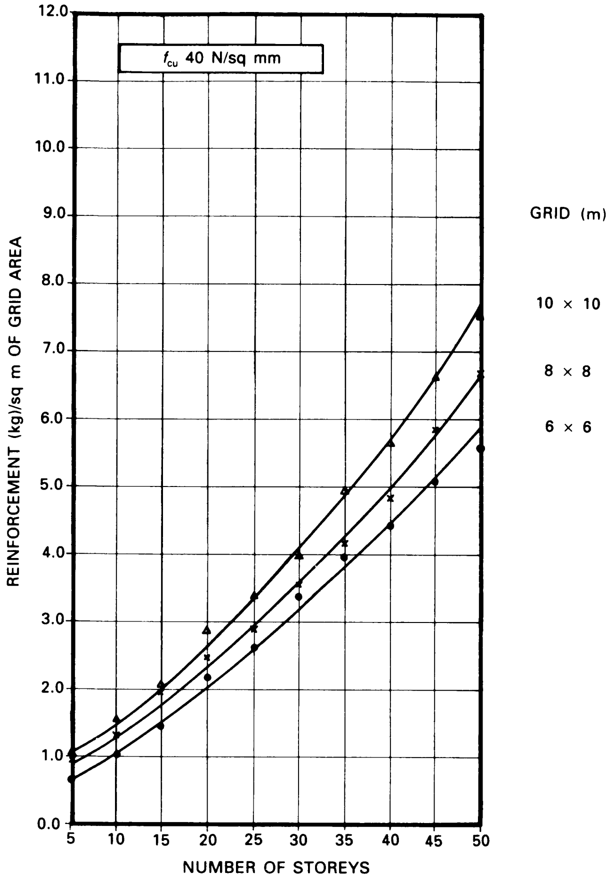


Figure 4.46 Quantities of reinforcement in corner columns for flat slab construction without column heads: 40 N/mm^2.

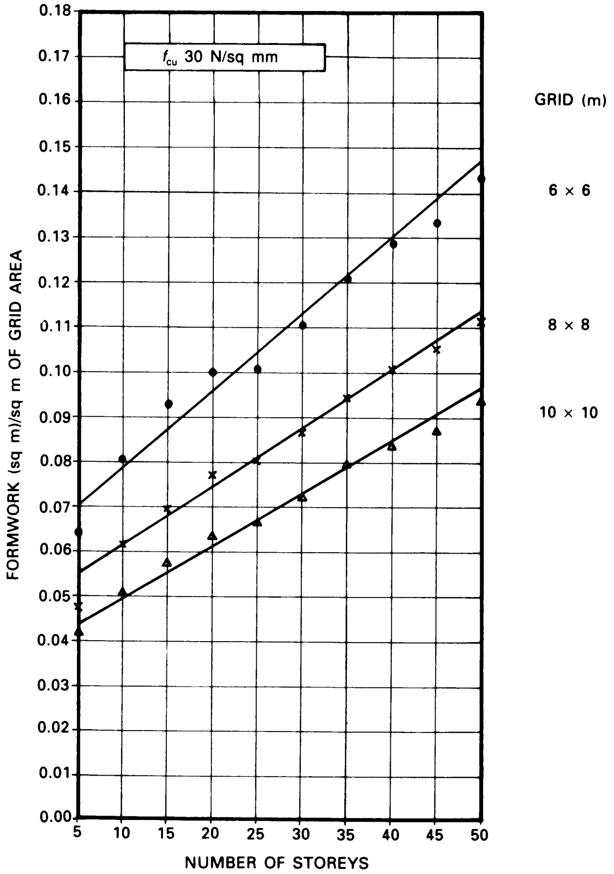


Figure 4.47 Quantities of formwork in corner columns for flat slab construction without column heads: 30 N/mm^2.

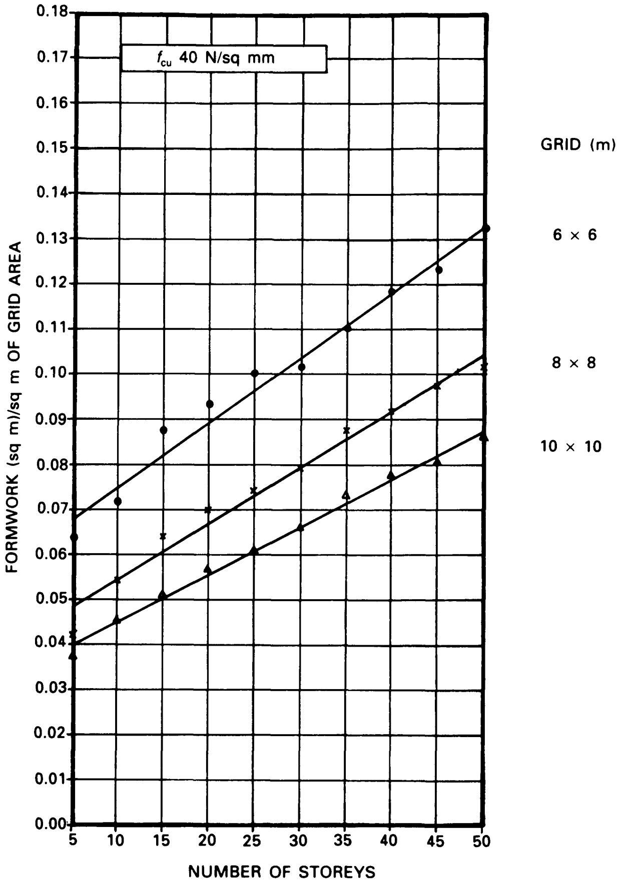


Figure 4.49 Quantities of formwork in corner columns for flat slab construction without column heads: 40 N/mm^2.

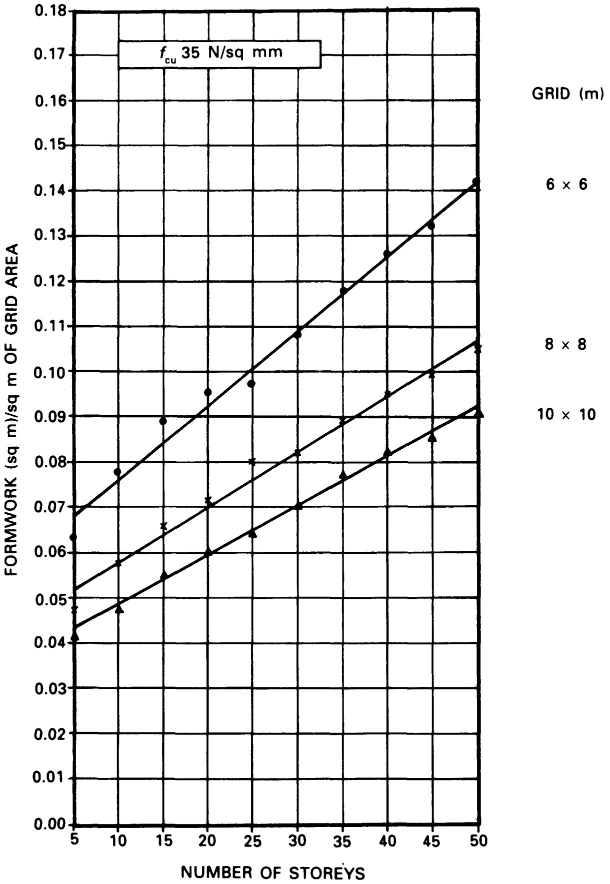


Figure 4.48 Quantities of formwork in corner columns for flat slab construction without column heads: 35 N/mm^2.

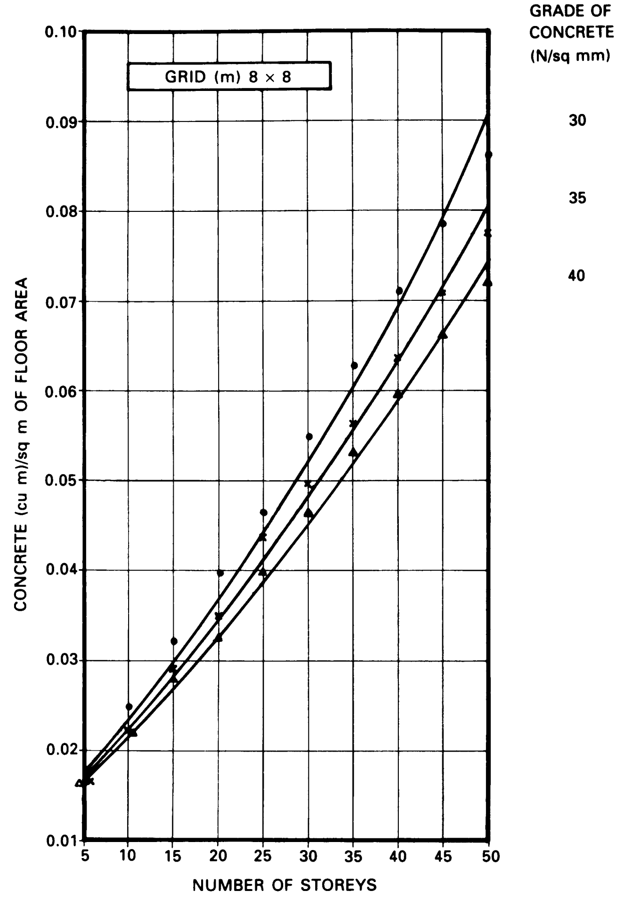


Figure 4.51 Effect of grade of concrete on quantities of concrete in interior columns for waffle slab construction without column heads. Grid (m) 8.0 × 8.0.

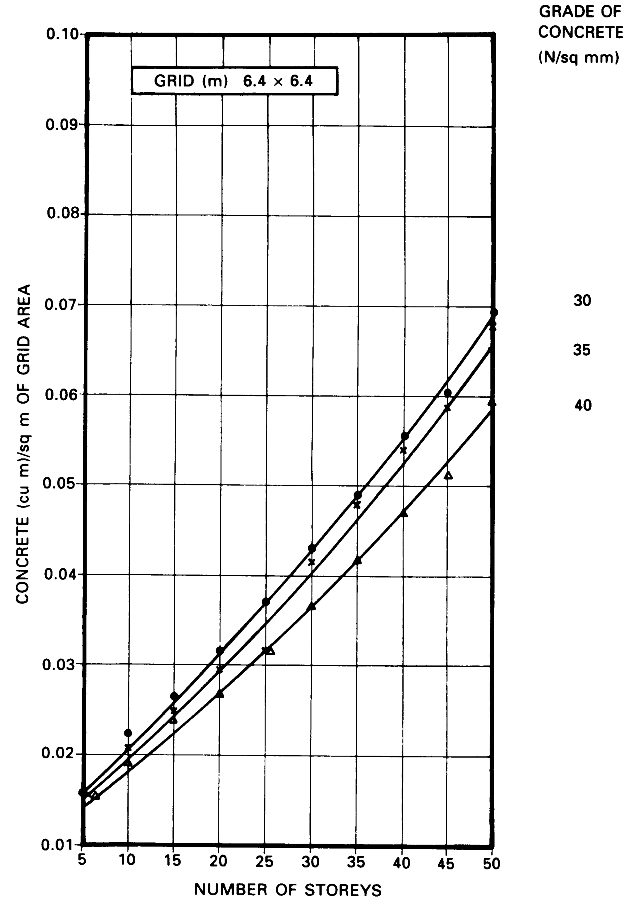


Figure 4.50 Effect of grade of concrete on quantities of concrete in interior columns for waffle slab construction without column heads. Grid (m) 6.4 × 6.4.

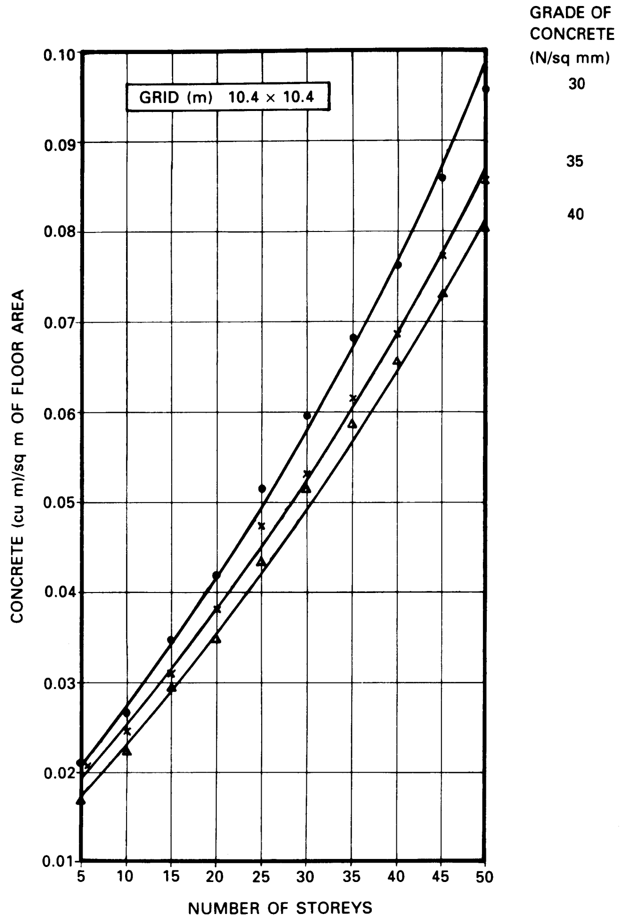


Figure 4.52 Effect of grade of concrete on quantities of concrete in interior columns for waffle slab construction without column heads. Grid (m) 10.4 × 10.4.

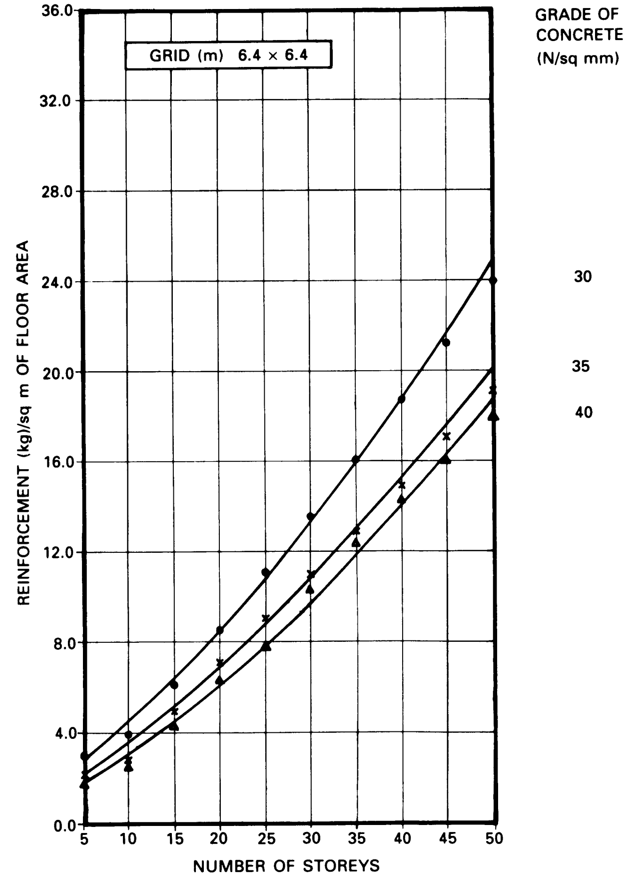


Figure 4.53 Effect of grade of concrete on quantities of reinforcement in interior columns for waffle slab construction without column heads. Grid (m) 6.4 × 6.4.

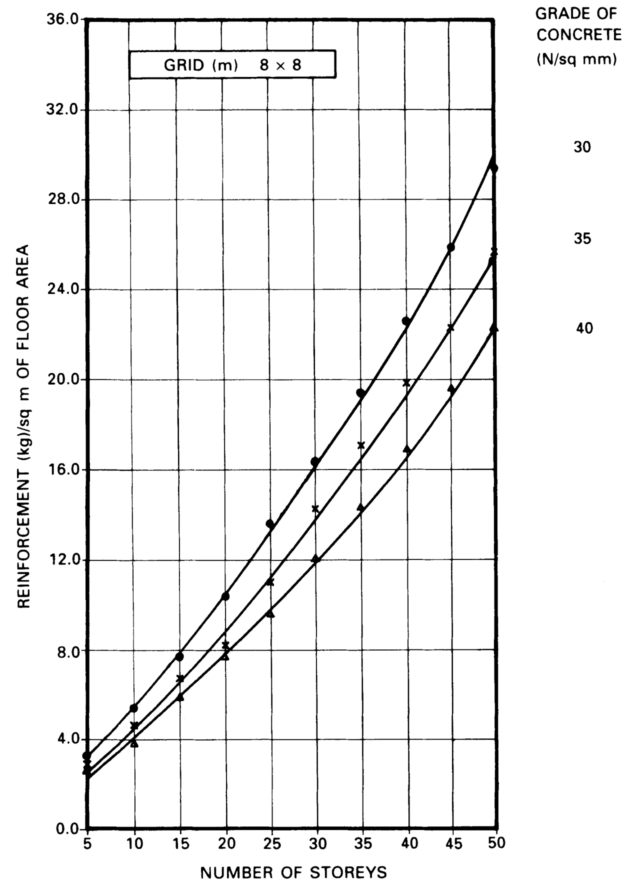


Figure 4.54 Effect of grade of concrete on quantities of reinforcement in interior columns for waffle slab construction without column heads. Grid (m) 8.0 × 8.0.

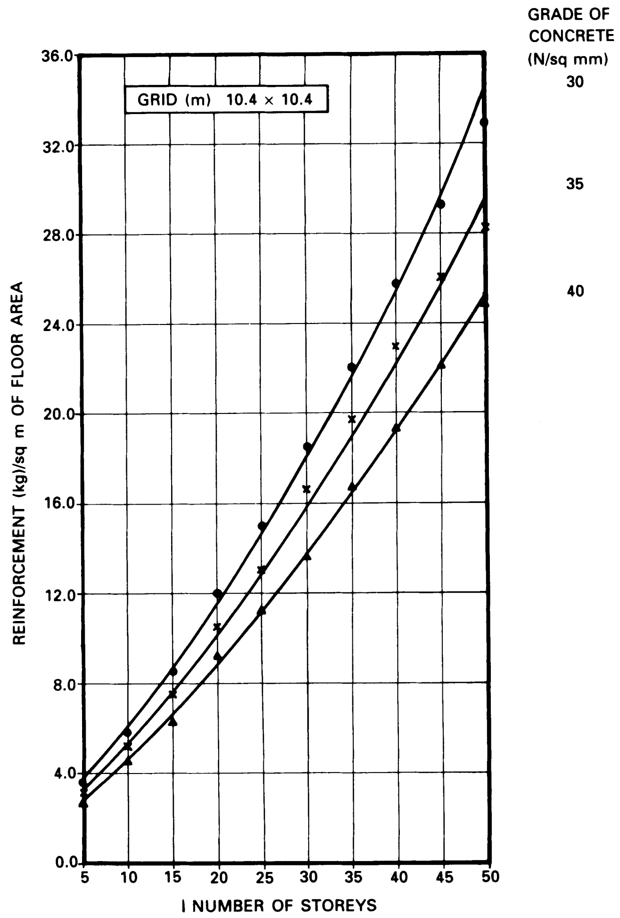


Figure 4.55 Effect of grade of concrete on quantities of reinforcement in interior columns for waffle slab construction without column heads. Grid (m) 10.4 × 10.4.

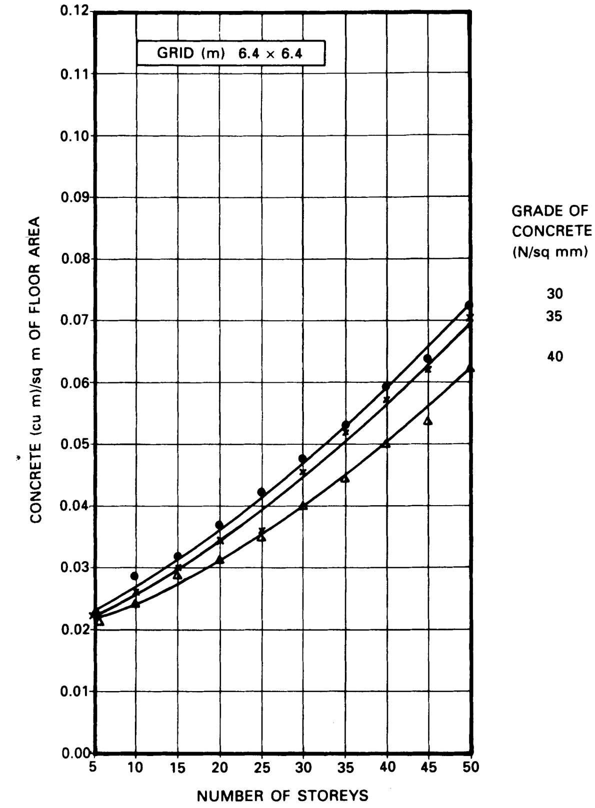


Figure 4.57 Effect of grade of concrete on quantities of concrete in interior columns for waffle slab construction with column heads. Grid (m) 6.4 × 6.4.

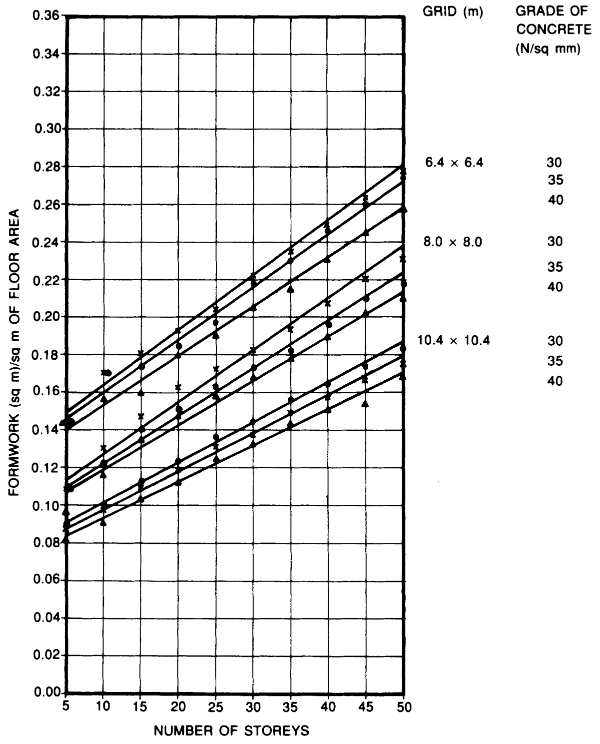


Figure 4.56 Effect of grade of concrete on quantities of formwork in interior columns for waffle slab construction without column heads.

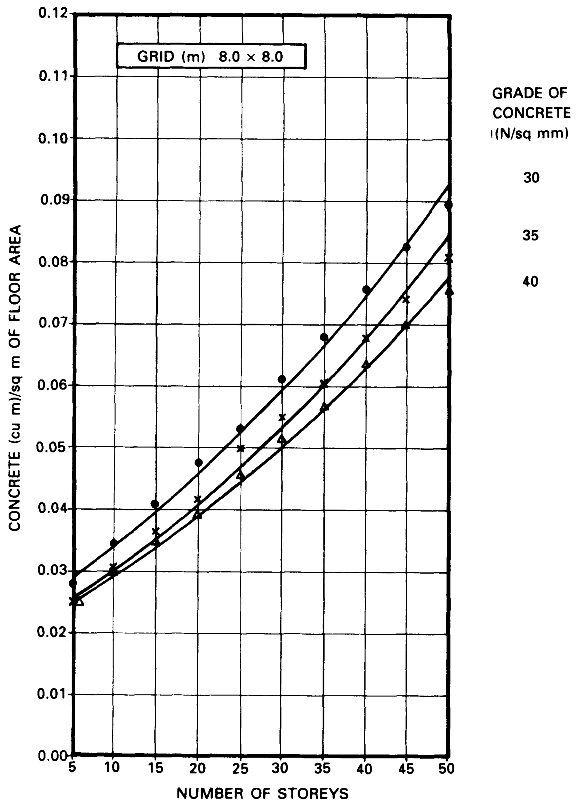


Figure 4.58 Effect of grade of concrete on quantities of concrete in interior columns for waffle slab construction with column heads. Grid (m) 8.0 × 8.0.

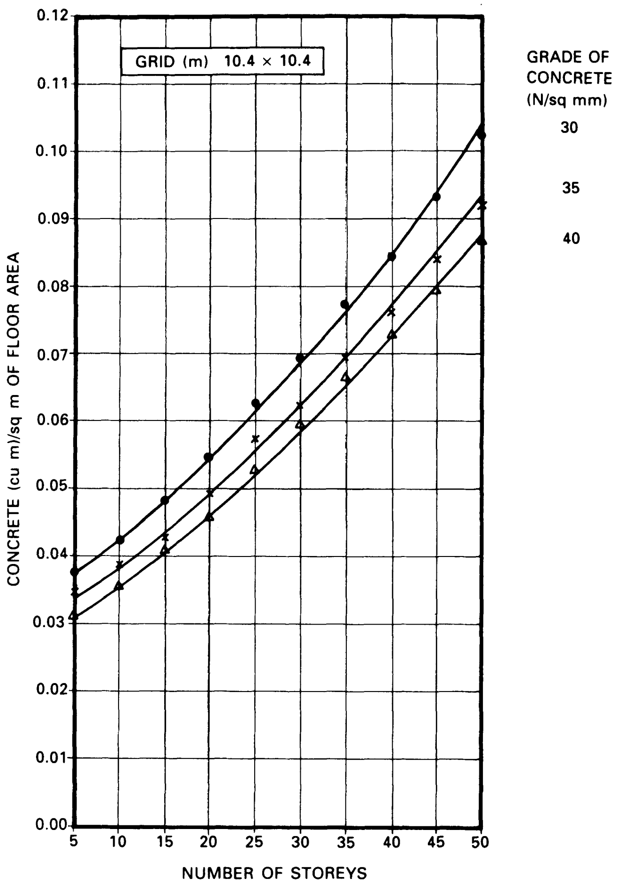


Figure 4.59 Effect of grade of concrete on quantities of concrete in interior columns for waffle slab construction with column heads. Grid (m) 10.4 × 10.4.

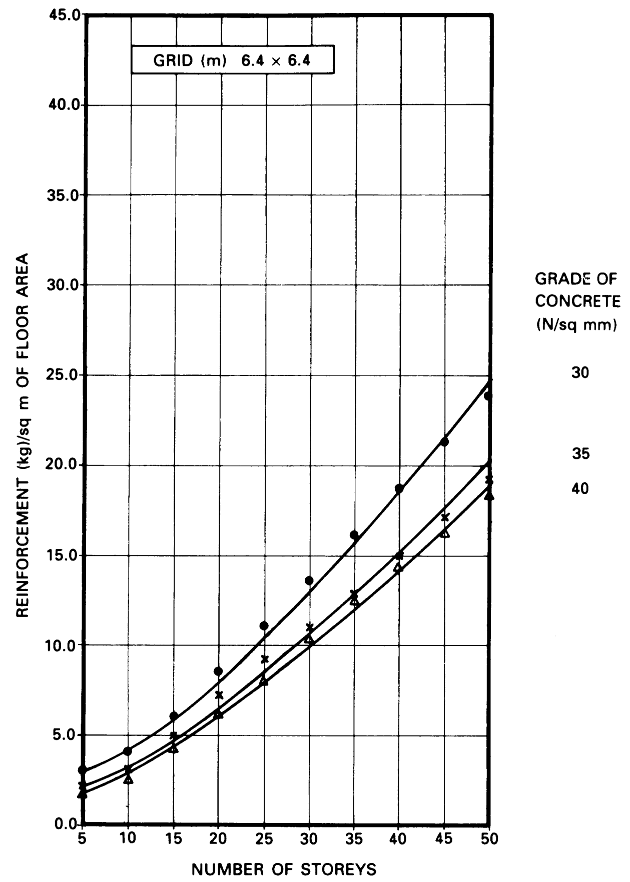


Figure 4.60 Effect of grade of concrete on quantities of reinforcement in interior columns for waffle slab construction with column heads. Grid (m) 6.4 × 6.4.

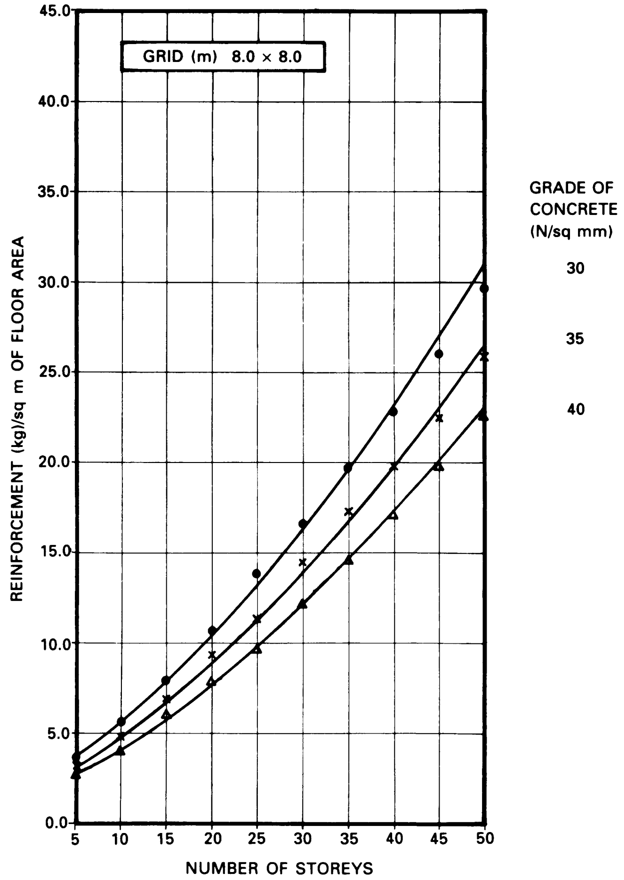


Figure 4.61 Effect of grade of concrete on quantities of reinforcement in interior columns for waffle slab construction with column heads. Grid (m) 8.0 × 8.0.

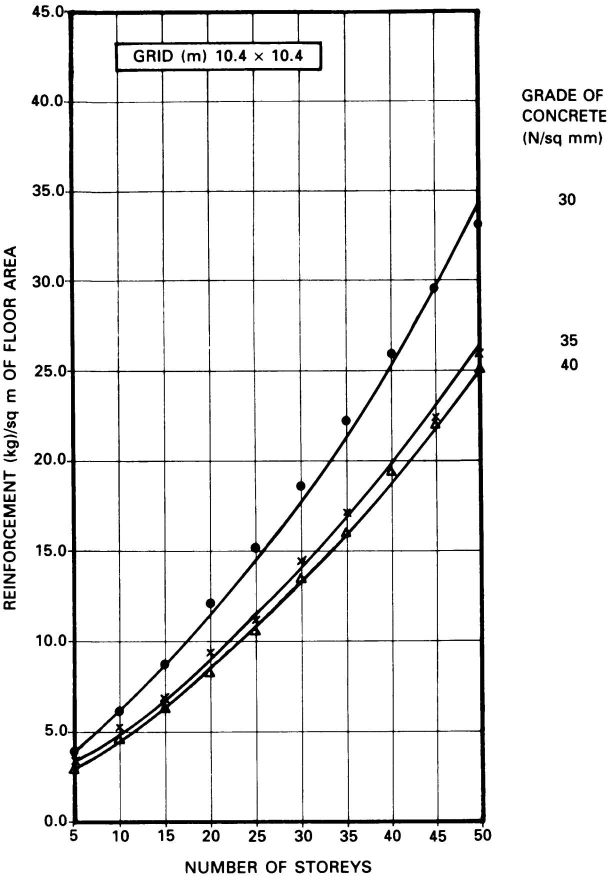


Figure 4.62 Effect of grade of concrete on quantities of reinforcement in interior columns for waffle slab construction with column heads. Grid (m) 10.4 × 10.4.

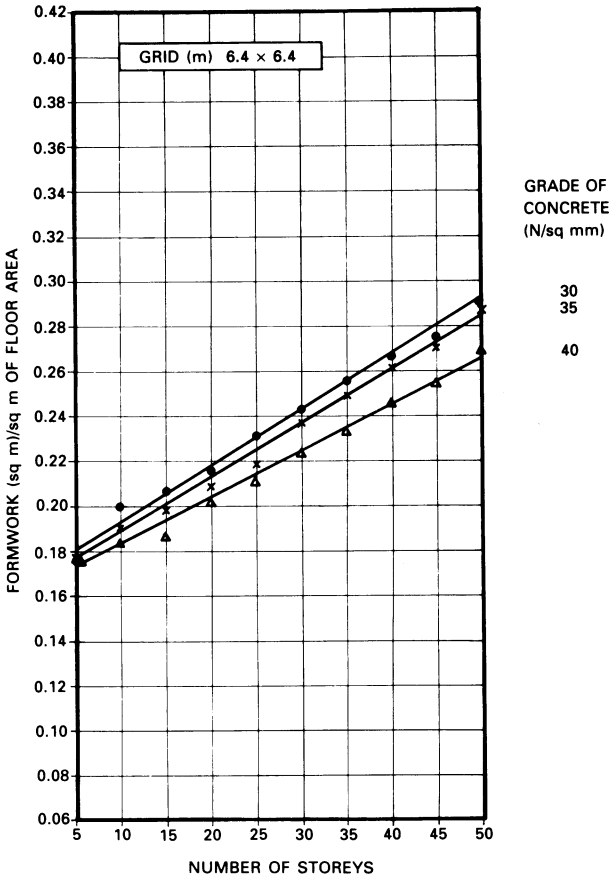


Figure 4.63 Effect of grade of concrete on quantities of formwork in interior columns for waffle slab construction with column heads. Grid (m) 6.4 × 6.4.

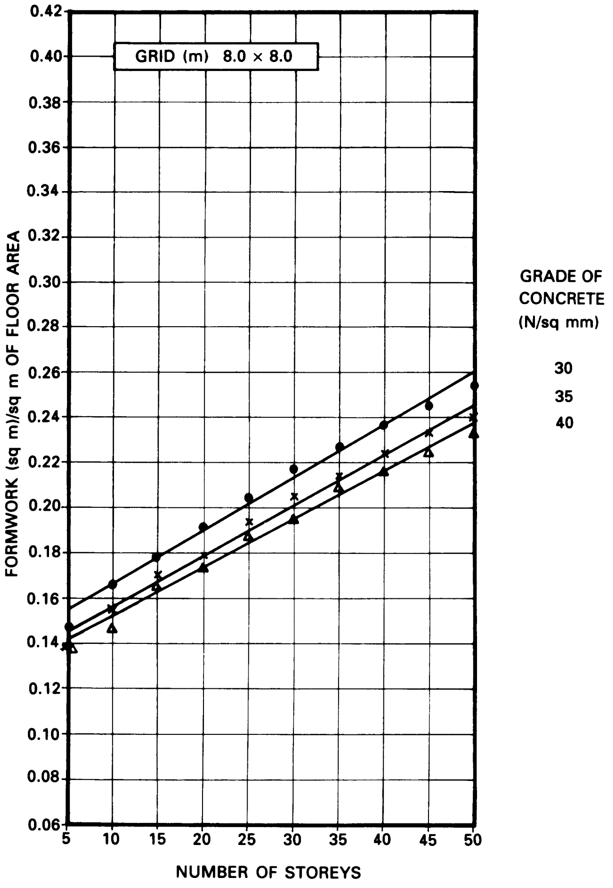


Figure 4.64 Effect of grade of concrete on quantities of formwork in interior columns for waffle slab construction with column heads. Grid (m) 8.0 × 8.0.

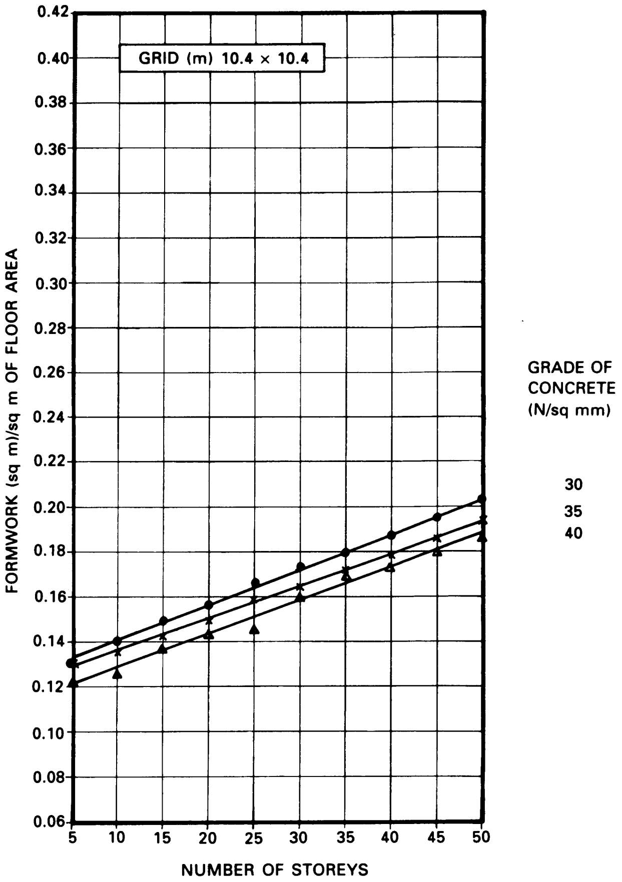


Figure 4.65 Effect of grade of concrete on quantities of formwork in interior columns for waffle slab construction with column heads. Grid (m) 10.4 × 10.4.

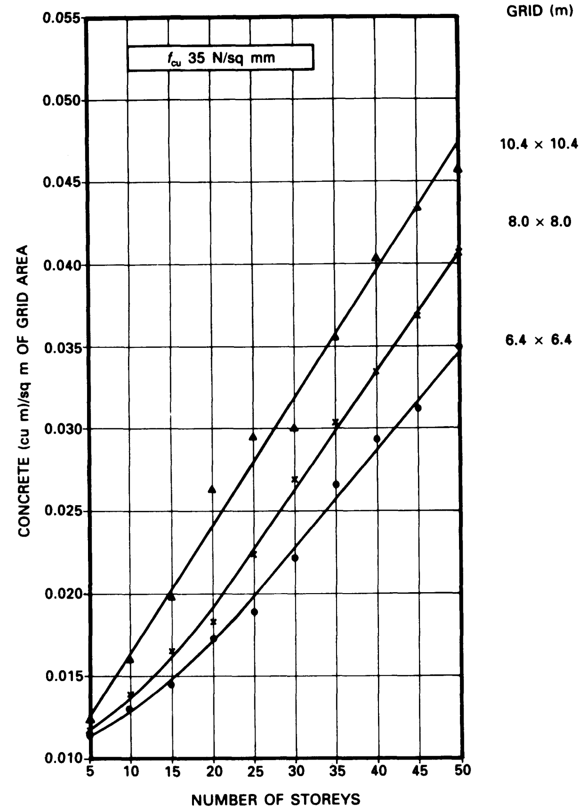


Figure 4.67 Quantities of concrete in exterior columns for waffle slab construction without column heads: 35 N/mm^2.

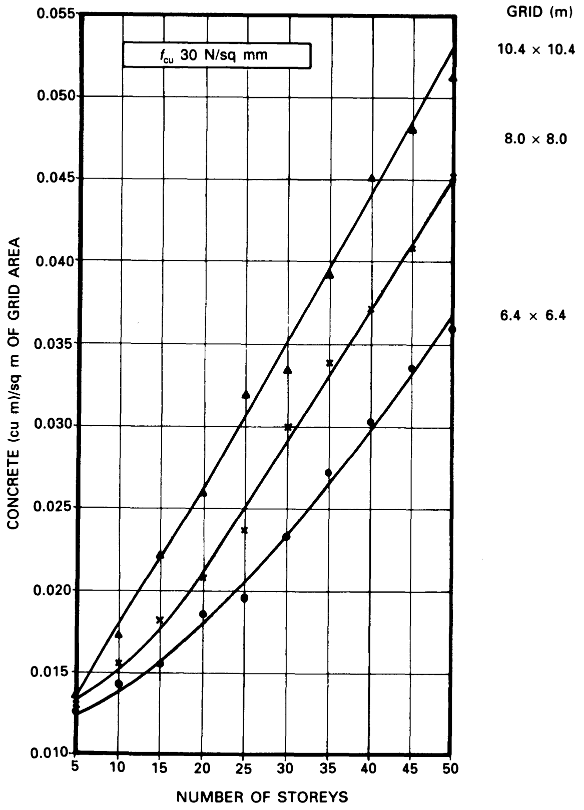


Figure 4.66 Quantities of concrete in exterior columns for waffle slab construction without column heads: 30 N/mm^2.

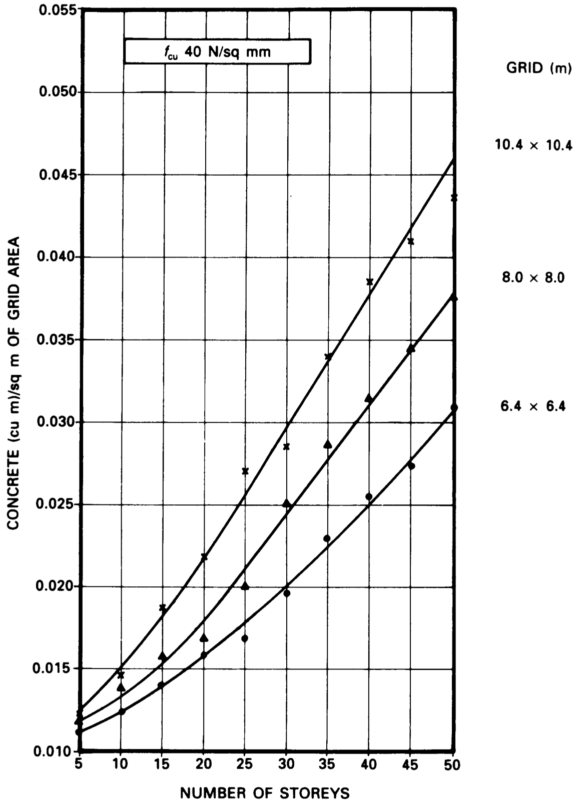


Figure 4.68 Quantities of concrete in exterior columns for waffle slab construction without column heads: 40 N/mm^2.

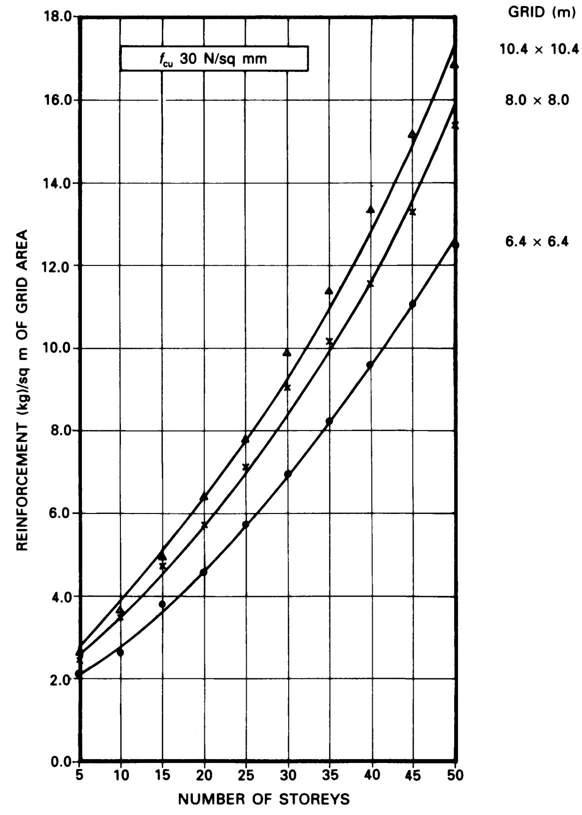


Figure 4.69 Quantities of reinforcement in exterior columns for waffle slab construction without column heads: 30 N/mm^2.

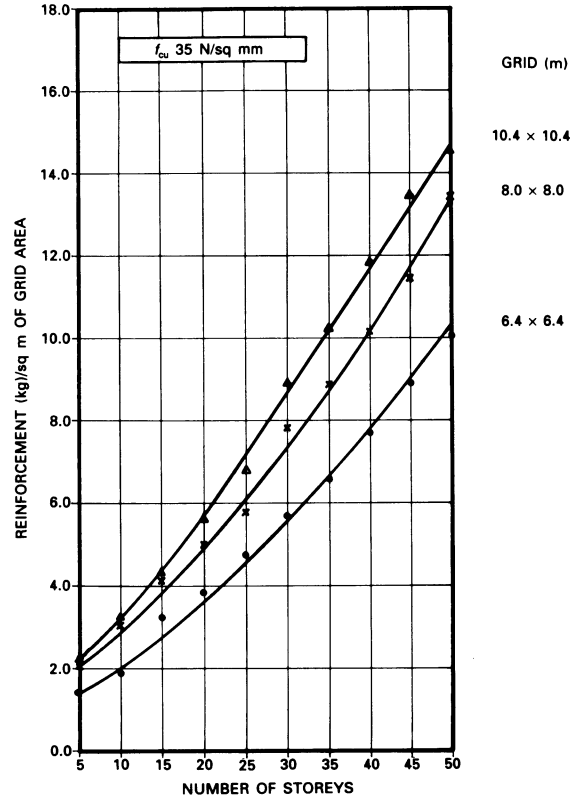


Figure 4.70 Quantities of reinforcement in exterior columns for waffle slab construction without column heads: 35 N/mm^2.

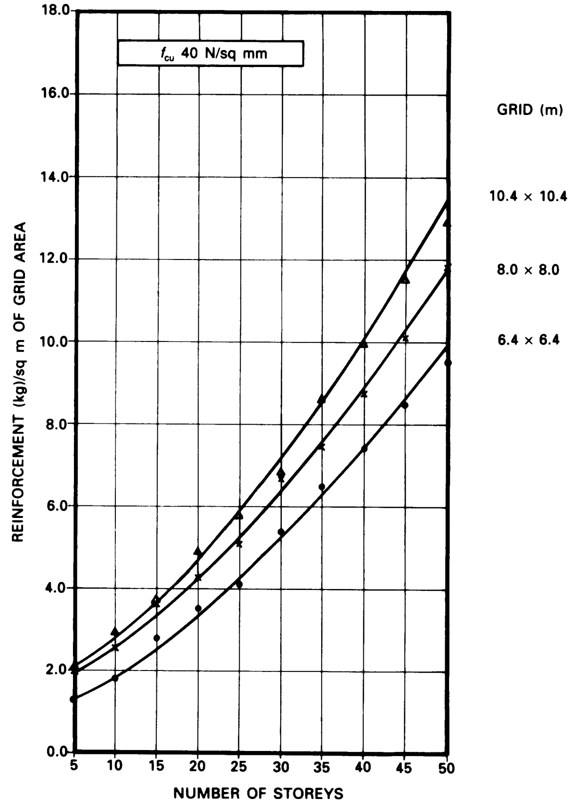


Figure 4.71 Quantities of reinforcement in exterior columns for waffle slab construction without column heads: 40 N/mm^2.

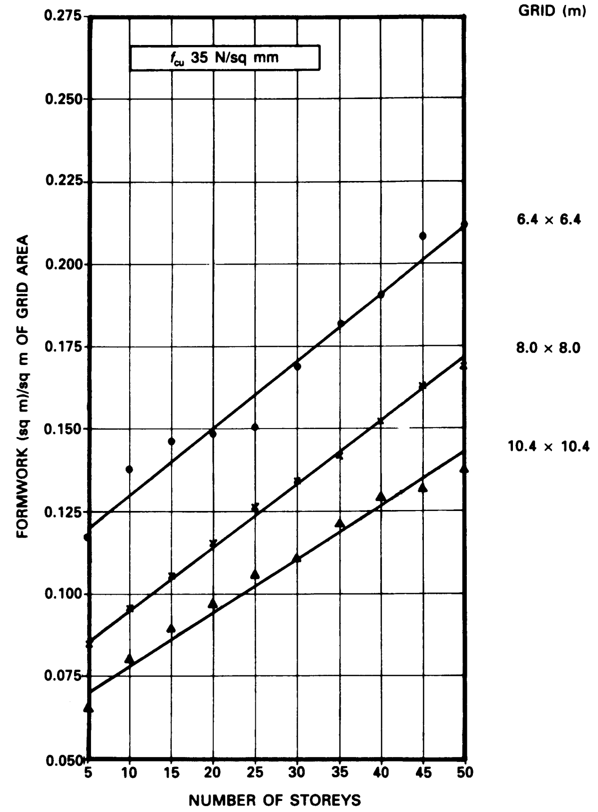


Figure 4.73 Quantities of formwork in exterior columns for waffle slab construction without column heads: 35 N/mm^2.

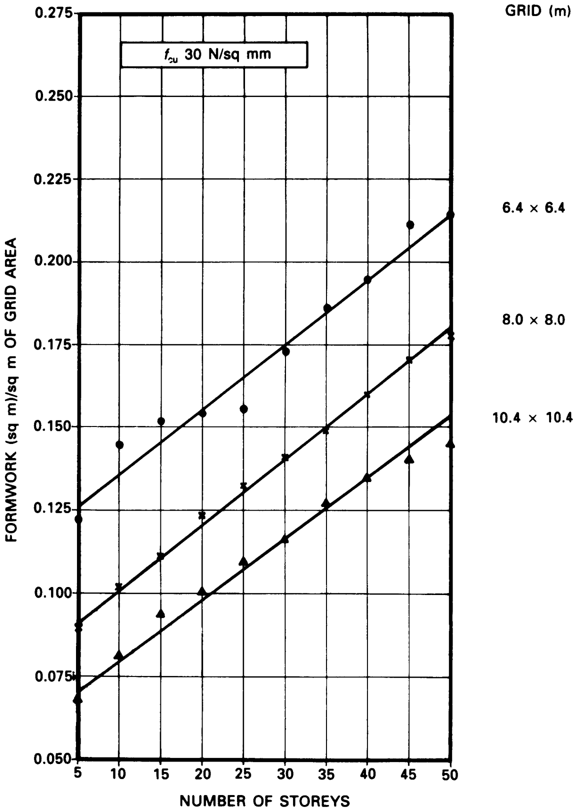


Figure 4.72 Quantities of formwork in exterior columns for waffle slab construction without column heads: 30 N/mm^2.

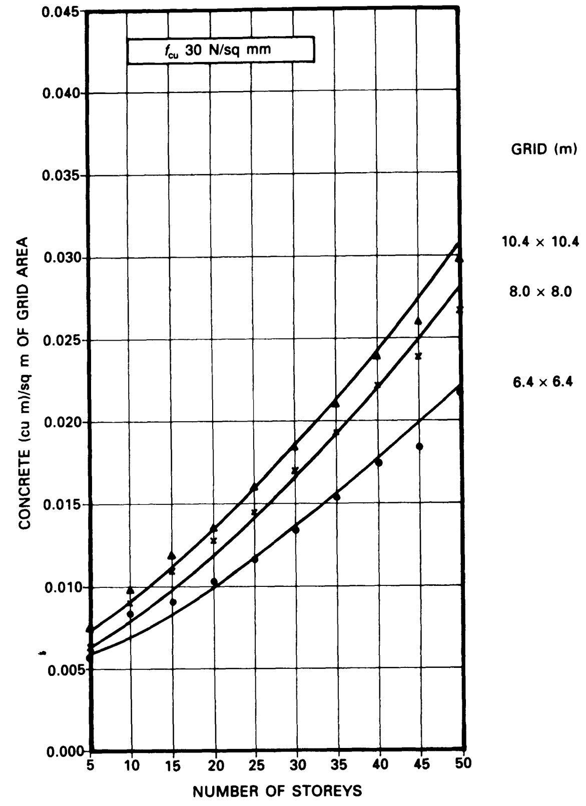


Figure 4.75 Quantities of concrete in corner columns for waffle slab construction without column heads: 30 N/mm^2.

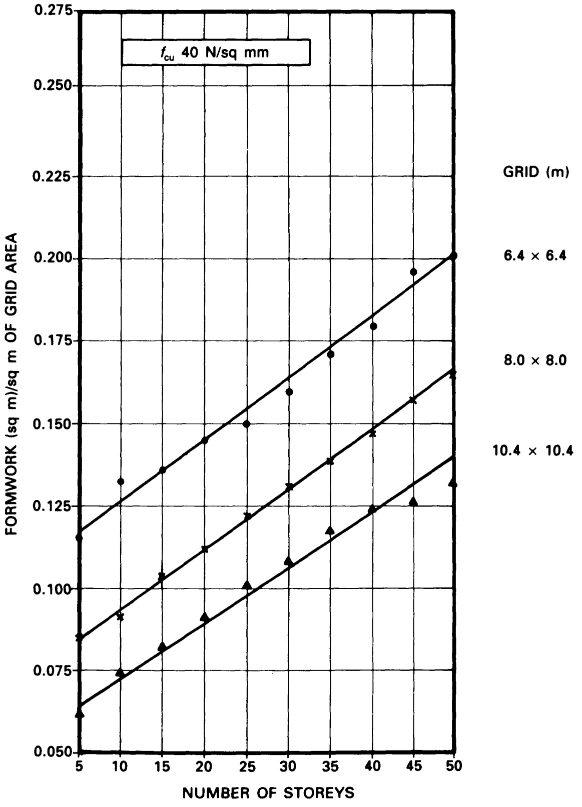


Figure 4.74 Quantities of formwork in exterior columns for waffle slab construction without column heads: 40 N/mm^2.

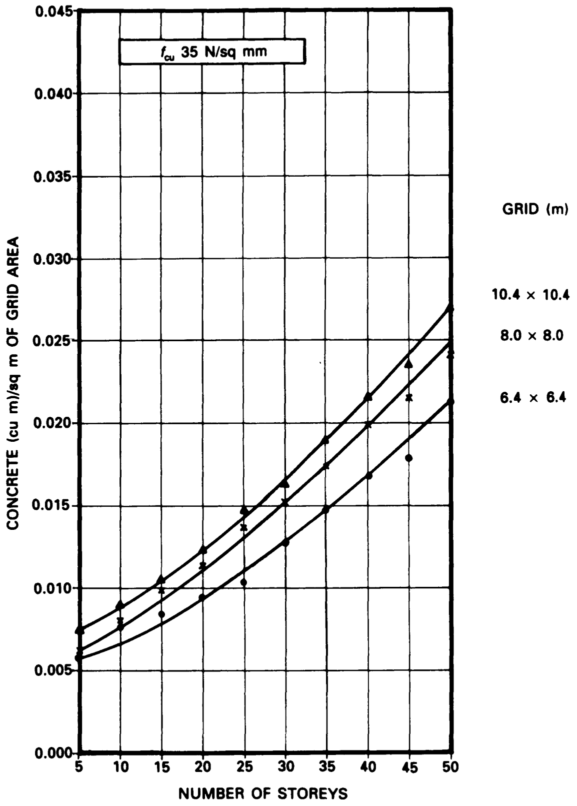


Figure 4.76 Quantities of concrete in corner columns for waffle slab construction without column heads: 35 N/mm^2.

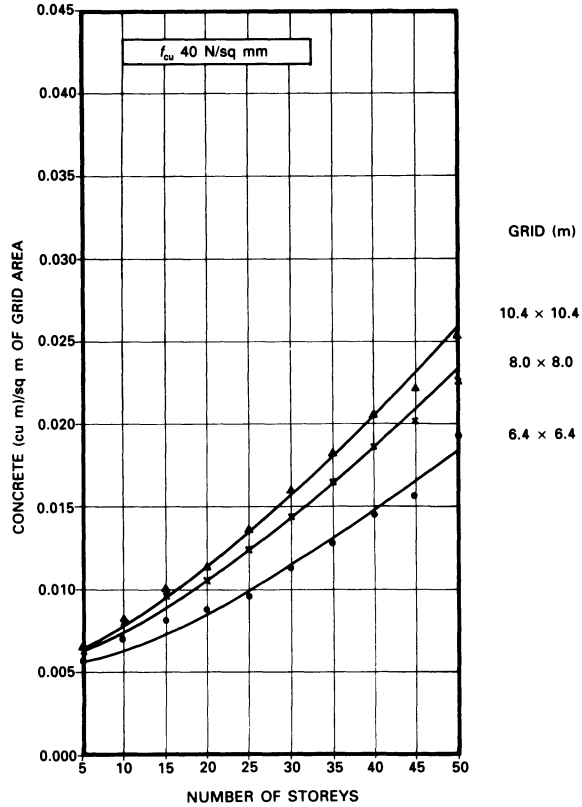


Figure 4.77 Quantities of concrete in corner columns for waffle slab construction without column heads: 40 N/mm^2.

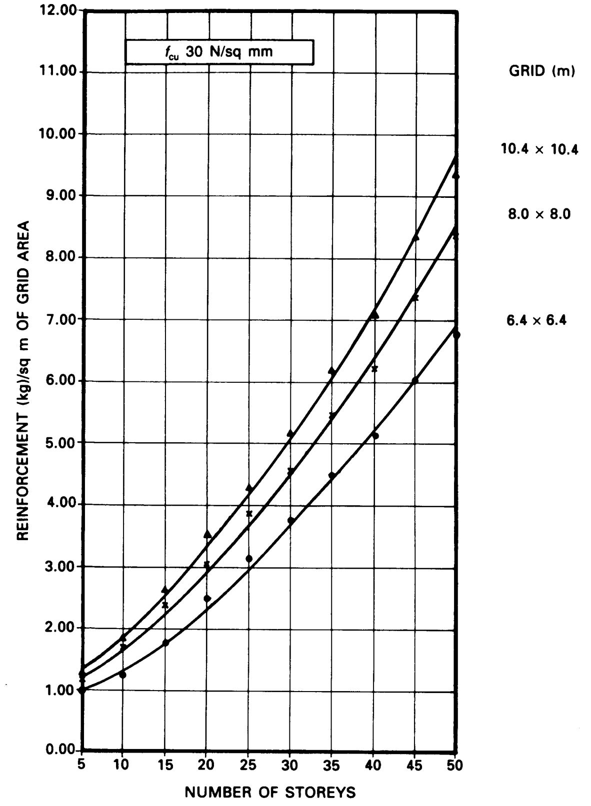


Figure 4.78 Quantities of reinforcement in corner columns for waffle slab construction without column heads: 30 N/mm^2.

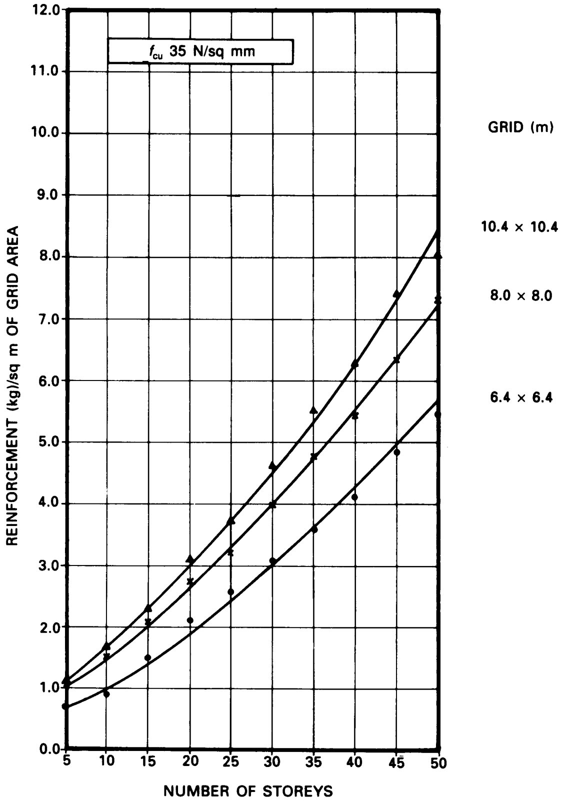


Figure 4.79 Quantities of reinforcement in corner columns for waffle slab construction without column heads: 35 N/mm^2.

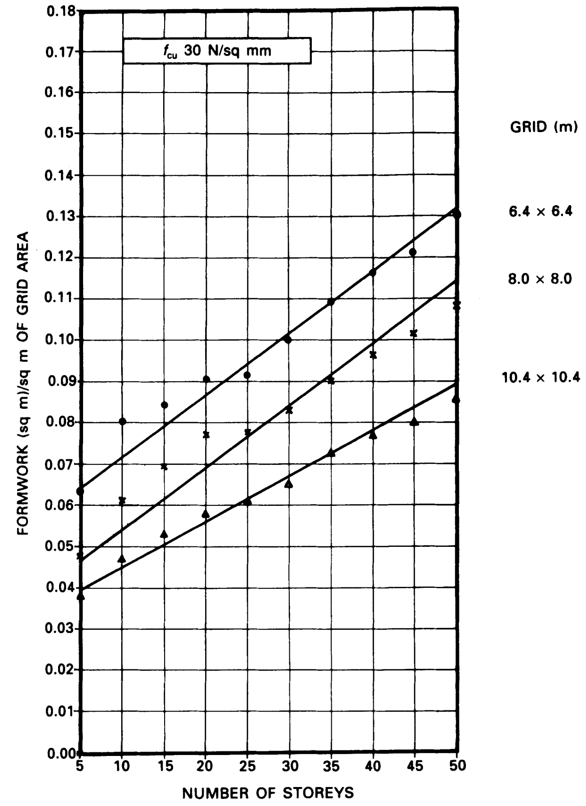


Figure 4.81 Quantities of formwork in corner columns for waffle slab construction without column heads: 30 N/mm^2.

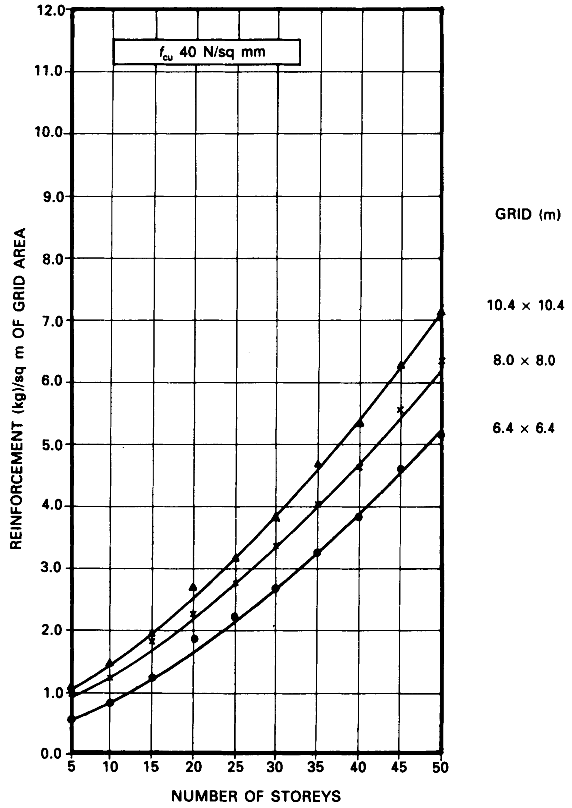


Figure 4.80 Quantities of reinforcement in corner columns for waffle slab construction without column heads: 40 N/mm^2.

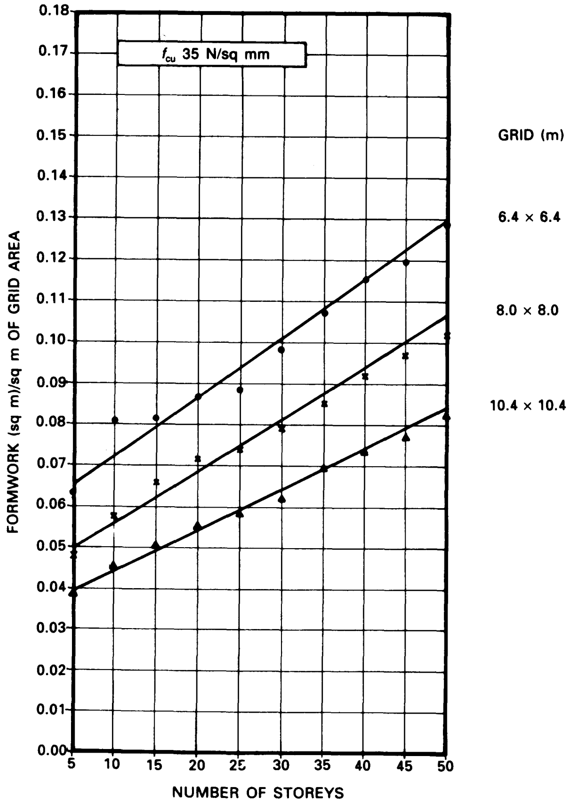


Figure 4.82 Quantities of formwork in corner columns for waffle slab construction without column heads: 35 N/mm^2.

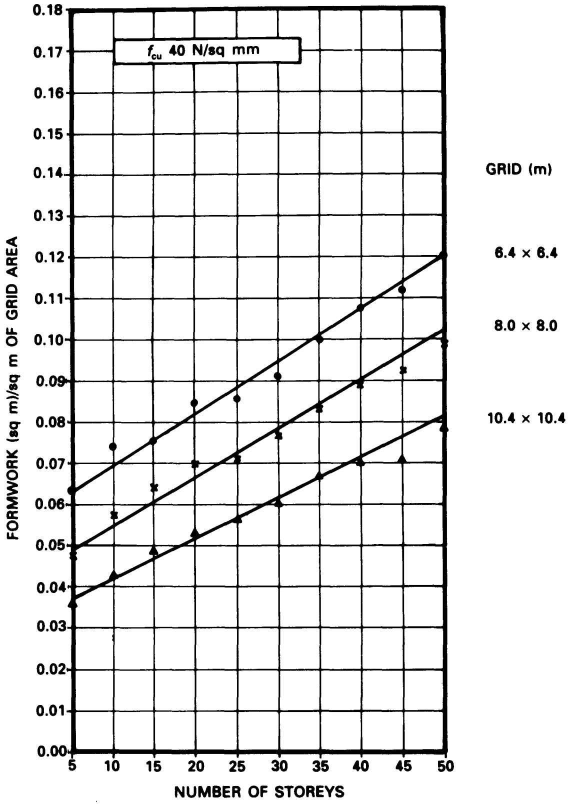


Figure 4.83 Quantities of formwork in corner columns for waffle slab construction without column heads: 40 N/mm^2.

4.4.4 Shear Walls

Quantities (per unit area) of constituents in shear walls for flat and waffle slab schemes are illustrated in Figures 4.84 to 4.87 for different numbers of storeys of construction.

4.4.5 Total Structure

The relationships between the number of storeys and quantities per square metre of floor area for different design parameters could be established based on the results already presented in this section. However, for uniformity (Section 3.4.5) the relationships for total structure are presented for an interior grid and for different grid sizes in Chapter 7.

4.5 Effect of Number of Spans on Constituent Quantities

The effect of different numbers of spans on constituent quantities for structures using flat and waffle slabs is similar to that discussed in the previous chapter. Thus the multiplying factors shown in Tables 3.2 and 3.3 to adjust the constituent quantities for columns and shear walls can be used, if required.

4.6 Effect of Number of Shopping Floors

Office floors were considered for the charts developed (Figures 4.3 to 4.87). However, to adjust the constituent quantities for any structure having 1 to 5 shopping floors, multiplying factors as provided in the previous chapter (Table 3.4) can be used to adjust the constituent quantities shown in the figures in this chapter.

4.7 Computing Constituent Quantities for Structures

Guidelines given under Section 3.7 can be used to compute constituent quantities for slabs, columns and shear walls.

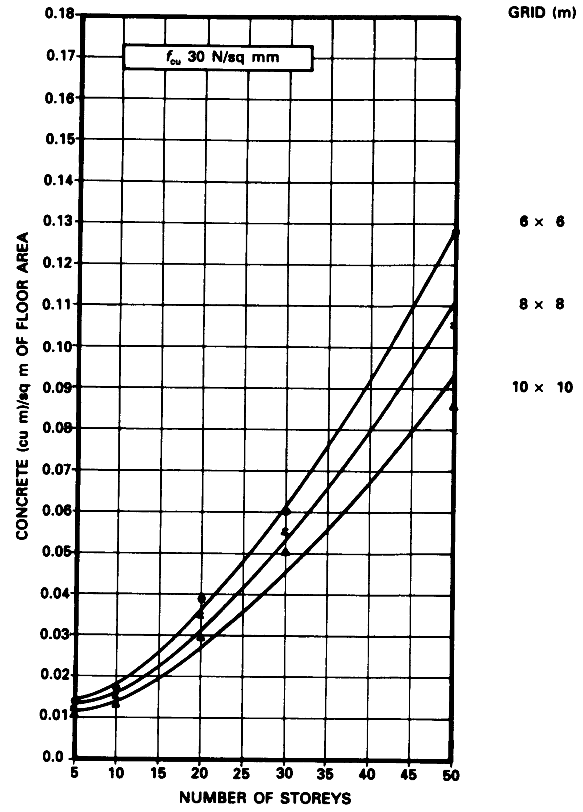


Figure 4.84 Quantities of concrete in shear walls for flat or waffle slab construction.

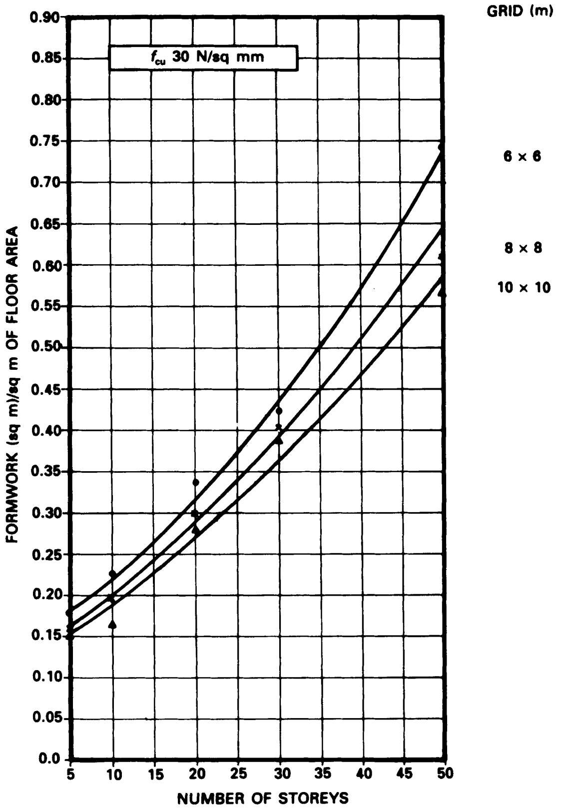


Figure 4.85 Quantities of formwork in shear walls for flat or waffle slab construction.

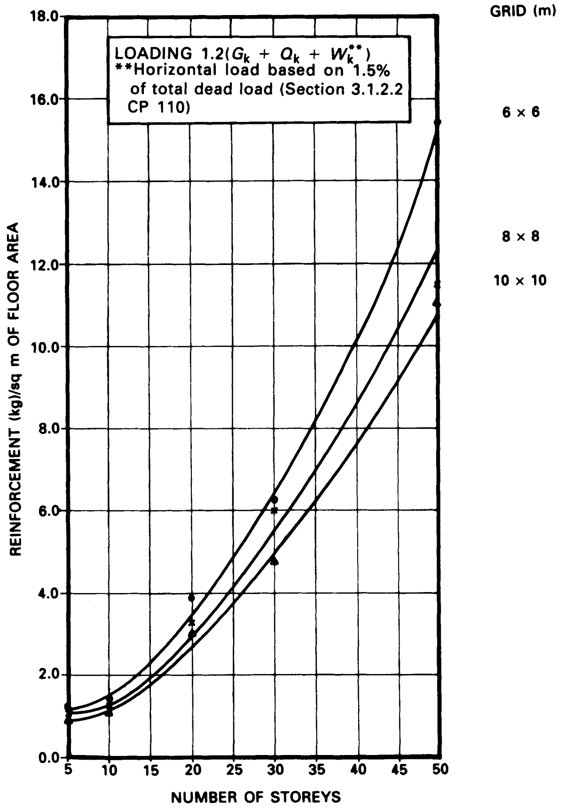


Figure 4.86 Quantities of reinforcement in shear walls for flat slab construction.

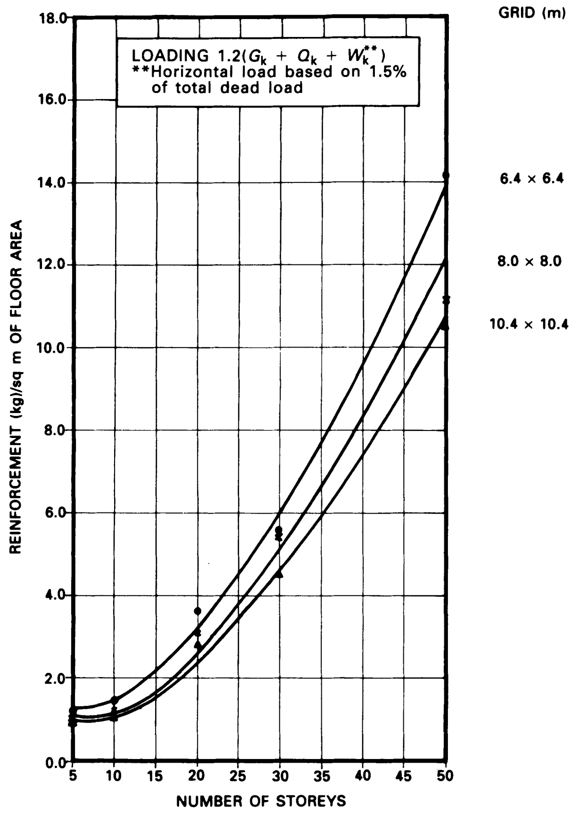


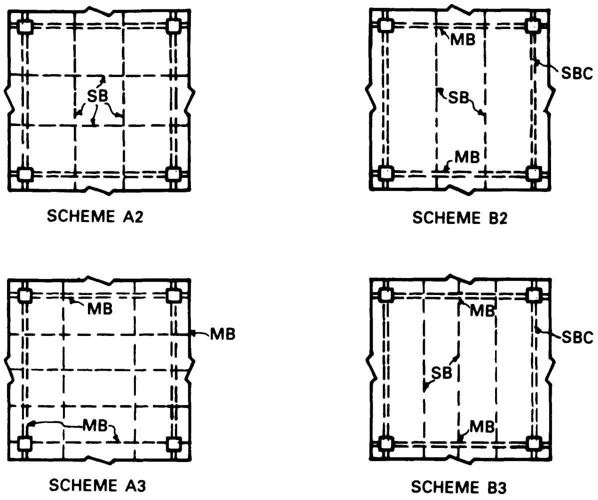
Figure 4.87 Quantities of reinforcement in shear walls for waffle slab construction.

References

1. Mosley, W.H. and Bungey, J.H. *Reinforced Concrete Design*. Macmillan Press, London, 4th edn, 1990, pp. 114.
2. GKN (UK) Pte. Ltd. *GKN Floors M Moulds*, April l977, London.
3. Singh, S. *Cost models for approximate cost estimation of structural systems in commercial high rise buildings*. PhD thesis, Vol. 2, National University of Singapore, 1986.
4. *BS 8110: Part 1: British Standard for the Structural Use of Concrete – Code of Practice for Design and Construction*. British Standard Institution, London, 1985.
5. Royal Institution of Chartered Surveyors and Building Employers Confederation. *Standard Method of Measurement of Building Works*, 7th edn, London, 1988.

5 Prestressed Concrete Beam and Reinforced Concrete Slab System

Using a prestressed concrete beam and an RC slab system, the effects of design parameters such as column grid size, location of structural element, number of storeys, arrangement of beams and the grade of concrete on the quantities of the various constituents of reinforced and prestressed concrete construction have been investigated for square grids varying from 10 m × 10 m to 14 m × 14 m.



NOTATION: MB - MAIN BEAM
SB - SECONDARY BEAM
SBC - SECONDARY BEAM OVER COLUMNS

Figure 5.1 Designation of structural schemes and components (prestressed beams and RC slab construction).

5.1 Introduction

Prestressed concrete structures have been found to be more suitable than reinforced concrete structures for long spans and heavy loads. In the case of commercial buildings, though the loads are not so heavy as in the case of certain other types of buildings structures, there is a general tendency to go for larger spans especially in podium blocks with the objective of achieving greater column-free space. From this aspect it was considered worthwhile to examine the use of prestressed post-tensioned beams in conjunction with traditional solid slab and columns as a structural system for the buildings under study, and to investigate the effect of different design parameters on the quantities of constituents. A parabolic profile of prestressing strands in the beams was considered. The analysis and design procedures for such structural systems have been presented in this chapter.

Results presented in this chapter can form the basic data for an interactive computer program using the prestressed concrete beam and RC slab system.

5.2 Structures

Three square grids, with sides of 10, 12 and 14 m for structural schemes with slabs spanning in one or both directions were considered as shown in Figure 5.1. Structural arrangements with a minimum of two secondary beams were adopted since Singh and Murthy [1] have shown that, compared to having one secondary beam, such arrangements were more economical.

5.3 Loadings

Vertical and lateral loadings as described in Sections 3.2.1 and 3.2.2 were considered for the analysis of frames.

5.4 Analysis of Frames

The analyses for vertical and lateral loads were carried out in a manner similar to those described in Sections 3.2.4 and 3.2.5. The dead load was considered in two parts, namely the self weight of the beam and slab (Gk1) and the weight of ceiling, finishes and partitions (Gk2). The bending moments derived by loading all the spans with Gk1 was necessary for checking serviceability limit state stresses at the time of transfer. The combined effects of Gk1, Gk2 and the imposed loads with pattern loading to give the most severe stresses were determined for checking the final stresses.

Factored loads as discussed in Sections 3.2.4 and

3.2.5 were used in the analyses to determine moments and shears for the ultimate limit state design.

5.5 Design of Structural Members

Design of structural members was carried out according to the requirements given in British Standard BS 8110: Part 1: 1985 using computer programs developed by the author with the additional capability of computing the quantities of concrete, reinforcement and formwork. Characteristic strengths of 35 N/mm^2, 460 N/mm^2 and 1874 N/mm^2 were considered for concrete, high yield steel and prestressing strands respectively.

5.5.1 *Solid Slabs*

The computer program described in Section 3.3.1 was used to design slabs spanning in one or two directions at right angles. The coefficients given in BS 8110 for one-way continuous slabs and two-way restrained slabs were used. A minimum slab thickness of 100 mm was assumed. Requirements of minimum and maximum areas of reinforcements as codified were adopted and reinforcement spacing rules to control cracking were taken care of. Further, overall depth of slab and spacing of reinforcement were adjusted so as to be in modules of 5 mm.

5.5.2 *Prestressed Beams*

Prestressed beams were designed as class 3 members [2] with a limiting crack width of 0.2 mm. A computer program [3] was developed by the author to determine the prestressing force required in the beams to satisfy the serviceability and ultimate limit states as required by BS 8110. In selecting a preliminary value for the prestressing force, the program assumed decompression to take place under the dead load of slab and beam as suggested by Ramaswamy [4] and Walther and Bahl [5].

The program then checks the beam sections for the ultimate limit state in accordance with section 4.3.7 of BS 8110 and provides untensioned steel, if necessary, to satisfy the requirement. The stresses at transfer and final are checked to see if the serviceability limit state according to section 4.3.4 of BS 8110 is satisfied. Additional untensioned steel is provided, if required, subject to the tensile stress at the final stage not exceeding the maximum permissible value of 7.8 N/mm^2 in accordance with section 4.3.4.3 of BS 8110. Finally, if any of the stresses at the transfer and final stages exceed the permissible limits, the depth of the beam section is increased and the design process is repeated.

For main beams a minimum width based on a span–width ratio of 22 was considered and for depth, span–depth ratios of 18.75 to 19.4 were taken, the higher figure being for the longer spans. For secondary beams, the width was fixed at three-quarters that of main beams while keeping the same depth as that of main beams from deflection considerations.

5.5.3 *Columns*

The computer program described in Section 3.3.3 was used to design columns in denominations of 75 mm. As before, square column sections were considered for interior columns and the elevation of exposed columns was maintained the same in any specific number of storeys for aesthetic considerations. Further, after every 5-storey interval, the sections of columns were reduced where possible for economy and within the same section the reinforcement was varied for each storey if feasible, depending upon the values of the forces.

5.5.4 *Shear Walls*

Shear walls were designed for different numbers of storeys of construction based on the considerations described in Section 3.3.4.

5.6 Quantities of Constituents

As in the reinforced concrete beam and slab system (Chapter 3), the portion of the beam common with the slab has been measured with the latter in accordance with the Standard Method of Measurement (6) and the common portion of slabs, beams and columns has been accounted for in columns.

5.6.1 *Solid Slabs*

The quantities of concrete, reinforcement and formwork per square metre of floor area for solid slabs in different panel locations and structural schemes are shown in Figures 5.2 to 5.6. In calculating the quantities of reinforcement for slabs, flange reinforcement for beams has been measured with the former in accordance with the Standard Method of Measurement [6].

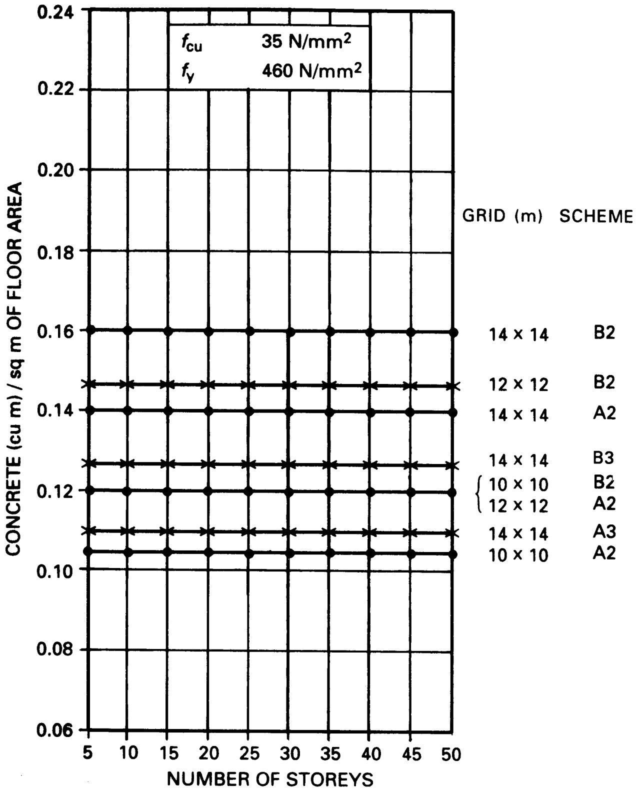


Figure 5.2 Quantities of concrete in slabs for prestressed concrete beam and RC slab construction.

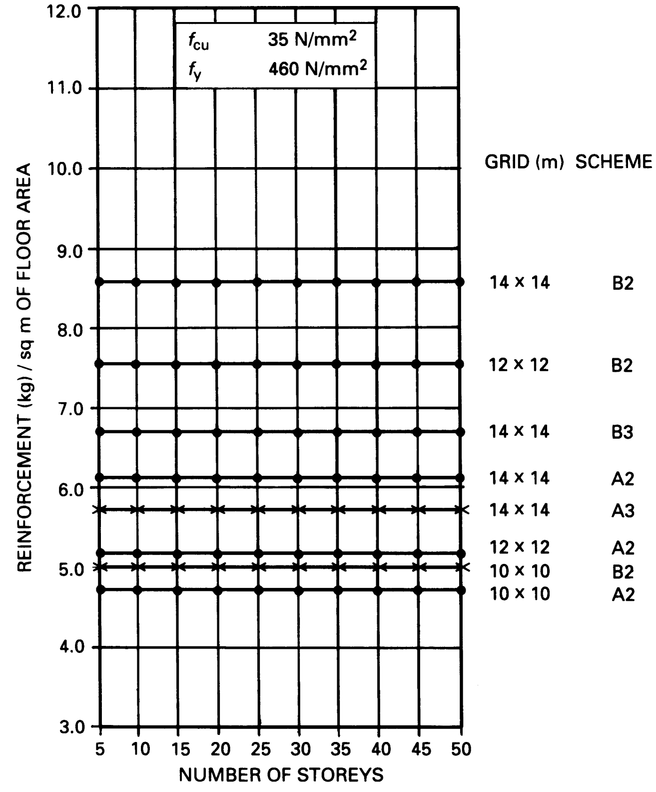


Figure 5.3 Quantities of reinforcement in slabs – interior panels.

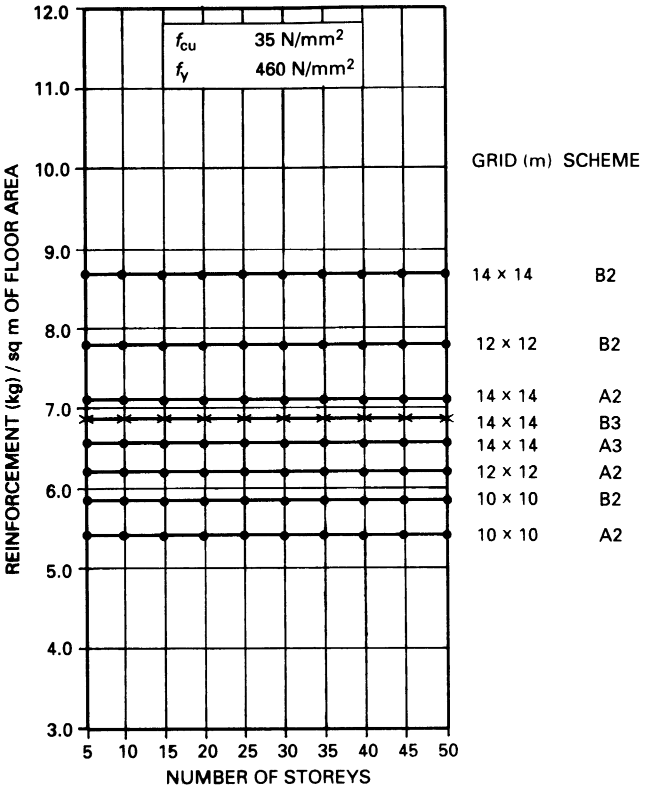


Figure 5.4 Quantities of reinforcement in slabs – first interior panel (slabs spanning in one direction) and panel with one edge discontinuous (slabs spanning in two directions).

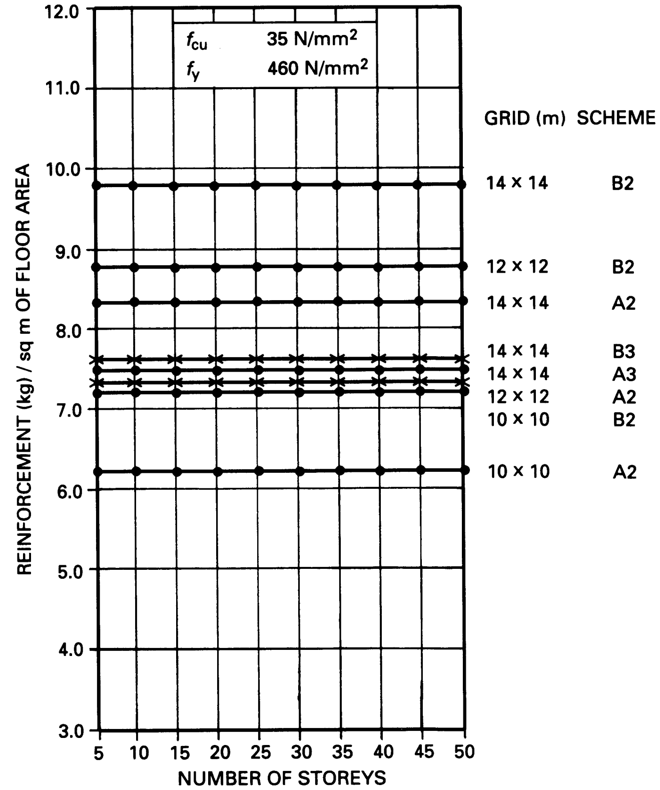


Figure 5.5 Quantities of reinforcement in slabs – edge panel (slabs spanning in one direction) and panel with two edges discontinuous (slabs spanning in two directions).

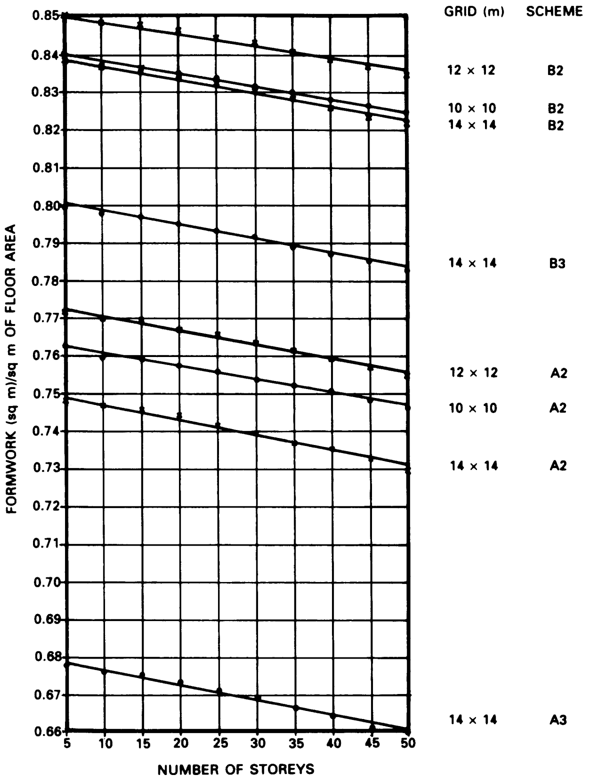


Figure 5.6 Quantities of formwork in slabs for prestressed concrete beam and RC slab construction.

5.6.2 *Prestressed Beams*

The quantities of constituents in main prestressed beams for different grid sizes and grid locations are shown in Figures 5.7 to 5.9 for concrete, Figures 5.10 to 5.13 for reinforcement, Figures 5.14 to 5.16 for prestressing strands and Figures 5.17 to 5.19 for formwork.

The quantities of constituents in prestressed secondary beams are shown in Figures 5.20, 5.21 to 5.25 and 5.26 for concrete, reinforcement and formwork respectively.

The quantities of constituents in prestressed secondary beams over columns are shown in Figures 5.27 and 5.28, Figures 5.29 to 5.32, Figures 5.33 and 5.34 and Figures 5.35 and 5.36 for concrete, reinforcement, prestressing strands and formwork respectively.

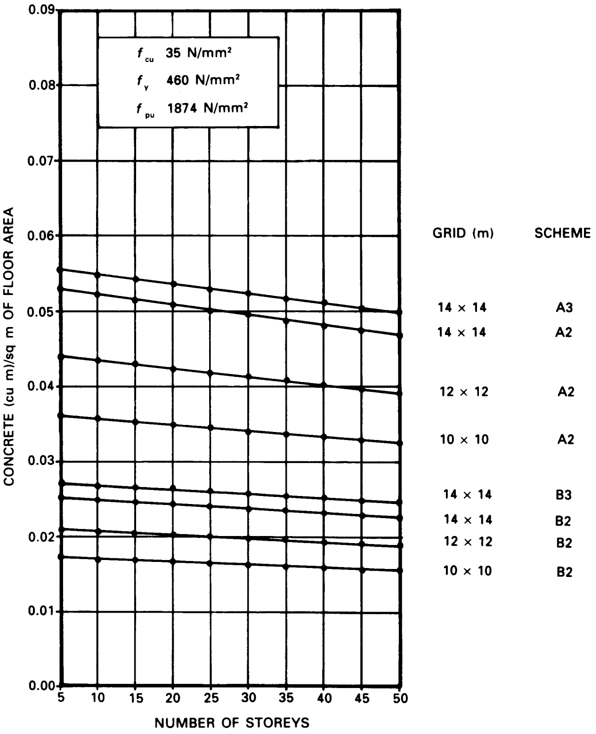


Figure 5.7 Quantities of concrete in main beams in interior/first interior grids.

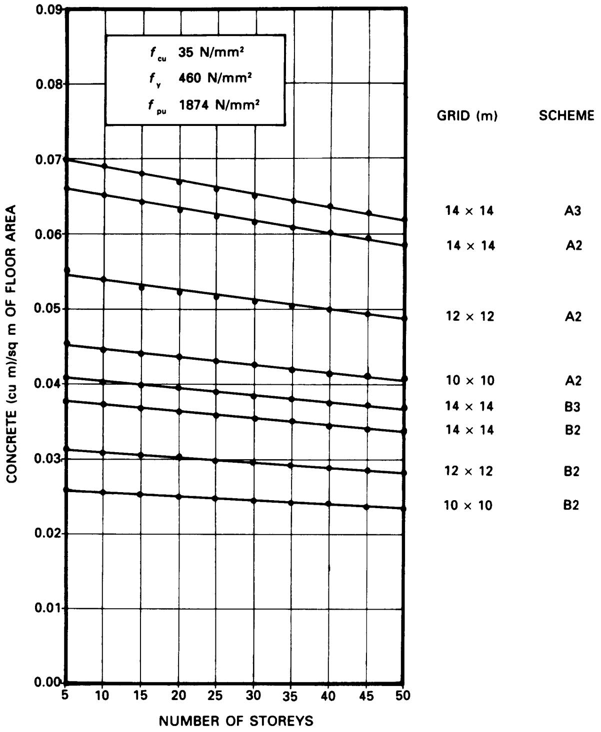


Figure 5.8 Quantities of concrete in main beams in the external grid.

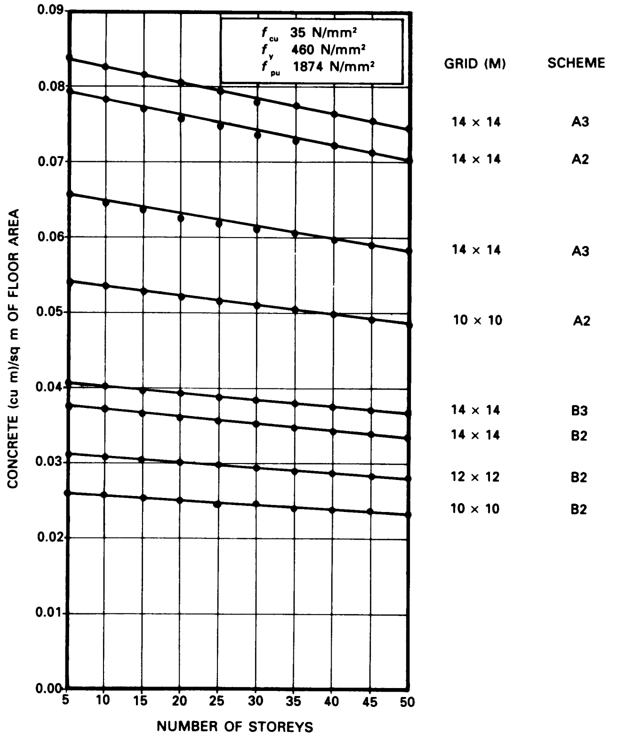


Figure 5.9 Quantities of concrete in main beams in the corner grid.

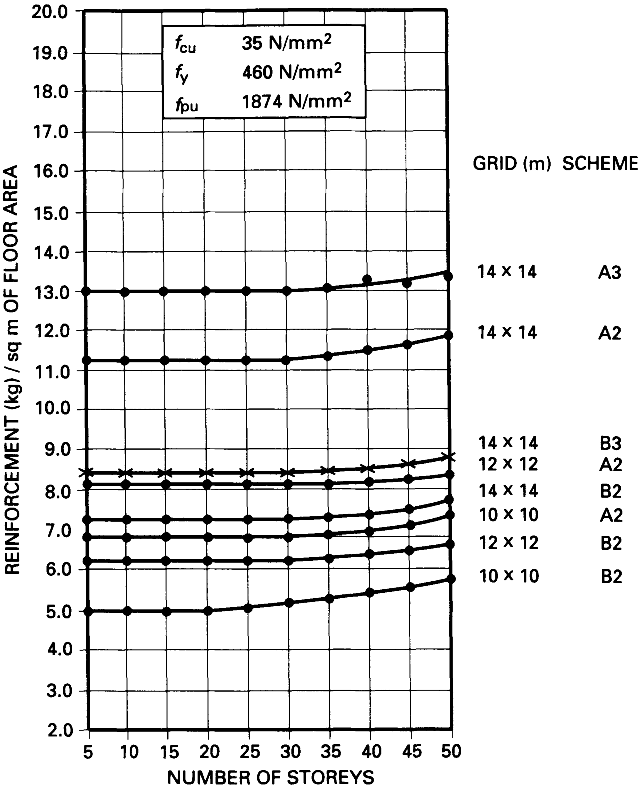


Figure 5.10 Quantities of reinforcement in main beams in the interior grid.

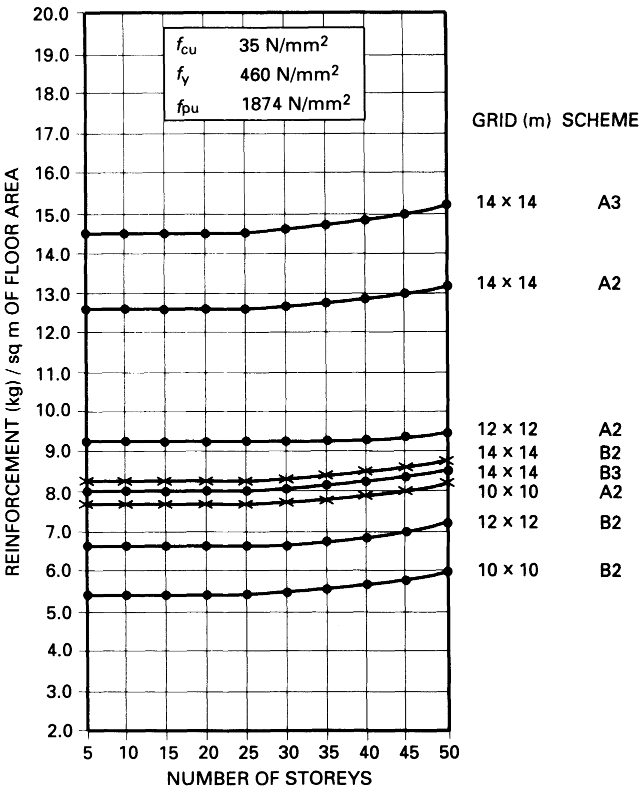


Figure 5.11 Quantities of reinforcement in main beams in the first interior grid.

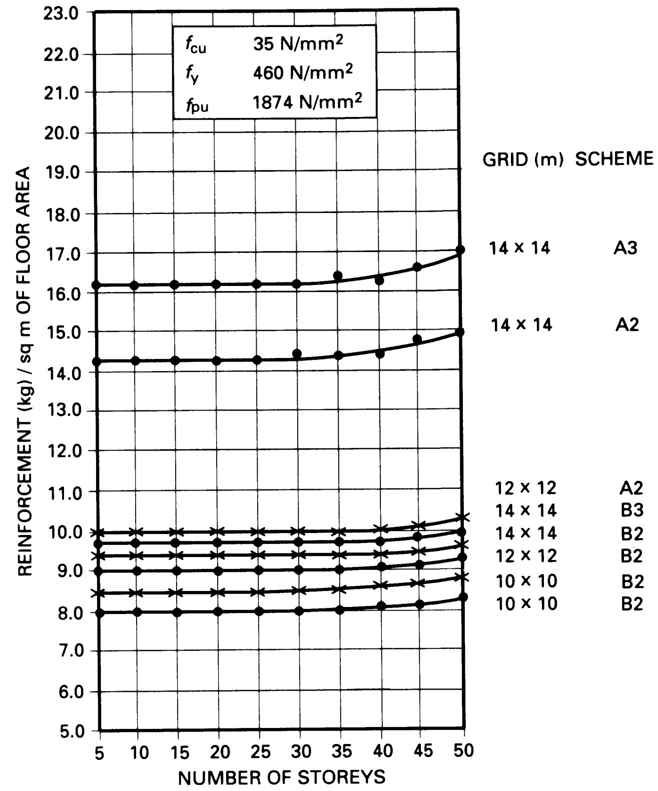


Figure 5.13 Quantities of reinforcement in main beams in the corner grid.

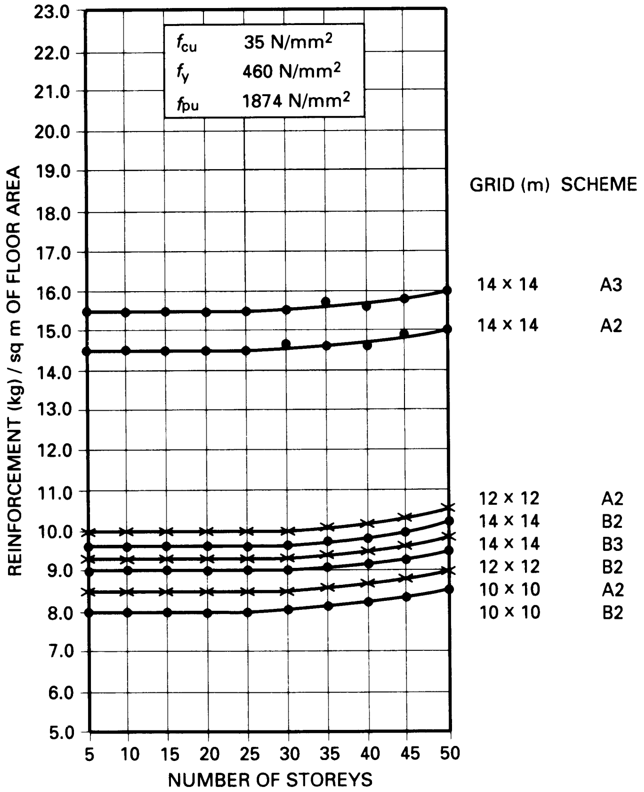


Figure 5.12 Quantities of reinforcement in main beams in the external grid.

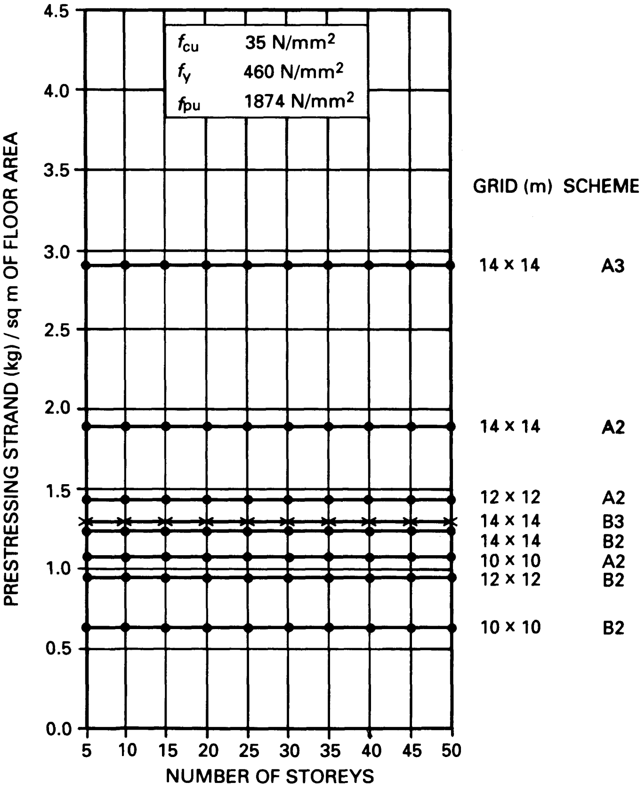


Figure 5.14 Quantities of prestressing strands in main beams in interior/first interior grids.

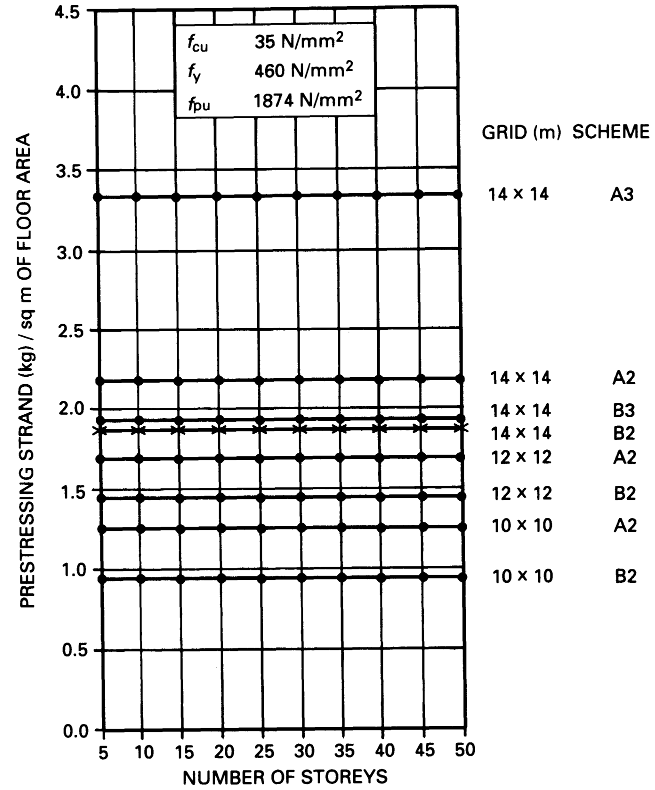


Figure 5.15 Quantities of prestressing strands in main beams in the corner grid.

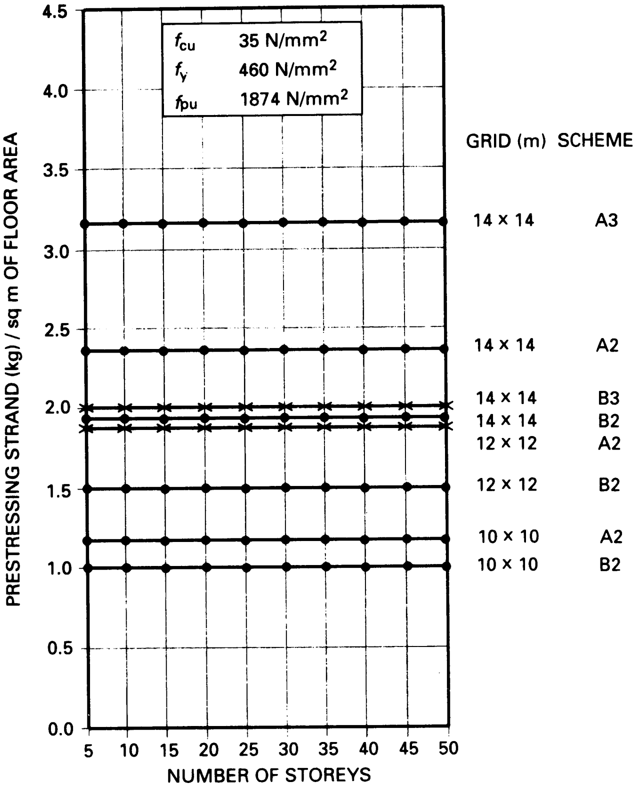


Figure 5.16 Quantities of prestressing strands in main beams in the external grid.

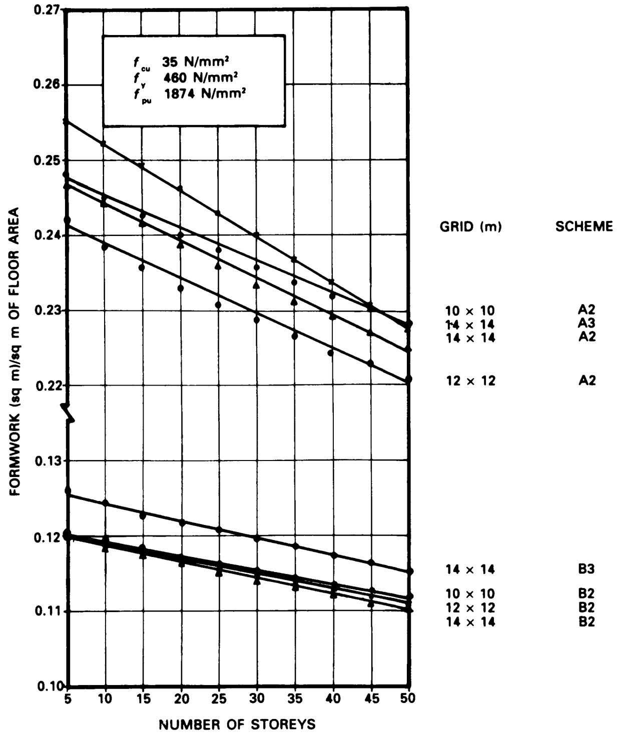


Figure 5.17 Quantities of formwork in main beams in interior/first interior grids.

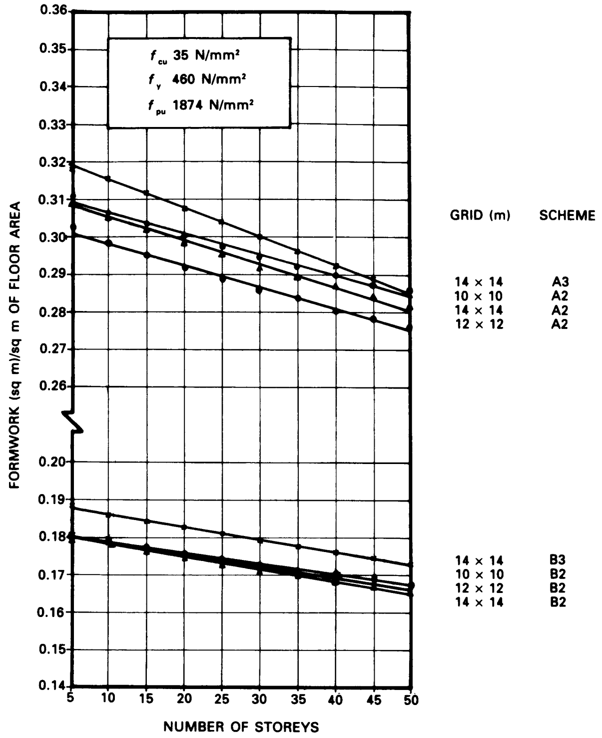


Figure 5.18 Quantities of formwork in main beams in the external grid.

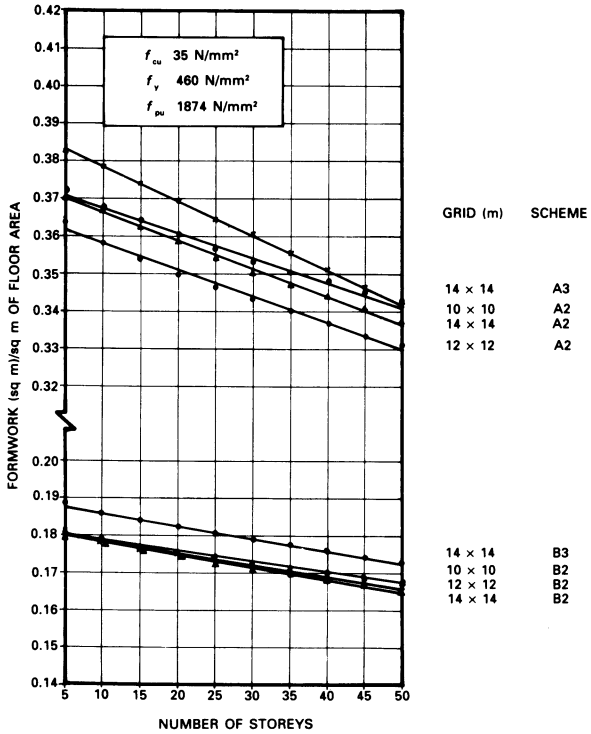


Figure 5.19 Quantities of formwork in main beams in the corner grid.

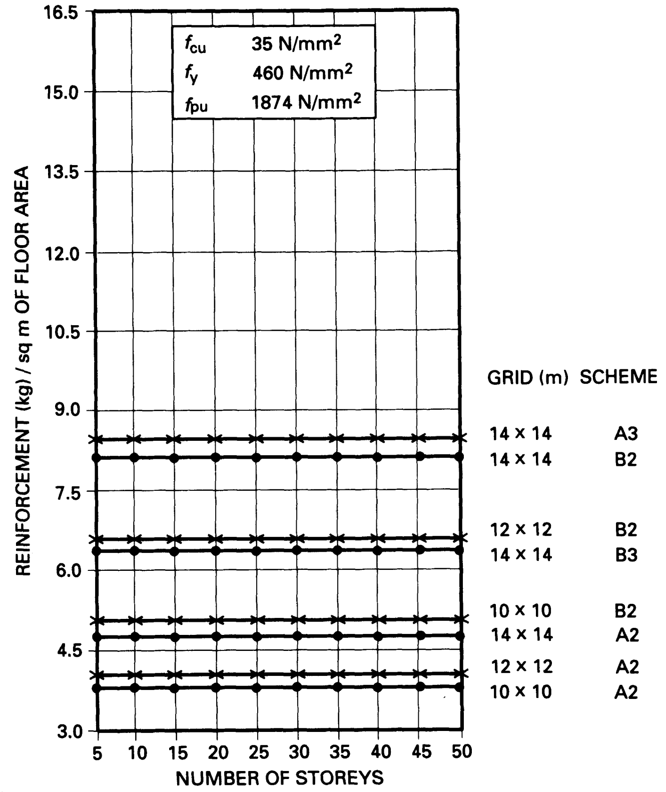


Figure 5.21 Quantities of reinforcement in prestressed secondary beams in the interior grid.

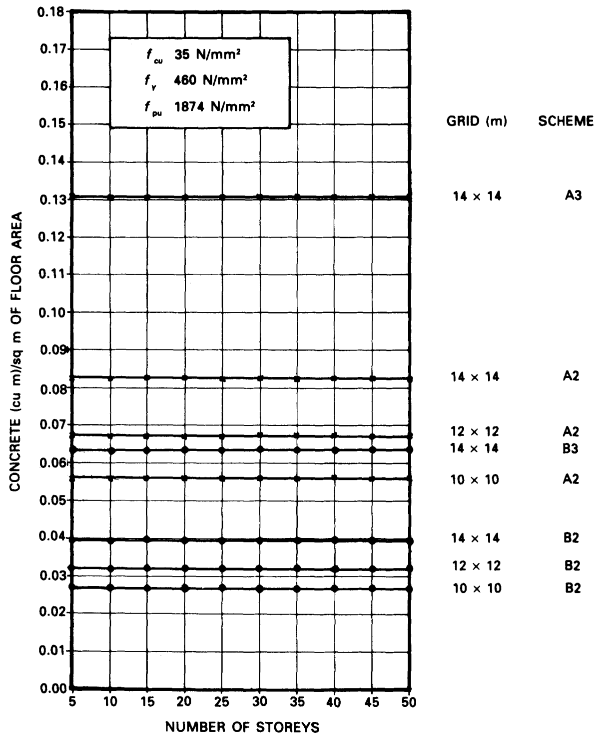


Figure 5.20 Quantities of concrete in secondary beams.

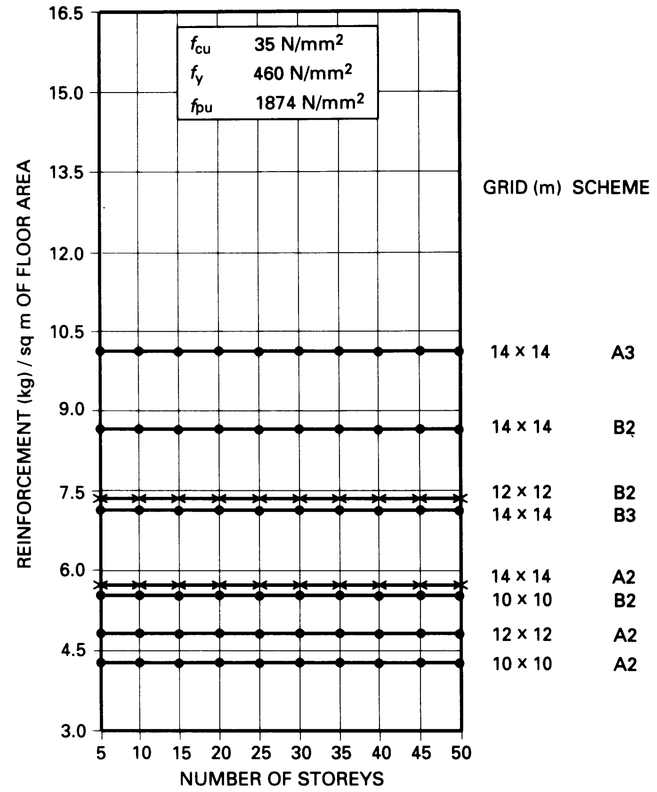


Figure 5.23 Quantities of reinforcement in secondary beams in the external grid.

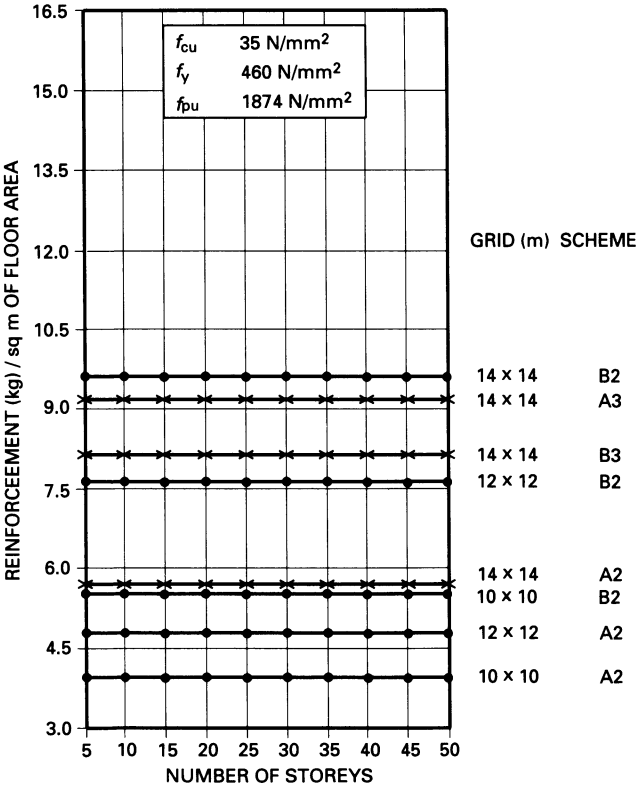


Figure 5.22 Quantities of reinforcement in secondary beams in the first interior grid.

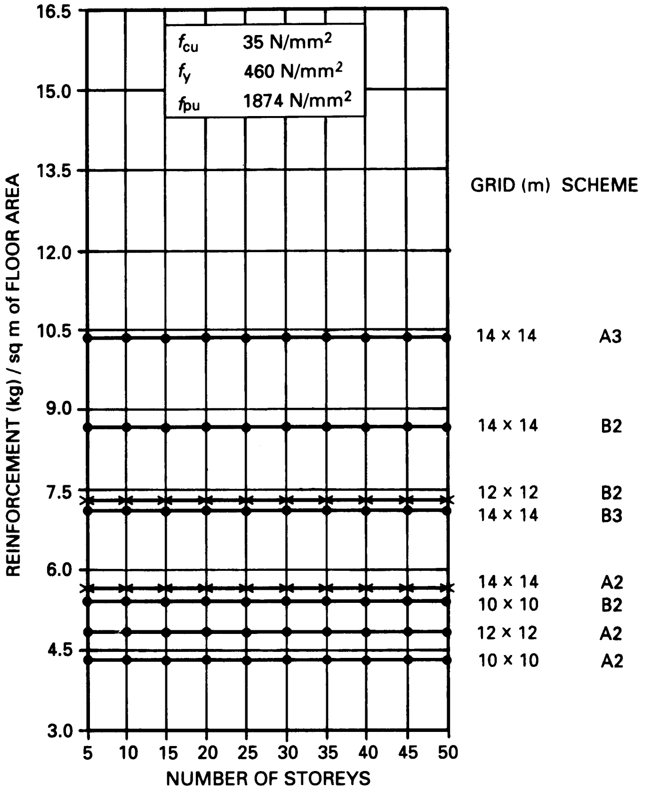


Figure 5.24 Quantities of reinforcement in secondary beams in the corner grid.

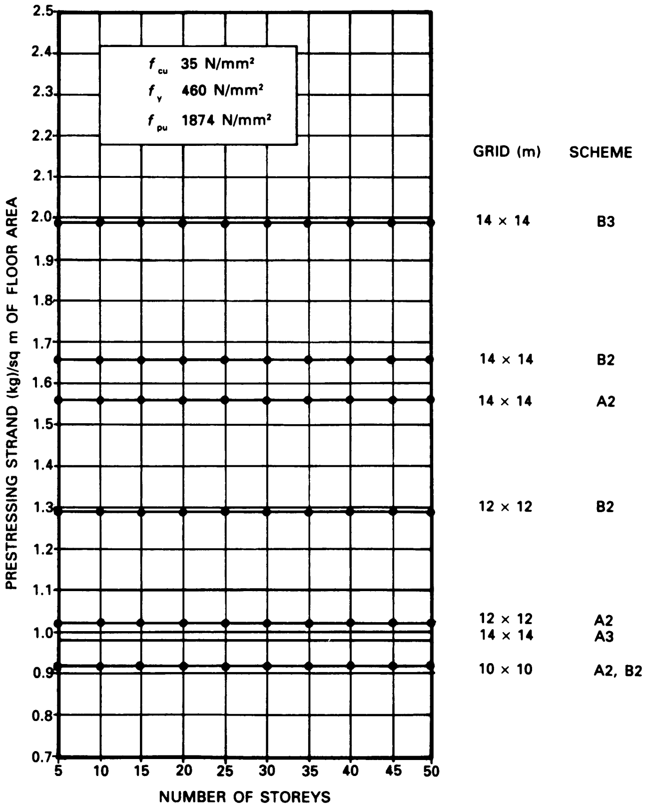


Figure 5.25 Quantities of prestressing strands in secondary beams.

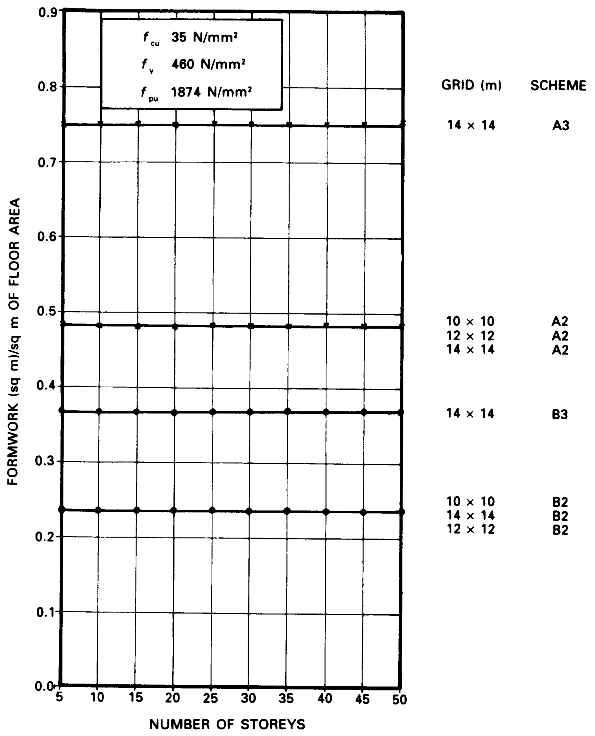


Figure 5.26 Quantities of formwork in secondary beams.

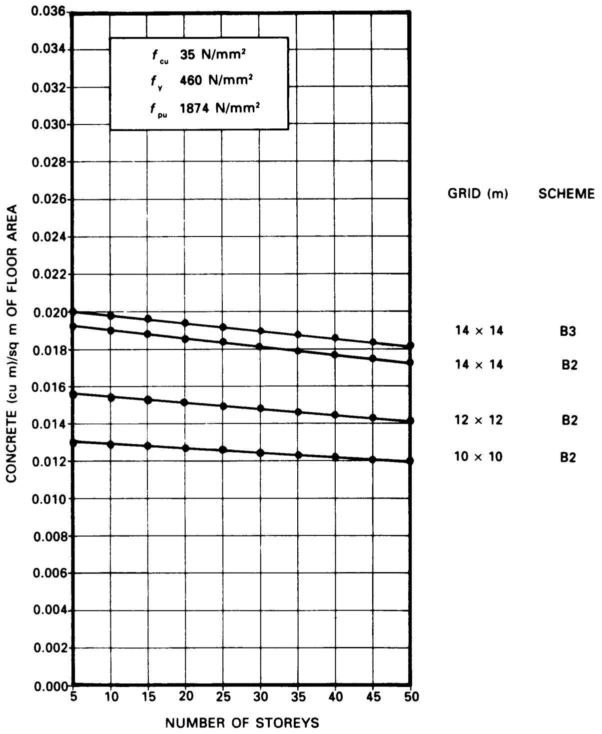


Figure 5.27 Quantities of concrete in secondary beams over columns – interior/first interior/external grids.

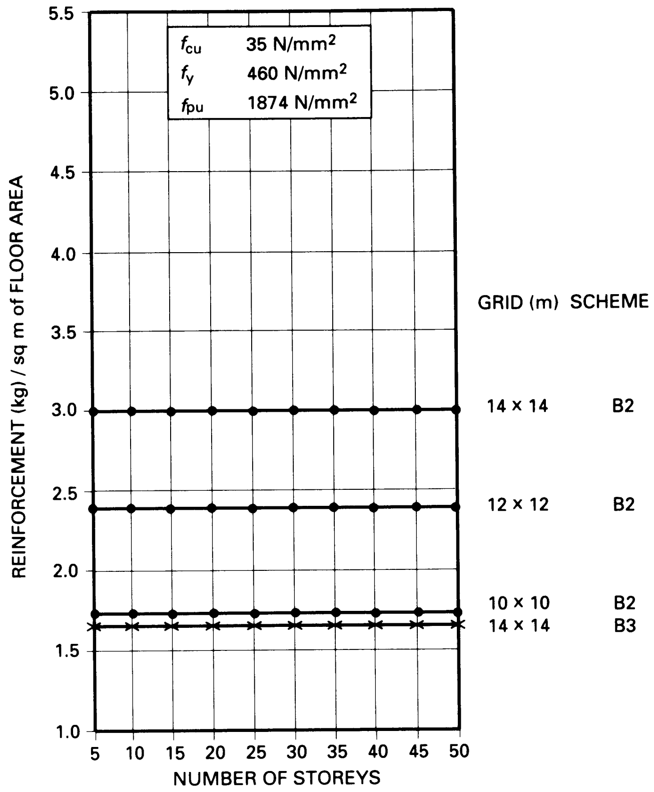


Figure 5.29 Quantities of reinforcement in secondary beams over columns – interior grid.

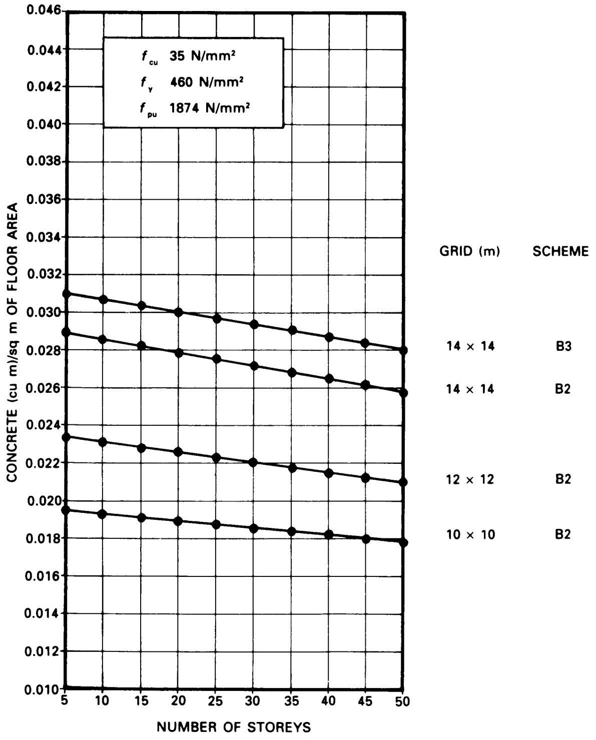


Figure 5.28 Quantities of concrete in secondary beams over columns – corner grid.

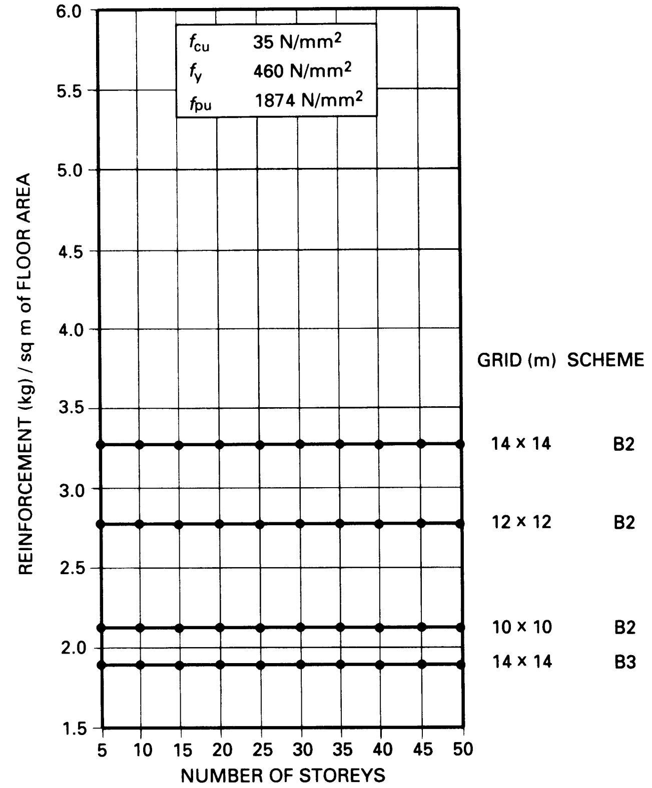


Figure 5.31 Quantities of reinforcement in secondary beams over columns – external grid.

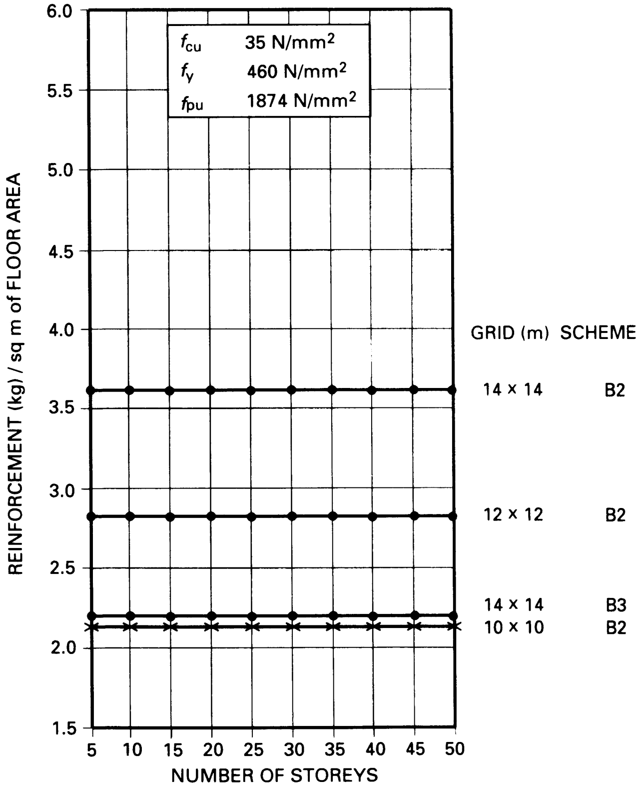


Figure 5.30 Quantities of reinforcement in secondary beams over columns – first interior grid.

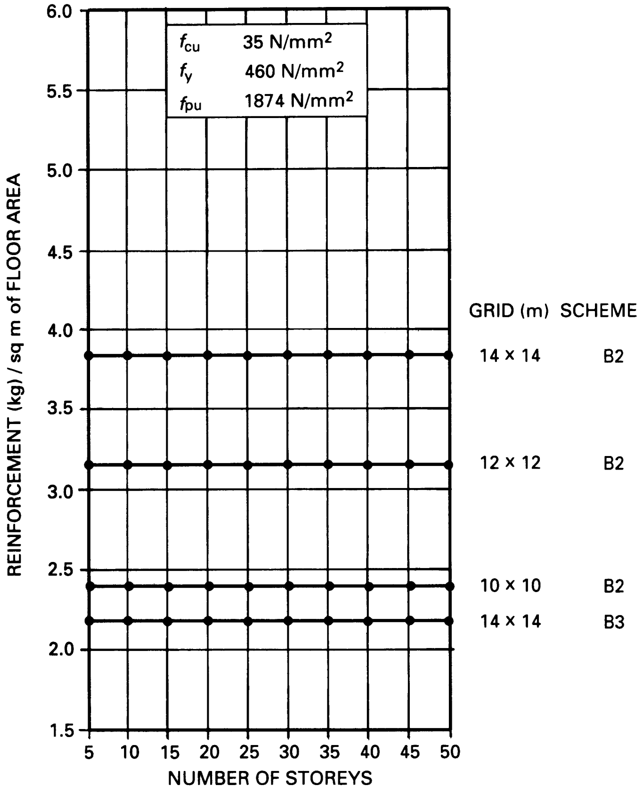


Figure 5.32 Quantities of reinforcement in secondary beams over columns – corner grid.

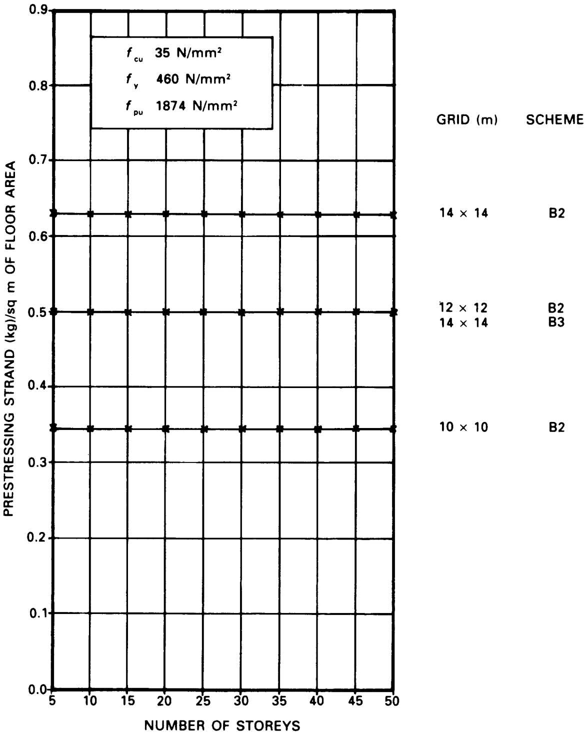


Figure 5.33 Quantities of prestressing strands in secondary beams over columns – interior/first interior/external grids.

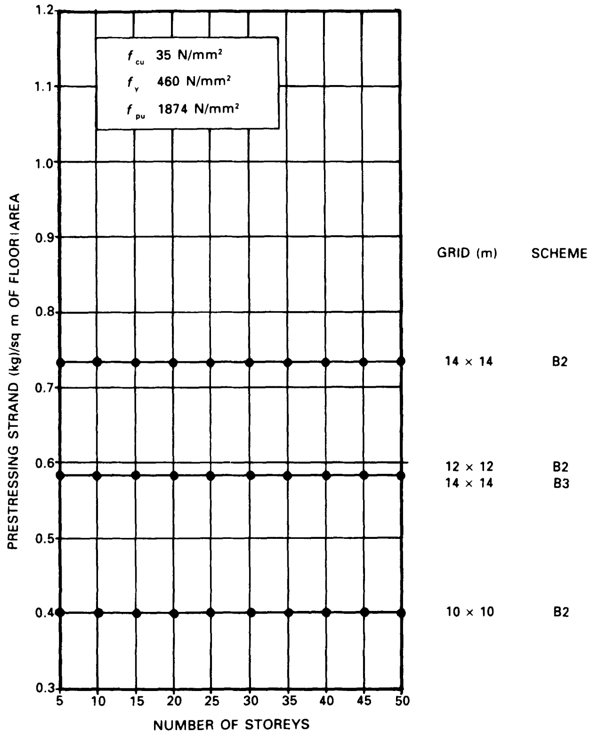


Figure 5.34 Quantities of prestressing strands in secondary beams over columns – corner grid.

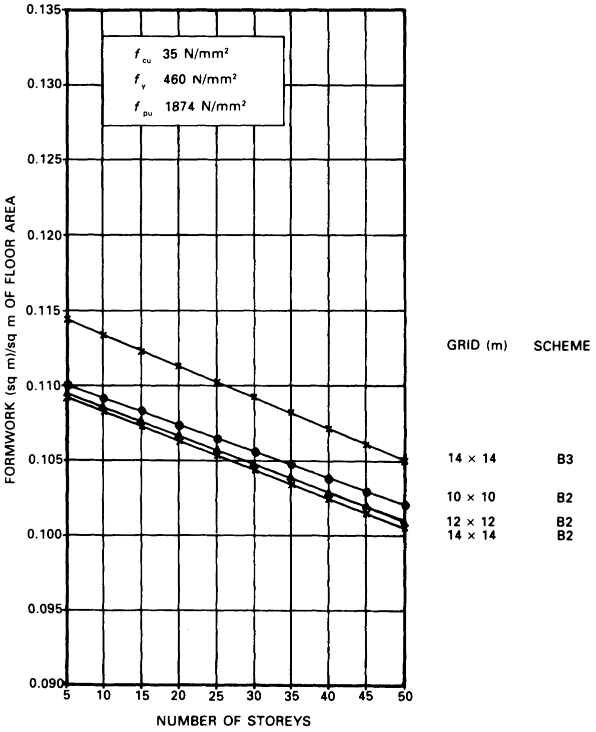


Figure 5.35 Quantities of formwork in secondary beams over columns – interior/first interior/external grids.

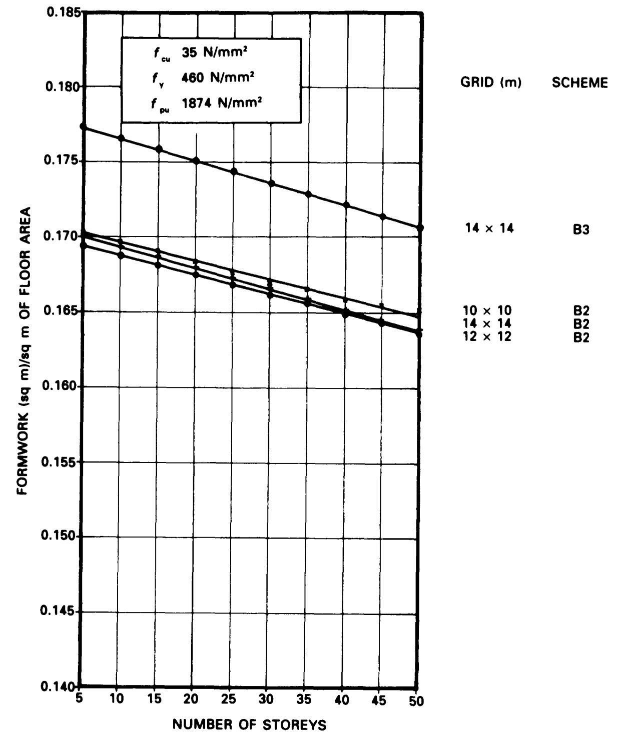


Figure 5.36 Quantities of formwork in secondary beams over columns – corner grid.

5.6.3 Columns

The quantities of constituents for the interior column of different grid sizes and structural schemes in terms of concrete, reinforcement and formwork are shown in Figures 5.37 to 5.39, while for exterior and corner columns the same parameters are shown in Figures 5.40 to 5.42 and Figures 5.43 to 5.45 respectively. The quantities of constituents for the interior column, using grade 40 concrete, are shown in Figures 5.46 to 5.48.

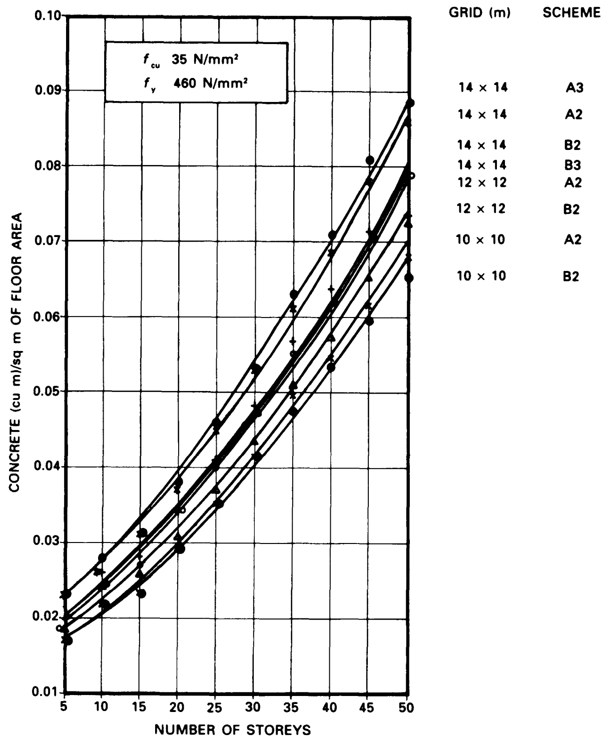


Figure 5.37 Quantities of concrete in columns – interior/first interior grids.

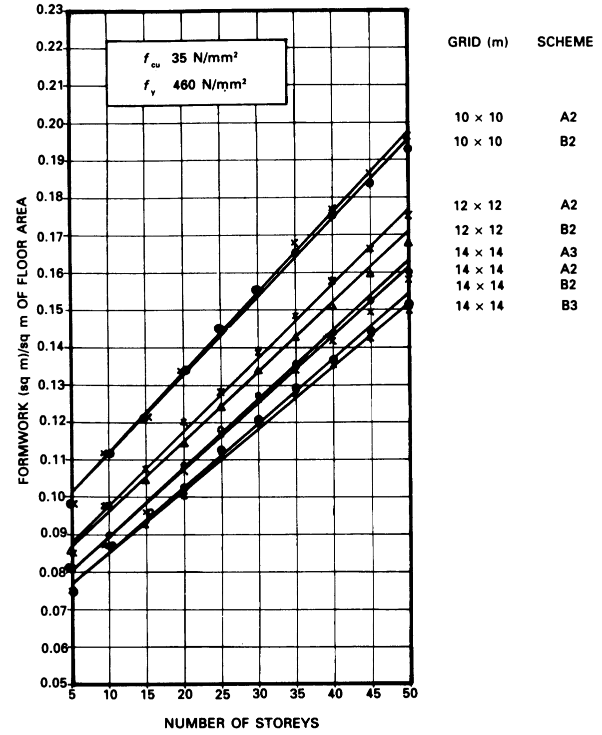


Figure 5.39 Quantities of formwork in columns – interior/first interior grids.

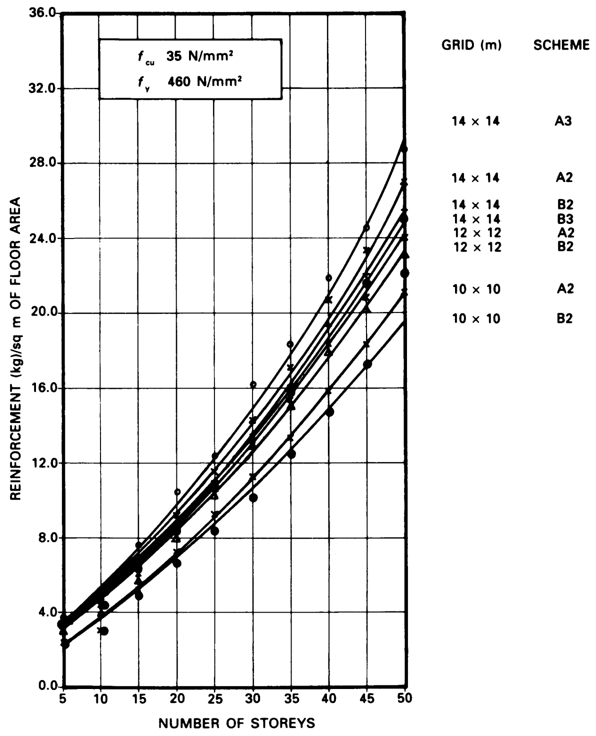


Figure 5.38 Quantities of reinforcement in columns – interior/first interior grids.

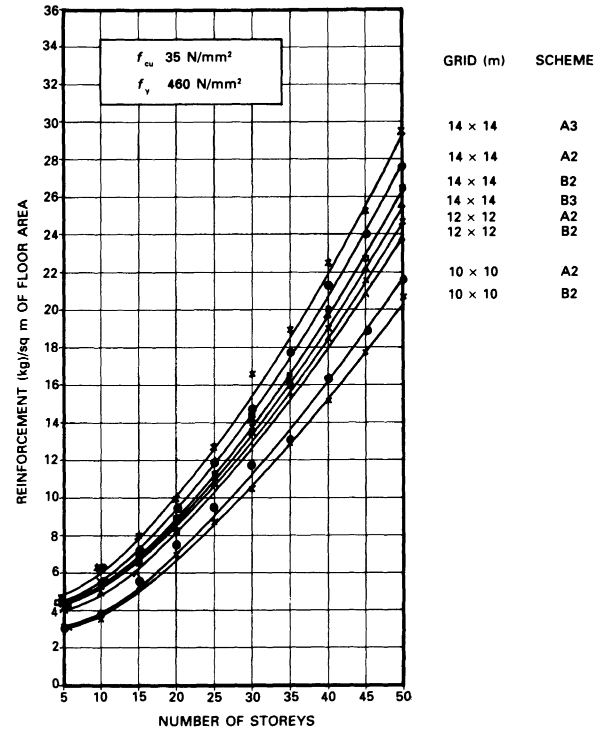


Figure 5.41 Quantities of reinforcement in columns – exterior grid.

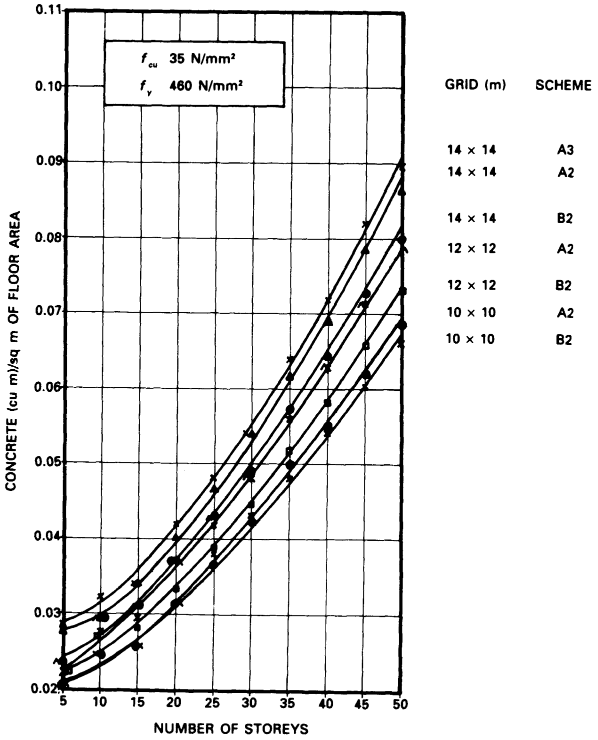


Figure 5.40 Quantities of concrete in columns – exterior grid.

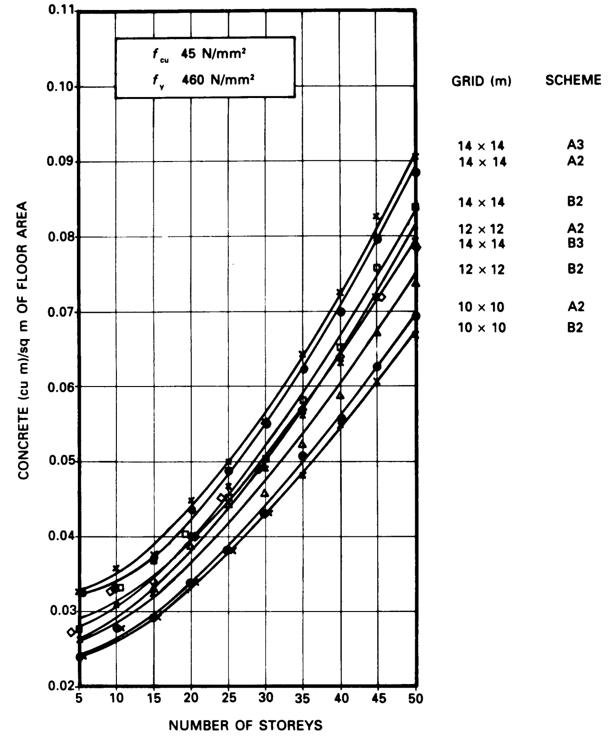


Figure 5.43 Quantities of concrete in columns – corner grid.

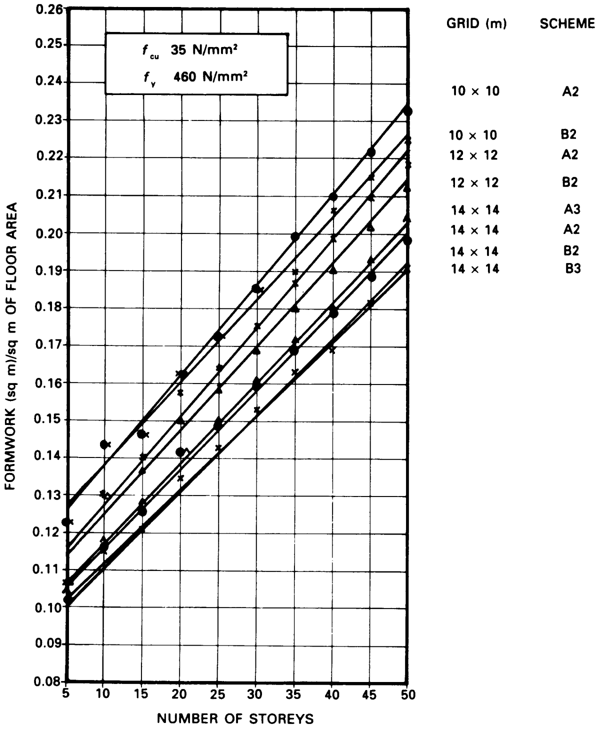


Figure 5.42 Quantities of formwork in columns exterior grid.

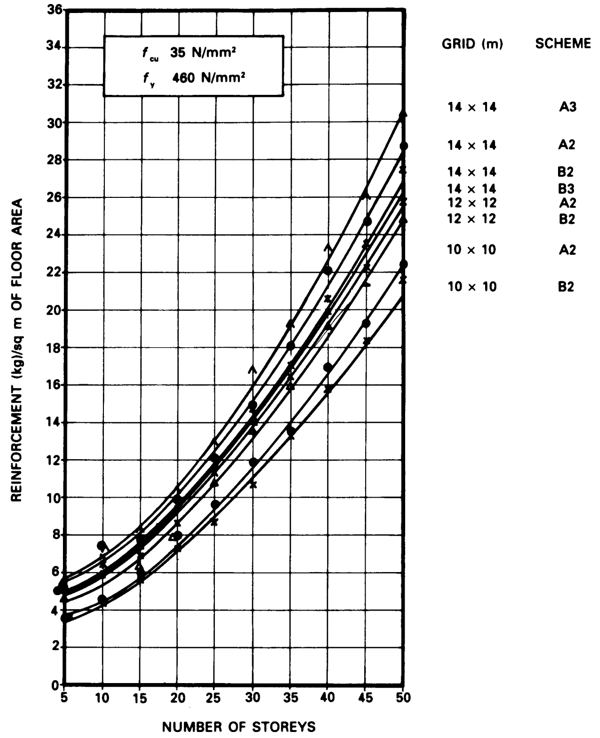


Figure 5.44 Quantities of reinforcement in columns – corner grid.

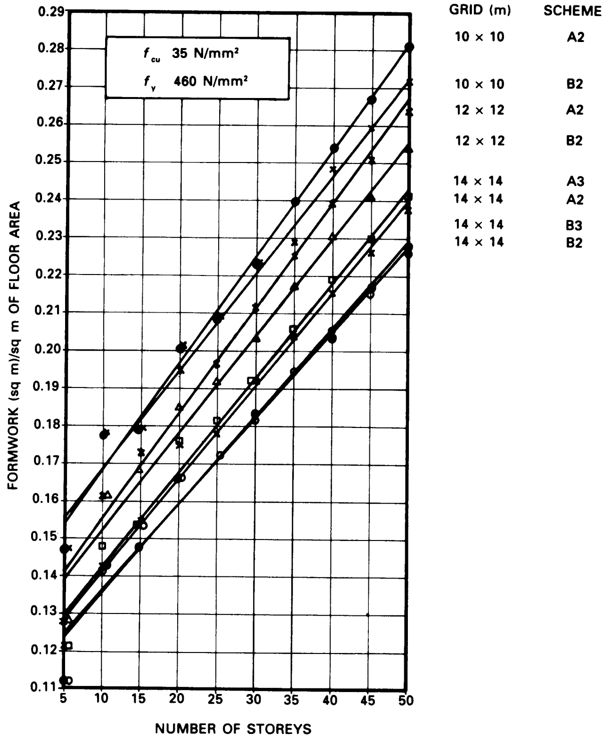


Figure 5.45 Quantities of formwork in columns – corner grid.

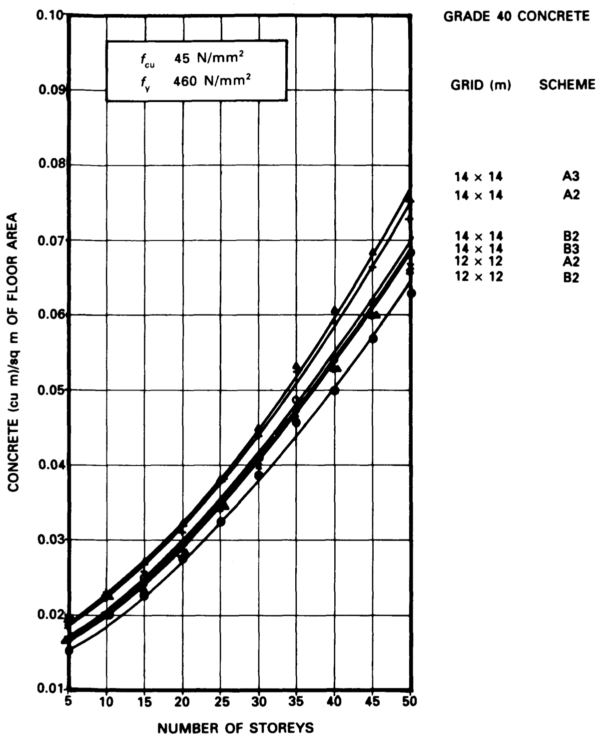


Figure 5.46 Quantities of concrete in columns – interior/first interior grids: f_{cu} = 45 N/mm^2.

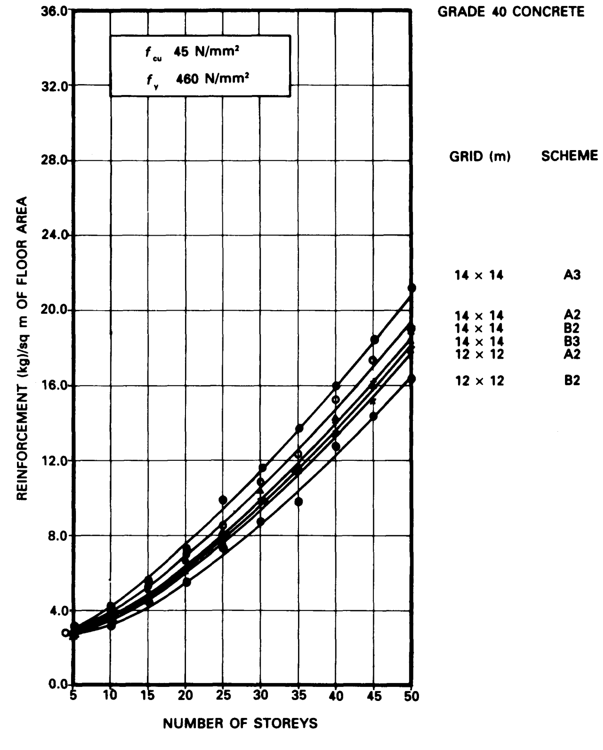


Figure 5.47 Quantities of reinforcement in columns – interior/first interior grids: f_{cu} = 45 N/mm^2.

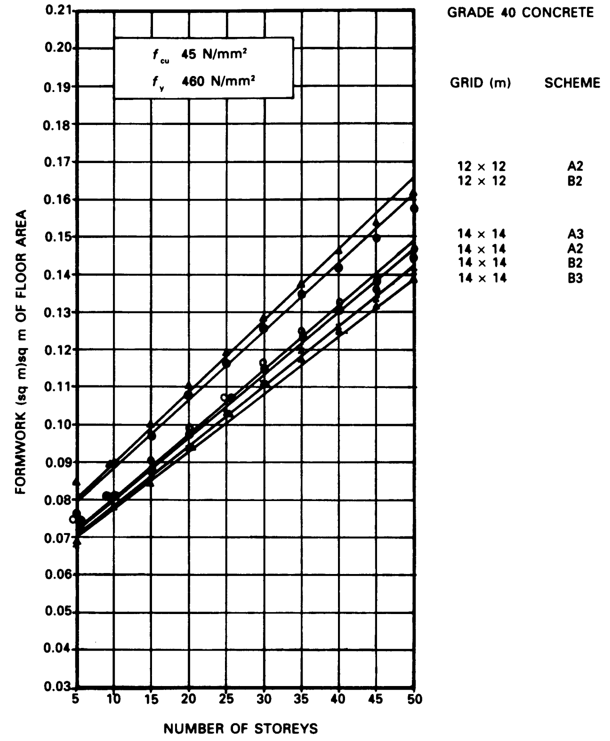


Figure 5.48 Quantities of formwork in columns – interior/first interior grids: $f_{cu} = 45$ N/mm^2.

5.6.4 *Shear Walls*

The quantities of constituents for the shear walls are shown in Figures 5.49 to 5.51 for different grid sizes and structural schemes.

5.6.5 *Total Structure*

The quantities of constituents for the total structure can be built up based on the results of elements already covered (Sections 5.6.1to 5.6.4). However, for an interior grid and different grid sizes, charts have been developed and are shown in Figures 7.10 to 7.13.

5.7 Effect of Number of Spans on Constituent Quantities

The charts developed in this chapter are based on structures having five or more continuous spans. The

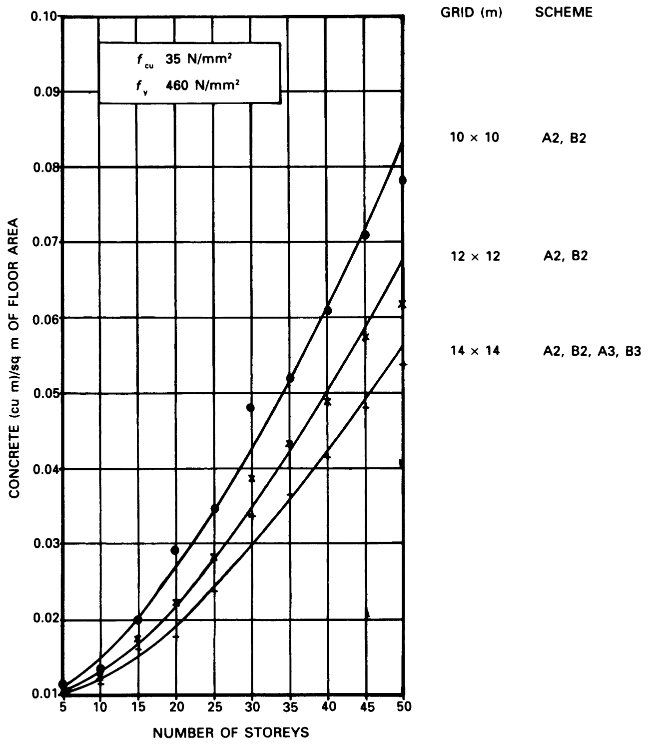


Figure 5.49 Quantities of concrete in shear walls.

effect of varying continuity (less than 5) was studied, and based on this investigation multiplying factors were established. These showed similar results to those in Chapter 3. For structures having fewer than 5 spans, the constituent quantities as obtained using the charts in this chapter need to be adjusted by using multiplying factors (Tables 3.1 to 3.3).

5.8 Effect of Number of Shopping Floors

The charts developed for different constituents (Figures 5.2 to 5.51) are meant for office floors only. However for structures having 1 to 5 shopping floors at the lower end, multiplying factors for different structural components were calculated and these showed similar values to those shown in Table 3.4. The effect on constituent quantities for structures with shopping floors can thus be worked out using the charts developed in this chapter and the multiplying factors shown in Table 3.4.

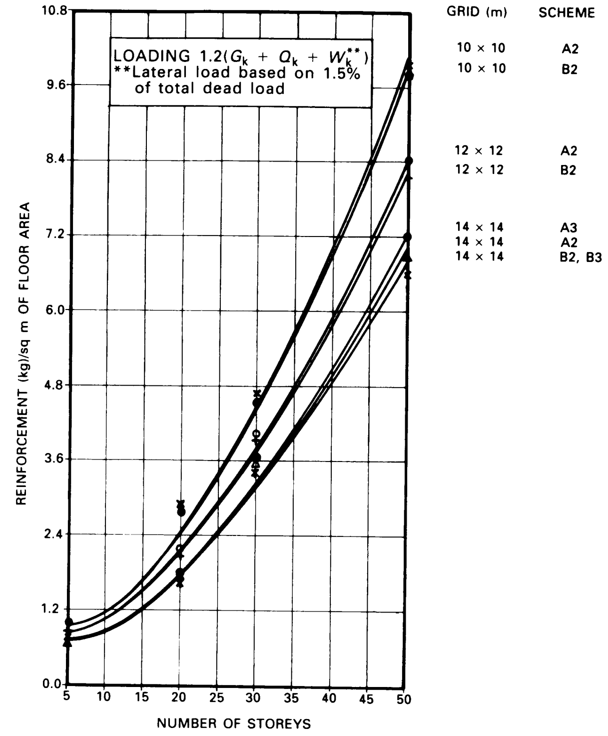


Figure 5.51 Quantities of reinforcement in shear walls.

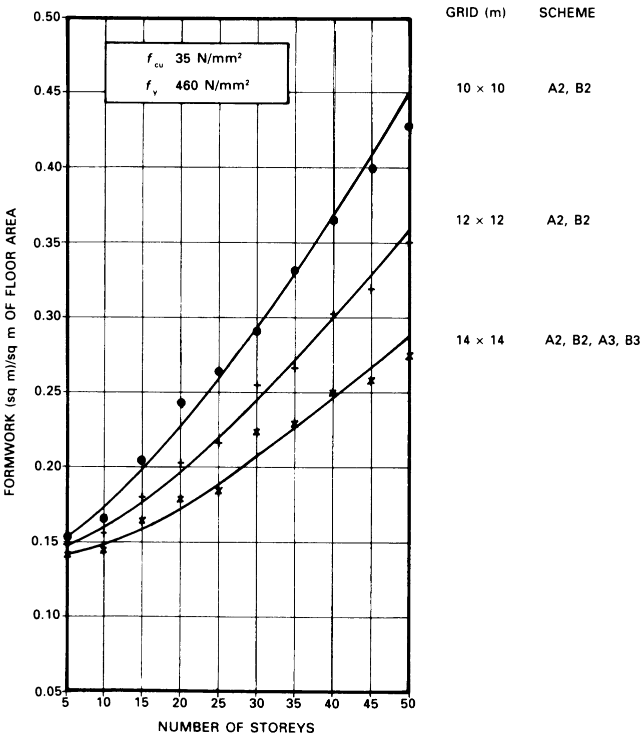


Figure 5.50 Quantities of formwork in shear walls.

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2. *BSCP 110: Part 1: Code of Practice for the Structural Use of Concrete*. British Standard Institution, London, 1972.
3. Singh, S. *Cost models for approximate cost estimation of structural systems in commercial high rise buildings*, PhD thesis, Vol. 2. National University of Singapore, 1986.
4. Ramaswamy, G.S. *Modern Prestressed Concrete Design*. Pitman, New York, 1976.
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6 Applications

The application of charts developed for RC beam and slab construction (Chapter 3), flat/waffle slab constructions (Chapter 4) and prestressed beam and RC slab construction (Chapter 5) has been demonstrated for (a) comparative cost estimation to assess the effect of various design parameters, (b) approximate structural cost estimation of an overall project given its design features, (c) checking the estimates for structural works, (d) calculation of quantity index for structural works and (e) various other building economics studies. For clarity, problems have been defined and, using the charts/statistical relationships, solutions to these problems obtained are shown. The applications given are merely illustrative although the charts developed are capable of generating valuable and voluminous quantity/cost information about the effects of various design parameters for each of the structural elements.

6.1 Introduction

The usefulness of any research investigation can be assessed from the applications for which the results or findings can be utilised in practice. In this chapter efforts have been made to show the usefulness of the charts developed (Chapters 3 to 5): for comparative cost estimation to determine the effect of design parameters on structural cost; for approximate structural cost estimation of an overall project; for checking of estimates for structural works; for calculation of quantity and cost index for structural schemes and systems; for budgeting of materials; and for use in academic studies in building economics.

The application shown is merely for illustration purposes although the charts developed are capable of generating valuable and voluminous quantity/cost information about different constituents to indicate the effect of various design parameters on structural cost.

6.2 Comparative Cost Estimation – Effect of Design Variables

One of the objectives laid down (Section 1.2) in this book is that the charts developed should be capable of supplying comparative cost information for the effects of different design parameters on the structural cost which is needed at the architectural design stage. This requirement can be seen to have been fulfilled from the solutions presented in this chapter. For clarity, in each case, the design problem has been defined first and, based on the data given, a solution using the charts/statistical relationships has been obtained.

In actual practice, an architect does not really need to consider grid sizes over such a large range as that in some of the problems which follow; the various grid sizes have been included to show the flexibility and usefulness of the charts developed in carrying out such studies.

6.2.1 Problem 1 – Structural Schemes

A design team is involved in the planning of a 40-storey commercial high-rise building and the design is at the beginning of the initial stage. The Structural Engineer has been asked to present the comparative unit costs, for a typical interior panel in a structure having five continuous spans, for the following structural schemes using the given data:

Structural scheme	*Grid size (m)*
RC beam and slab with one secondary beam (Scheme B1, Figure 3.1)	6.0 × 6.0 8.0 × 8.0 10.0 × 10.0
RC beam and slab with two secondary beams (Scheme B2, Figure 3.1)	10.0 × 10.0
Flat slab without column heads (Figure 4.1)	10.0 × 10.0
Waffle slab without column heads (Figure 4.2)	10.0 × 10.0
Prestressed beam and RC slab with two secondary beams (Scheme B2, Figure 5.1)	10.0 × 10.0
Prestressed beam and RC slab with two secondary beams (Scheme B2, Figure 5.1)	12.0 × 12.0

Structural scheme	*Grid size (m)*
Prestressed beam and RC slab with two secondary beams (Scheme B2, Figure 5.1)	14.0 × 14.0
Prestressed beam and RC slab with three secondary beams (Scheme B3, Figure 5.1)	14.0 × 14.0

Prevailing rates of materials (London, 1993):

Concrete (£/cu m) grade 30 N/sq mm	
Slab	65.82
Beams	69.10
grade 35 N/sq mm	
Slab	67.22
Beams	70.50
Columns	77.96
Shear walls	68.32
Reinforcement (£/kg) High yield steel	
Slab	0.49
Beams	0.43
Columns	0.43
Shear walls	0.49
Prestressing strands (£/kg)	3.00
Formwork (£/sq m)	
Solid slab and beam construction	
Slab	15.34
Beams	20.24
Columns	19.62
Shear walls	20.94
Flat slab and column construction	
Slab	5.34
Columns	19.62
Shear walls	20.94
Waffle slab	25.34

The solution obtained using the appropriate charts developed in Chapters 3 to 5 is shown in Tables 6.1a–j. In the solution it has been assumed that the structure has five continuous spans and is meant for an office block.

The reader should recall that the charts developed are for office floors and for structures having five continuous spans. In cases where it is desired to compute constituent quantities/cost for structures having fewer than 5 continuous spans, the quantities read from the charts need to be adjusted using the appropriate multiplying factors (Tables 3.1 to 3.3). Likewise, if the lower part of the structure has a few floors for shopping, multiplying factors (Table 3.4) need to be applied.

Table 6.1a Reinforced concrete beam and slab construction (quantities/cost per sq m of floor area).

SALIENT FEATURES
Grid size (m): 6.0 × 6.0 Grid location: Interior
Number of storeys: 40 Scheme: B1

Element	*Concrete grade (N/sq mm)*	*Concrete (cu m)*	*Steel (kg)*	*Formwork (sq m)*	*Cost (£)*
Slab	30	0.110	4.7	0.87	22.89
Main beams	30	0.012	4.5	0.12	5.19
Secondary beams	30	0.009	2.5	0.13	4.32
Secondary beams over columns	30	0.009	1.6	0.11	3.54
Columns	35	0.053	14.0	0.27	12.54
Shear walls	35	0.080	8.3	0.45	18.96
Total					67.44
Add 17.5 per cent for preliminaries and oncosts					11.80
Total structure					79.24

Table 6.1b Reinforced concrete beam and slab construction (quantities/cost per sq m of floor area).

SALIENT FEATURES
Grid size (m): 8.0 × 8.0 Grid location: Interior
Number of storeys: 40 Scheme: B1

Element	*Concrete grade (N/sq mm)*	*Concrete (cu m)*	*Steel (kg)*	*Formwork (sq m)*	*Cost (£)*
Slab	30	0.140	6.5	0.86	22.59
Main beams	30	0.016	4.5	0.13	5.67
Secondary beams	30	0.013	3.3	0.14	5.15
Secondary beams over columns	30	0.012	2.3	0.12	4.25
Columns	35	0.061	18.7	0.22	16.66
Shear walls	35	0.079	8.0	0.45	18.74
Total					76.06
Add 17.5 per cent for preliminaries and oncosts					13.31
Total structure					89.37

6.2.2 Problem 2 – Structural Schemes

Evaluate the comparative economics of using the following structural schemes for a 30-storey commercial building. A uniform column grid size of 8.0 m × 8.0 m is proposed for use.

Table 6.1c Reinforced concrete beam and slab construction (quantities/cost per sq m of floor area).

SALIENT FEATURES
Grid size (m): 10.0 × 10.0 Grid location: Interior
Number of storeys: 40 Scheme: B1

Element	*Concrete grade (N/sq mm)*	*Concrete (cu m)*	*Steel (kg)*	*Formwork (sq m)*	*Cost (£)*
Slab	30	0.176	8.2	0.86	28.79
Main beams	30	0.019	7.0	0.12	6.75
Secondary beams	30	0.016	4.4	0.13	5.63
Secondary beams over columns	30	0.014	3.2	0.11	4.57
Columns	35	0.062	20.0	0.18	16.97
Shear walls	35	0.072	7.3	0.40	16.87
Total					79.58
Add 17.5 per cent for preliminaries and oncosts					13.93
Total structure					93.51

Table 6.1d Reinforced concrete beam and slab construction (quantities/cost per sq m of floor area).

SALIENT FEATURES
Grid size (m): 10.0 × 10.0 Grid location: Interior
Number of storeys: 40 Scheme: B2

Element	*Concrete grade (N/sq mm)*	*Concrete (cu m)*	*Steel (kg)*	*Formwork (sq m)*	*Cost (£)*
Slab	30	0.120	5.3	0.83	23.23
Main beams	30	0.022	6.3	0.14	7.06
Secondary beams	30	0.035	5.4	0.29	10.61
Secondary beams over columns	30	0.016	2.0	0.13	4.60
Columns	35	0.060	17.7	0.18	15.82
Shear walls	35	0.072	7.3	0.40	16.87
Total					78.19
Add 17.5 per cent for preliminaries and oncosts					13.68
Total structure					91.87

Flat slab construction without column heads using high yield steel reinforcement

Flat slab construction without column heads using mild steel reinforcement in slab and high yield steel in other components

Waffle slab construction without column heads using high yield steel reinforcement

Table 6.1e Reinforced concrete flat slab construction (quantities/cost per sq m of floor area).

SALIENT FEATURES
Grid size (m): 10.0 × 10.0 Grid location: Interior
Number of storeys: 40 Scheme: 2*

Element	*Concrete grade (N/sq mm)*	*Concrete (cu m)*	*Steel (kg)*	*Formwork (sq m)*	*Cost (£)*
Slab	30	0.317	16.3	1.00	39.99
Columns	35	0.074	24.1	0.17	19.47
Shear walls	35	0.068	8.0	0.46	18.05
Total					81.87
Add 17.5 per cent for preliminaries and oncosts					14.33
Total structure					96.20

* 1 indicates flat slab construction with column heads using high yield steel reinforcement in slab.
2 indicates flat slab construction without column heads using high yield steel reinforcement in slab.
3 indicates flat slab construction with column heads using mild steel reinforcement in slab.
4 indicates flat slab construction without column heads using mild steel reinforcement in slab.
(Refer to Figure 4.1.)

Table 6.1f Reinforced concrete waffle slab construction (quantities/cost per sq m of floor area).

SALIENT FEATURES
Grid size (m): 10.0 × 10.0 Grid location: Interior
Number of storeys: 40 Scheme: 2*

Element	*Concrete grade (N/sq mm)*	*Concrete (cu m)*	*Steel (kg)*	*Formwork (sq m)*	*Cost (£)*
Slab	30	0.282	12.3	0.98	48.04
Columns	35	0.067	22.4	0.16	18.00
Shear walls	35	0.068	7.5	0.46	17.95
Total					83.99
Add 17.5 per cent for preliminaries and oncosts					14.70
Total structure					98.69

* 1 indicates waffle slab construction with column heads.
2 indicates waffle slab construction without column heads.
(Refer to Figure 4.2.)

Any reasonable prevailing unit rates for member constituents can be adopted.

The solution obtained using the appropriate charts developed in Chapter 4 is shown in Tables 6.2a–c.

Table 6.1g Prestressed beam and RC slab construction (quantities/cost per sq m of floor area).

SALIENT FEATURES
Grid size (m): 10.0 × 10.0 Grid location: Interior
Number of storeys: 40 Scheme: B2

Element	*Concrete grade (N/sq mm)*	*Concrete (cu m)*	*Steel (kg)*	*Strands (kg)*	*Formwork (sq m)*	*Cost (£)*
Slab	35	0.120	5.0	—	0.83	23.25
Main beams	35	0.016	5.4	0.7	0.11	7.78
Secondary beams	35	0.027	5.0	0.9	0.24	11.61
Secondary beams over columns	35	0.012	1.8	0.3	0.10	4.54
Columns	35	0.054	14.7	—	0.17	13.87
Shear walls	35	0.062	7.0	—	0.36	15.20
Total						76.25
Add 17.5 per cent for preliminaries and oncosts						13.34
Total structure						89.59

Table 6.1h Prestressed beam and RC slab construction (quantities/cost per sq m of floor area).

SALIENT FEATURES
Grid size (m): 12.0 × 12.0 Grid location: Interior
Number of storeys: 40 Scheme: B2

Element	*Concrete grade (N/sq mm)*	*Concrete (cu m)*	*Steel (kg)*	*Strands (kg)*	*Formwork (sq m)*	*Cost (£)*
Slab	35	0.150	7.6	—	0.84	26.69
Main beams	35	0.019	6.4	1.0	0.11	9.32
Secondary beams	35	0.032	6.5	1.3	0.24	13.80
Secondary beams over columns	35	0.014	2.4	0.5	0.11	5.75
Columns	35	0.058	17.8	—	0.15	15.12
Shear walls	35	0.050	5.8	—	0.30	12.54
Total						83.22
Add 17.5 per cent for preliminaries and oncosts						14.56
Total structure						97.78

Table 6.1i Prestressed beam and RC slab construction (quantities/cost per sq m of floor area).

SALIENT FEATURES
Grid size (m): 14.0 × 14.0 Grid Location: Interior
Number of storeys: 40 Scheme: B2

Element	*Concrete grade (N/sq mm)*	*Concrete (cu m)*	*Steel (kg)*	*Strands (kg)*	*Formwork (sq m)*	*Cost (£)*
Slab	35	0.160	8.6	—	0.83	27.70
Main beams	35	0.023	7.4	1.2	0.11	10.60
Secondary beams	35	0.040	8.1	1.7	0.24	16.26
Secondary beams over columns	35	0.018	3.0	0.6	0.11	6.59
Columns	35	0.064	19.1	—	0.14	15.95
Shear walls	35	0.042	5.0	—	0.24	10.35
Total						87.48
Add 17.5 per cent for preliminaries and oncosts						15.31
Total structure						102.79

Table 6.1j Prestressed beam and RC slab construction (quantities/cost per sq m of floor area).

SALIENT FEATURES
Grid size (m): 14.0 × 14.0 Grid location: Interior
Number of storeys: 40 Scheme: B3

Element	*Concrete grade (N/sq mm)*	*Concrete (cu m)*	*Steel (kg)*	*Strands (kg)*	*Formwork (sq m)*	*Cost (£)*
Slab	35	0.130	6.8	—	0.79	24.19
Main beams	35	0.025	8.4	1.3	0.12	11.71
Secondary beams	35	0.064	6.3	1.0	0.37	20.71
Secondary beams over columns	35	0.019	1.7	0.5	0.11	5.80
Columns	35	0.063	18.8	—	0.14	15.74
Shear walls	35	0.042	5.0	—	0.24	10.35
Total						88.50
Add 17.5 per cent for preliminaries and oncosts						15.49
Total structure						103.99

Table 6.2a Reinforced concrete flat slab construction (quantities/cost per sq m of floor area).

SALIENT FEATURES
Grid size (m): 8.0 × 8.0 Grid location: Interior
Number of storeys: 30 Scheme: 2*

Element	*Concrete grade (N/sq mm)*	*Concrete (cu m)*	*Steel (kg)*	*Formwork (sq m)*	*Cost (£)*†
Slab	30	0.252	12.5	1.01	36.97
Columns	30	0.057	16.5	0.19	15.07
Shear walls	30	0.053	6.0	0.39	14.65
Total					66.69
Add 17.5 per cent for preliminaries and oncosts					11.67
Total structure					78.36

* 1 indicates flat slab construction with column heads using high yield steel reinforcement in slab.
2 indicates flat slab construction without column heads using high yield steel reinforcement in slab.
3 indicates flat slab construction with column heads using mild steel reinforcement in slab.
4 indicates flat slab construction without column heads using mild steel reinforcement in slab.
(Refer to Figure 4.1.)

† Unit rates for constituents (1992):

Element	*Concrete (£/cu m)*	*Steel (£/kg)*	*Formwork (£/sq m)*
Slab	60.91	0.49	25.34
Columns	74.56	0.43	19.62
Shear walls	66.92	0.49	20.94

Table 6.2b Reinforced concrete flat slab construction (quantities/cost per sq m of floor area).

SALIENT FEATURES
Grid size (m): 8.0 × 8.0 Grid location: Interior
Number of storeys: 30 Scheme: 4*

Element	*Concrete grade (N/sq mm)*	*Concrete (cu m)*	*Steel (kg)*	*Formwork (sq m)*	*Cost (£)*†
Slab	30	0.222	22.5	1.01	50.14
Columns	30	0.055	14.5	0.19	14.06
Shear walls	30	0.053	6.0	0.39	14.65
Total					74.85
Add 17.5 per cent for preliminaries and oncosts					13.10
Total structure					87.95

* 1 indicates flat slab construction with column heads using high yield steel reinforcement in slab.
2 indicates flat slab construction without column heads using high yield steel reinforcement in slab.
3 indicates flat slab construction with column heads using mild steel reinforcement in slab.
4 indicates flat slab construction without column heads using mild steel reinforcement in slab.
(Refer to Figure 4.1.)

† Unit rates for constituents (1992):

Element	*Concrete (£/cu m)*	*Steel (£/kg)*	*Formwork (£/sq m)*
Slab	60.91	0.49	25.34
Columns	74.56	0.43	19.62
Shear walls	66.92	0.49	20.94

6.3 Approximate Structural Cost Estimation of an Overall Project

Given the salient design features of a commercial building project, the charts developed in Chapters 3 to 5 can be used to compute the approximate structural cost for an overall project. It is pointed out that interpolation between the quantities of constituents of different grid sizes can be made to obtain constituent quantities for any other given size. This is illustrated in the next problem.

6.3.1 Problem 3 – Total Structural Cost

Determine the total structural cost for a 25-storey commercial building project (Figure 9.1) using prestressed beams and an RC slab construction given the following design features:

(i) Details of grid sizes, grid locations and their numbers

Grid size	*Grid location*	*No. of grids*
12.7 × 12.0	Corner	4 × 25
12.7 × 12.0	Exterior	8 × 25
12.0 × 11.5	Exterior	6 × 25
12.0 × 11.5	First interior	8 × 25
12.0 × 11.5	Interior	4 × 25

(ii) Shear core areas 553.92 m^2/floor
Concrete grade of 35 N/sq mm to be used in all components
Structural scheme with 2 secondary beams at right angle to main beams is to be used

(iii) Unit rates of different constituents: same as in Problem 1.

Table 6.2c Reinforced concrete waffle slab construction (quantities/cost per sq m of floor area).

SALIENT FEATURES
Grid size (m): 8.0 × 8.0 Grid location: Interior
Number of storeys: 30 Scheme: 2*

Element	*Concrete grade (N/sq mm)*	*Concrete (cu m)*	*Steel (kg)*	*Formwork (sq m)*	*Cost (£)*†
Slab	30	0.219	8.7	0.98	42.44
Columns	30	0.055	16.0	0.19	14.71
Shear Walls	30	0.053	5.3	0.39	14.31
Total					71.46
Add 17.5 per cent for preliminaries and oncosts					12.51
Total structure					83.97

* 1 indicates waffle slab construction with column heads.
2 indicates waffle slab construction without column heads. (Refer to Figure 4.2.)

† Unit rates for constituents (1992):

Element	Concrete *(£/cu m)*	Steel *(£/kg)*	Formwork *(£/sq m)*
Slab	60.91	0.49	25.34
Columns	74.56	0.43	19.62
Shear walls	66.92	0.49	20.94

The solution obtained using the appropriate charts developed in Chapter 5 is shown in Table 6.3.

Table 6.3 Prestressed beam and RC slab construction (quantities/cost for the overall structure).

SALIENT FEATURES
Floor area (sq m): 107 820.00
Shear core area (sq m): 13 848.00

Grid size (m)	*Grid location***	*Numbers*
12.7 × 12.0	4	100
12.7 × 12.0	3	200
12.0 × 11.5	3	150
12.0 × 11.5	2	200
12.0 × 11.5	1	100

Number of storeys: 25 Scheme: 2*

Element	*Concrete grade (N/sq mm)*	*Concrete (cu m)*	*Steel (× 10^3) (kg)*	*Strands (× 10^3) (kg)*	*Formwork (sq m)*	*Cost*† *(£ M)*
Slab	35	15 704.5	823.01	—	90 980	2.85
Main beams	35	2 158.0	698.68	120.33	12 525	1.07
Secondary beams	35	3 475.2	726.11	156.22	25 208	1.54
Secondary beams over columns	35	1 622.0	272.91	59.94	12 525	0.67
Columns	35	3 998.0	1 121.35	—	13 546	1.06
Shear walls	35	3 040.7	308.49	—	23 549	0.85
Total						8.04
Add 17.5 per cent for preliminaries and oncosts						1.41
Total structure						9.45

* 1 indicates scheme A2.
2 indicates scheme B2.
3 indicates scheme A3.
4 indicates scheme B3.
(Refer to Figure 5.1.)

** 1 indicates interior grid.
2 indicates first interior grid.
3 indicates exterior grid.
4 indicates corner grid.

† Unit rates for constituents (1992):

Element	*Concrete (£/cu m)*	*Steel (£/kg)*	*Strands (£/kg)*	*Formwork (£/sq m)*
Slab	67.22	0.49	—	15.34
Beams	70.50	0.43	3.00	20.24
Columns	77.96	0.43	—	19.62
Shear walls	68.32	0.49	—	20.94

6.4 Checking of Estimates for Structural Works

Another important application area of the charts developed is in making an overall check of the structural estimates prepared based on the details supplied by the Structural Engineer. The objective here is to find out if substantial differences exist between the initial estimates and those computed with the help of the charts. If differences exist, there is a need to look into the original working and reason out the differences. In so doing the errors made, whether by the Structural Engineer or the Estimator, can be located and the necessary corrections made.

It should be pointed out here that the charts developed use the basic design features of the project as illustrated in Sections 6.2 and 6.3 and work out the quantities of different constituents strictly in accordance with BS 8110: 1985, whereas in practice there is a general tendency to be comparatively liberal in the design. Hence, it can always be expected that there will be a difference between the two estimates, i.e. between the original estimate based on the structural details and that computed with the help of the charts/statistical relationships. The extent of the difference between the two estimates can give an indication to the designer about whether the initial design and estimates are suspect and whether there is a need to re-check the design/estimate.

It should be further emphasised that generally the estimated quantities based on the details supplied by a structural designer are expected to be on the high side. However, in cases where a reverse trend is found outside the reasonable limits, it can be taken that an error has been made either in giving the structural details or in taking-off. In such cases there is definitely a need to have another look at the details supplied/take-off.

A reasonable difference between the two estimates discussed in the section can be taken to be about 5–10 per cent.

6.5 Calculation of Quantity Index for Structural Works

Past historical information of constituent quantities for structural works in completed projects is of immense value for computation of approximate cost estimates for present/future projects. However, invariably there are always variations between the design features of different projects. To adjust constituent quantities arising from these variations, a quantity index for structural works can be a useful device.

The charts presented in this book (Chapters 3 to 5) can be utilised in computing the constituent quantities, for a desired set of design features, which in turn can be utilised for establishing the quantity index. The quantity index so established can in turn be utilised in adjusting the quantities of the past projects so as to arrive at the quantities for the new projects. This is illustrated in the solution of the following problem.

6.5.1 Problem 4 – Quantity Estimates

It is required to estimate the constituent quantities for structural works needed for a proposed 30-storey commercial building having design features similar to the one recently completed within the organisation but with the following differences:

	BUILDINGS	
	Proposed	Completed
Number of storeys	30	25
Grid size (m)	12.0 × 11.8	10.0 × 10.2
Structural scheme	Prestressed beams and RC slab construction	Prestressed beams and RC slab construction
Floor area (m^2)	4248	3030
Constituent quantities		
Slab		
Concrete (cu m)	?	10645.4
Reinforcement (t)	?	474.9
Formwork (sq m)	?	71045.9
Prestressed beams		
Concrete (cu m)	?	7417.1
Reinforcement (t)	?	1431.7
Prestressing Strands (t)	?	272.7
Formwork (sq m)	?	35100.0
Columns		
Concrete (cu m)	?	3708.7
Reinforcement (t)	?	1018.1
Formwork (sq m)	?	9165.8
Shear Walls		
Concrete (cu m)	?	2138.0
Reiforcement (t)	?	236.4
Formwork (sq m)	?	17422.5

The solution obtained using the appropriate charts is shown in Table 6.4.

Table 6.4 Quantity estimate for a proposed building.

Quantities per sq m of floor area are computed separately using the charts/statistical relationships developed for prestressed beam and RC slab construction for 25 storeys (completed building) and 30 storeys (proposed building) and the given grid sizes. Based on the relative quantity index for structural components, the quantities of completed building are modified as under:

		Completed building	*Quantity index*	*Proposed building*
Number of storeys		25		30
Grid size (m)		10.0 × 10.2		12.0 × 11.8
Floor area/floor (sq m)		3030		4248
CONSTITUENT QUANTITIES				
SLAB				
Concrete	(cu m)	10 645.4	0.1446/0.1222	21 192.5*
Reinforcement	(tonne)	474.9	7.6/5.5	1 104.0
Formwork	(sq m)	71 045.9	0.84/0.83	120 964.4
PRESTRESSED BEAMS				
Concrete	(cu m)	7 417.2	0.0813/0.0818	12 402.1
Reinforcement	(tonne)	1 431.7	18.9/18.9	2 408.6
Prestressing strands	(tonne)	272.7	3.6/3.6	458.8
Formwork	(sq m)	35 100.0	0.46/0.47	57 795.0
COLUMNS				
Concrete	(cu m)	3 708.7	0.0481/0.0408	7 355.8
Reinforcement	(tonne)	1 018.1	13.8/11.2	2 110.4
Formwork	(sq m)	9 165.8	0.12/0.11	16 822.2
SHEAR WALLS				
Concrete	(cu m)	2 138.0	0.0311/0.0252	4 439.0
Reinforcement	(tonne)	236.4	3.4/2.6	520.1
Formwork	(sq m)	17 422.5	0.21/0.20	30 776.8

* Quantities for the proposed building are computed by multiplying the quantities for the completed building by the respective quantity index, floor index and ratio of number of storeys, namely 10645.4 × (0.1446/0.1222) × (4248/3030) × (30/25) = 21192.5

6.6 Establishing Cost Index for Structural Works

The utility of the overall building cost index is well established and it has further been recognised that there is a need to determine these indices for different types of construction based on the types of materials used. Hence the RICS Building Cost Information Service establishes indices for four different classes of buildings, namely steel frame, concrete frame, brick and general building. Further, the use of such indices is well recognised for bringing a tender figure for a previous similar project up to current prices.

The cost index for structural works in a building can be established using the quantities obtained from the charts, and the index so established can be used for estimating the cost of structural works in new buildings based on similar projects executed in the past.

6.7 Budgeting of Materials

Budgets of materials are always needed for arranging the supply of materials for construction projects in good time. In cases where the details of projects are not available in time to place the supply orders, computations of total requirements for structural works can be calculated using the charts.

6.8 Building Economics Studies

The structural costs of buildings are influenced by a variety of factors, some of which are interrelated. It is essential that building economists should be fully aware of the cost consequences resulting from changes in shape, size, structural system, structural scheme, number of storeys, grid size and grid location. The charts developed can be used to compute quantities/cost for each of these variables. The results, once established in terms of cost, for all of these variables will not remain constant, since the change in rates with time for different materials is not proportionate. From this, it is inferred that the required information must be established with the prevailing market rates rather than being based on outdated information. This is made possible by using charts developed to supply the desired information quickly.

The effects of some of the design variables were illustrated in Section 6.2. The effect of some other variables is illustrated in the solutions of problems given in subsequent sections.

6.8.1 Problem 5 – Variation with Number of Storeys and Structural Schemes

Considering a grid size of 10 m × 10 m and the following structural schemes/unit rates of constituents, generate cost per sq metre of floor area for an interior grid in various storeys of construction ranging from 5 to 50.

Structural Schemes:

B1 & B2	using RC beam and slab construction (Figure 3.1)
B2	using prestressed beam and RC slab construction (Figure 5.1)

Flat slab and waffle slab constructions without column heads

The unit rates for constituents vary with the number of storeys, on average, at 1.0 per cent per floor. The following rates for 5-storey construction can be considered for costing:

Concrete (£/cu m)	
grade 30 N/sq mm	
slab	65.82
beams	69.10
columns	74.56
shear walls	66.92
grade 35 N/sq mm	
slab	67.22
beams	70.50
columns	77.96
shear walls	68.32
Reinforcement (£/kg)	
High yield steel	
slab	0.49
beams	0.43
columns	0.43
shear walls	0.49
Prestressing strands	3.00
Formwork (£/sq m)	
Solid slab	15.34
Waffle slab	25.34
Beams	20.24
Columns	19.62
Shear walls	20.94

The solution obtained using the appropriate charts is shown in Table 6.5.

Table 6.5 Effect of number of storeys and structural schemes on cost per sq m of floor area (grid size 10 m × 10 m)

Structural scheme	*Number of storeys*	*Cost (£)*
RC beam and slab construction		
Scheme B1 (Figure 3.1)	5	67.50
	10	69.20
	15	72.00
	20	76.50
	25	81.20
	30	86.10
	35	91.20
	40	96.50
	45	101.90
	50	107.80
RC beam and slab construction		
Scheme B2 (Figure 3.1)	5	66.70
	10	68.20
	15	71.00
	20	74.90
	25	79.20
	30	84.01
	35	88.60
	40	93.50
	45	98.70
	50	104.20
Prestressed beam and slab construction		
Scheme B (Figure 5.1)	25	69.79
	10	70.01
	15	71.92
	20	74.72
	25	78.42
	30	82.19
	35	86.03
	40	89.95
	45	94.13
	50	98.90
Flat slab construction without column heads		
(Figure 4.1a)	5	62.50
	10	64.03
	15	67.52
	20	72.04
	25	77.04
	30	82.29
	35	87.69
	40	93.35
	45	99.38
	50	105.84
Waffle slab construction without column heads		
(Figure 4.1b)	5	63.26
	10	65.76
	15	69.43
	20	73.90
	25	78.91
	30	84.27
	35	90.12
	40	95.81
	45	102.07
	50	108.90

6.8.2 Variation with Number of Storeys and Grid Sizes

In section 9.8.1, variation with number of storeys and structural schemes has been shown for a grid size of 10 m × 10 m. The charts (Chapters 3 to 5) developed are also capable of varying the grid sizes in addition to the number of storeys and the structural schemes.

6.8.3 Problem 6 – Variation with Number of Storeys and Use of Different Grades of Concrete

Determine the variation in cost with the change in number of storeys (from 5 to 50) and use of different grades of concrete (30/35/40 N/sq mm) in columns for commercial buildings. For illustration, a column grid size of 8.0 m × 8.0 m may be taken and computations be made for an interior grid using reinforced concrete beam and slab system, scheme B1 (Figure 3.1).

The unit rates for constituents vary with the number of storeys, the increase on average being 1.2 per cent per floor over and above 5 storeys. The following rates for a 5-storey construction can be used for costing:

Concrete (£/cu m)	
grade 30 N/sq mm	
Columns	74.56
grade 35 N/sq mm	
Columns	77.96
grade 40 N/sq mm	
Columns	81.36
Reinforcement (£/kg)	
Columns	0.43

Formwork (£/sq m)
Columns 19.62

The solution obtained using the appropriate charts (Chapter 3) is shown in Tables 6.6a–c.

6.9 Structures with Continuity other than Five

To compute constituent quantity for a structure with continuity other than five, the quantity as read from the appropriate chart should be modified using the relevant multiplying factor (Tables 3.1 to 3.3). Likewise, if the lower floors of the structure are to be used for shopping, the necessary modification in the constituent quantity can be made using the appropriate multiplying factor given in Table 3.4.

Table 6.6a Effect of number of storeys and concrete grades on quantities of constituents/cost for columns in RC beam and slab construction (quantities/cost per sq m of floor area)

Structural scheme: 2* Grade of concrete: 30
Grid location: 1**

Grid size	*Number of Storeys*	*Concrete (cu m)*	*Steel (kg)*	*Formwork (sq m)*	*Cost*† *(£)*
8.5 × 8.5	5	0.0212	2.5	0.13	6.12
8.5 × 8.5	10	0.0263	4.2	0.14	7.87
8.5 × 8.5	15	0.0320	6.5	0.16	10.40
8.5 × 8.5	20	0.0382	9.2	0.17	13.00
8.5 × 8.5	25	0.0451	12.0	0.18	15.84
8.5 × 8.5	30	0.0524	14.8	0.20	19.28
8.5 × 8.5	35	0.0601	17.6	0.21	22.47
8.5 × 8.5	40	0.0681	20.5	0.22	25.88
8.5 × 8.5	45	0.0763	23.4	0.24	29.72
8.5 × 8.5	50	0.0844	26.6	0.25	33.90

* 1 indicates scheme A1.
2 indicates scheme B1.
3 indicates scheme B2.

** 1 indicates interior grid.
2 indicates first interior grid.
3 indicates exterior grid.
4 indicates corner grid.

† Unit rates for constituents (1992):

Storeys	*Concrete (£/cu m)*	*Steel (£/kg)*	*Formwork (£/sq m)*
1– 5	74.56	0.43	19.62
6–10	76.80	0.44	20.21
11–15	79.03	0.46	20.80
16–20	81.27	0.47	21.39
21–25	83.51	0.48	21.97
26–30	85.74	0.50	22.56
31–35	87.98	0.51	23.15
36–40	90.22	0.52	23.74
41–45	92.45	0.53	24.32
46–50	94.69	0.55	24.92

Table 6.6b Effect of number of storeys and concrete grades on quantities of constituents/cost for columns in RC beam and slab construction (quantities/cost per sq m of floor area).

Structural scheme: 2* Grade of concrete: 35
Grid location: 1**

Grid size	*Number of storeys*	*Concrete (cu m)*	*Steel (kg)*	*Formwork (sq m)*	*Cost*† *(£)*
8.5 × 8.5	5	0.0209	2.2	0.12	5.79
8.5 × 8.5	10	0.0229	3.9	0.14	7.50
8.5 × 8.5	15	0.0277	6.0	0.15	9.60
8.5 × 8.5	20	0.0341	8.3	0.16	12.01
8.5 × 8.5	25	0.0410	10.9	0.17	14.74
8.5 × 8.5	30	0.0479	13.5	0.19	18.01
8.5 × 8.5	35	0.0546	16.3	0.20	21.11
8.5 × 8.5	40	0.0613	19.1	0.21	24.32
8.5 × 8.5	45	0.0683	21.9	0.22	27.68
8.5 × 8.5	50	0.0767	24.7	0.24	31.91

* 1 indicates scheme A1.
2 indicates scheme B1.
3 indicates scheme B2.

** 1 indicates interior grid.
2 indicates first interior grid.
3 indicates exterior grid.
4 indicates corner grid.

† Unit rates for constituents (1992):

Storeys	*Concrete (£/cu m)*	*Steel (£/kg)*	*Formwork (£/sq m)*
1– 5	77.96	0.43	19.62
6–10	80.30	0.44	20.21
11–15	82.64	0.46	20.80
16–20	84.98	0.47	21.39
21–25	87.32	0.48	21.97
26–30	89.65	0.50	22.56
31–35	91.99	0.51	23.15
36–40	94.33	0.52	23.74
41–45	96.67	0.53	24.32
46–50	99.01	0.55	24.92

Table 6.6c Effect of number of storeys and concrete grades on quantities of constituents/cost for columns in RC beam and slab construction (quantities/cost per sq m of floor area).

Structural scheme: 2* Grade of concrete: 40
Grid location: 1**

Grid size	*Number of Storeys*	*Concrete (cu m)*	*Steel (kg)*	*Formwork (sq m)*	*Cost*† *(£)*
8.5 × 8.5	5	0.0165	2.2	0.12	5.46
8.5 × 8.5	10	0.0215	3.3	0.13	6.91
8.5 × 8.5	15	0.0268	4.9	0.14	8.79
8.5 × 8.5	20	0.0325	7.0	0.16	11.27
8.5 × 8.5	25	0.0384	9.2	0.17	13.69
8.5 × 8.5	30	0.0447	11.5	0.18	16.44
8.5 × 8.5	35	0.0512	13.8	0.19	19.21
8.5 × 8.5	40	0.0579	16.2	0.21	22.45
8.5 × 8.5	45	0.0646	18.7	0.22	25.59
8.5 × 8.5	50	0.0711	21.5	0.23	29.26

* 1 indicates scheme A1
2 indicates scheme B1
3 indicates scheme B2

** 1 indicates interior grid.
2 indicates first interior grid.
3 indicates exterior grid.
4 indicates corner grid.

† Unit rates for constituents (1992):

Storeys	*Concrete (£/cu m)*	*Steel (£/kg)*	*Formwork (£/sq m)*
1– 5	81.36	0.43	19.62
6–10	83.80	0.44	20.21
11–15	86.24	0.46	20.80
16–20	88.68	0.47	21.39
21–25	91.12	0.48	21.97
26–30	93.56	0.50	22.56
31–35	96.00	0.51	23.15
36–40	98.44	0.52	23.74
41–45	100.89	0.53	24.32
46–50	103.33	0.55	24.92

7 Quantities/Cost – Observations, Trends and Variations

The components constituting any structure can be classified under two categories – namely the horizontal components like beams and slabs and vertical components such as columns and shear walls. Observations, trends and variations in this chapter clearly indicate that with the increase in number of storeys from 5 to 50, the variation in the constituent quantities for horizontal components is minimal while that for vertical components is substantial.

7.1 Quantities of Constituents

Based on the numerous charts developed in Chapters 3 to 5, one can arrive at a substantial number of trends and variations relating to quantities of constituents. However, in this chapter an attempt has been made to study the salient trends and variations in constituent quantities in different structural systems/components. For clarity, each structural system will be discussed separately.

7.1.1 Reinforced Concrete Beam and Slab System

Observations on trends and variations of constituent quantities are made component-wise as well as for the total structures described in the following sections.

7.1.1.1 Slab

For a specific grid size and structural scheme, the quantities of concrete per unit of floor area remain uniform (Figure 3.13). The consumption of concrete, in an interior panel, is minimal for Scheme A1 of the 6 m x 6 m grid, the increase in quantity above this for the other grids ranging between 20 and 75 per cent depending on the number of storeys of construction, grid size and structural scheme. The maximum consumption of concrete is for Scheme B1 of the 10 m × 10 m grid.

The quantity of reinforcement is directly proportional to the size of the grid for a given scheme and number of storeys, and is maximal at 8.2 kg/sq m of floor area for Scheme B1 of the 10 m × 10 m grid compared with 4.13 kg/sq m of floor area for Scheme A1 of the 6 m × 6 m grid, five storeys being considered in both cases (Figure 3.15). The quantity of formwork is about 83 per cent of the floor area for schemes involving two-way slabs as compared with about 87.5 per cent for those with one-way slabs, with the exception of the 10 m × 10 m grid, Scheme B2.

7.1.1.2 Beams

There is a falling trend in the consumption of concrete from 5 to 50 storeys of construction mainly due to the reduction necessitated in the length of beams to accommodate the increased sections of columns in taller buildings. The decrease in quantity is however negligible, being only about 5 per cent for 50 storeys compared with the value for 5 storeys. The increase in the quantity of concrete per square metre of floor area is about 30 per cent for the 8 m × 8 m grid and 60 per cent for the 10 m × 10 m grid compared with the 6 m × 6 m grid, considering similar structural schemes and the same number of storeys of construction.

The trend for the variation in the quantity of reinforcement is unique since it remains uniform up to a certain limit with increase in number of storeys and then rises. The magnitude of this rise is inversely proportional to the grid size (Figure 3.20). The reason for the subsequent upward trend is the interaction of the frame with the shear walls constructed to resist the horizontal load (Section 3.2.5).

The quantity of formwork in various grids with two-way slabs (Scheme A1) varies from about 0.55 square metre per square metre of floor area in 5-storey constructions to about 0.53 square metre in 50 storey constructions. The corresponding values in various grids with one-way slabs are about 0.39 square metre and 0.37 square metre with the exception of the 10 m × 10 m, Scheme B2.

7.1.1.3 Columns

The increase in the consumption of concrete per square metre of floor area is about 300 per cent for 50 storeys compared with 5 storeys of construction or, in other words, about 33 per cent of 5-storey construction for each increase of 5 storeys. Similarly the increase in the consumption of reinforcement per square metre of floor area is about 700 per cent for 50 storeys compared with 5 storeys of construction, or about

80 per cent of 5-storey construction for each increase of 5 storeys. Of the three schemes for the 10 m × 10 m grid, the least steel is consumed in Scheme B2, being about 6.0 per cent less compared with Scheme A1 and about 7.3 per cent less compared with Scheme B1 in a 50-storey construction.

The quantity of formwork is inversely related to the grid size and on average, for any specific grid size, the increase in its consumption is about 10 per cent for each increase of 5 storeys compared with a 5-storey construction (Figure 3.57).

7.1.1.4 Shear Walls

The quantities of concrete, reinforcement and formwork in shear walls are inversely proportional to the grid sizes, while these vary directly with the increase in the number of storeys.

On average, the increase in the quantities of concrete and reinforcement is about 800 per cent for a 50-storey construction compared with a 5-storey construction. However, the increase in the quantity of formwork is much less, namely about 225 per cent for the same increase in the number of storeys.

7.1.1.5 Total Structure

The consumption of constituents of construction, in an interior grid, for different number of storeys, grid sizes and structural schemes is illustrated in Figures 7.1 to 7.3 for concrete, reinforcement and formwork respectively. It can be seen from these figures that the consumption of concrete and reinforcement is directly proportional to grid size and number of storeys. The trend of the consumption of formwork in various grids is however reversed, this being greater for small-sized grids when considering similar structural schemes.

An analysis of the total requirements of the constituents for the structure as a whole indicates that on average the increase in consumption of concrete, reinforcement and formwork per unit of floor area is about 59 to 89, 140 to 192 and 26 to 36 per cent respectively for 50 storeys compared with 5 storeys of construction (Table 7.1).

The effects of grid size, grid location and structural scheme on constituent quantities for the total structure are illustrated in Tables 7.2 to 7.4 respectively.

7.1.2 Reinforced Concrete Flat Slab and Waffle Slab Systems

Observations on trends and variations of constituent quantities are given component-wise as well as for the total structure in the following sections.

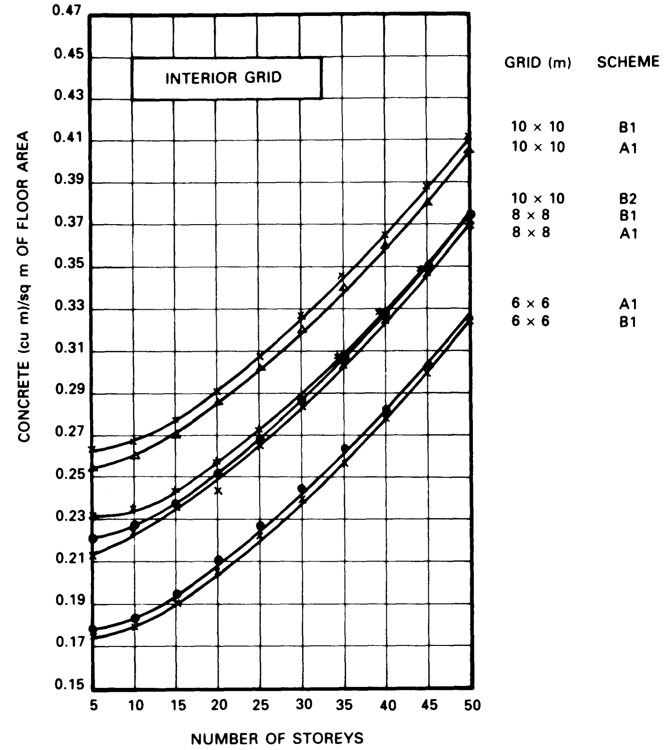


Figure 7.1 Quantities of concrete in total structure for reinforced concrete beam and slab construction.

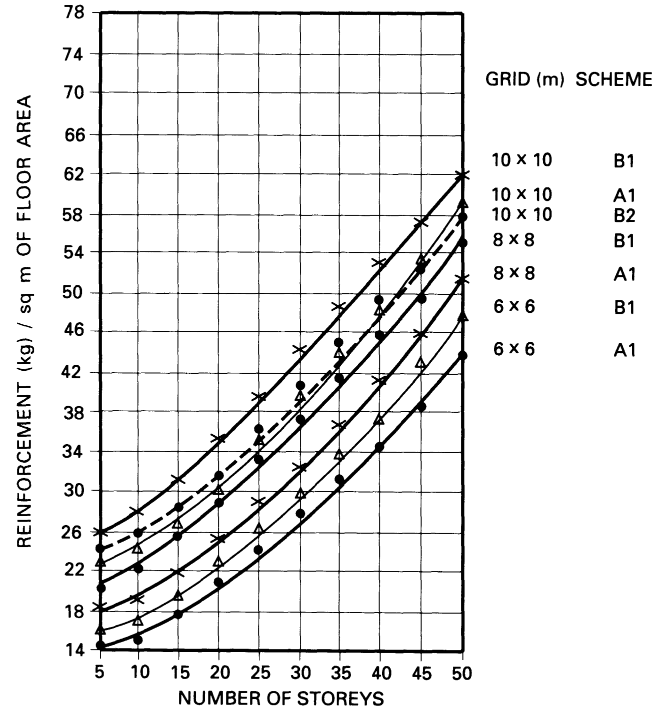


Figure 7.2 Quantities of reinforcement in total structure for reinforced beam and slab construction.

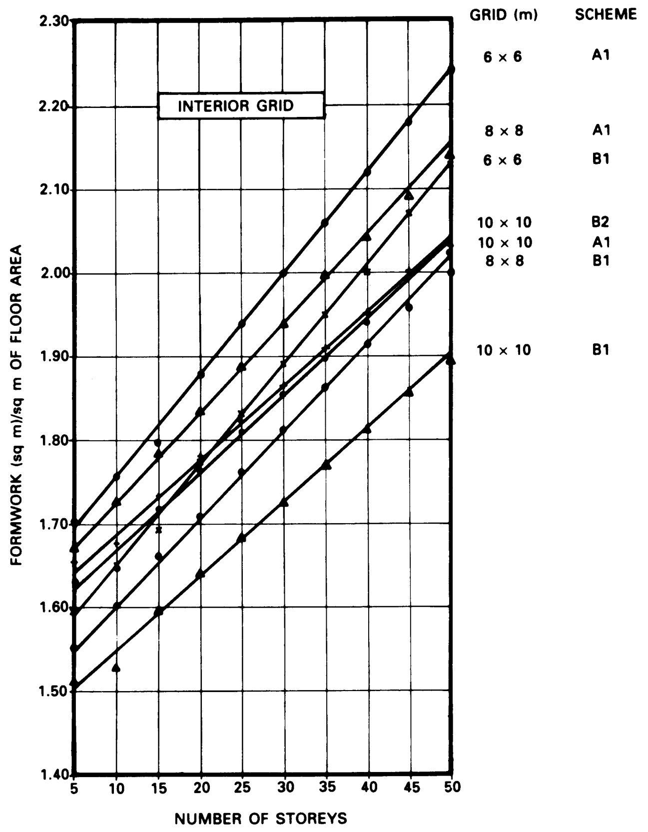


Figure 7.3 Quantities of formwork in total structure for reinforced concrete beam and slab construction.

Table 7.1 Effect of number of storeys on constituent quantities of total structure using reinforced concrete beam and slab system.

Grid size (m)/ No. of storeys	*Constituent quantities/sq m of floor area*		
	Concrete (cu m)	*Reinforcement (kg)*	*Formwork (sq m)*
Scheme B1			
6 × 6			
5-storey	0.1715	16.4	1.59
50-storey	0.3239	48.0	2.16
Percentage change	+89	+192	+36
8 × 8			
5-storey	0.2165	20.6	1.57
50-storey	0.3738	56.0	2.03
Percentage change	+73	+172	+30
10 × 10			
5-storey	0.2585	25.8	1.52
50-storey	0.4106	61.9	1.91
Percentage change	+59	+140	+26

Table 7.2 Effect of grid size on constituent quantities of total structure using reinforced concrete beam and slab system.

No. of storeys/ Grid size (m)	*Constituent quantities/sq m of floor area*		
	Concrete (cu m)	*Reinforcement (kg)*	*Formwork (sq m)*
Scheme B1			
5-storey			
6 × 6	0.1715	17.4	1.59
10 × 10	0.2585	25.8	1.52
Percentage change	+51	+57	−5
50-storey			
6 × 6	0.3239	48.0	2.16
10 × 10	0.4106	61.9	1.91
Percentage change	+27	+29	−12

Table 7.3 Effect of grid location on constituent quantities of total structure using reinforced concrete beam and slab system.

No. of storeys/ Grid location	*Constituent quantities/sq m of floor area*		
	Concrete (cu m)	*Reinforcement (kg)*	*Formwork (sq m)*
Grid size (m) 6 × 6			
Scheme B1			
5-storey			
Interior	0.1715	16.4	1.59
Exterior	0.1748	17.3	1.66
Percentage change	+2	+6	+4
Interior	0.1715	16.4	1.59
Corner	0.1768	17.7	1.71
Percentage change	+3	+8	+8
50-storey			
Interior	0.3239	48.0	2.16
Exterior	0.3254	49.5	2.24
Percentage change	+1	+3	+4
Interior	0.3239	48.0	2.16
Corner	0.3259	50.4	2.28
Percentage change	+1	+5	+6
Grid size (m) 10 × 10			
Scheme B1			
5-Storey			
Interior	0.2585	25.8	1.52
Exterior	0.2625	27.6	1.55
Percentage change	+2	+7	+2
Interior	0.2585	25.8	1.52
Corner	0.2650	29.2	1.57
Percentage change	+3	+13	+3
50-storey			
Interior	0.4106	61.9	1.91
Exterior	0.4149	64.7	1.98
Percentage change	+1	+5	+4
Interior	0.4106	61.9	1.91
Corner	0.4192	65.6	2.02
Percentage change	+2	+6	+6

Table 7.4 Effect of structural scheme on constituent quantities of total structure using reinforced concrete beam and slab system.

No. of storeys/ Structural scheme	*Constituent quantities/sq m of floor area*		
	Concrete (cu m)	*Reinforcement (kg)*	*Formwork (sq m)*
Grid size (m) 10 x 10			
5-storey			
Scheme A1	0.2532	23.1	1.64
Scheme B1	0.2585	25.8	1.52
Percentage change	+2	+12	−7
Scheme A1	0.2532	23.1	1.64
Scheme B2	0.2258	24.1	1.66
Percentage change	−11	+4	+1
50-storey			
Scheme A1	0.4030	58.6	2.04
Scheme B1	0.4106	61.9	1.91
Percentage change	+2	+6	−6
Scheme A1	0.4030	58.6	2.04
Scheme B2	0.3708	57.8	2.04
Percentage change	−8	+1	—

7.1.2.1 Slabs

The consumption of concrete and reinforcement is dependent on the grid size, higher consumption being for the bigger grid sizes, while the trend for formwork is reversed (Figures 4.3 to 4.12).

Relatively, the waffle slabs consume less reinforced concrete constituents as compared with flat slabs, the decrease in consumption being about 22, 2 and 3 per cent in concrete, reinforcement and formwork respectively for a grid size of 6 m x 6 m (Figures 4.3 to 4.8 and 4.9 to 4.12).

7.1.2.2 Columns

In an interior grid location, using a flat slab, the consumption of constituents in columns is directly proportional to the number of storeys and the grid size. Considering a grid size of 8 m × 8 m, with the increase in the number of storeys from 5 to 50, the increase is about 400 per cent in concrete, about 750 per cent in reinforcement and about 115 per cent in formwork. The corresponding values using the waffle slabs are about 400 per cent in concrete, about 720 per cent in reinforcement and about 110 per cent in formwork.

7.1.2.3 Shear Walls

The trends for variations in the quantities of constituents for shear walls are similar to those discussed in Section 7.1.1.4.

7.1.2.4 Total Structure

The quantities of concrete, reinforcement and formwork in the total structure for reinforced concrete flat slab construction without column heads and for different number of storeys and grid sizes are illustrated in Figures 7.4 to 7.6 respectively, while the corresponding quantities for reinforced concrete waffle slab construction are shown in Figures 7.7 to 7.9. It can be seen from these figures that the quantities of concrete and reinforcement are directly proportional to the grid size and the number of storeys, while the trend for formwork is different. The quantities of formwork are directly proportional to the number of storeys but are inversely proportional to the grid sizes.

The effects of the number of storeys, grid sizes and grid locations on constituent quantities for the total structure using the flat slab system are shown in Tables 7.5 to 7.7 respectively, while those using waffle slab system are illustrated in Tables 7.8 to 7.10 respectively.

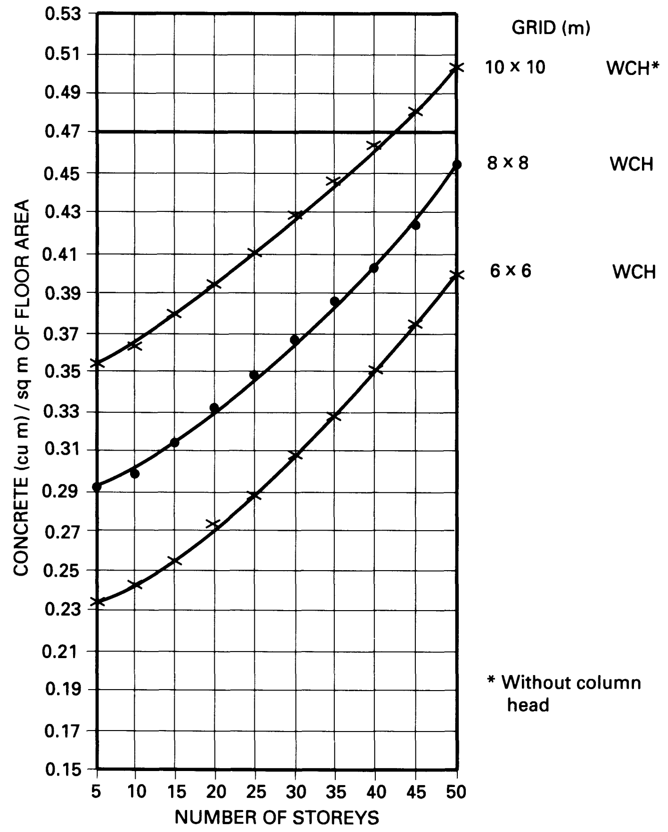


Figure 7.4 Quantities of concrete in total structure for reinforced concrete flat slab construction without column heads.

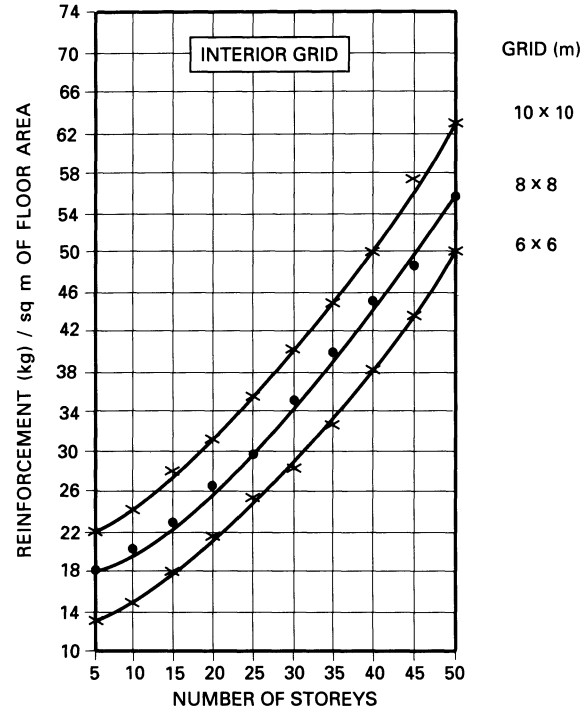


Figure 7.5 Quantities of reinforcement in total structure for reinforced concrete flat slab construction without column heads.

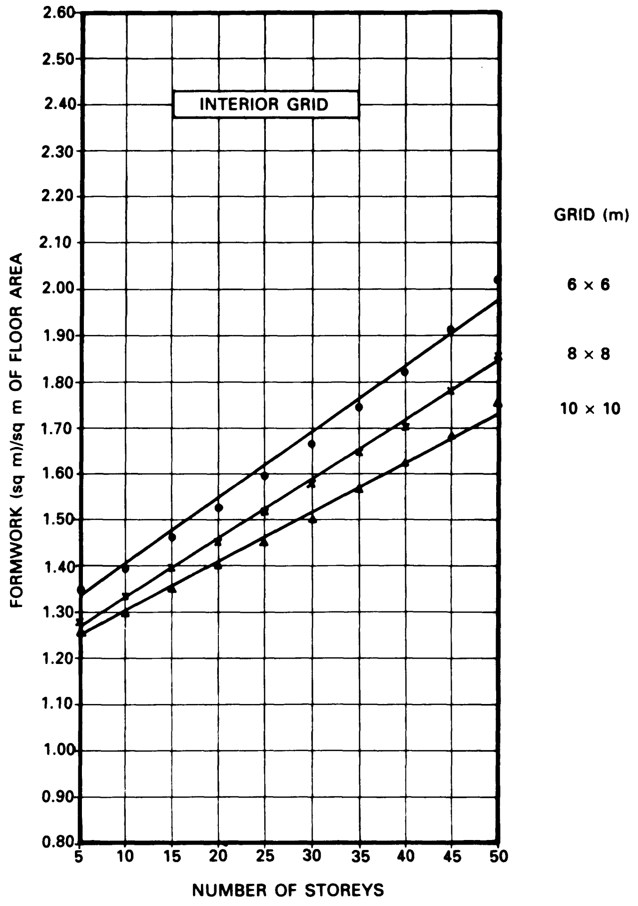


Figure 7.6 Quantities of formwork in total structure for reinforced concrete flat slab construction without column heads.

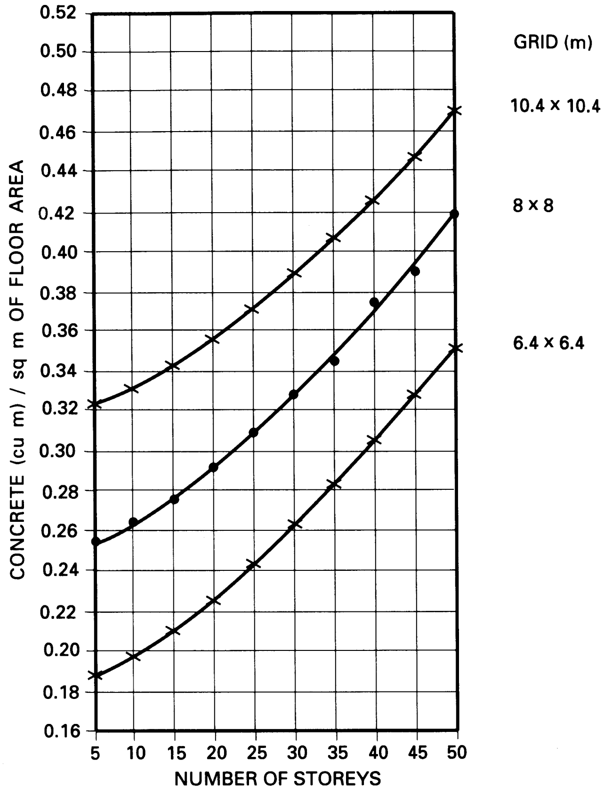


Figure 7.7 Quantities of concrete in total structure for reinforced concrete waffle slab construction without column heads.

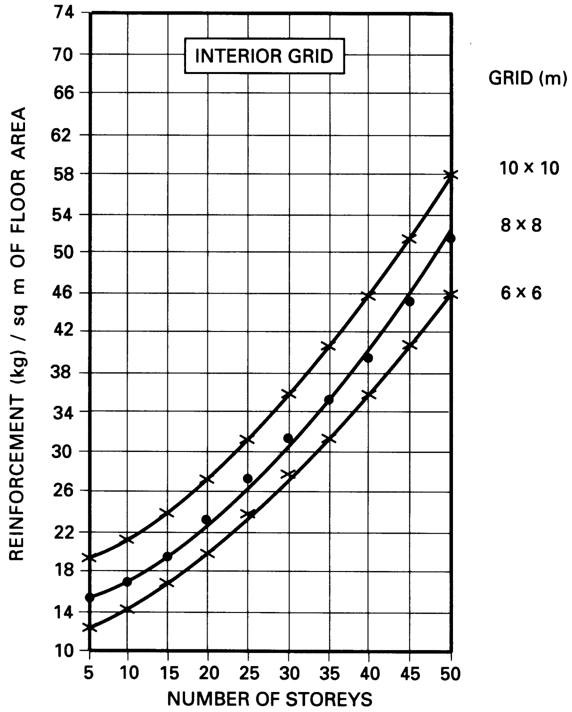


Figure 7.8 Quantities of reinforcement in total structure for reinforced concrete waffle slab construction without column heads.

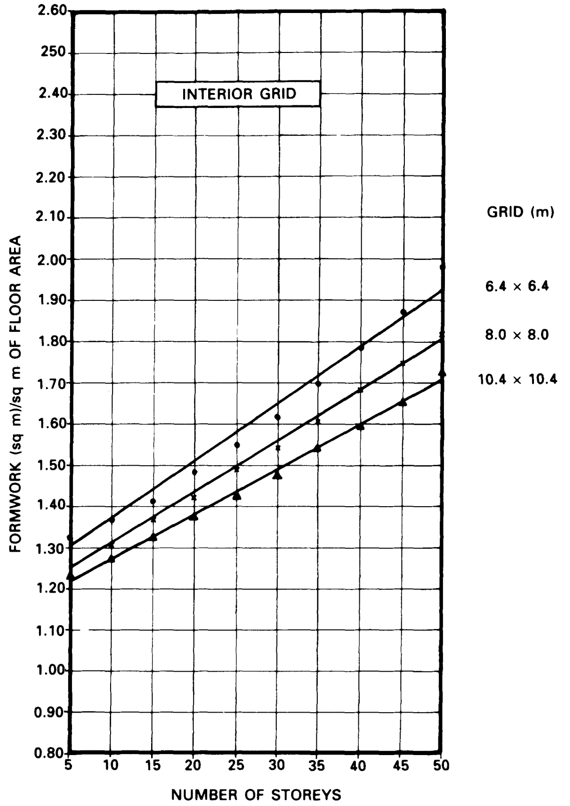


Figure 7.9 Quantities of formwork in total structure for reinforced concrete waffle slab construction without column heads.

Table 7.5 Effect of number of storeys on constituent quantities of total structure using reinforced concrete flat slab system.

Grid size (m)/ No. of storeys	*Constituent quantities/sq m of floor area*		
	Concrete (cu m)	*Reinforcement (kg)*	*Formwork (sq m)*
6 × 6			
5-storey	0.2330	13.5	1.35
50-storey	0.4005	50.3	2.05
Percentage change	+72	+274	+52
8 × 8			
5-storey	0.2905	17.9	1.31
50-storey	0.4530	56.1	1.89
Percentage change	+56	+213	+44
10 × 10			
5-storey	0.3230	22.4	1.28
50-storey	0.5035	63.5	1.78
Percentage change	+56	+183	+39

Table 7.6 Effect of grid size on constituent quantities of total structure using reinforced concrete flat slab system.

No. of storeys/ Grid size (m)	*Constituent quantities/sq m of floor area*		
	Concrete (cu m)	*Reinforcement (kg)*	*Formwork (sq m)*
5-storey			
6 × 6	0.2330	13.5	1.35
10 × 10	0.3230	22.4	1.28
Percentage change	+39	+66	−5
50-storey			
6 × 6	0.4005	50.3	2.05
10 × 10	0.5035	63.5	1.78
Percentage change	+26	+26	−13

Table 7.7 Effect of grid location on constituent quantities of total structure using reinforced concrete flat slab system.

No. of storeys/ Grid location	*Constituent quantities/sq m of floor area*		
	Concrete (cu m)	*Reinforcement (kg)*	*Formwork (sq m)*
Grid size (m) 6 × 6			
5-storey			
Interior	0.2330	13.5	1.35
Exterior	0.2500	17.2	1.52
Percentage change	+ 7	+27	+13
Interior	0.2330	13.5	1.35
Corner	0.2581	17.5	1.56
Percentage change	+11	+30	+16
50-storey			
Interior	0.4005	50.3	2.05
Exterior	0.4450	64.6	2.37
Percentage change	+11	+28	+16
Interior	0.4005	50.3	2.05
Corner	0.4513	65.4	2.44
Percentage change	+13	+30	+19
Grid size (m) 10 × 10			
5-storey			
Interior	0.3230	22.4	1.28
Exterior	0.3730	29.1	1.39
Percentage change	+16	+30	+9
Interior	0.3230	22.4	1.28
Corner	0.4208	29.5	1.41
Percentage change	+30	+32	+10
50-storey			
Interior	0.5035	63.5	1.78
Exterior	0.5708	84.1	2.00
Percentage change	+13	+32	+12
Interior	0.5035	63.5	1.78
Corner	0.5813	85.0	2.05
Percentage change	+25	+34	+15

Table 7.8 Effect of number of storeys on constituent quantities of total structure using reinforced concrete waffle slab system.

Grid size (m)/ No. of storeys	*Constituent quantities/sq m of floor area*		
	Concrete (cu m)	*Reinforcement (kg)*	*Formwork (sq m)*
6.4 × 6.4			
5-storey	0.1875	13.1	1.33
50-storey	0.3530	46.4	1.99
Percentage change	+88	+254	+50
8.0 × 8.0			
5-storey	0.2550	15.1	1.28
50-storey	0.4190	51.9	1.85
Percentage change	+64	+244	+45
10.4 × 10.4			
5-storey	0.3230	19.2	1.25
50-storey	0.4700	58.3	1.74
Percentage change	+46	+204	+39

Table 7.9 Effect of grid size on constituent quantities of total structure using reinforced concrete waffle slab system.

No. of storeys/ Grid size (m)	*Constituent quantities/sq m of floor area*		
	Concrete (cu m)	*Reinforcement (kg)*	*Formwork (sq m)*
5-storey			
6.4 × 6.4	0.1875	13.1	1.33
10.4 × 10.4	0.3230	19.2	1.25
Percentage change	+72	+47	−6
50-storey			
6.4 × 6.4	0.3530	46.4	1.99
10.4 × 10.4	0.4700	58.3	1.74
Percentage change	+33	+26	−13

Table 7.10 Effect of grid location on constituent quantities of total structure using reinforced concrete waffle slab system.

No. of storeys/ Grid location	*Constituent quantities/sq m of floor area*		
	Concrete (cu m)	*Reinforcement (kg)*	*Formwork (sq m)*
Grid size (m) 6.4 × 6.4			
5-storey			
Interior	0.1875	13.1	1.33
Exterior	0.1928	13.7	1.38
Percentage change	+3	+5	+4
Interior	0.1875	13.1	1.33
Corner	0.1985	13.9	1.40
Percentage change	+4	+6	+5
50-storey			
Interior	0.3530	46.4	1.99
Exterior	0.3550	46.8	2.07
Percentage change	+1	+1	+4
Interior	0.3530	46.4	1.99
Corner	0.4065	47.2	2.13
Percentage change	+15	+2	+7
Grid size (m) 10.4 × 10.4			
5-storey			
Interior	0.3230	19.2	1.25
Exterior	0.3263	20.0	1.26
Percentage change	+1	+4	+1
Interior	0.3230	19.2	1.25
Corner	0.3286	20.3	1.28
Percentage change	+2	+6	+2
50-storey			
Interior	0.4700	57.3	1.74
Exterior	0.4740	58.4	1.80
Percentage change	+1	+2	+4
Interior	0.4700	57.3	1.74
Corner	0.4796	59.4	1.84
Percentage change	+2	+4	+6

7.1.3 Prestressed Concrete Beam and Slab System

Observations about trends and variations of constituent quantities are now discussed component-wise.

7.1.3.1 Slab

As in the reinforced concrete beam and slab system (Section 7.1.1.1), the quantities of concrete per unit of floor area remain uniform (Figure 5.2). The requirement of concrete, in an interior panel, is minimal for Scheme A2 of the 10 m × 10 m grid, the increase in quantity above this for the other grids ranging between 14 to 52 per cent depending on the number of storeys of construction, grid size and structural scheme. The maximum consumption of concrete is for Scheme B2 of the 14 m × 14 m grid.

The consumption of reinforcement is directly proportional to the size of the grid for a given scheme and is maximal at 8.6 kg/sq m of floor area for Scheme B2 of the 14 m × 14 m grid compared with 4.8 kg/sq m of the floor area for Scheme A2 of the 10 m × 10 m grid, 5 storeys being considered in both cases (Figure 5.3). The quantity of formwork is about 75 per cent for the floor area for schemes involving two-way slabs compared with about 84 per cent for those with one-way slabs, with the exception of the 14 m × 14 m grid, Schemes A3 and B3.

7.1.3.2 Beams

In a similar way to the reinforced concrete beam and slab system (Section 7.1.1.2) there is a falling trend in the consumption of concrete from 5 to 50 storeys of construction. This is due to the reduction in the length of beams needed to accommodate the increased sections of columns in taller buildings (Figure 5.7). The decrease in quantity is however quite small.

The quantity of concrete is directly proportional to the grid size. The increase in the quantity of concrete per square metre of floor area is about 20 per cent for the 12 m × 12 m grid and about 46 per cent for the 14 m × 14 m grid compared with the 10 m × 10 m grid, considering similar structural schemes and the same number of storeys of construction.

The trend for the variation in the quantity of reinforcement is very similar to that discussed in Section 7.1.1.2, para 2, for the reinforced concrete beam and slab system.

The quantity of prestressing strand is directly proportional to the grid size and is relatively greater for schemes involving secondary beams running in two directions at right angles to each other (Figure 5.14).

The quantity of formwork is inversely proportional to the grid size and varies from about 0.47 to 0.72 square metre per square metre of floor area in 5-storey constructions to about 0.45 to 0.70 square metre in 50-storey constructions. The higher figures are for schemes with secondary beams running in two directions at right angles to each other.

7.1.3.3 Columns

In an interior grid, the increase in the consumption of concrete per square metre of floor area is about 300 per cent for 50 storeys compared with 5 storeys of construction or, in other words, about 33 per cent of 5-storey construction for each increase of 5 storeys. Similarly, the increase in the quantity of reinforcement per square metre of floor area is about 700 per cent for 50 storeys compared with 5 storeys. In other words, the increase is about 77 per cent of 5-storey construction for each increase of 5 storeys.

The quantity of formwork is inversely related to the grid size and on average, for any specific grid size, the increase in its consumption is about 10 per cent for each increase of 5 storeys compared with 5-storey construction (Figure 5.39).

7.1.3.4 Shear Walls

As before (Sections 7.1.1.4 and 7.1.2.3), the quantities of constituents in shear walls are inversely proportional to the grid sizes, while these vary directly with increase in the number of storeys.

On average, the increase in the quantities of concrete and reinforcement is about 570 and 1000 per cent for 50-storey construction compared with 5-storey construction. However, the increase in the quantity of formwork is much less, namely about 140 per cent for the same increase in the number of storeys.

7.1.3.5 Total Structure

The quantities of constituents of construction, in an interior grid, for different number of storeys, grid sizes and structural schemes are shown in Figures 7.10 to 7.13 for concrete, reinforcement, prestressing strand and formwork respectively. It can be seen from these figures that the consumption of concrete and reinforcement is directly proportional to the grid size and the number of storeys. However, the trend for formwork quantities is different, this being greater for small-sized grids when considering similar structural schemes.

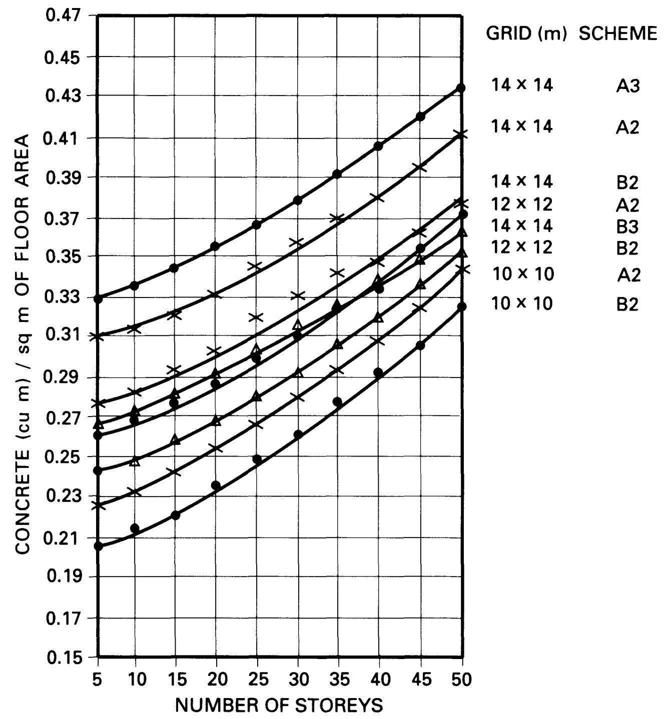


Figure 7.10 Quantities of concrete in total structure for prestressed concrete beam and RC slab construction.

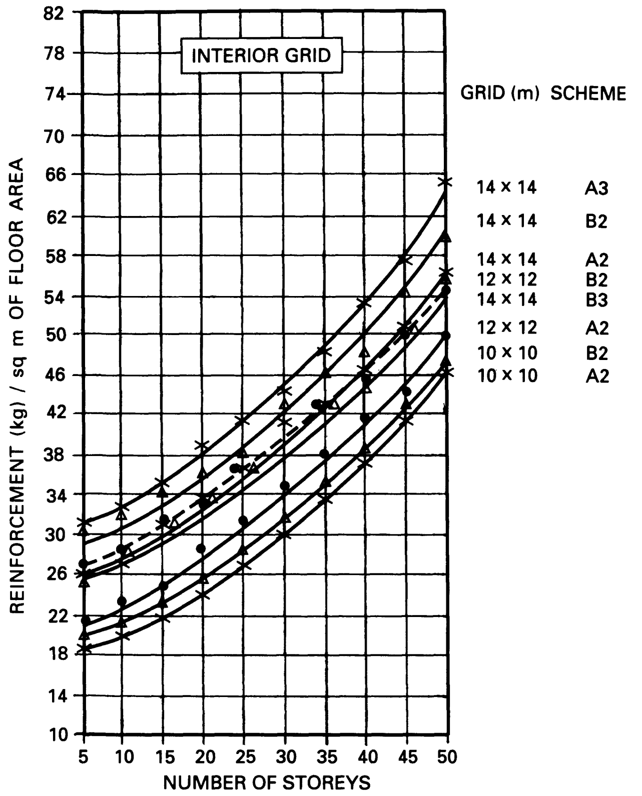


Figure 7.11 Quantities of reinforcement in total structure for prestressed concrete beam and RC slab construction.

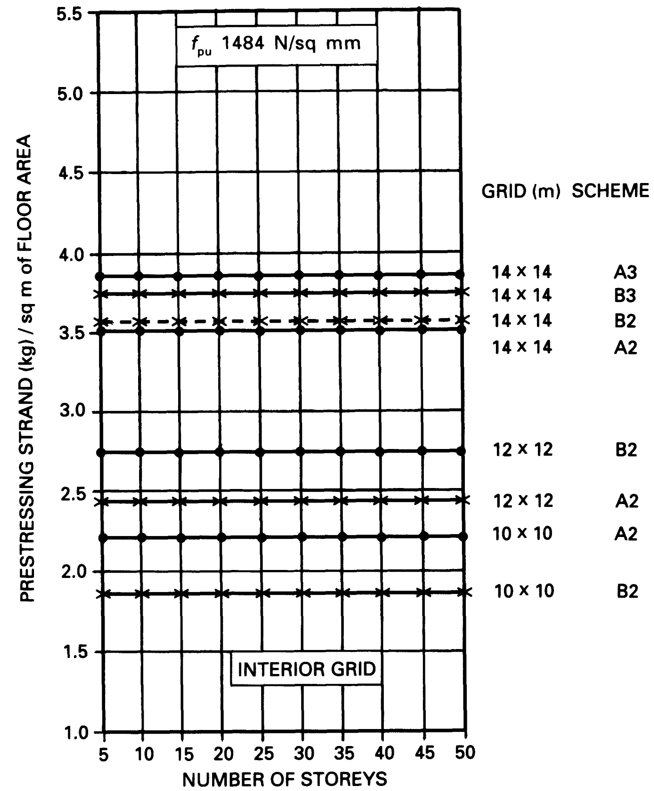


Figure 7.12 Quantities of prestressing strands in total structure for prestressed concrete beam and slab construction.

The effects of number of storeys, grid sizes, grid locations and structural schemes on constituent quantities for the total structure using prestressed concrete beams and reinforced concrete slab system are shown in Tables 7.11 to 7.14 respectively.

The effect of number of storeys on constituent quantities, for Scheme B2, indicates that the percentage increase in the quantity of concrete for different grid sizes varies from 37 to 58 per cent when the number of storeys is varied from 5 to 50, the higher figure being for the smallest grid (Table 7.11). Similarly, the values vary from 96 to 136 per cent for reinforcement while the corresponding values for formwork are 11 to 23 per cent.

The effect of grid size on constituent quantities indicates that, considering a similar number of storeys, the range of variation in the quantities of concrete is +16 to +34 per cent when the grid size is changed from 10 m × 10 m to 14 m × 14 m (Table 7.12). The corresponding values are +29 to +56 per cent for reinforcement and -2 to -11 per cent for formwork.

7.2 Cost of Structures

The cost of any structure has always been contentious and thus debatable since, firstly, at any time there are always a number of rates prevailing for the same item of work and, secondly, there are always fluctuations in rates with time. So far as the first difficulty is concerned, to arrive at the cost of any structure one can price the relevant quantities with appropriate rates taken from the prevailing Standard Schedule of Rates; while for the latter problem there is no solution except to revise the cost from time to time depending on the need. Keeping the above in mind, the cost of different structural systems using different schemes, grid sizes and number of storeys were computed for typical interior grids using the relevant charts and applying the appropriate rates given in the *Architect's and Builders' Price Book*, edited by Davis, Langdon and Everest (Spon, London, 1992 edition). Further, an allowance of 17.5 per cent was added for preliminaries and oncosts. The result are

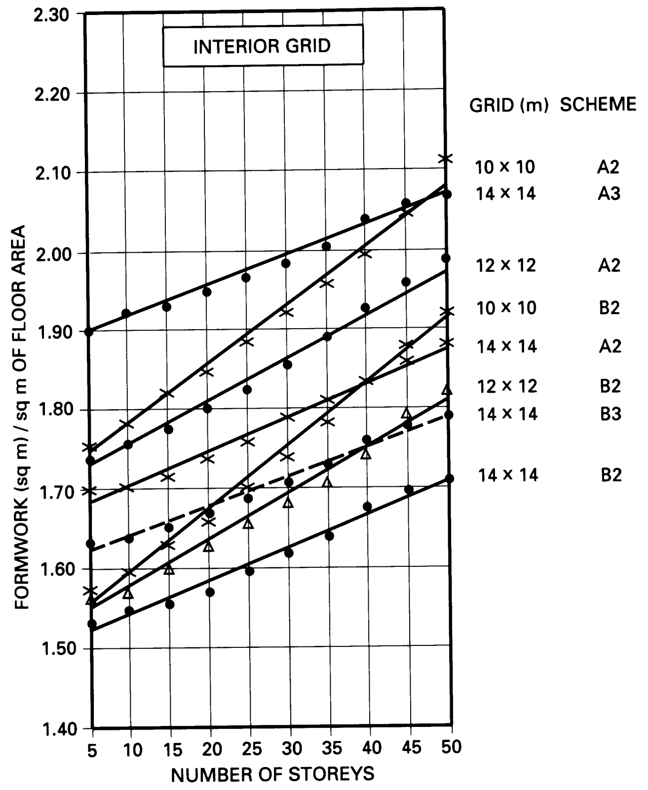


Figure 7.13 Quantities of formwork in total structure for prestressed concrete beam and RC slab construction.

Table 7.11 Effect of number of storeys on constituent quantities of total structure using prestressed beams and reinforced concrete slab system.

Grid size (m)/ No. of storeys	*Constituent quantities/sq m of floor area*			
	Concrete (cu m)	*Reinforcement (kg)*	*Strands (kg)*	*Formwork (sq m)*
Scheme B2				
10 × 10				
5-storey	0.2057	19.8	1.9	1.56
50-storey	0.3255	46.8	1.9	1.92
Percentage change	+58	+136	—	+23
12 × 12				
5-storey	0.2431	26.7	2.7	1.56
50-storey	0.3515	54.7	2.7	1.82
Percentage change	+45	+105	—	+17
14 × 14				
5-storey	0.2752	30.8	3.5	1.53
50-storey	0.3762	60.5	3.5	1.70
Percentage change	+37	+96	—	+11

Table 7.12 Effect of grid size on constituent quantities of total structure using prestressed beams and reinforced concrete slab system.

No. of storeys/ Grid size (m)	*Constituent quantities/sq m of floor area*			
	Concrete (cu m)	*Reinforcement (kg)*	*Strands (kg)*	*Formwork (sq m)*
Scheme B2				
5-storey				
10 × 10	0.2057	19.8	1.9	1.56
14 × 14	0.2752	30.8	3.5	1.53
Percentage change	+34	+56	+84	-2
50-storey				
10 × 10	0.3255	46.8	1.9	1.92
14 × 14	0.3762	60.5	3.5	1.70
Percentage change	+16	+29	+84	−11

Table 7.13 Effect of grid location on constituent quantities of total structure using prestressed concrete beams and reinforced concrete slab system.

No. of storeys/ Grid location	*Constituent quantities/sq m of floor area*			
	Concrete (cu m)	*Reinforcement (kg)*	*Strands (kg)*	*Formwork (sq m)*
Grid size (m) 10 × 10 *Scheme B2*				
5-storey				
Interior	0.2057	19.8	1.9	1.56
Exterior	0.2182	26.6	2.3	1.71
Percentage change	+6	+34	+21	+10
Interior	0.2057	19.0	1.9	1.56
Corner	0.2276	27.8	2.6	1.68
Percentage change	+11	+40	+37	+8
50-storey				
Interior	0.3255	46.8	1.9	1.92
Exterior	0.3325	53.4	2.3	2.07
Percentage change	+3	+14	+21	+8
Interior	0.3255	46.8	1.9	1.92
Corner	0.3383	54.3	2.6	2.06
Percentage change	+4	+16	+28	+7
Grid size (m) 14 × 14 *Scheme B2*				
5-storey				
Interior	0.2752	30.8	3.5	1.53
Exterior	0.2912	36.6	4.4	1.67
Percentage change	+6	+23	+22	+9
Interior	0.2752	30.8	3.5	1.53
Corner	0.2937	38.0	5.1	1.63
Percentage change	+7	+23	+45	+7

No. of storeys/ Grid location	*Constituent quantities/sq m of floor area*			
	Concrete (cu m)	*Reinforcement (kg)*	*Strands (kg)*	*Formwork (sq m)*
50-storey				
Interior	0.3762	60.5	3.5	1.70
Exterior	0.3970	65.2	4.4	1.86
Percentage change	+6	+8	+26	+9
Interior	0.3762	60.5	3.5	1.70
Corner	0.3907	66.1	5.1	1.83
Percentage change	+4	+9	+45	+8

Table 7.14 Effect of structural scheme on constituent quantities of total structure using prestressed concrete beams and reinforced concrete slab system.

No. of storeys/ Structural scheme	*Constituent quantities/sq m of floor area*			
	Concrete (cu m)	*Reinforcement (kg)*	*Strands (kg)*	*Formwork (sq m)*
Grid size (m) 14 × 14				
5-storey				
Scheme A2	0.3100	26.2	3.5	1.70
Scheme A3	0.3304	31.4	3.9	1.90
Percentage change	+7	+20	+11	+12
Scheme A2	0.3100	26.2	3.5	1.70
Scheme B2	0.2752	30.8	3.5	1.53
Percentage change	−11	+18	—	−10
Scheme A2	0.3100	26.2	3.5	1.70
Scheme B3	0.2670	26.1	3.8	1.63
Percentage change	−14	—	+9	−4
50-storey				
Scheme A2	0.4125	56.4	3.5	1.87
Scheme A3	0.4355	63.9	3.9	2.07
Percentage change	+3	+13	+11	+11
Scheme A2	0.4125	56.4	3.5	1.87
Scheme B2	0.3762	60.5	3.5	1.70
Percentage change	−9	+7	—	−9
Scheme A2	0.4125	56.4	3.5	1.87
Scheme B3	0.3665	55.0	3.8	1.79
Percentage change	−13	−2	+9	−4

shown in Figures 7.14 to 7.17 for different structural systems.

7.2.1 Reinforced Concrete Beam and Slab System

The cost/square metre of floor area for various grids and structural schemes using the reinforced concrete beam and slab system is shown in Figure 7.14. A cost comparison between Schemes A1 and B1 indicates that Scheme B1 is invariably economical for all grid sizes, the range of economy being about 2 to 5 per cent. However, the most economical scheme for a grid size of 10 m × 10 m is Scheme B2, the savings being of the order of about 3 per cent compared with Scheme A1 and about 7 per cent compared with Scheme B1.

7.2.1.1 Effect of Number of Storeys on Cost of Total Structure

Figure 7.14 shows the effect of number of storeys (5–50) on cost of total structure for various grid sizes and structural schemes. The percentage increase in cost/square metre of floor area varies from 56 to 75 per cent (Table 7.15) for the structural schemes considered, the highest value in the range being applicable to the smallest grid size, namely 6 m × 6 m and vice versa.

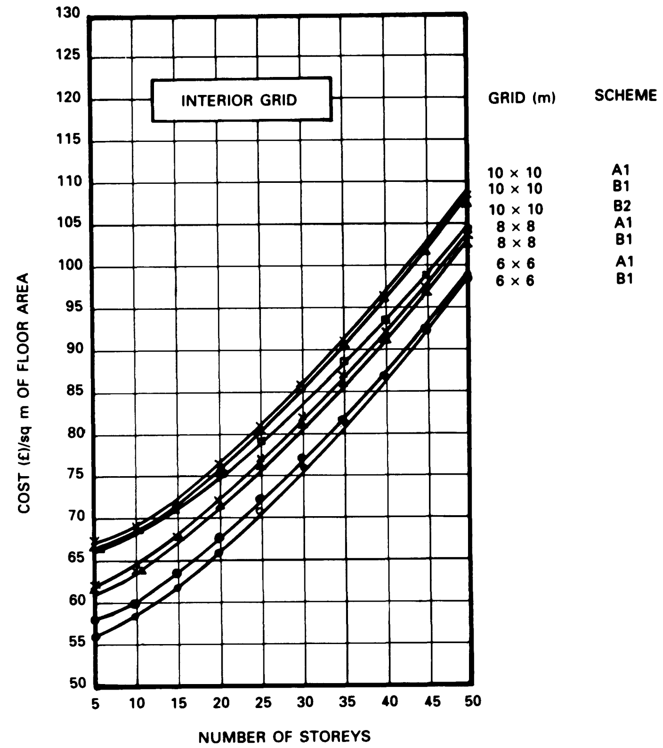


Figure 7.14 Cost/sq m of floor area for different grids and schemes using reinforced concrete beam and slab construction.

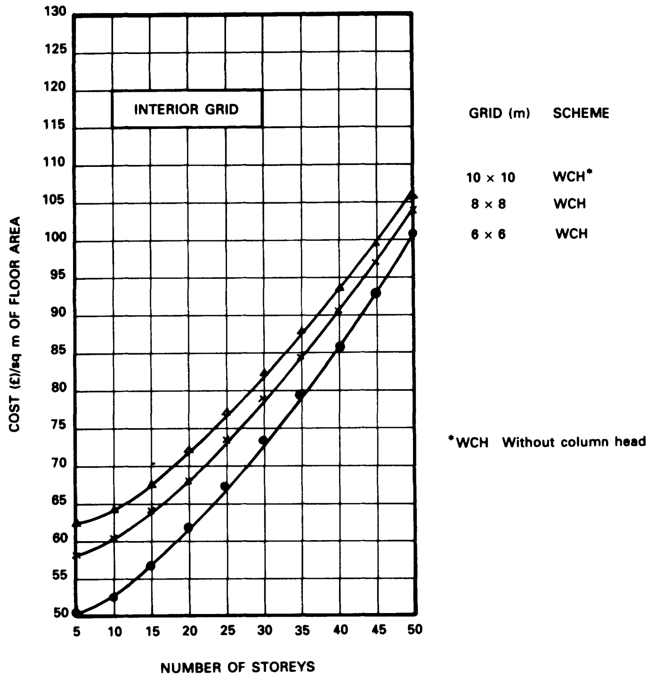


Figure 7.15 Cost/sq m of floor area for different grids using reinforced concrete flat slab construction.

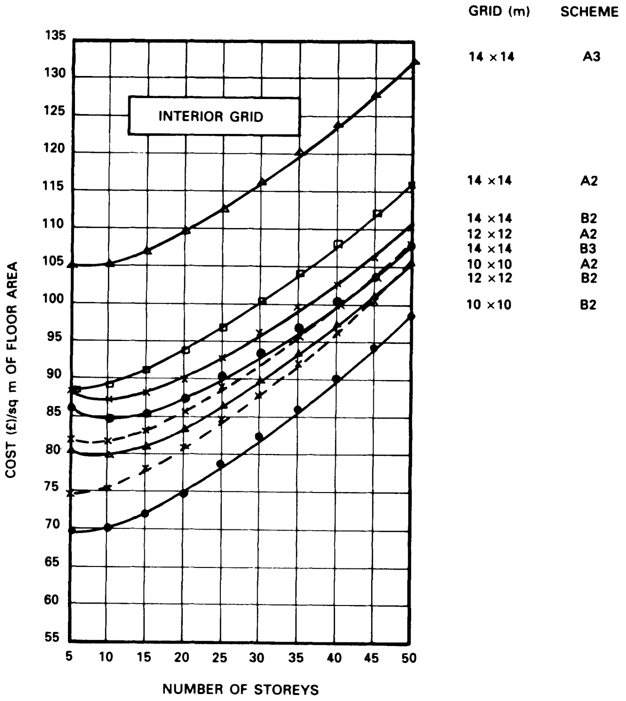


Figure 7.17 Cost/sq m of floor area for different grids and schemes using prestressed concrete beam and RC slab construction.

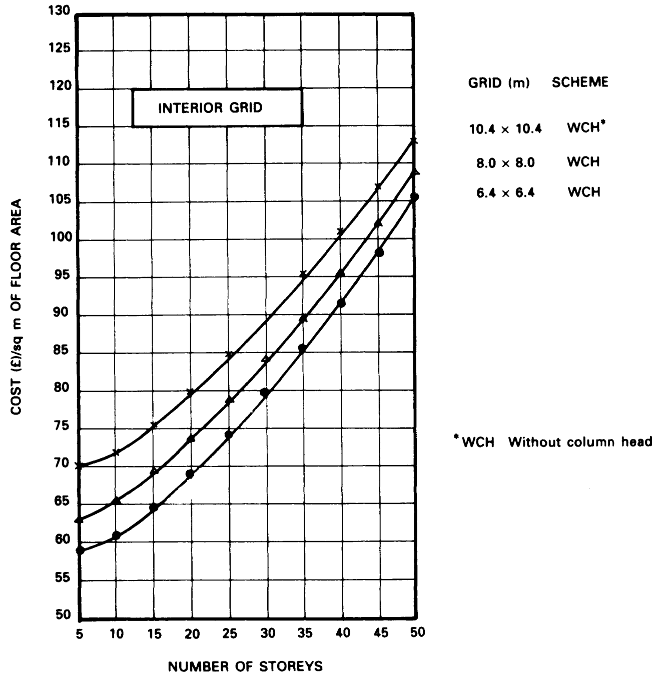


Figure 7.16 Cost/sq m of floor area for different grids using reinforced concrete waffle slab construction.

7.2.1.2 Effect of Grid Size on Cost of Total Structure

Considering any specific structural scheme and number of storeys, the cost of the total structure is proportional to the grid size (Figure 7.14). The effect of grid size on the cost of the total structure using different structural schemes and number of storeys is shown in Table 7.16. The percentage increase ranges from 9 to 20, the latter value being for 5-storey construction while the former is for 50-storey construction.

7.2.1.3 Effect of Grid Location on Cost of Total Structure

The effect of grid location on the cost of the total structure for different grid sizes and number of storeys is shown in Table 7.17 for a specific structural scheme. The increase in total cost ranges between 3 and 7 per cent, the higher value being for a corner grid and the lower for an exterior grid.

7.2.1.4 Effect of Structural Scheme on Cost of Total Structure

Considering any specific number of storeys and grid size, the percentage change in the cost of the total

Table 7.15 Effect of number of storeys on cost of total structure using reinforced concrete beam and slab system and different structural schemes.

Grid size(m)/ structural scheme	*Number of storeys*	*Cost (£)/sq m of floor area*
6 × 6		
A1	5	57.90
	50	98.70
Percentage increase		+71
B1	5	56.30
	50	98.70
Percentage increase		+75
8 × 8		
A1	5	62.20
	50	103.30
Percentage increase		+66
B1	5	61.90
	50	102.70
Percentage increase		+66
10 × 10		
A1	5	66.70
	50	107.30
Percentage increase		+61
B1	5	67.50
	50	107.80
Percentage increase		+60
B2	5	66.70
	50	104.20
Percentage increase		+56

Table 7.16 Effect of grid size on cost of total structure using reinforced concrete beam and slab system and different structural schemes.

No. of storeys/ Grid size (m)	*Structural scheme*	*Cost (£)/sq m of floor area*
5-storey		
6 × 6	A1	57.90
10 × 10	A1	66.70
Percentage increase		+15
6 × 6	B1	56.30
10 × 10	B1	67.50
Percentage increase		+20
50-storey		
6 × 6	A1	98.70
10 × 10	A1	107.30
Percentage increase		+9
6 × 6	B1	98.70
10 × 10	B1	107.80
Percentage increase		+9

Table 7.17 Effect of grid location on cost of total structure using reinforced concrete beam and slab system.

Grid size/ No. of storeys	*Grid location*	*Cost (£)/sq m of floor area*
Grid size (m) 6 × 6 Scheme B1		
5-storey		
	Interior	56.30
	Exterior	58.75
Percentage increase		+4
	Interior	56.30
	Corner	60.28
Percentage increase		+7
50-storey		
	Interior	98.70
	Exterior	101.17
Percentage increase		+3
	Interior	98.70
	Corner	103.17
Percentage increase		+5
Grid size (m) 10 × 10 Scheme B1		
5-storey		
	Interior	67.50
	Exterior	69.56
Percentage increase		+3
	Interior	67.50
	Corner	70.97
Percentage increase		+5
50-storey		
	Interior	107.80
	Exterior	109.75
Percentage increase		+2
	Interior	107.80
	Corner	111.74
Percentage increase		+4

structure is minimal (Table 7.18) when compared with the effects of the other parameters considered in Sections 7.2.1.1 to 7.2.1.3. With the unit rates considered for various constituents, Scheme B2 is the most economical for a 10 m × 10 m grid size.

7.2.2 Reinforced Concrete Flat and Waffle Slab Systems

The total cost/square metre of floor area for various grids using flat slab construction is shown in Figure 7.15 and for waffle slab construction in Figure 7.16.

Table 7.18 Effect of structural scheme on cost of total structure using reinforced concrete beam and slab system.

Grid size/ No. of storeys	*Structural scheme*	*Cost (£)/sq m of floor area*
Grid size (m) 10 × 10		
5-storey		
	A1	66.70
	B1	67.50
Percentage change		+1
	A1	66.70
	B2	66.70
Percentage change		—
50-storey		
	A1	107.30
	B1	107.80
Percentage change		+1
	A1	107.30
	B2	104.20
Percentage change		–3

Table 7.19 Effect of number of storeys on cost of total structure using reinforced concrete flat slab system.

Grid size (m)	*No. of storeys*	*Cost (£)/sq m of floor area*
6 × 6	5	50.16
	50	100.91
Percentage increase		+101
8 × 8	5	57.69
	50	103.75
Percentage increase		+80
10 × 10	5	62.50
	50	105.84
Percentage increase		+69

In each case, a structural scheme without column heads has been considered.

7.2.2.1 Effect of Number of Storeys on Cost of Total Structure

The cost of the total structure varies with the number of storeys for any specific grid size (Figures 7.15 and 7.16). The percentage increase in cost from 5 to 50 storeys varies from 69 to 101 for the flat slab system (Table 7.19) and from 62 to 80 for the waffle slab system (Table 7.20). The higher values in each range are for the smallest grid size.

Table 7.20 Effect of number of storeys on cost of total structure using reinforced concrete waffle slab system.

Grid size (m)	*No. of storeys*	*Cost (£)/sq m of floor area*
6.4 × 6.4		
	5	59.03
	50	105.96
Percentage increase		+80
8.0 × 8.0		
	5	63.26
	50	108.90
Percentage increase		+72
10.4 × 10.4		
	5	70.18
	50	113.37
Percentage increase		+62

Table 7.21 Effect of grid size on cost of total structure using reinforced concrete flat slab system.

No. of storeys	*Grid size (m)*	*Cost (£)/sq m of floor area*
5		
	6 × 6	50.16
	10 × 10	62.50
Percentage increase		+25
50		
	6 × 6	100.91
	10 × 10	105.84
Percentage increase		+5

7.2.2.2 Effect of Grid Size on Cost of Total Structure

The effect of grid size on the cost of the total structure using flat slab construction is shown in Figure 7.15 and that for waffle slab construction in Figure 7.16. The cost of the total structure is directly proportional to the grid size, for a specific number of storeys. The increase in cost from the 6 m × 6 m grid to the 10 m × 10 m grid is about 5 to 25 per cent using the flat slab system, the lower value being for the highest storeys of construction (Table 7.21) while the corresponding range using the waffle slab system is 7 to 19 per cent (Table 7.22).

7.2.2.3 Effect of Grid Location on Cost of Total Structure

The cost of the total structure varies with the location of the grid, all other parameters being the same. The cost of an exterior grid is always more than the

Table 7.22 Effect of grid size on cost of total structure using reinforced concrete waffle slab system.

No. of storeys	*Grid size (m)*	*Cost (£)/sq m of floor area*
5	6.4 × 6.4	59.03
	10.4 × 10.4	70.18
Percentage increase		+19
50	6.4 × 6.4	105.96
	10.4 × 10.4	113.37
Percentage increase		+7

Table 7.23 Effect of grid location on cost of total structure using reinforced concrete flat slab system.

No. of storeys	*Grid location*	*Cost (£)/sq m of floor area*
Grid size (m) 6 × 6		
5-storey	Interior	50.16
	Exterior	58.63
Percentage increase		+17
	Interior	50.16
	Corner	60.96
Percentage increase		+22
50-storey	Interior	100.91
	Exterior	117.49
Percentage increase		+16
	Interior	100.91
	Corner	120.29
Percentage increase		+19
Grid size (m) 10 × 10		
5-storey	Interior	62.50
	Exterior	73.23
Percentage increase		+16
	Interior	62.50
	Corner	73.64
Percentage increase		+18
50-storey	Interior	105.84
	Exterior	131.44
Percentage increase		+24
	Interior	105.84
	Corner	132.69
Percentage increase		+25

cost of an interior grid. The range of variation is between 16 and 24 per cent for flat slab construction (Table 7.23) while the corresponding range is 2 to 5 per cent for waffle slab construction (Table 7.24).

Table 7.24 Effect of grid location on cost of total structure using reinforced concrete waffle slab system.

No. of storeys	*Grid location*	*Cost (£)/sq m of floor area*
Grid size (m) 6.4 × 6.4		
5-storey	Interior	59.03
	Exterior	61.06
Percentage increase		+3
	Interior	59.03
	Corner	62.13
Percentage increase		+5
50-storey	Interior	105.96
	Exterior	108.50
Percentage increase		+2
	Interior	105.96
	Corner	110.77
Percentage increase		+5
Grid size (m) 10.4 × 10.4		
5-storey	Interior	70.18
	Exterior	72.12
Percentage increase		+3
	Interior	70.18
	Corner	73.28
Percentage increase		+4
50-storey	Interior	113.37
	Exterior	115.89
Percentage increase		+2
	Interior	113.37
	Corner	118.40
Percentage increase		+4

7.2.3 Prestressed Concrete Beam and Reinforced Concrete Slab System

The total cost/square metre of floor area for various grid sizes, number of storeys and structural schemes using prestressed beams and a reinforced concrete slab system is shown in Figure 7.17. With the unit rates of constituents considered, for Schemes A2 and B2 the latter is invariably the more economical.

In the case of the 14 m × 14 m grid, the most economical Scheme is B3 followed by B2, A2 and A3.

The range of variation in cost is about £70 to £132 for an interior grid of the grid sizes and number of storeys considered.

7.2.3.1 Effect of Number of Storeys on Cost of Total Structure

Considering Scheme B2 and the grid sizes investigated, the increase in cost of the total structure varies from 25 to 42 per cent (Table 7.25) when the number

Table 7.25 Effect of number of storeys on cost of total structure using prestressed beams and reinforced concrete slab system.

Grid size (m)	*No. of storeys*	*Cost (£)/sq m of floor area*
Scheme B2		
10 × 10	5	69.79
	50	98.90
Percentage increase		+42
12 × 12	5	80.45
	50	105.28
Percentage increase		+31
14 × 14	5	88.53
	50	110.50
Percentage increase		+25

Table 7.26 Effect of grid size on cost of total structure using prestressed beams and reinforced concrete slab system.

No. of storeys	*Grid size (m)*	*Cost (£)/sq m of floor area*
Scheme B2		
5-storey	10 × 10	69.79
	14 × 14	88.53
Percentage increase		+27
50-storey	10 × 10	98.90
	14 × 14	110.50
Percentage increase		+12

of storey changes from 5 to 50, the higher value of the increase being for the lowest grid size considered, namely 10 m × 10 m and vice versa.

7.2.3.2 Effect of Grid Size on Cost of Total Sructure

The cost of the total structure increases with increase in grid size, other factors being the same (Table 7.26). The range of increase is between 12 and 27 per cent when the grid size changes from 10 m × 10 m to 14 m × 14 m, the lower value of increase being for 50-storey construction and vice versa.

Table 7.27 Effect of grid location on cost of total structure using prestressed concrete beams and reinforced concrete slab system.

No. of storeys	*Grid location*	*Cost (£)/sq m of floor area*
Grid size (m) 10 × 10		
Scheme B2		
5-storey	Interior	69.79
	Exterior	77.32
Percentage increase		+11
	Interior	69.79
	Corner	81.56
Percentage increase		+17
50-storey	Interior	98.90
	Exterior	107.80
Percentage increase		+9
	Interior	98.90
	Corner	114.30
Percentage increase		+16
Grid size (m) 14 × 14		
Scheme B2		
5-storey	Interior	88.53
	Exterior	99.01
Percentage increase		+12
	Interior	88.53
	Corner	103.69
Percentage increase		+17
50-storey	Interior	110.50
	Exterior	117.50
Percentage increase		+6
	Interior	110.50
	Corner	122.30
Percentage increase		+11

7.2.3.3 Effect of Grid Location on Cost of Total Structure

As in other structural systems (Sections 7.2.1.3 and 7.2.2.3), the cost of the total structure is minimal for interior grid locations as compared with exterior and corner grids. Considering different grid sizes and number of storeys, the range of increase is between 6 and 17 per cent (Table 7.27).

7.2.3.4 Effect of Structural Scheme on Cost of Total Structure

Considering a grid size of 14 m x 14 m and different structural schemes, the variation in cost of the total structure is of the order of -3 to +19 per cent (Table 7.28), the most economical being Scheme B3.

Table 7.28 Effect of structural scheme on cost of total structure using prestressed concrete beams and reinforced concrete slab system.

No. of storeys	*Structural scheme*	*Cost (£)/sq m of floor area*
Grid size (m) 14 × 14		
5-storey	A2	88.67
	A3	105.10
Percentage increase		+19
	A2	88.67
	B2	88.53
Percentage change		Nil
	A2	88.67
	B3	85.95
Percentage decrease		−3
50-storey	A2	116.14
	A3	132.26
Percentage increase		+14
	A2	116.14
	B2	110.50
Percentage decrease		−5
	A2	116.14
	B3	107.59
Percentage decrease		−7

7.2.4 Relative Economics

A true cost comparison can only be made on a common basis. In other words, in a given situation, unless the effect of different structural schemes on the foundation cost due to their differences in dead weight is ascertained, a true comparison is difficult. However, the trends arrived at and discussed above can be adjusted for such differences based on one's experience and prevailing local conditions.

8 Computer-Based Cost Model for Reinforced Concrete Beam and Slab System

An interactive cost model for the reinforced concrete beam and slab system was developed using the results of 80 charts presented in Chapter 3. Based on the charts developed, 390 statistical relationships were established subsequently. The model elements for which quantities and cost can be computed by this program are solid slab, beams, columns, shear walls and total structure. The various design variables for each of these model elements have been enumerated; the flowcharts developed to write the computer program are presented; an illustration for using the interactive computer program is given and some of the sample results for different model elements are shown. Overall, the model developed runs to 54 normal computer printout pages and uses 10 subroutines for different model elements.

8.1 Introduction

The availability of cheap computer power in recent years has made it possible to save costly professional hours which hitherto were wasted in working out similar details/information for any new project that was taken up. Efforts have therefore been made in the last few years to develop computer-based cost models in almost every field where repetitive use of such models can be made (Section 1.1).

Two types of computer models, namely interactive and non-interactive, can be developed for repetitive use, depending upon whether or not the users are familiar with the computer language which has been used in writing the program. In developing the models for the construction industry it is considered preferable to write interactive types of programs since all users who are expected to make use of them may not be familiar with computer hardware and languages. This is an important requirement in the author's view, since the professionals who may be interested in making use of such a model, in addition to structural engineers, include architects, building economists, quantity surveyors and cost economists.

The author developed three computer-based cost models (1, 2, 3), however only one is discussed in this book, owing to limitations of space.

The charts developed for the reinforced concrete beam and slab system (Chapter 3) and the statistical relationships subsequently established for them form the basis for developing a computer model for computing quantities and cost of any model element. This chapter describes the model elements and considers the design variables; flowcharts for the computer model are developed; and an illustration is provided for usage, together with some of the sample results for different model elements.

8.2 Model Elements and Design Variables

The elements in this model are solid slab, beams, columns, shear walls and total structure. Total structures, although not being an element of the structural system, have been considered as an element of the computer model. This was considered necessary since in practice quantities and cost are required for this, in addition to other model elements. The model is capable of computing quantities and cost for each of these elements with different sets of values for various design variables. The design variables considered for different model elements are discussed in the subsequent sections.

8.2.1 Solid Slabs

The effects of the following design variables are covered under this model element:

- Grid size
- Structural scheme
- Grid location
- Number of storeys
- Grade of concrete.

In order to obtain quantities and cost for any specific value of a design variable, the values of other variables having an influence are to be supplied as an input. This is made clear in section 8.4. For each of the above design variables, the model is capable of printing an appropriate table of quantities and costs with essential explanatory notes for clarity.

8.2.2 Beams

Beams have been classified as main beams, secondary beams and secondary beams over columns (Chapter 3, Figure 3.l). In each category of these beams, the design variables considered are:

- Grid size
- Structural scheme
- Number of storeys
- Grid location
- Size of beam
- Number of continuous spans

In the case of main beams, an additional design variable considered is 'lateral loading', since main beams are parts of the lateral load resisting frames, and two values of lateral loads have been considered in the analysis and design of structural frames (Chapter 3, Section 3.2).

8.2.3 Columns

Columns have been classified, based on their location, as interior column, exterior column and corner column. For each of these, the design variables considered are:

- Grid size
- Number of storeys
- Structural scheme
- Grid location
- Grade of concrete
- Number of continuous spans.

The model is thus capable of giving quantities and cost for any grid size, structural scheme, number of storeys, grid location, number of continuous spans and grade of concrete. Three grades of concrete, namely 30, 35 and 40 N/sq mm, have been considered. The design variable 'lateral loading' was ignored in this model element since the two cases considered for this did not make any difference in the quantities of their constituents.

8.2.4 Shear Walls

In this element, the design variables incorporated are:

- Grid size
- Structural scheme
- Number of storeys
- Loading
- Number of continuous spans.

8.2.5 Total Structure

The design variables considered for this model element are:

- Grid size
- Structural scheme
- Grid location
- Number of storeys
- Grade of concrete
- Number of continuous spans
- Lateral loading.

This model element is capable of computing the cost/square metre of floor area as well as the total cost of a project, given its design features such as gross floor area, shear wall area, grid size(s), structural scheme, number of storeys, number of continuous spans, concrete grade and grid locations. The computation of quantities/cost is built up element-wise based on the model elements already discussed (Sections 8.2.1, 8.2.2, 8.2.3 and 8.2.4).

8.3 Flow Charts

Skeleton and detailed flowcharts were developed before writing the computer program for this model. A brief skeleton flowchart of the model is shown in Figure 8.1 and another one for the model elements in Figure 8.2. The latter indicates certain links which in turn are referred to in the subsequent flowcharts for other model elements. The concept adopted for all elements is substantially uniform, hence flowcharts for only two elements, namely solid slab and total structure, are presented to avoid repetition. These are shown in Figures 8.3 and 8.4 for solid slab and total structure respectively. For each model element in the main program (Figures 8.3 and 8.4) certain subroutines are called, into which have been incorporated the statistical relations established earlier and the logic of using appropriate relationships. Detailed flowcharts for all such subroutines used in the program were worked out for various model elements. It may be mentioned here that the subroutine for the model element 'total structure' utilises within itself subroutines of other elements.

8.4 Computer Model and Illustrative Usage

The computer model based on the flowcharts (Section 8.3) was developed and perfected to run on an IBM 3081 mainframe computer. The program was written in the FORTRAN language and a microcomputer version of the same was also made.

For clarity in illustrating the usage of the model developed, a problem is defined below for solution.

> *Problem*: Compute the cost of slab per unit area for grid sizes (m) of 6.3 x 6.3, 8.1 × 8.1 and 9.5 × 9.5 using the following structural schemes, grid location, number of storeys, concrete grade and unit rates:
>
> - Scheme A1 (Figure 3.1)
> - Scheme B1 (Figure 3.1)
> - Grid location – Interior
> - Number of storeys – 27
> - Concrete grade – 30 N/sq mm
>
> Unit rates for
>
> | | |
> |---|---|
> | Concrete (£/cu m) | 65.82 |
> | Reinforcement (£/kg) | 0.49 |
> | Formwork (£/sq m) | 15.34 |

The solution for the above problem is illustrated in the steps below.

8.4.1 First Display and Input – Choice of Element

```
THIS PROGRAM IS DESIGNED TO HELP THE
CONCERNED PROFESSIONALS TO ESTIMATE THE
EFFECT OF DIFFERENT PARAMETERS ON
QUANTITIES/COST OF CONSTITUENTS OF
REINFORCED CONCRETE BEAM AND SLAB
CONSTRUCTION IN COMMERCIAL HIGH RISE
BUILDINGS

PLEASE INDICATE THE ELEMENT ON THE
QUANTITIES OF WHICH THE EFFECT OF DIFFERENT
PARAMETERS IS DESIRED:

     1) SOLID SLAB
     2) BEAMS
     3) COLUMNS
     4) SHEAR WALLS
     5) TOTAL STRUCTURE

YOUR CHOICE IS (1,2,3,4 OR 5) ?
```

Using the keyboard, the user is required to enter any digit from 1 to 5 depending upon the requirement. The user enters 1 for the problem defined.

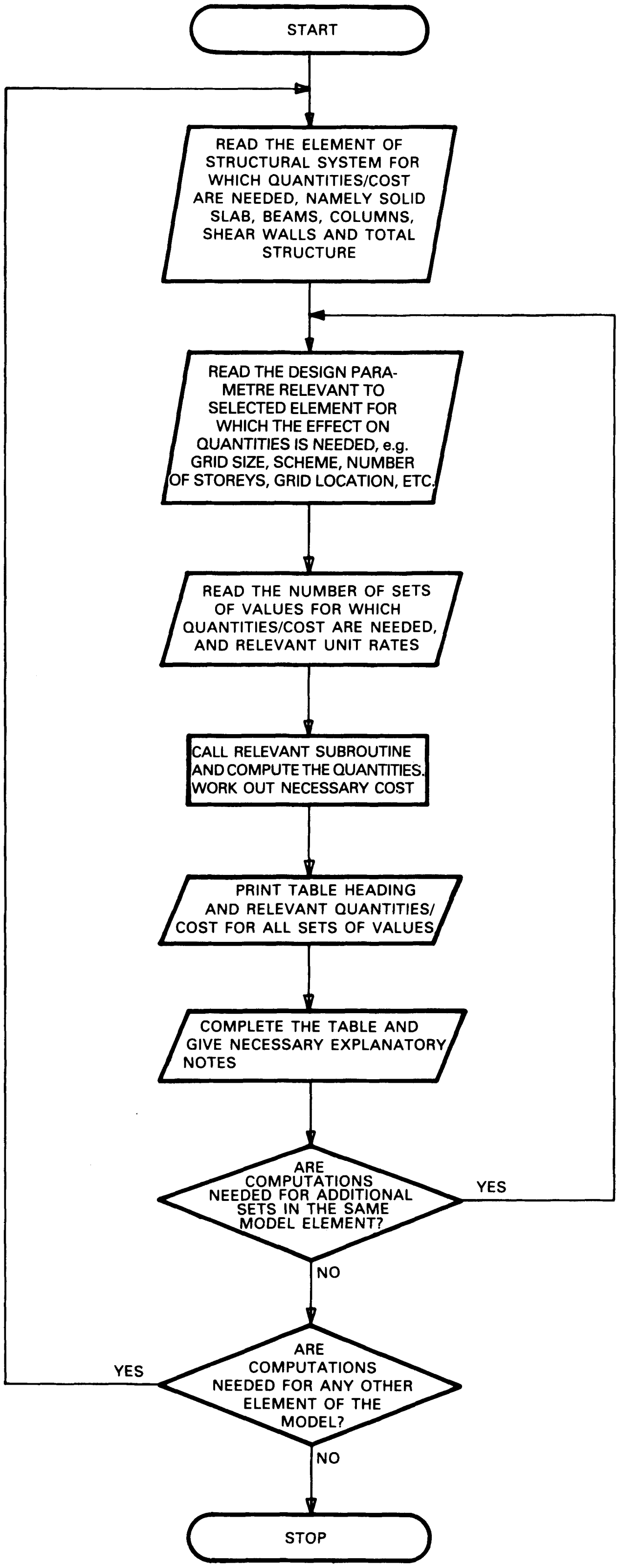


Figure 8.1 Skeleton flowchart for the computer model – reinforced concrete beam and slab construction.

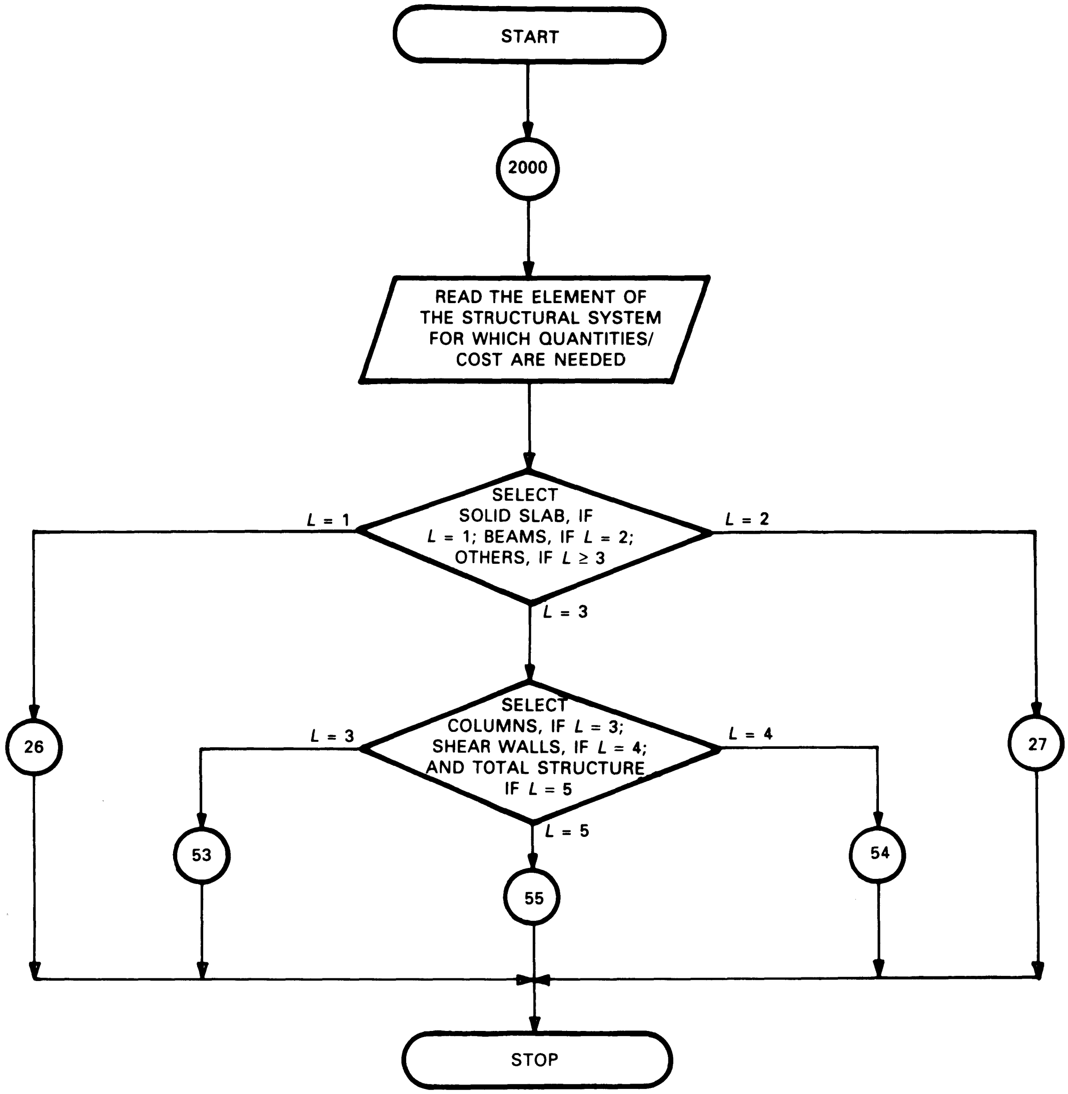


Figure 8.2 Skeleton flowchart indicating model elements of reinforced concrete beam and slab construction.

8.4.2 Second Display and Input – Choice of Primary Design Parameter

```
THE EFFECTS OF FOLLOWING PARAMETERS ARE
COVERED FOR SOLID SLAB:

        1) GRID SIZE
        2) STRUCTURAL SCHEME
        3) LOCATION OF GRID
        4) NUMBER OF STOREYS
        5) GRADE OF CONCRETE

YOUR CHOICE IS (1,2,3,4 OR 5)
```

Enter 1.

8.4.3 Third Display and Input – Design Parameters

```
YOU HAVE THE FOLLOWING CHOICES/RANGES
FOR DIFFERENT PARAMETERS IN THIS MODEL:

GRID SIZE: THE RANGE COVERED VARIES
        FROM 6 M x 6 M TO 10 M x 10 M

STRUCTURAL SCHEME
1) SCHEME A1:  MAIN BEAMS IN TWO
   DIRECTIONS SUPPORTED ON COLUMNS; TWO
```

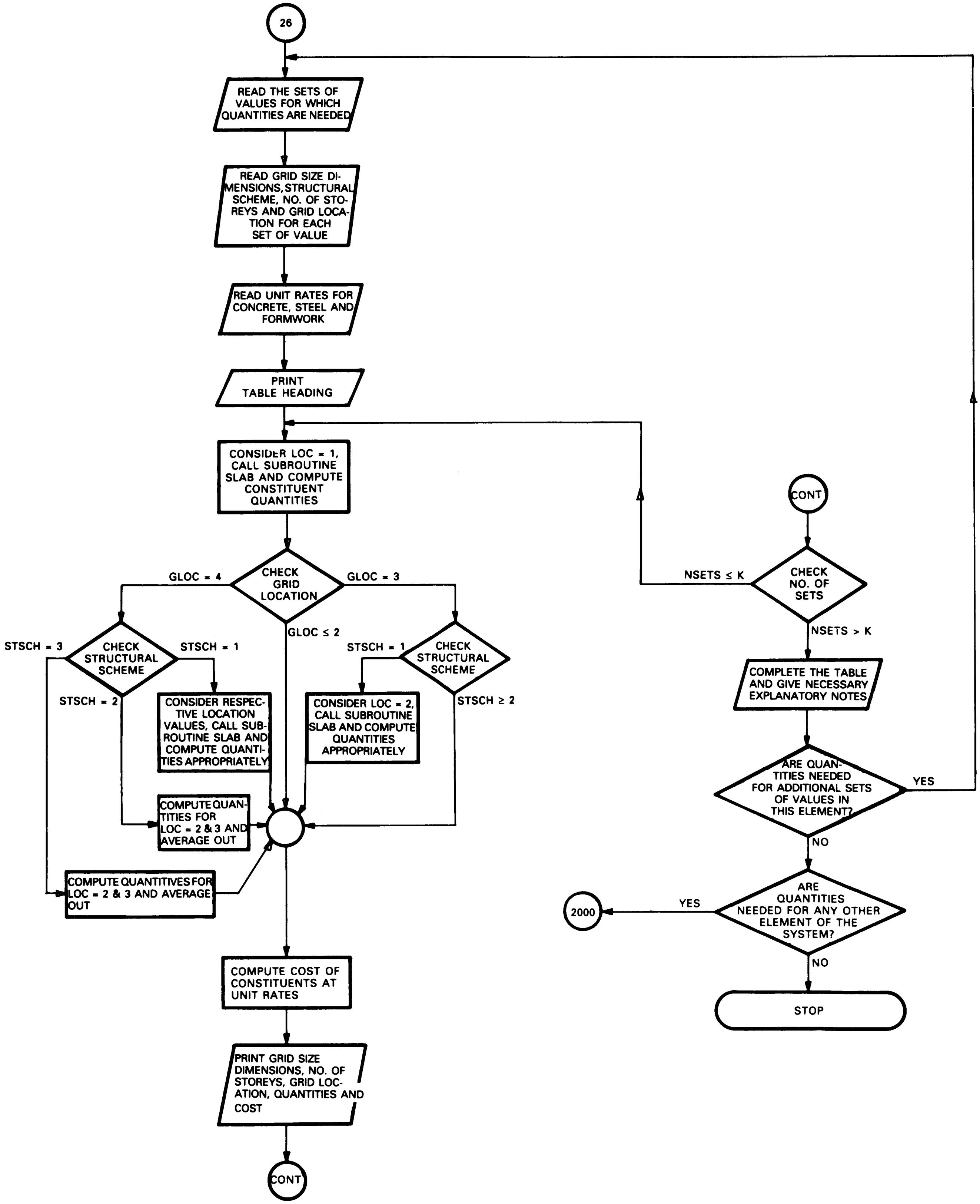


Figure 8.3 Flowchart for the model element – solid slab.

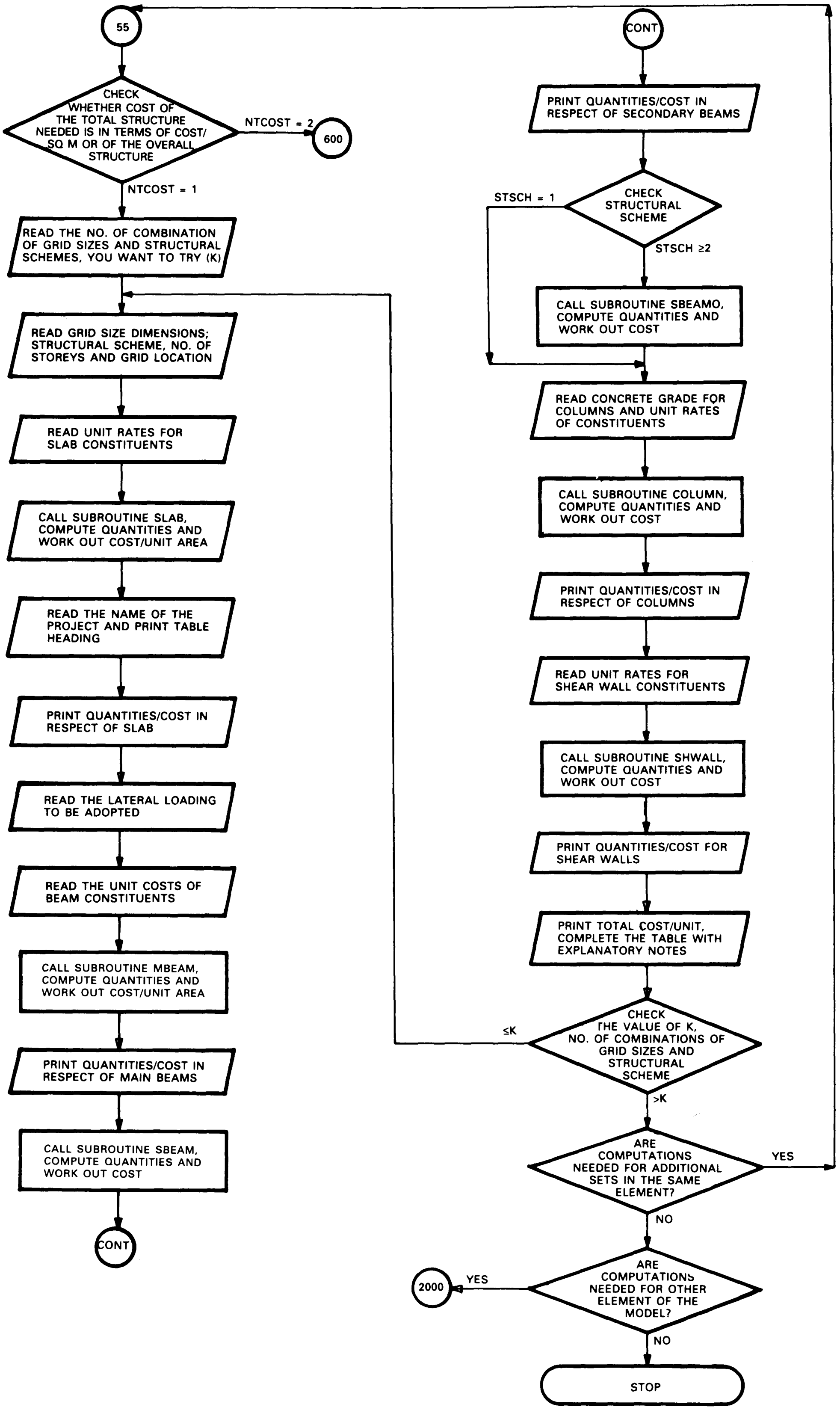


Figure 8.4 Flowchart for the model element – total structure (cost/sq m of floor area).

SECONDARY BEAMS AT RIGHT ANGLES TO ONE ANOTHER SUPPORTED ON MAIN BEAMS

2) SCHEME B1: MAIN BEAMS IN ONE DIRECTION SUPPORTED ON COLUMNS AND SECONDARY BEAMS IN THE OTHER DIRECTION AT A SPACING EQUAL TO HALF THE GRID SIZE
3) SCHEME B2: MAIN BEAMS IN ONE DIRECTION SUPPORTED ON COLUMNS AND SECONDARY BEAMS IN THE OTHER DIRECTION AT A SPACING EQUAL TO ONE-THIRD THE GRID SIZE (APPLICABLE ONLY TO 10 M × 10 M GRID)

LOCATION OF GRID: YOU HAVE 4 CHOICES FOR GRID LOCATIONS

1) INTERIOR GRID
2) FIRST INTERIOR GRID
3) EXTERIOR GRID
4) CORNER GRID

NUMBER OF STOREYS: THE RANGE CONSIDERED FOR NUMBERS OF STOREYS VARIES FROM 5 TO 50

DATA ARE TO BE ENTERED LATER FOR THE FOLLOWING VARIABLES IN THE ORDER SPECIFIED

GRID SIZE FIRST DIMENSION, GRID SIZE SECOND DIMENSION,
STRUCTURAL SCHEME, NUMBER OF STOREYS, AND GRID LOCATION

FOR EXAMPLE 10.0, 10.0, 2, 50, 1 FORMS ONE SET OF COMBINATION

FOR HOW MANY COMBINATIONS OF VARIABLES DO YOU WISH TO COMPUTE QUANTITIES/COSTS?

YOU ARE ALLOWED ANY NUMBER OF COMBINATIONS

The user needs to enter 6 since there are 3 grid sizes and 2 structural schemes for each of the given grid sizes, and the value of each of the other parameters is not more than 1.

8.4.4 *Fourth Display and Input – Combinations*

PLEASE INPUT THE VALUES OF 6 COMBINATIONS?

The user inputs the following sets of values:

6.3, 6.3, 1, 27, 1
6.3, 6.3, 2, 27, 1
8.1, 8.1, 1, 27, 1
8.1, 8.1, 2, 27, 1
9.5, 9.5, 1, 27, 1
9.5, 9.5, 2, 27, 1

8.4.5 *Fifth Display and Input – Unit Rates*

PLEASE SUPPLY THE UNIT RATES FOR CONCRETE (£/CU M),
REINFORCEMENT (£/KG) AND FORMWORK (£/SQ M) IN SLAB

Enter 65.82, 0.49, 15.34.

8.4.6 *Sixth Display – Output*

The computer systems works out the required quantities/cost for set of values and displays the results as under:

EFFECT OF GRID SIZE AND STRUCTURAL SCHEME ON QUANTITIES OF CONSTITUENTS/COST FOR SLAB IN REINFORCED CONCRETE BEAMS AND SLAB CONSTRUCTION (QUANTITIES/COST PER SQ M OF SLAB AREA

GRID SIZE	SCHEME*	NUMBER OF STOREYS	GRID** LOCATION	CONCRETE (CU M)	STEEL (KG)	FORMWORK (SQ M)	COST+ (£)
6.3 × 6.3	1	27	1	0.1030	4.2	0.83	21.57
6.3 × 6.3	2	27	1	0.1154	5.0	0.87	23.39
8.1 × 8.1	1	27	1	0.1212	4.6	0.83	22.96
8.1 × 8.1	2	27	1	0.1427	6.6	0.87	25.97
9.5 × 9.5	1	27	1	0.1387	5.2	0.83	24.41
9.5 × 9.5	2	27	1	0.1672	7.9	0.87	28.22

*1 INDICATES SCHEME A1
2 SCHEME B1
3 SCHEME B2

** 1 INDICATES INTERIOR GRID
2 FIRST INTERIOR GRID
3 EXTERIOR GRID
4 CORNER GRID

```
*UNIT RATES FOR CONSTITUENTS:
                    CONCRETE              STEEL              FORMWORK
                    (£/CU M)              (£/KG)             (£/SQ M)
                     65.82                 0.49               15.34
```

8.4.7 Seventh Display and Input – Additional Combinations

```
DO YOU WANT TO COMPUTE QUANTITIES/COST
FOR OTHER VALUES IN THIS ELEMENT
  1) YES
  2) NO
YOUR CHOICE IS (1 OR 2)?
```

Enter 2.

8.4.8 Seventh Display and Input – Other Elements

```
DO YOU WISH TO CONTINUE WITH SOME OTHER
ELEMENT OF THIS MODEL
  1) YES
  2) NO
YOUR CHOICE IS (1 OR 2)?
```

If the user wishes to continue to solve some other problem, he needs to enter 1. However, since the solution of the defined problem has already been displayed it is assumed that he wants to stop and thus has entered 2. This brings the user to the end of the computations.

8.5 Sample Results

The model developed is capable of producing about 40 different types of tables for various model elements. It would occupy too much space to illustrate each one. However, it can be mentioned that the models (1, 2, 3) can be applied to all the applications covered in Chapter 6.

References

1. Singh, S. Cost model for reinforced concrete beam and slab structures. *Journal of the Construction Division (ASCE)*. Accepted for publication, 1993.
2. Singh, S. Cost estimation of prestressed concrete beam and reinforced concrete slab construction. *Construction Management and Economics*, Vol. 9, 1991, pp. 205–215.
3. Singh, S. Computer based cost model for reinforced concrete flat slab and waffle slab systems. *International Journal of Project Management*. Accepted for publication, 1993.

9 Case Studies for Comparison of Results

Case studies of six completed projects were made with the objective of comparing actual quantities of constituents taken from their bills of quantities with those obtained by using the established charts (Chapter 3 to 5). The comparison has indicated that the actual quantities consumed in different projects are always more than those quantities when computed theoretically. The difference varies from project to project, the overall range being 4.8–10.3 per cent. This suggests that an allowance of about 5–10 per cent should be added to the quantities obtained theoretically.

9.1 Introduction

Research investigations are of little value unless their validity is checked by comparison with the actual data from the industry. The objective of such comparison is twofold, namely to check the extent of differences between the two results and to establish guidelines for the use of analytical investigations in practice. With these objectives, the comparison was made for six completed commercial building projects designed by different consultants in the local construction industry. In this chapter is described the basis of comparison, salient features of the projects considered, theoretical results, collection of information, comparison of results and the observations.

9.2 Basis of Comparison

Theoretically, a true comparison should always be made on the same basis. For example, if only equal spans have been considered in the analysis, design and computation of quantities for establishing the models, then only those building projects satisfying such a requirement should be considered for comparison. However, looking for projects satisfying such a strict requirement will yield disappointing results since the number of such buildings may be negligible. Further, in practice, certain structural components are provided which do not form part of the structural frame. Therefore it was decided to bear in mind the following points in selecting the projects and also in collecting the relevant information for comparison:

- Generally the range of grid sizes and other design parameters in a project should be within those limits taken for investigation pertaining to a relevant structural system.
- Only structural beams that take a load from slabs and transfer it to columns are taken. Fascia beams and beams to support flower boxes and gutters are not included.
- Columns on the ground floor supporting canopy and stiffeners in long walls are excluded, not being an inherent part of the structural system.
- Parapet walls, fascia walls and fins are excluded as they are not part of the structure.
- The total floor area is measured from the structural drawings and is taken to be the area between external structural grid lines.

9.3 Salient Features of Projects

Centre line plans for only three projects are shown, in Figures 9.1 to 9.3. The salient features in respect of each project, such as number of storeys, floor area,

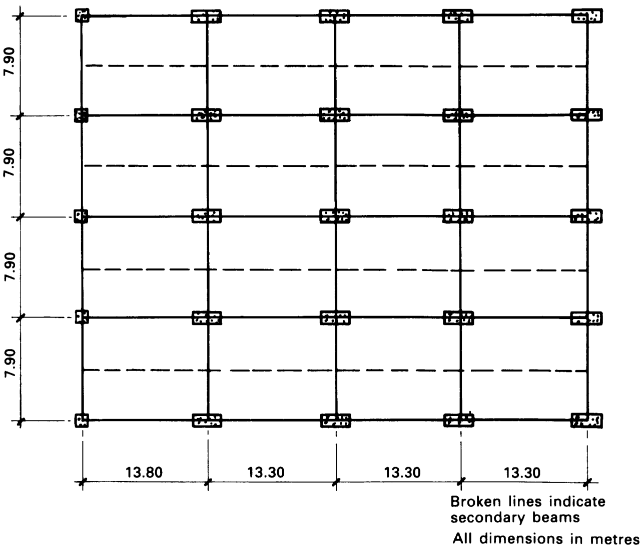
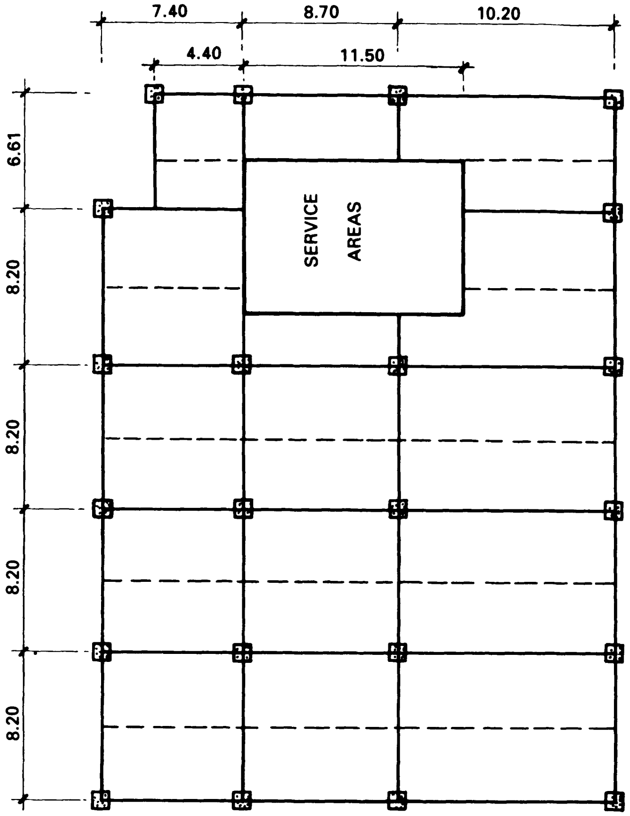


Figure 9.1 Centre line typical floor plan of project A.



Broken lines indicate secondary beams

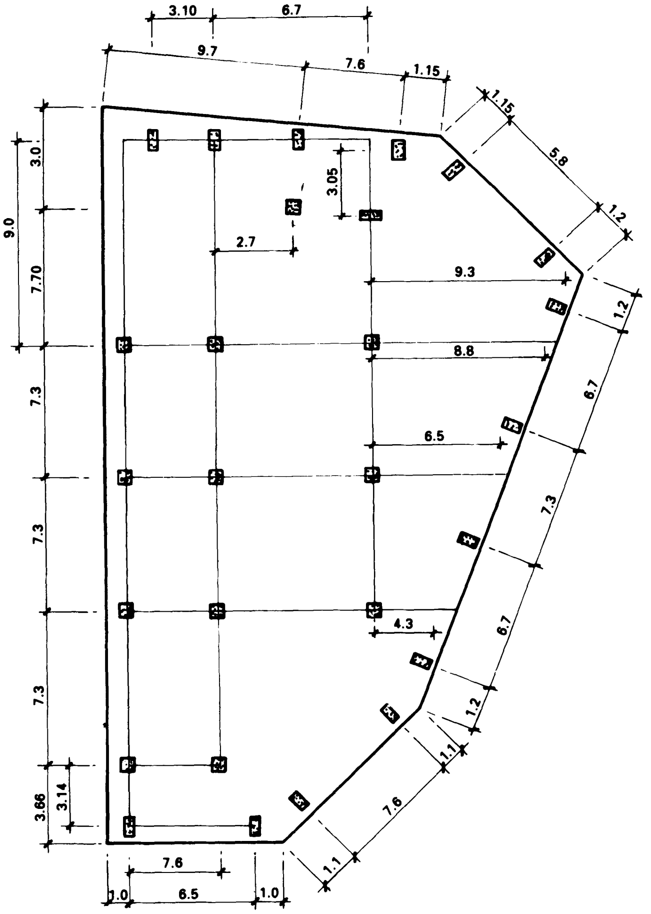
All dimensions in metres

Figure 9.2 Centre line typical floor plan of project B.

shear wall area, grid size range, podium and tower block details, continuity and structural system adopted, are listed in Table 9.1.

9.4 Theoretical Results

Using the appropriate charts and multiplying factors, if required (Chapters 3 to 5), and based on the design parameters for an individual project, quantities for different structural elements were computed and the results are shown in Tables 9.2 to 9.4 for projects 1 to 3 respectively under the column 'Theoretical'. In computing the quantities for projects with podium and tower blocks, computations are made separately.



All dimensions in metres

Figure 9.3 Centre line typical floor plan of project C.

Table 9.1 Salient features of projects.

Project title	*Number of storeys*	*Podium block*	*Tower block*	*Floor area (sq m)*	*Shear core (sq m)*	*Continuity**	*Structural system/ Scheme*
A	11	—	11	23487	3901	4	Prestressed beam and slab, B2
B	20	4	20	27634	3874	3	RC beam and slab, B1
C	8	—	8	4755	571	2–3	RC beam and slab, B1

* Number of continuous spans.

9.5 Collection of Information

The construction industry has always resisted giving historical information about completed projects. Such a tendency is more severe in the developing countries compared with the developed ones. The author also faced the same problem, but the position was eased when the purpose and the usefulness of the study was explained.

Table 9.2 Comparison of actual and theoretical quantities of constituents in different components. Project title: A.

Component/ Constituents		*Quantities*		*Percentage difference*
		Actual	*Theoretical*	
Slab				
Concrete	(cu m)	3252.93	3048.00	+ 6.3
Reinforcement	(t)	170.72	153.89	+ 9.9
Formwork	(sq m)	21032.36	19497.00	+ 7.3
Beams				
Concrete	(cu m)	1602.39	1441.60	+10.0
Reinforcement	(t)	440.45	396.85	+ 9.9
Strands	(t)	51.89	46.97	+ 9.5
Formwork	(sq m)	12187.56	11176.00	+ 8.3
Columns				
Concrete	(cu m)	570.65	514.10	+ 9.9
Reinforcement	(t)	102.51	92.07	+10.2
Formwork	(sq m)	2817.65	2535.00	+10.0
Shear walls				
Concrete	(cu m)	620.91	558.20	+10.1
Reinforcement	(t)	49.90	44.73	+10.4
Formwork	(sq m)	7953.33	7120.00	+10.5

Table 9.3 Comparison of actual and theoretical quantities of constituents in different components. Project title: B.

Component/ Constituents		*Quantities*		*Percentage difference*
		Actual	*Theoretical*	
Slab				
Concrete	(cu m)	4651.56	4190.60	+ 9.9
Reinforcement	(t)	220.60	200.19	+ 9.3
Formwork	(sq m)	26938.82	24105.00	+10.5
Beams				
Concrete	(cu m)	1350.19	1231.10	+ 8.8
Reinforcement	(t)	371.15	340.04	+ 8.4
Formwork	(sq m)	11983.73	10741.00	+10.4
Columns				
Concrete	(cu m)	1011.65	906.30	+10.4
Reinforcement	(t)	241.79	219.50	+ 9.2
Formwork	(sq m)	4849.69	4345.00	+10.4
Shear walls				
Concrete	(cu m)	1156.21	10[illegible]2.70	+10.7
Reinforcement	(t)	118.18	107.41	+ 9.1
Formwork	(sq m)	10917.13	9807.00	+10.2

The actual quantities of constituents in respect of each project were extracted from the bills of quantities, considering the criteria laid down (Section 9.2).

In order to maintain confidentiality, ficticious names have been given to the various projects.

Table 9.4 Comparison of actual and theoretical quantities of constituents in different components. Project title: C.

Component/ Constituents		*Quantities*		*Percentage difference*
		Actual	*Theoretical*	
Slab				
Concrete	(cu m)	636.20	605.90	+ 4.8
Reinforcement	(t)	31.11	28.26	+ 9.2
Formwork	(sq m)	4411.72	4162.00	+ 5.7
Beams				
Concrete	(cu m)	187.13	171.60	+ 8.3
Reinforcement	(t)	51.12	46.86	+ 8.3
Formwork	(sq m)	1982.30	1844.00	+ 7.0
Columns				
Concrete	(cu m)	114.88	103.60	+ 9.8
Reinforcement	(t)	17.56	15.85	+ 9.7
Formwork	(sq m)	846.93	763.00	+ 9.9
Shear walls				
Concrete	(cu m)	97.44	89.50	+ 8.2
Reinforcement	(t)	8.82	8.15	+ 7.6
Formwork	(sq m)	1369.76	1223.00	+10.7

9.6 Comparison of Results

The comparison between the theoretical results (Section 9.4) and the actual quantities used (Section 9.5) was made and the percentage difference computed. The results for various projects are shown in Tables 9.2 to 9.4. The percentage difference was obtained by comparing actual and theoretical quantities.

9.7 Observations

Invariably, the percentage difference is positive, which indicates that the actual quantities consumed in different projects is always more than those computed from the computer model. The difference varies from project to project and, considering all projects, the overall range is about 4.8–10.3 per cent.

Generally, among all the structural components, the percentage difference is lowest for slab and, considering different constituents within this element, the lowest percentage is for concrete. Among the remaining components, there is no regular trend.

The possible reasons for the above differences appear to be the differing analysis and design methods: for example, adoption of the simplified method of analysis which does not consider interaction of frames and shear walls; non-curtailment of reinforcement in accordance with BS 8110 1985; measuring non-structural concrete components for architectural features under structural concrete; adoption of external brick walls instead of light-weight concrete block walls; and the use of available stocks of reinforcement.

10 Additional Data for Preliminary Cost Estimation

10.1 Quantities of Constituents in Overall Structures

Experience has shown that the relative variation in the unit rates of constituents of construction with change in time is never uniform. Because of this, a structural system or scheme which is economical at any given time may not always remain so. For accuracy, it is therefore essential to consider the prevailing unit rates of constituents for cost estimation. With this aim in mind, quantities of constituents in an interior grid of an overall structure using the reinforced concrete beam and slab system are shown in Table 10.1 for different design parameters. The same information, for the reinforced concrete flat slab and waffle slab systems, is shown in Tables 10.2 and 10.3 respectively, while for the prestressed concrete beam and reinforced concrete slab system it is exhibited in Table 10.4.

It should be noticed from these tables that the constituent quantities given are for the structure as a whole. It is therefore necessary to consider average prevailing unit rates for related structural elements in any system.

10.2 Effect of Different Live Loads on Constituent Quantities

The basic data developed in Chapters 3–5 are based on live loads for commercial buildings (Sections 3.2.1, 4.2 and 5.3). However, the effect of increased live loads on constituent quantities has been given in Table 10.5 so that the basic data after modification for any increased live load can be used for cost estimation of other categories of buildings such as industrial, educational, etc.

Table 10.1 Quantities of constituents in overall structure using reinforced concrete beam and slab system (interior grid).

Number of storeys	*Grid size (m)/ Structural scheme (refer to Figure 3.1)*	*Quantities of constituents/ sq m of floor area*		
		Cpncrete (cu m)	*Reinforcement (kg)*	*Formwork (sq m)*
5	6 × 6 A1	0.18	14.4	1.68
	B1	0.17	16.4	1.59
	8 × 8 A1	0.22	18.8	1.68
	B1	0.22	20.6	1.57
	10 × 10 A1	0.25	23.1	1.64
	B1	0.26	25.8	1.52
	B2	0.23	24.1	1.66
10	6 × 6 A1	0.18	15.6	1.74
	B1	0.18	17.7	1.65
	8 × 8 A1	0.22	19.7	1.73
	B1	0.23	23.0	1.62
	10 × 10 A1	0.26	24.6	1.68
	B1	0.27	28.1	1.56
	B2	0.23	25.9	1.70
15	6 × 6 A1	0.20	17.9	1.81
	B1	0.19	20.2	1.71
	8 × 8 A1	0.23	21.8	1.78
	B1	0.24	26.1	1.67
	10 × 10 A1	0.27	26.8	1.73
	B1	0.28	31.3	1.61
	B2	0.24	28.6	1.75
20	6 × 6 A1	0.21	20.9	1.87
	B1	0.21	23.5	1.78
	8 × 8 A1	0.25	25.7	1.83
	B1	0.25	29.5	1.72
	10 × 10 A1	0.28	30.6	1.77
	B1	0.29	35.1	1.65
	B2	0.26	31.9	1.79
25	6 × 6 A1	0.23	24.3	1.93
	B1	0.22	26.9	1.84
	8 × 8 A1	0.26	29.3	1.88
	B1	0.27	33.8	1.78
	10 × 10 A1	0.30	34.9	1.82
	B1	0.31	39.1	1.70
	B2	0.27	35.9	1.83
30	6 × 6 A1	0.24	28.0	2.00
	B1	0.24	31.0	1.90
	8 × 8 A1	0.28	33.4	1.93
	B1	0.29	38.0	1.83
	10 × 10 A1	0.32	39.3	1.86
	B1	0.33	43.5	1.75
	B2	0.29	39.9	1.87
35	6 × 6 A1	0.26	31.4	2.06
	B1	0.26	34.8	1.97
	8 × 8 A1	0.30	37.5	1.98
	B1	0.31	42.1	1.88
	10 × 10 A1	0.34	43.7	1.90
	B1	0.35	47.8	1.78
	B2	0.33	44.6	1.92

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Table 10.1 *continued*

Number of storeys	*Grid size (m)/ Structural scheme (refer to Figure 3.1)*	*Quantities of constituents/ sq m of floor area*		
		Concrete (cu m)	*Reinforcement (kg)*	*Formwork (sq m)*
40	6 × 6 A1	0.28	35.2	2.13
	B1	0.28	38.1	2.03
	8 × 8 A1	0.33	41.6	2.03
	B1	0.33	46.6	1.93
	10 × 10 A1	0.36	48.7	1.95
	B1	0.37	52.8	1.83
	B2	0.33	48.9	1.96
45	6 × 6 A1	0.30	39.2	2.19
	B1	0.30	43.2	2.09
	8 × 8 A1	0.35	46.4	2.08
	B1	0.35	51.1	1.98
	10 × 10 A1	0.38	53.5	1.99
	B1	0.39	57.1	1.87
	B2	0.35	53.3	2.00
50	6 × 6 A1	0.33	43.8	2.26
	B1	0.32	48.0	2.16
	8 × 8 A1	0.37	51.3	2.13
	B1	0.37	56.0	2.03
	10 × 10 A1	0.40	58.6	2.04
	B1	0.41	61.9	1.91
	B2	0.37	57.8	2.05

Table 10.2 Quantities of constituents in overall structure using reinforced concrete flat slab system with columns without column heads (interior grid).

Number of storeys	*Grid size (m)*	*Quantities of constituents/sq m of floor area*		
		Concrete (cu m)	*Reinforcement (kg)*	*Formwork (sq m)*
5	6 × 6	0.23	13.5	1.35
	8 × 8	0.29	17.9	1.31
	10 × 10	0.36	22.4	1.28
10	6 × 6	0.24	15.4	1.42
	8 × 8	0.30	20.0	1.35
	10 × 10	0.37	24.5	1.32
15	6 × 6	0.26	17.8	1.48
	8 × 8	0.32	23.3	1.41
	10 × 10	0.38	27.8	1.37
20	6 × 6	0.27	21.4	1.55
	8 × 8	0.33	26.4	1.47
	10 × 10	0.39	31.0	1.43
25	6 × 6	0.29	25.1	1.62
	8 × 8	0.35	39.5	1.53
	10 × 10	0.41	35.4	1.48
30	6 × 6	0.31	29.4	1.70
	8 × 8	0.37	34.2	1.60
	10 × 10	0.43	40.1	1.54
35	6 × 6	0.33	32.8	1.78
	8 × 8	0.39	38.8	1.67
	10 × 10	0.45	45.1	1.59
40	6 × 6	0.35	38.4	1.86
	8 × 8	0.41	43.7	1.74
	10 × 10	0.46	50.4	1.66
45	6 × 6	0.38	43.8	1.96
	8 × 8	0.43	49.3	1.82
	10 × 10	0.48	57.8	1.72
50	6 × 6	0.40	50.3	2.05
	8 × 8	0.45	56.1	1.89
	10 × 10	0.50	63.5	1.78

Table 10.3 Quantities of constituents in overall structure using reinforced concrete waffle slab system with columns without column heads (interior grid).

Number of storeys	*Grid size (m)*	*Quantities of constituents/sq m of floor area*		
		Concrete (cu m)	*Reinforcement (kg)*	*Formwork (sq m)*
5	6.4 × 6.4	0.19	13.1	1.33
	8 × 8	0.26	15.1	1.28
	10.4 × 10.4	0.32	19.2	1.25
10	6.4 × 6.4	0.20	14.5	1.38
	8 × 8	0.26	16.8	1.32
	10.4 × 10.4	0.33	21.4	1.28
15	6.4 × 6.4	0.21	16.8	1.44
	8 × 8	0.28	19.5	1.37
	10.4 × 10.4	0.34	24.2	1.33
20	6.4 × 6.4	0.23	19.7	1.50
	8 × 8	0.29	22.9	1.43
	10.4 × 10.4	0.36	27.7	1.39
25	6.4 × 6.4	0.24	23.4	1.57
	8 × 8	0.31	26.7	1.50
	10.4 × 10.4	0.37	31.7	1.43
30	6.4 × 6.4	0.26	27.3	1.64
	8 × 8	0.33	31.3	1.56
	10.4 × 10.4	0.39	36.3	1.49
35	6.4 × 6.4	0.28	31.6	1.72
	8 × 8	0.35	35.8	1.63
	10.4 × 10.4	0.41	40.4	1.55
40	6.4 × 6.4	0.30	36.5	1.80
	8 × 8	0.37	40.4	1.71
	10.4 × 10.4	0.43	46.0	1.61
45	6.4 × 6.4	0.33	40.9	1.90
	8 × 8	0.39	46.3	1.78
	10.4 × 10.4	0.45	51.9	1.68
50	6.4 × 6.4	0.35	46.4	2.00
	8 × 8	0.42	51.9	1.85
	10.4 × 10.4	0.47	58.3	1.74

Table 10.4 Quantities of constituents in overall structure using prestressed concrete beam and reinforced concrete slab system (interior grid).

Number of storeys	*Grid size (m)/ Structural scheme (refer to Figure 5.1)*		*Quantities of constituents/sq m of floor area*			
			Concrete (cu m)	*Reinforcement (kg)*	*Strands (kg)*	*Formwork (sq m)*
5	10 × 10	A2	0.23	18.7	2.0	1.75
		B2	0.21	19.8	1.9	1.56
	12 × 12	A2	0.26	21.4	2.5	1.73
		B2	0.24	26.7	2.8	1.56
	14 × 14	A2	0.31	26.2	3.5	1.70
		B2	0.28	30.8	3.6	1.53
		A3	0.33	31.4	3.9	1.90
		B3	0.27	26.1	3.8	1.63
10	10 × 10	A2	0.23	20.4	2.0	1.77
		B2	0.21	21.5	1.9	1.60
	12 × 12	A2	0.27	23.4	2.5	1.75
		B2	0.25	28.3	2.8	1.58
	14 × 14	A2	0.32	28.1	3.5	1.71
		B2	0.28	32.3	3.6	1.55
		A3	0.34	32.3	3.9	1.92
		B3	0.27	28.7	3.8	1.65
15	10 × 10	A2	0.24	22.4	2.0	1.81
		B2	0.22	23.5	1.9	1.63
	12 × 12	A2	0.28	25.4	2.5	1.78
		B2	0.26	30.6	2.8	1.60
	14 × 14	A2	0.32	30.5	3.5	1.73
		B2	0.29	34.5	3.6	1.56
		A3	0.34	35.1	3.9	1.93
		B3	0.28	31.0	3.8	1.66
20	10 × 10	A2	0.25	25.2	2.0	1.84
		B2	0.24	25.9	1.9	1.66
	12 × 12	A2	0.29	28.2	2.5	1.80
		B2	0.27	33.1	2.8	1.62
	14 × 14	A2	0.33	33.3	3.5	1.74
		B2	0.30	35.1	3.6	1.57
		A3	0.35	38.8	3.9	1.95
		B3	0.29	33.6	3.8	1.67
25	10 × 10	A2	0.27	28.2	2.0	1.88
		B2	0.25	29.0	1.9	1.70
	12 × 12	A2	0.30	30.8	2.5	1.83
		B2	0.28	35.9	2.8	1.65
	14 × 14	A2	0.35	36.1	3.5	1.76
		B2	0.31	39.3	3.6	1.60
		A3	0.37	41.9	3.9	1.97
		B3	0.30	36.4	3.8	1.70
30	10 × 10	A2	0.28	31.0	2.0	1.92
		B2	0.26	31.7	1.9	1.74
	12 × 12	A2	0.31	34.3	2.5	1.86
		B2	0.29	39.0	2.8	1.68
	14 × 14	A2	0.36	41.0	3.5	1.79
		B2	0.33	42.3	3.6	1.62
		A3	0.38	44.9	3.9	2.00
		B3	0.31	39.2	3.8	1.72
35	10 × 10	A2	0.30	34.8	2.0	1.96
		B2	0.27	35.2	1.9	1.78
	12 × 12	A2	0.32	37.7	2.5	1.89
		B2	0.30	42.4	2.8	1.71
	14 × 14	A2	0.37	43.0	3.5	1.81
		B2	0.34	45.9	3.6	1.65
		A3	0.39	49.2	3.9	2.02
		B3	0.32	42.6	3.8	1.74
40	10 × 10	A2	0.31	38.8	2.0	2.00
		B2	0.29	38.9	1.9	1.83
	12 × 12	A2	0.34	41.8	2.5	1.93
		B2	0.32	46.3	2.8	1.75
	14 × 14	A2	0.38	47.1	3.5	1.83
		B2	0.35	48.4	3.6	1.67
		A3	0.41	53.7	3.9	2.04
		B3	0.34	45.7	3.8	1.76
45	10 × 10	A2	0.33	42.7	2.0	2.05
		B2	0.31	42.8	1.9	1.87
	12 × 12	A2	0.36	45.7	2.5	1.96
		B2	0.34	50.2	2.7	1.78
	14 × 14	A2	0.40	51.3	3.5	1.86
		B2	0.36	54.9	3.6	1.69
		A3	0.42	58.2	3.9	2.06
		B3	0.35	50.7	3.8	1.78
50	10 × 10	A2	0.35	47.0	2.0	2.10
		B2	0.33	46.8	1.9	1.92
	12 × 12	A2	0.37	49.9	2.5	1.99
		B2	0.35	54.7	2.8	1.82
	14 × 14	A2	0.41	56.4	3.5	1.87
		B2	0.38	60.5	3.6	1.71
		A3	0.44	63.9	3.9	2.08
		B3	0.37	55.0	3.8	1.80

Table 10.5 Effect of increased live load on constituent quantities (taken as 1.00 for live load 2.5 kN/sq m).

Live load (kN/sq m)	*Constituents*		
	Concrete	*Reinforcement*	*Formwork*
2.5	1.00	1.00	1.00
3.0	1.02	1.06	1.02
4.0	1.04	1.18	1.03
5.0	1.06	1.23	1.05
6.0	1.09	1.40	1.08
8.0	1.14	1.55	1.13
10.0	1.20	1.85	1.19

Source: Lee Seng Kee. *Study on the effects of reinforced concrete constituents under various uniformly distributed live loads*. MSc (Building Science), School of Building and Estate Management, National University of Singapore, 1991/92.

10.3 Effect of Increased Wind Load on Constituent Quantities

The constituent quantities are affected by the magnitude of wind loading, generally above about 15 storeys. As far as the basic data of constituent quantities in this book is concerned (Chapters 3–5), a basic wind speed of 38 m/s is assumed. However, the effect of increased wind on constituent quantities is shown in Table 10.6, which can be utilised to modify the basic constituent quantities for regions where the prevailing basic wind speeds are greater.

Table 10.6 Effect of increased wind load on constituent quantities (taken as 1.00 for basic wind speed of 38 m/s).

Structural element	*Wind speed (m/s)*	*Constituents*		
		Concrete	*Reinforcement*	*Formwork*
Beams	38	1.00	1.00	1.00
	42	1.03	1.05	1.03
	46	1.10	1.14	1.08
	50	1.20	1.24	1.18
	54	1.30	1.34	1.28
Columns	38	1.00	1.00	1.00
	42	1.04	1.06	1.04
	46	1.12	1.16	1.12
	50	1.22	1.26	1.22
	54	1.32	1.36	1.32
Shear walls	38	1.00	1.00	1.00
	42	1.06	1.08	1.06
	46	1.14	1.18	1.14
	50	1.24	1.28	1.24
	54	1.34	1.38	1.34

Source: Chin Moon Cheong. *Effect of different wind speeds on reinforced concrete constituent quantities.* MSc (Building Science), School of Building and Estate Management, National University of Singapore, Singapore, 1991/92.

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