ENG 215-(EQC 1991/79)

Vertical Lateral Load Resisting Elements for Low to Medium Rise Buildings-Information for Architects

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VERTICAL LATERAL LOAD RESISTING ELEMENTS FOR LOW TO MEDIUM RISE BUILDINGS

Information for Architects

A Report to the New Zealand
Earthquake and War
Damage Commission.

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June 1992

ABSTRACT

This report describes the development of a computer program for architects to determine requirements for wind and earthquake lateral load resisting structure for low to medium-rise New Zealand buildings. Information for architects by way of design guides that can provide more general lateral load resisting structural information for commonly used structural systems and materials, appropriate to a preliminary design stage, is also presented and discussed.

PREFACE

This project has arisen from my experience of teaching architecture students about building structures. I have been dissatisfied with my approach to a typical question raised during discussion of a student design project: "How long do these structural walls need to be to resist wind and earthquake loads?"

An experienced structural engineer can give an answer based on a combination of experience and intuition, but it leaves the student in a position of having to accept what is usually no more than someone else's "gut feeling". The student is unable to verify the answer personally. Also, there is a sense of being continually reliant on another's opinion, based on personal knowledge and unobtainable by the student.

As there was no published information for either students or practising architects answering that typical question, I have written a computer program RESIST. It enables non-engineer building designers to investigate the lateral load resisting requirements of low to medium rise buildings.

It is hoped this report and RESIST will be particularly useful at the early stages of a architectural design. Advice is provided on the adequacy of various structural solutions. That information will then provide the basis for more detailed design by the project structural engineer.

Andrew Charleson
June 1992

ACKNOWLEDGEMENTS

The financial support of the New Zealand Earthquake and War Damage Commission is gratefully acknowledged.

The constructive comments of structural engineering and architectural colleagues have been greatly appreciated, as have comments from several classes of architectural students who have used RESIST at various stages of development.

Thanks must also go to Andrew Vere-Jones for his work in enhancing the user friendliness of the program, generating and plotting the graphs and writing the RESIST manual.

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1. INTRODUCTION

1.1 Need for Information

At the preliminary stages of a building design an architect requires approximate sizes of structural members in order to develop a conceptual design that can be described by drawings and models. If the architect has designed similar sized buildings and structural layouts in the past, that experience may enable reasonably accurate estimates of vertical lateral load resisting structural element sizes to be made. Without prior experience, other sources of information are necessary, usually provided by structural engineers.

Early in the design process, the architect may feel it is premature to involve the services of an engineer, but is still interested in the investigating the use of structure to provide order and form to the design. What may be desired is a series of structural alternatives which address questions similar to the following. If structural walls are selected, how many are required and how long need they be? How might each option make the best contribution to the overall architectural design objectives?

A design tool or design aids are needed to provide information so that the most appropriate structural layout is adopted. This is especially important for structure required to resist the building's lateral loads in New Zealand. It is generally far more substantial, and usually has far greater impact on architectural planning than structure necessary to resist gravity loads.

Often it is convenient to conceptualize a building structure as consisting of two structural systems; one for resisting gravity loads and the other providing strength, stability and stiffness against lateral loads that arise from wind and earthquakes. Frequently these two systems are considered independently for reasons both of structural clarity and construction economy. This is frequently the case in seismic design.

For establishing the size of gravity load resisting structural elements there is ample published information. In many texts for architects structural sizes of, for example, beams and columns, are presented for wide ranges of systems, structural materials and spans [1, 6]. Similar, less general information is available from trade literature and publications promoting a particular structural material. This is readily accessible to architects. However, for lateral load resisting structure there is no published information. Texts [6, 7] describe the range of lateral load resisting systems, and even how preliminary structural analyses can be undertaken, but no guidance is provided concerning approximate size of structural elements. For a building of specific size, construction, function, and location, information on lateral load resisting structural requirements must be obtained elsewhere.

1.2 Information Contained in this Report and Its Intended Use

The objective of this research project is to provide information to be used during initial design stages. Viable lateral load resisting structural options can be investigated, and that finally chosen can then be integrated into the overall design concept. Information developed during this project is presented using two separate media.

Firstly a computer program, RESIST has been developed to be used easily by architects to investigate structural options at a preliminary stage in the design process. The program is a design tool to provide accurate information for the building under consideration. Quickly and easily, a large number of structural alternatives can be explored, enabling the designer to move towards a preferred option.

Secondly, graphs and other printed information are included in this report. This may enable preliminary sizing to occur. However, it is limited in its application. Only a few possible structural layouts, given the infinite range of building sizes, shapes, locations and functions have been covered.

During this design process, sooner rather than later, there should be input from other members of the design team. An experienced structural engineer can suggest additional, and perhaps more technically refined alternatives (for example, arising from knowledge of the site), and advise at a more detailed level on the implications of each lateral load resisting system option. However, this interaction will be more fruitful if the architect already has some initial informed ideas and has an appreciation of member sizes and location requirements.

The report continues with an overview and a description of the computer program RESIST. Architectural design guides in graphical form are then presented.

2. RESIST - AN OVERVIEW

2.1 Introduction

RESIST is a computer program written specifically to provide architects of New Zealand buildings with information on how much lateral load resisting structure is required. The basis of the program is the requirements of current New Zealand and Codes of Practice. These Codes of Practice are expected to remain in force as acceptable solutions under the New Zealand Building Code.

The approach taken in the development of this program is to require as little input and knowledge of structural behaviour as possible from the user, compatible with obtaining sufficient accuracy. This approach is also consistent with the necessary feature of program "user friendliness". Architects are often not as computer literate as members of some other professions in the building industry, such as structural engineers. Given the requirement to reduce the amount of user input, various simplifying assumptions and expectations have been included in the program.

The results from RESIST are primarily presented graphically on the screen. Fig 2.1 shows an example of output for one design. For a design to be suitable the calculated performance of each structural criterion is to be less than or equal to 100%. The designer can see immediately if the design is acceptable, or if modification is required.

Additional results are also given for architectural implications of the chosen system. Designers of reinforced concrete walls are given guidance regarding size of penetrations and possible need for thickening or returns to walls to prevent compression chord buckling. Frame users are given the width of beam and column members. After a bracing system has been analysed, chord dimensions are provided. For all structural configurations, information is presented on likely foundation types. If tension piles are needed to prevent overturning of the structure, the pile stem diameter is available. The architect can then appreciate the size of foundations to support the superstructure elements.

The program is completely menu driven, and, as described in the manual (Appendix 1) the user must work through the menu structure in the given sequence. The RESIST menu "tree" is shown in Fig 2.2. As indicated, INFO screens provide information on all aspects of the program. Users can access INFO by a single key stroke which will provide context-sensitive information, or by choosing from the RESIST information menus which are listed in Table 2.1. The intention is that the program be used without the need of a manual or other reference material. There are approximately thirty screens of this additional information.

RESIST is not a direct design program. It requires the designer to first specify a structural material and then chose a structural configuration for the building being designed. The program then reports on the structural performance. The designer may then choose to change some parameters and will iterate towards a structural system and configuration whose structural performance, when compared with New Zealand Codes of Practice and current structural engineering wisdom, is adequate. The chosen structural system should at the least, be consistent with, and preferably, enhance the architectural design objectives.

RESIST can be run on most IBM-compatible computers. The program has been written using a Lotus 1-2-3 spreadsheet which has then been compiled. For further details on program use, refer to the manual (Appendix 1).

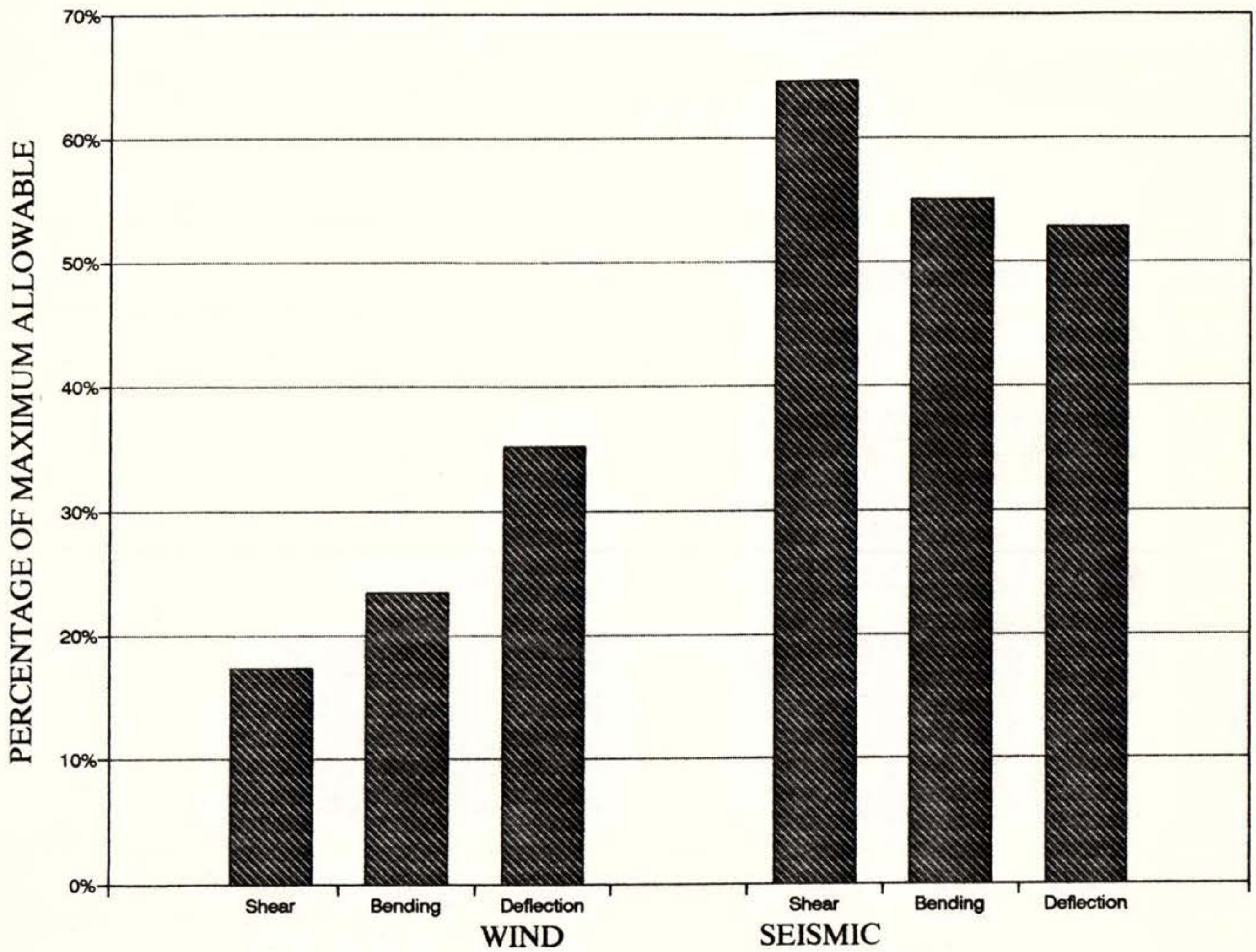


Fig. 2.1 Example of RESIST screen output for one structural configuration.

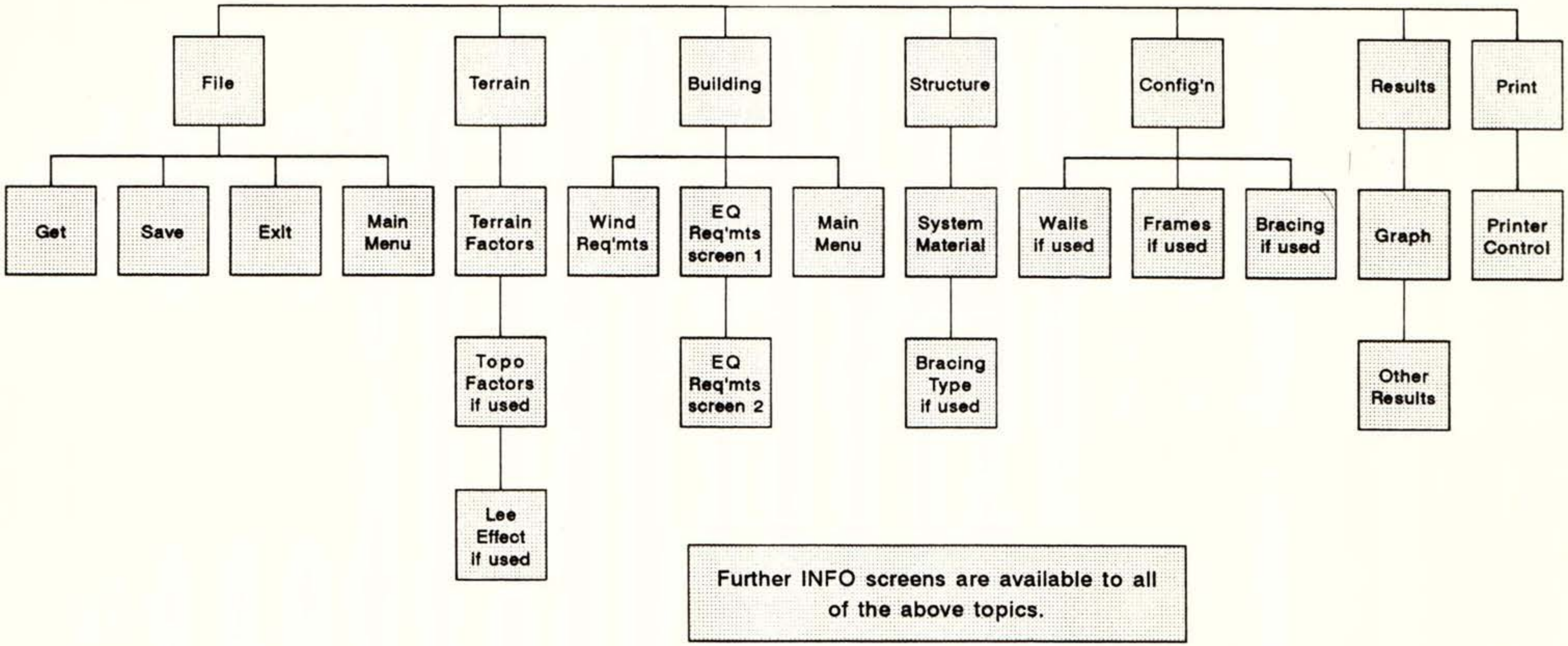


Fig. 2.2 RESIST menu tree

Table 2.1 RESIST Information Menu

PRIMARY MENU
How to use Program
Introduction to Program
Symmetry of Building in Plan
Diaphragm Requirements
Terrain (general)
Building Construction Information
Configuration of Structure to Resist Horizontal Loads
Results
Printing Features
SECONDARY MENU
Terrain Information
Building Information for Calculating Wind Loads
Building Information for Calculating Earthquake Loads
Walls
Frames
Bracing Type
Bracing
Structural Materials
Filing Utilities
Bibliography
Acknowledgements

2.2 Scope and Limitations of RESIST

BUILDING SIZE

RESIST is to be used for buildings up to and including eight storeys, and less than 30 m high. It is not possible, with the simplified calculations used in the program, to design higher buildings for wind and earthquake loads with sufficient accuracy, unless the amount of design input and computational effort is greatly increased. For example, the draft New Zealand loadings code [9] gives both a simplified and a detailed design procedure for wind loads. RESIST uses the simplified approach, which, according to the code, is to be used only for buildings up to 15 m in height. However, this research has shown that the simplified procedure gives sufficiently reliable results up to 30 m. Above this height results may not be conservative. In this program it is not practical to use the detailed design approach as it requires extensive site information and analysis. The detailed approach should be used by the structural engineer at developed sketch plan stage if preliminary studies indicate that wind is more severe than seismic load, and if a minimum structural solution is necessary.

Building height needs to be restricted also for the purpose of maintaining sufficient accuracy in the seismic design. Use of a simplified analysis may be too conservative for some buildings and unsafe for others due to possible detrimental effects of plan or elevational irregularities. A simple analytical approach is therefore suited to only simple structures of modest height.

There is no restriction on building size in plan.

SIMPLICITY OF THE STRUCTURAL SYSTEM

The program has capacity to analyze only one-way lateral load resisting structure. Each building is therefore to be considered separately along each of its two major orthogonal axes. Further, only one type of structural system is permitted in each direction, and if several elements are used, they all must have the same material and dimensions. For example, if five shear walls are proposed they all must have the same length, height and thickness. It is assumed member sizes remain constant up the building height. Where these requirements impose serious limitations on the design, structural engineering advice should be sought.

BUILDING REGULARITY IN ELEVATION AND PLAN

RESIST requires the building to possess considerable regularity. Interstorey heights are assumed to be equal and all floors the same area and of the same building material. The plan configuration of vertical lateral load resisting elements is expected to be reasonably symmetrical. Otherwise a more sophisticated analysis is necessary as significant seismic torsional response is likely.

Modest torsional response is allowed for by a 20% base shear increase per structural element where more than one element resists lateral loads in a given direction.

DIAPHRAGM ACTION

Structural diaphragms are assumed to be present and effective at each floor level to distribute lateral forces at that level to the vertical elements. The presence of large penetrations in floor slabs could invalidate RESIST results.

FOUNDATION CONDITIONS

Foundation conditions are assumed to be "average". In reality, soil type and profile may affect structural performance significantly, so results from simplified analyses must be used cautiously and be subject to comment by a structural engineer. If the soil is softer than the assumed "average", wind induced horizontal deflections and seismic response, caused by soft-soil amplification, may be underestimated by the program.

STRUCTURAL MATERIALS AND SYSTEMS

Designers have a limited range of options with respect to choice of structural materials and systems. All those combinations of material and systems commonly used in New Zealand may be designed using RESIST. It offers timber, structural steel, reinforced concrete masonry and reinforced concrete as available choices of structural materials. Lateral load resisting systems offered are structural walls (shear walls), moment resisting frames and braced frames. Bracing options are: compression/tension concentric, tension-only and eccentric bracing. It is hoped that architects will be prepared to go beyond the limited number of options available in RESIST when a given brief requires an uncommon or innovative structural system.

3. DESCRIPTION OF ENGINEERING BASIS OF PROGRAM

3.1 Introduction

This project is focused on New Zealand architects and their need for seismic and wind load structural design information. Primary sources used in the development of RESIST therefore have been New Zealand Codes of Practice for design loads and structural materials [8 to 14].

3.2 Determination of Lateral Loads

Loads are primarily determined by the building form and construction. Wind loads are affected by factors including terrain, building, location, size, and roof shape. For seismic load calculation, additional information including construction weight types for roof, floors, exterior and interior walls, occupancy loads, seismic zone and building classification is required.

Simplified methods for calculating wind and seismic loads as specified in the Loadings Code have been used. For wind loads, this will result in conservative results for low-rise buildings of heights less than 15 m in areas of the country with lower than average wind speeds. For example, the simplified method used by RESIST, when applied to a rectilinear building 15 m high situated on flat terrain in an exposed suburban setting anywhere in New Zealand gives a design wind pressure of 1.5 kPa. The Code's detailed design procedure gives values of 1.1 kPa and 1.26 kPa for Auckland and Wellington respectively. However for building heights of 25 m and 30 m the simplified calculated pressures for the two locations are 1.31 kPa and 1.50 kPa, and for the detailed approach 1.40 kPa and 1.60 kPa respectively. This underestimation of wind pressure by RESIST for the latter case will be offset by slightly conservative assumptions elsewhere in the program. If RESIST indicates wind loading is the critical lateral load on a given building, the code detailed design procedure should later be used by a structural engineer to refine the structural requirements.

Other simplifications and assumptions have been made in the calculation of wind loads. First, the basic wind speed has been simplified by using the average of wind speed of each of the Code's seven wind regions, using a single limit state multiplier. Further, all buildings are assumed to be sited on the edge of the user's specified terrain, so terrain with the next greatest exposure is automatically used. The Code's shielding multiplier has not been used due to the extensive site survey and analysis required. Also some minor simplification has been made to the Code's escarpment zone length to simply input requirements.

For seismic loads the equivalent static design method is used. This approach does not result in the modest conservatism noted for wind loads, but it does rely on a high degree of structural regularity for acceptable accuracy. The first natural period of vibration is calculated from the Raleigh formula. Response spectra for normal soils have been used. In all other respects designs comply with the Loadings Code.

3.3 Foundation Conditions

For all analyses, vertical foundation deformations have been calculated using an equation for elastic settlement [2] for spread footings and allowing for acknowledged conservativeness in deformation calculations by dividing results by a factor of 2.0. Soil properties are assumed to be the average of a medium saturated clay and medium dense sand. A contact pressure of 300 kPa for lateral load induced vertical load has been used to size footings and enable deformations to be calculated. Designers have the option of reducing settlement by up to a factor of 4.0. This facility is to allow for use of supplementary foundation beams, piling and other methods to reduce vertical elastic settlement. Vertical settlement at foundation level causes tilting of the building which results in additional lateral deflections. If designers chose a large value (greater than 10) for the "foundation type factor", a "fixed base" model will be analysed.

Foundation deformations are included in the determination of structural performance for both wind and seismic loads. For slender ductile structural systems such as eccentrically braced steel frames, foundation deformations may have a large impact on deflection performance.

3.4 Structural Modelling Assumptions

MOMENT RESISTING FRAMES: GENERAL

The "portal" method [7], commonly used by structural engineers for preliminary design analysis has been used. It assumes points of inflection at mid-heights and mid-spans of columns and beams respectively under the influence of lateral load. Other assumptions include:-

- column bases are fixed against rotation.
- columns and beams have the same dimensions, except for steel frames where the column depth is provided by the user and beams with the same moment of inertia, but of deeper cross-section are analysed. Beam depths are displayed with "other analysis" results.
- gross section properties are used for wind loads, but are reduced for reinforced concrete members subjected to seismic loads to allow for cracking.

For reinforced concrete and timber frames the designer inputs a member depth and RESIST calculates an appropriate thickness. For reinforced concrete sections the width is assumed to be 60% of the depth and for timber 70%. A lower ratio for timber members was found to lead to column shear performance being the limiting factor. For structural steel the member depth is input. RESIST then calculates section width and other section properties. Universal columns and beams are the assumed steel cross-sections.

The degree of ductility assigned to a frame is material dependent. Reinforced concrete frames are assumed fully ductile, whereas, based on HERA recommendations [3] steel frames are designed for limited ductility. Timber moment resisting frames are considered to respond elastically, although in due course, incorporation of special ductile connections may allow for a reduction in seismic load level.

REINFORCED CONCRETE FRAMES

For ultimate limit state seismic loads, ductile action has been assumed as noted previously.

Frames are designed to the provisions of NZS 3101 [14]. Where appropriate, advantage is taken of moment redistribution for ultimate limit state loads.

For wind and seismic loads, maximum achievable frame flexural strength is based on beam reinforcement ratios of 2.25% and 1.5% respectively, using Grade 300 reinforcing steel. Maximum column strength is calculated assuming Code maximum allowable percentage of Grade 430 steel. The specified compression strength of concrete at 28 days is 30 MPa.

STEEL FRAMES

Frames are designed to the provisions of NZS 3404 [12] and the HERA Design Guides [3].

The HERA recommendations acknowledge the inherent flexibility of steel by suggesting that frames are designed as structures of limited ductility ($\mu=3$). This approach has been followed. Beam moments are determined from code loads at $\mu=3$, but column design actions are obtained from nominally elastic response forces in the case of interior columns, or capacity beam actions for exterior columns, which ever is less.

Composite action between beams and concrete slab is assumed. Grade 350 MPa structural steel is used for all members.

As mentioned previously, column and beam depths are not equal. The user defines a column depth and RESIST calculates the section properties of an equivalently stiff universal beam.

Shear performance of steel frames is not reported on. It can be adjusted as necessary by techniques that have no architectural implications, such as increasing web thickness.

TIMBER FRAMES

Timber frames are of Pinus Radiata No.1 Framing Grade glue-laminated construction. The relevant provisions of NZS 3603 [11] are applied. Anticipated provision of ductile beam-column connections have allowed $\mu=4$ to be used for deflection calculations, but timber member design is based generally on elastic response ($\mu=1$), except for beams where the overstrength capacity of an assumed mild steel joint detail may be less.

REINFORCED CONCRETE STRUCTURAL (SHEAR) WALLS

Walls are assumed to be cantilevered from the ground floor of the building. Design loads for each structural configuration are based on the Concrete Design Code's maximum allowable ductility. This provides the designer with the opportunity of achieving minimum length wall structure. Wall ductility factors are as defined in the previous Loadings Code [8]. If the wall aspect ratio allows, full ductility is assumed, but for squatter walls the maximum limited ductility factor, consistent with the wall aspect ratio and Code requirements, is adopted.

Structural performance of a wall is evaluated for bending, shear and deflection. Bending performance is expressed as a percentage of the ultimate limit state design loads compared to the wall's maximum dependable flexural capacity. The latter value assumes 75% of the maximum code allowable wall reinforcement ratio is placed uniformly along the wall length. This approach is a mathematical simplification of current design practice where flexural reinforcement is concentrated at each wall end. Grade 430 reinforcing steel and 25 MPa concrete is assumed. Shear performance expresses the overstrength capacity shear stress as a percentage of the maximum code allowable concrete shear stress. A similar approach applies to deflection performance. This is the ratio, expressed as a percentage, of calculated deflection to maximum allowable code deflection. Allowance is made for seismic load related concrete cracking and reinforcing pull-out at foundation level [4]. Whereas bending and shear performances are governed by wall base actions, deflection performance is assessed using the maximum interstorey deflection. This may occur in any of the building's storeys.

RESIST assumes that the specified wall thickness remains constant up the building height. Any subsequent thickness reduction is not expected to affect the wall's structural performance significantly, but should be discussed with a structural engineer.

REINFORCED CONCRETE MASONRY STRUCTURAL WALLS

Design is in accordance with the Masonry Design Code [13]. The same approach used for reinforced concrete applies with the following modifications. A wall's dependable bending strength is based on one D20 bar per block flue. This is the maximum area of steel allowed, taking bar lapping into account. For the calculation of shear performance, Grade A masonry, with masonry compressive strength equal to or greater than 12 MPa is assumed. This allows the maximum grade-dependent shear stress values of 2.4 MPa or 1.8 MPa, as given by NZS 4230 to be used, depending on the ductility demand.

Shear performance is calculated using the lesser of the design shear (with a flexural overstrength factor of 2.0) or elastic response ($\mu = 1.25$).

TIMBER STRUCTURAL WALLS

The two materials design codes used are the Timber Design and the Construction Plywood Codes [11, 10].

As for concrete walls, the maximum permitted ductility factor has been used for seismic loads. However, wall sheathing thickness and wall chords have been designed for elastic response. This approach is somewhat conservative when compared to the approach of Thomas [17], but it does overcome the uncertainty in calculating the wall overstrength factor due to strength enhancement from the likely use of gib internal lining [15].

Shear performance is based on design shears resulting from factoring wind and seismic loads by 0.8. In the absence of a timber limit state code, working stress design has been used. Shear strength is taken as the maximum of the shear strength provided by double sided 21 mm ply clad walls, or two rows of 2.89 mm gun nails, as suggested by Stewart and Dean [16]. Nail spacing at 30 mm centres is assumed. This represents the practical upperbound achievable nailed strength of a ply clad wall.

RESIST calculates wall chord size constructed from sawn and dry No. 1 Framing Grade Pinus Radiata. Chords, which resist gravity and overturning compression and tension forces, have their performance evaluated from the number of ex 50 mm members required to be nailed together to construct a chord. The maximum practical number is considered to be 10; so bending performance expresses the number of members required as compared to 10. The depth of chord members, calculated by RESIST is a function of interstorey height and magnitude of maximum chord compression load.

Deflections from shear, bending and foundation deformations are calculated. Nail slip, as discussed by Thomas [17] has been allowed for. Base rotation of the wall is also calculated assuming a constant chord compression deformation of 3 mm and the extension of a steel rod, sized for strength, anchored at ground level (foundation) and connected to the chord at first floor level.

STEEL BRACED FRAMES

Designers may choose from several types of braced frames: tension-only, compression and tension cross-braced, concentric K bracing or eccentric K braced frames. The design rules from the Steel Design Code [12] have been followed except that maximum height limitations of some bracing configurations and some other provisions are taken from a draft version (October 1991) of Section 12.12 of NZS 3404.

For seismic loads, eccentrically braced frames are assigned a ductility factor $\mu=6$. For tension-only bracing, μ varies from 1.25 to 6 depending on the number of storeys, but for other types of bracing $\mu=1.25$ is used. Although this approach may be conservative, it has been taken so designs are controlled by loads rather than Code rules adherence to which is not able to develop such a good feel of structural behaviour.

Grade 350 steel is used for all members except for tension only bracing. In this case Grade 250 and solid round cross-sections are assumed.

For braced frames RESIST calculates the size of the chords (edge columns) to the braced bays assuming either a tube or universal column section. The designer is informed of both options when "other results" are viewed. The larger section properties of the two cross sections are used in the horizontal deflection calculations.

As mentioned previously, eccentrically braced frames are assumed to be fully ductile for ultimate limit state seismic loads. The inclined struts and edge columns are designed for twice Code load to allow for the fuse overstrength factor. Lateral deflections are calculated by first assuming concentric bracing, and then applying a modifying factor as recommended by Popov [5].

TIMBER BRACED FRAMES

For large column and bracing members (depths greater than 200 mm and 300 mm respectively) glue-laminated timber is assumed. Limit state timber stresses have been obtained from a draft Timber Code [18].

Elastic response ($\mu=1$) is the basis for seismic design.

As for steel bracing, designers are informed of chord sizes which are also used for deflection calculations. Information is given on bolting requirements for the critical brace.

4. INFORMATION ON LATERAL LOAD RESISTANCE

4.1 General

In this Section design information on each of the structural systems is presented. Comments are made to extend designers' appreciation of the relationship between lateral loads and the requirements of vertical building structure.

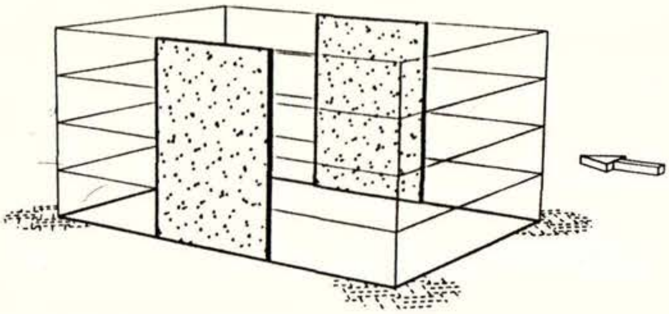
It is not practical to cover all combinations of structural configurations, materials and building sizes. Some typical lateral load resisting systems have been chosen for each structural material. Graphical information and commentary on each of the structural systems and typical configurations is presented. Using this material alone, designers will be able to appreciate some of the structural alternatives available to them, without the use of RESIST.

It is anticipated that for a thorough investigation of structural options for a particular building, RESIST will be used.

4.2 Structural Walls

REINFORCED CONCRETE WALLS TO RESIST SEISMIC LOADS

Minimum wall lengths and thicknesses for a range of buildings are presented in Fig. 4.1. Lateral loads in at least one direction on these buildings are resisted by two parallel walls. To use the graphs a vertical line should be projected above the building area per floor. Having made a choice of the number of storeys and the geographic location, the value of the minimum wall length can be located. As described in the building data box, the building construction can be described generally as heavy, although the roof is medium weight (eg. concrete tiles). A number of comments and observations on the influence of the building data input can be made in relation to the graphs.



BUILDING DATA

Floor Construction : Heavy
Wall Cladding : Heavy
Partitions : Heavy
Roof Construction : Medium
Interstorey Height : 3.5m
Occupancy Class : Office
Classification : 4
Foundations : Ordinary

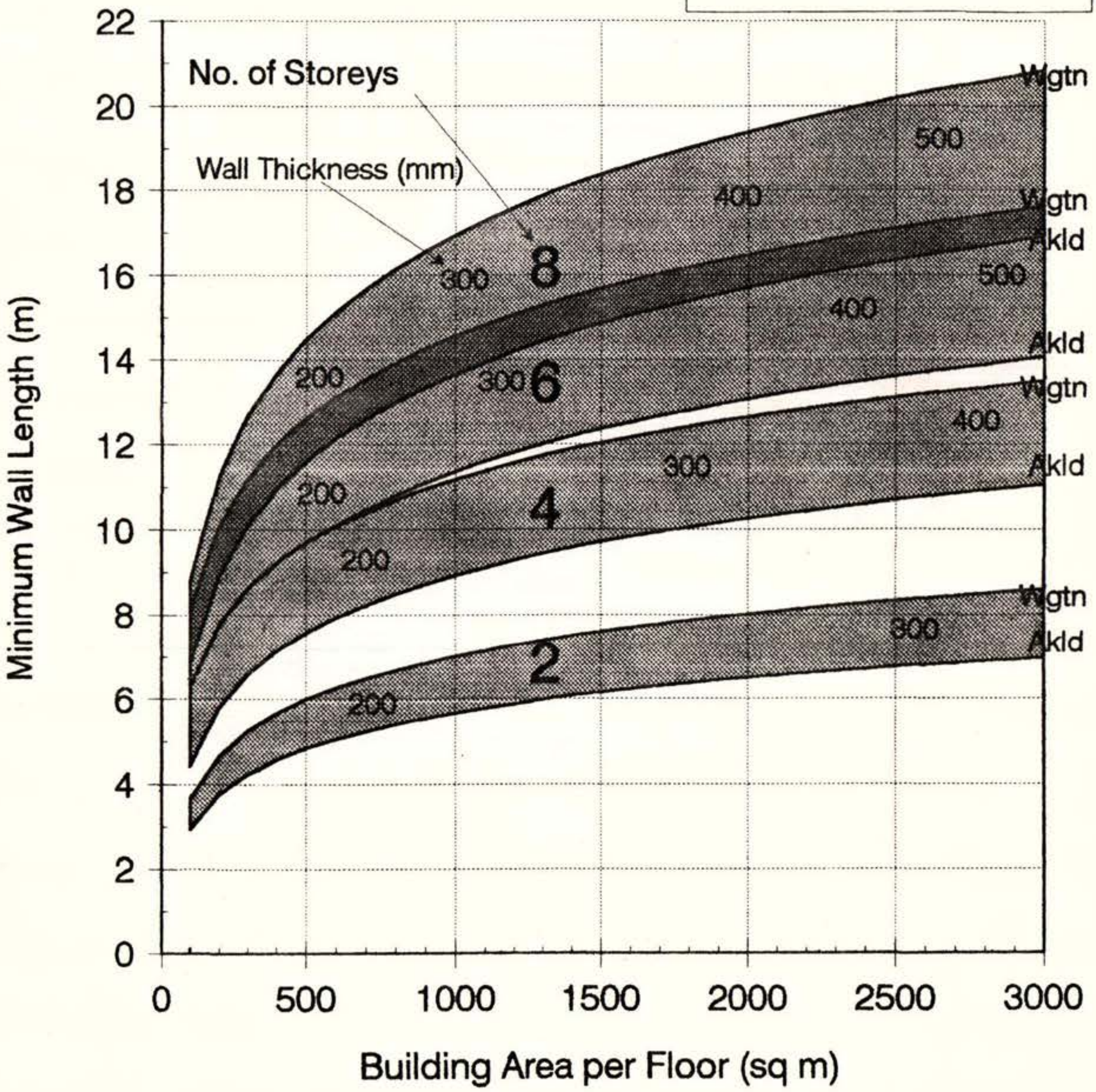


Fig. 4.1 Reinforced concrete structural walls. Minimum wall lengths required for various numbers of storeys with two walls: seismic loads

Table 4.1 Influence of construction type on wall lengths

Construction type	Minimum wall length (m)	% Variation compared to example in Fig 4.1
Heavy floors, partitions and cladding	14	
Heavy floors, light partitions and cladding	12.5	-11
Medium floors and light walls	11	-21
Light floors and light walls	9	-36

Influence of weight of construction material

It is widely appreciated that seismic forces are related to building mass or weight. It is therefore of interest to consider how lateral load resisting structure is affected by changes to construction materials. Table 4.1 summarizes the effect of reducing weight on a 6 storey 1000 m^2/floor building in Wellington. The building data is for that in Fig. 4.1.

The different floor weights described as heavy, medium and light relate to concrete hollow-core slabs on reinforced concrete beams and columns; concrete slab on permanent steel trough formwork on steel beams and columns, and to timber construction respectively. As weight is reduced there is a significant reduction in structural wall lengths.

Influence of foundation conditions

The wall lengths in Fig 4.1 are largely determined by vertical flexibility of the soil under the building. For the building considered above, ordinary foundations have been assumed. If however, more extensive and expensive foundations are constructed, wall deflections and hence minimum wall lengths may be reduced. If the most extensive foundation system assumed by RESIST is designed (foundation type factor = 4), the wall length can be reduced by 36% to 9 m. An increase in wall thickness is necessary however.

Influence of geographic location

Wellington and Auckland represent locations in New Zealand with the maximum and minimum seismic risk. The earthquake zone factor of Wellington (0.8) [9] is twice that of Auckland. However, as seen in Fig. 4.1 only a 30% greater wall length is required in Wellington. RESIST's input screen provides information on zone factors for most areas but for buildings in some towns, the earthquake zone map in NZS 4203 should be consulted.

Building classification

Category 4 buildings as assumed in Fig. 4.1 are the most common. However, more important or strategic buildings are required for be designed to higher seismic loads. For the building studied in Table 4.1 to be designed as Category 1, for example a hospital, a 15% increase in wall length is necessary.

Relationship between building size and wall lengths

From Fig. 4.1 it is evident that for reinforced concrete wall structures, wall lengths are not proportional to the number of storeys or to building area per floor. This illustrates how as a building becomes more flexible and has its natural period of vibration increased, relatively less earthquake load is attached. A two storey building with an area per floor of 500 m^2 requires a 230% increase in wall length when the number of storeys increases 400%. Similarly, when the area per floor increases 600% structural wall lengths only increase 50%.

Influence of number of walls

A four storey office building in Wellington with medium roof and otherwise heavy construction is analysed. Minimum wall lengths for various numbers of walls are shown in Fig. 4.2.

There is little difference in wall length if either one or two walls are used. The similarity of wall lengths is due to a 20% increase in seismic load for the case of two walls to allow for anticipated torsional response. Also, the additional stiffness of the two walled system reduces the building's natural period thereby attracting larger seismic forces.

Total minimum wall length for the building is obtained using as few walls as possible. As wall numbers increase from two (11.2 m long) to five (9.6 m long), total wall length increases by more than 200%.

REINFORCED CONCRETE WALLS TO RESIST WIND LOAD

Fig. 4.3 provides information on wall structure to resist wind loads. Assuming 2 parallel walls, the minimum length of wall is presented for building width and number of storeys. In this case the building is located in the most sheltered situation, an inner city site, flat terrain with no channelling or orographic lee effects. A comparison of Fig. 4.3 and Fig. 4.1 indicates that wind loads are not critical; at least for buildings of heavy construction, unless the building width is greater than about four times its depth. For lighter buildings wind will become the critical lateral load at a lesser width to depth ratio. The structural performance of all the walls is dominated by horizontal deflections.

The effect of varying the number of walls has been considered and results are shown in Fig. 4.4. Again, the most efficient structural solution is given by the minimum number of walls. Due to the greater influence of foundation deformations on short walls (in plan), wall lengths are not very sensitive to larger numbers of short walls. It should also be noted that wall thicknesses of 200 mm are always sufficient to resist wind loads.

The intensity of wind load acting on a building is largely determined by the Terrain Factors in RESIST. The influence of each of these factors on wall length has been investigated for a four storey building. Assuming wind loads are resisted by one wall, the percentage increase in wall length for the worst, as compared to the least load case for each individual factor is presented in Table 4.2.

Table 4.2 Influence of terrain factors on wall length

Worst case situation for wind load determination	% increase in wall length compared to example used in Fig 4.4 (situated in a city centre)
Terrain classification adjacent to site. (Open)	15
Topographic. (Steep high hill site)	25
Channelling occurs	10
Wellington region	10
Mountain range lee effect	10
Elevation of site	5

It is possible that a certain site will incorporate more than one of the worst case situations. In this case, the percentages may be added to give the total increase in wall length. For example, given the building defined previously, a steep hill site situated near Wellington will require a wall length increase of 35% when compared to a more sheltered situation.

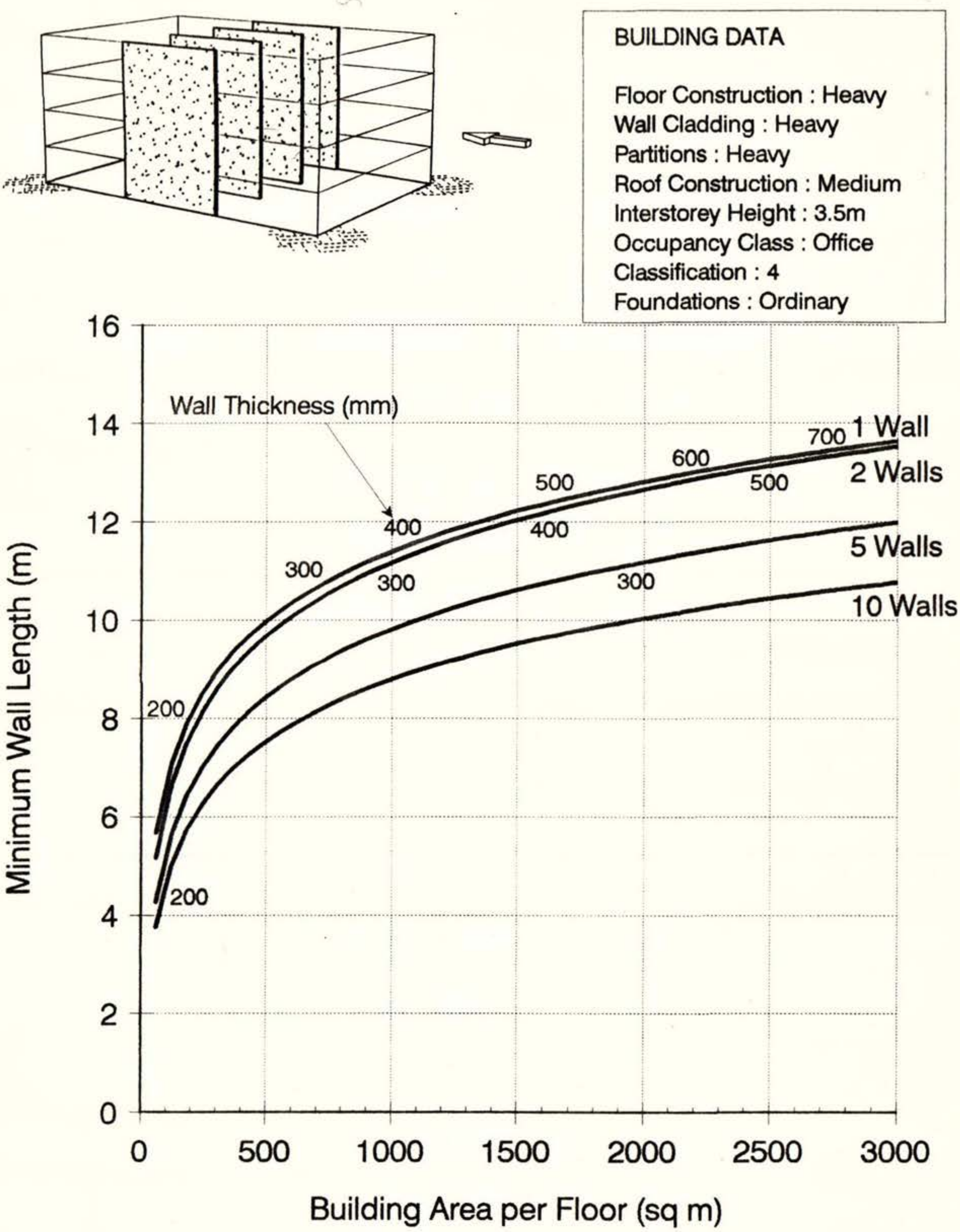
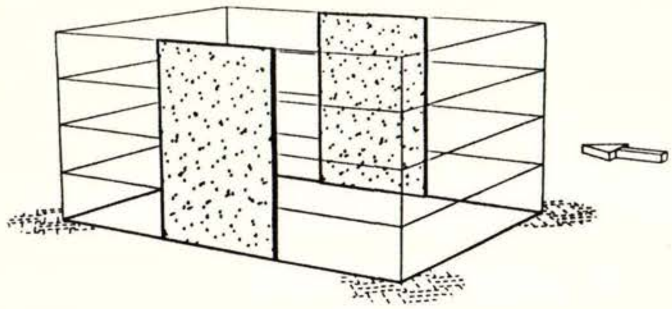


Fig. 4.2 Reinforced concrete structural walls. Minimum wall lengths for a four storey building with various numbers of walls: seismic loads, Wellington.



BUILDING DATA

Terrain Classification : City Centre
No Topographical Factors
No Channelling Factors
No Lee Effects
Interstorey Height : 3.5m
Roof Height : 0m
Foundations : Ordinary

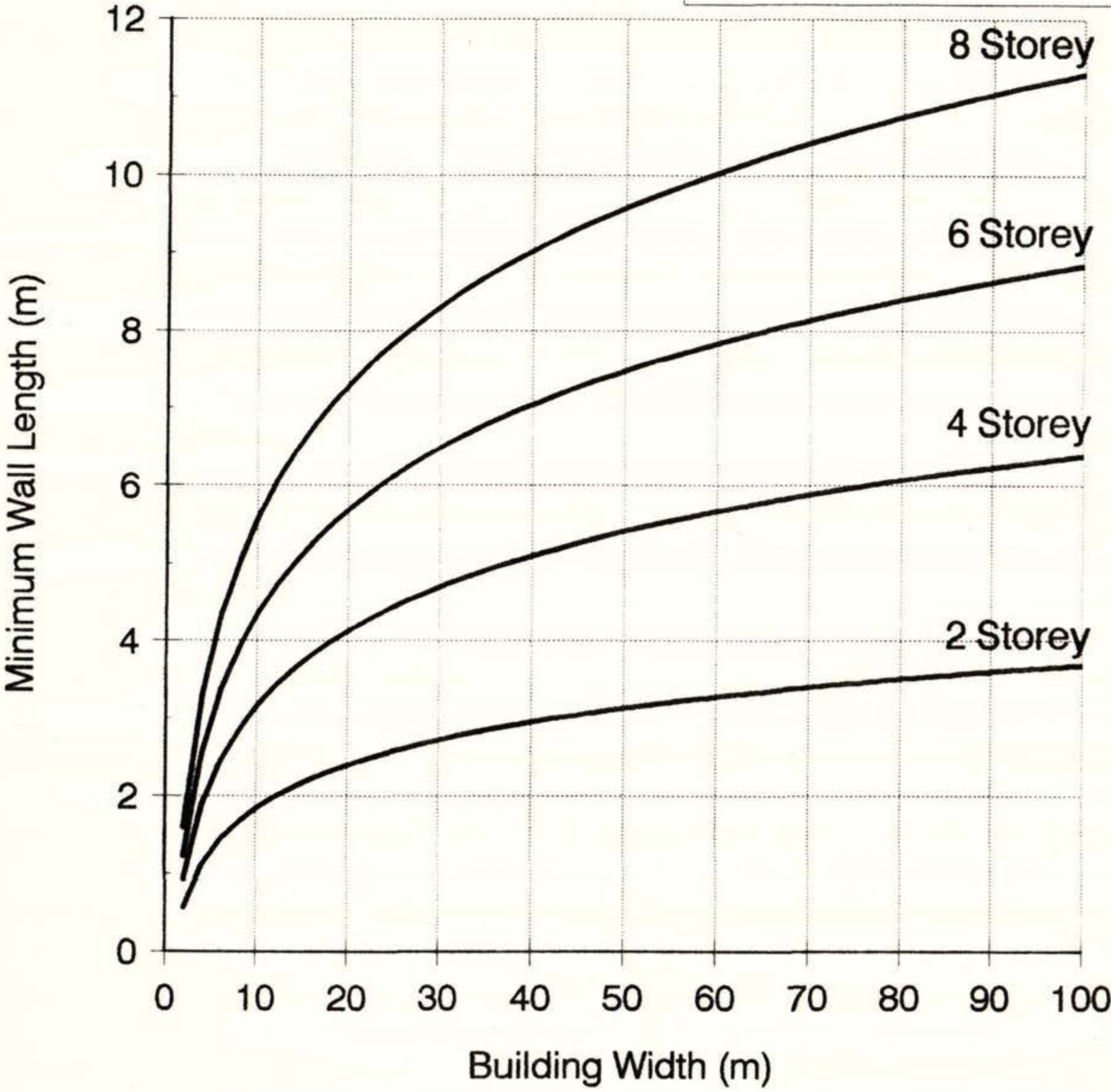
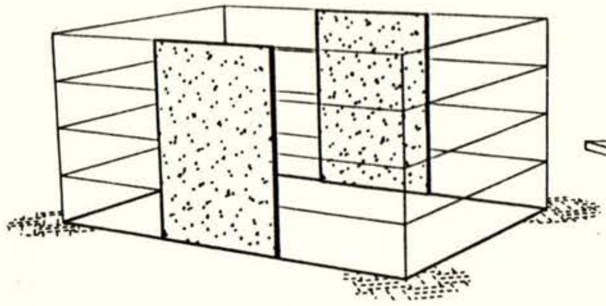


Fig. 4.3 Reinforced concrete structural walls. Minimum wall lengths for various numbers of storeys with two walls: wind loads



BUILDING DATA

Terrain Classification : City Centre
No Topographical Factors
No Channelling Factors
No Lee Effects
Number of Storeys : 4
Interstorey Height : 3.5m
Roof Height : 0m
Foundations : Ordinary

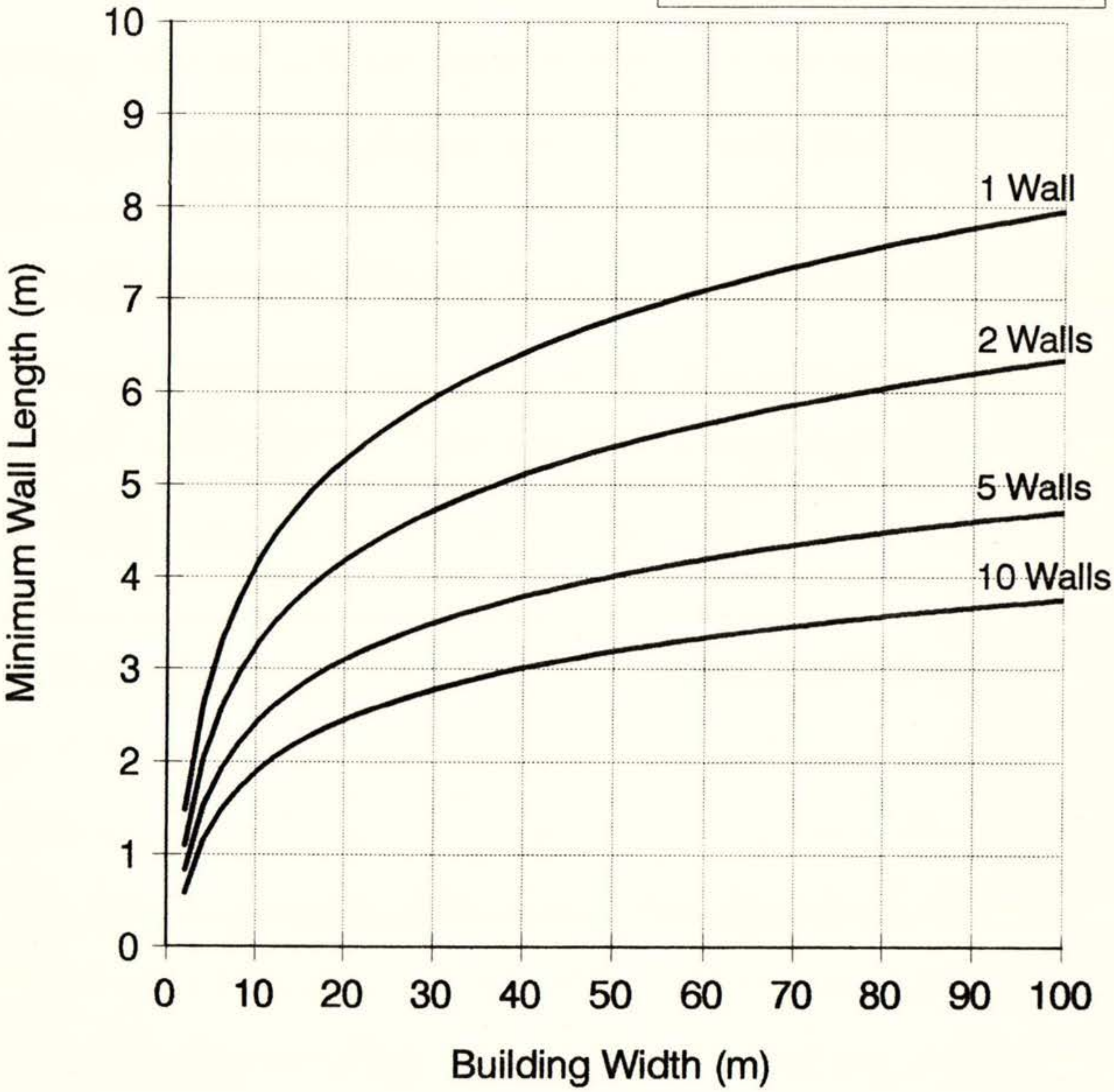


Fig. 4.4 Reinforced concrete structural walls. Minimum wall lengths for a four storey building with various numbers of walls: wind loads.

Seismic Loads

Fig. 4.5 provides information on wall lengths for 200 series masonry wall construction when two walls resist the lateral loads. Due to the relatively low shear strength of reinforced concrete masonry, at least as compared to reinforced concrete, long wall are required. In fact, for buildings square in plan with an area per floor of 1000 m^2, five and eight storeys is the maximum height of construction in Wellington and Auckland respectively as the maximum wall length required is restricted by the building plan dimensions.

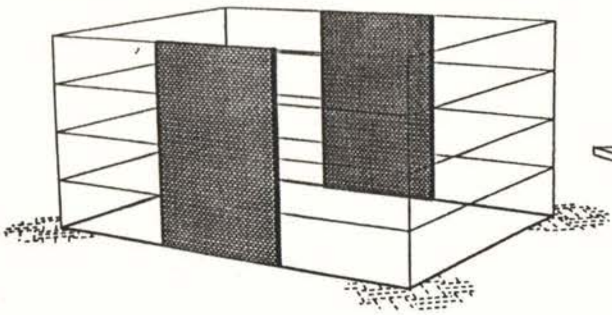
The influence of changing the number of walls is shown in Fig. 4.6 which is based on an analysis of buildings located in Wellington. Wall lengths are reasonably sensitive to numbers of walls but the total wall length is not so greatly affected by wall numbers as it is for reinforced concrete construction.

Wall lengths are very sensitive to the weight of construction materials. If light construction is used, wall length can be reduced to approximately one quarter of those required for heavy construction.

Wind Loads

Minimum lengths for a pair of reinforced concrete masonry walls to resist wind loads are given in Fig. 4.7. Lateral deflections, strongly influenced by foundation flexibility, again are critical. Quite modest wall lengths, equal to those of reinforced concrete construction are required.

The influence of varying the number of walls is exactly the same as for reinforced concrete. Therefore Fig. 4.4 also applies to reinforced concrete masonry construction.



BUILDING DATA

Floor Construction : Heavy
Wall Cladding : Heavy
Partitions : Heavy
Roof Construction : Medium
Interstorey Height : 3.5m
Occupancy Class : Office
Classification : 4
Foundations : Ordinary

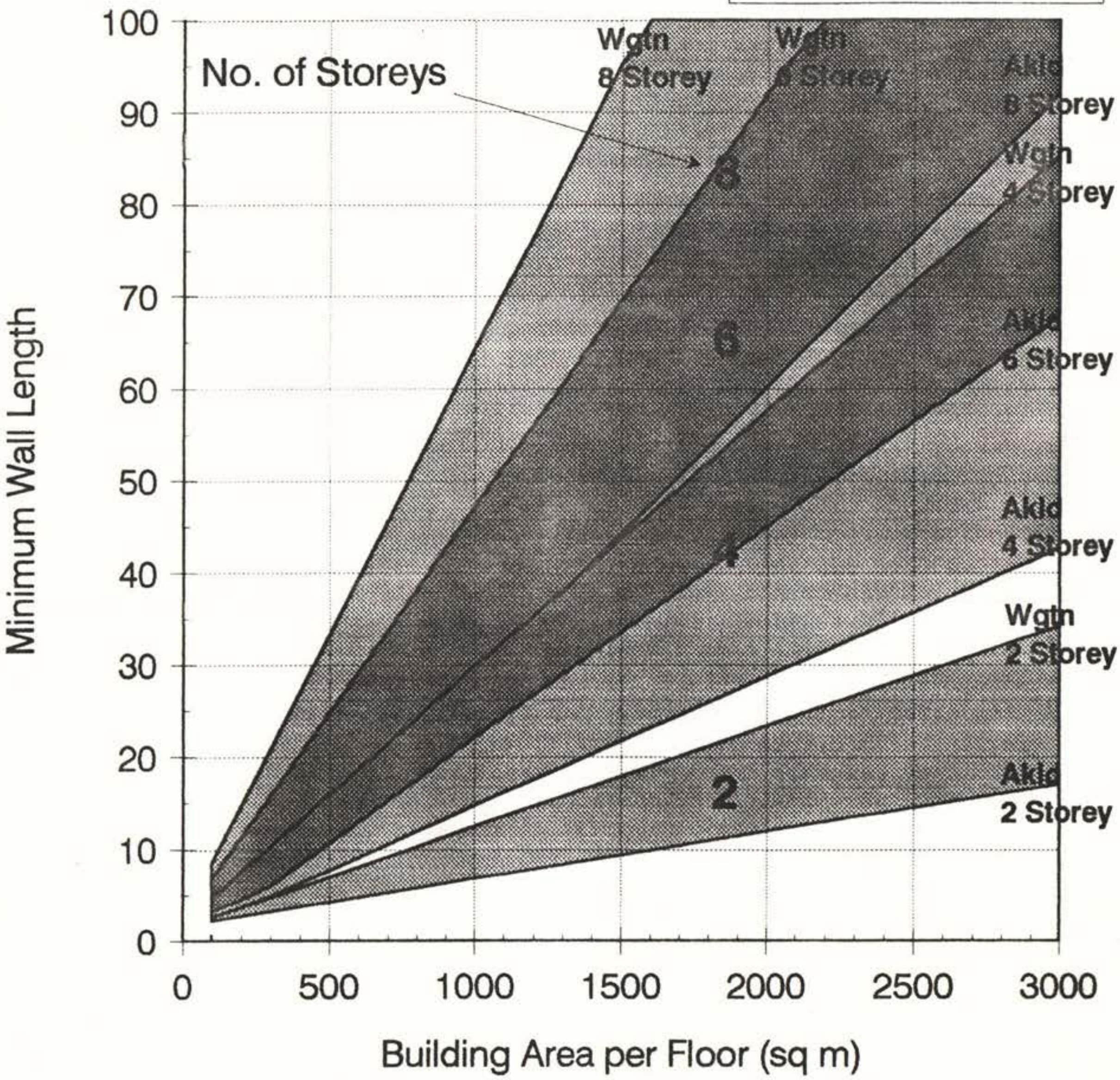
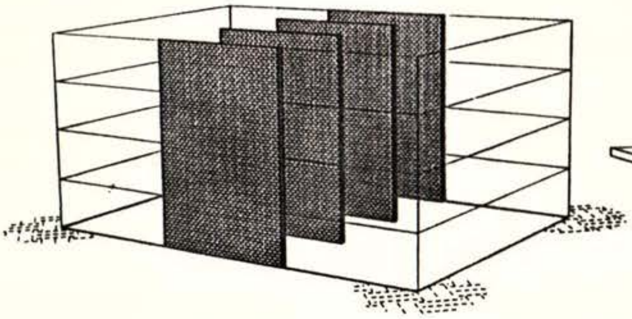


Fig. 4.5 Reinforced concrete masonry structural walls. Minimum wall lengths for various numbers of storeys with two walls: seismic loads



BUILDING DATA

Floor Construction : Heavy
Wall Cladding : Heavy
Partitions : Heavy
Roof Construction : Medium
Interstorey Height : 3.5m
Occupancy Class : Office
Classification : 4
Foundations : Ordinary

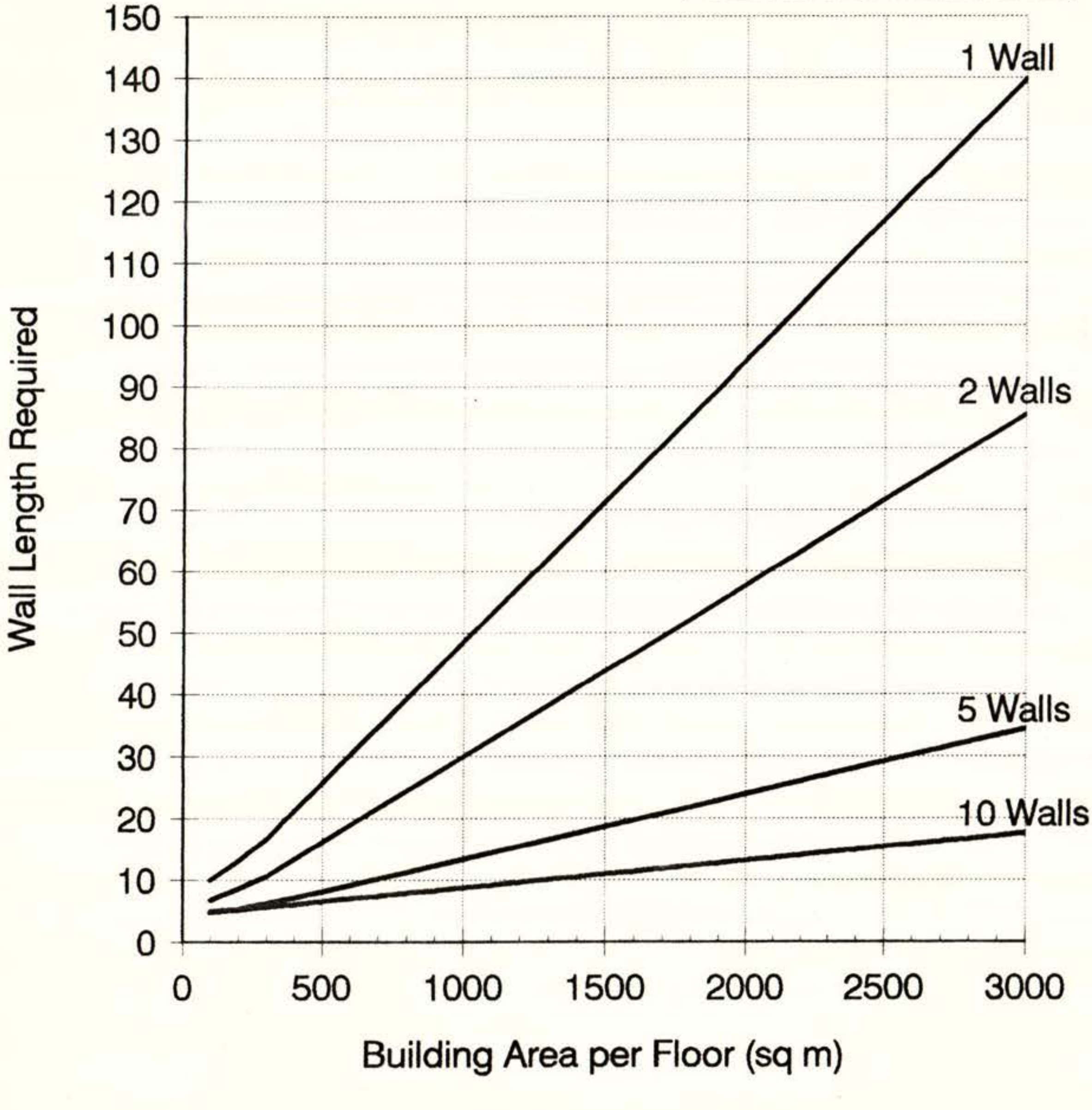
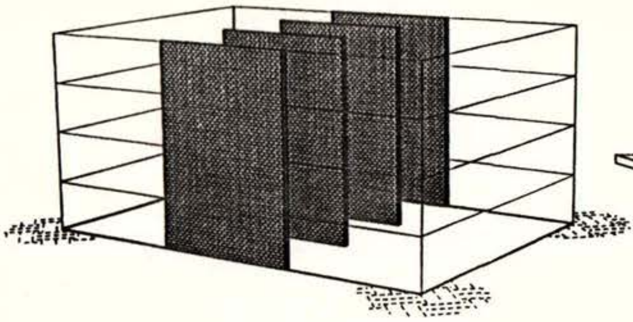


Fig. 4.6 Reinforced concrete masonry walls. Minimum wall lengths for a four storey building with various numbers of walls: seismic loads, Wellington.



BUILDING DATA

Terrain Classification : City Centre
No Topographic Factors
No Channelling Factors
No Lee Effects
Interstorey Height : 3.5m
Roof Height : 0m
Foundations : Ordinary

Fig. 4.7 Reinforced concrete masonry walls. Minimum wall lengths for various numbers of storeys with two walls: wind loads.

Seismic Loads

Fig. 4.8 shows minimum wall lengths of a pair of timber framed, plywood clad walls. Light-weight building construction has been assumed. What is of interest is that the wall lengths are of a similar magnitude to those of a reinforced concrete building construction with floors and partitions of heavy construction.

Timber walls in Fig. 4.8 have their structural performance controlled by horizontal deflections, however performance is not very sensitive to foundation flexibility. Changing the foundation type factor from 1 to 4 reduced wall length by approximately 10%. This is due to the significant flexibility of the wall structure itself.

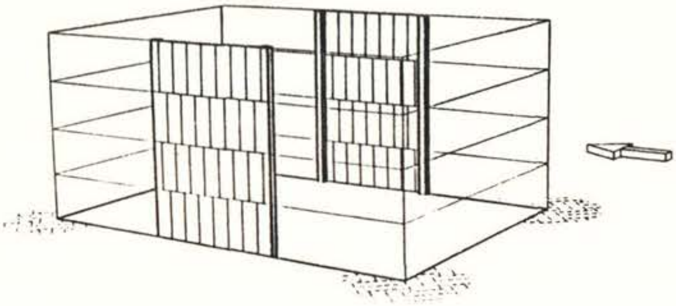
Depending on the number of storeys, the wall chord depth varies from 100 to 300 mm. Where RESIST suggests large chord members are necessary but where walls have returns (in plan), the chord depth may be as for normal timber wall framing.

Variation of wall numbers for buildings located in Wellington is investigated in Fig. 4.9. As for walls of the other structural materials, economies are gained by using as few as possible.

Wind Loads

Fig. 4.10 gives minimum wall lengths for various building heights and widths. Lengths are similar to those required for seismic loads. Horizontal deflections again control the design. The buildings represented by Fig. 4.10 are assumed square in plan as there is a small influence of seismic loads on wind design. If seismic load is the greater horizontal load, its value determines ply thickness and nail spacing which affect both seismic and wind deflections.

The requirements for various numbers of walls are presented for a four storey building in Fig. 4.11. The pattern is similar to that obtained for seismic loads.



BUILDING DATA

Floor Construction : Light
Wall Cladding : Light
Partitions : Light
Roof Construction : Light
Interstorey Height : 3.5m
Occupancy Class : Office
Classification : 4
Foundations : Ordinary

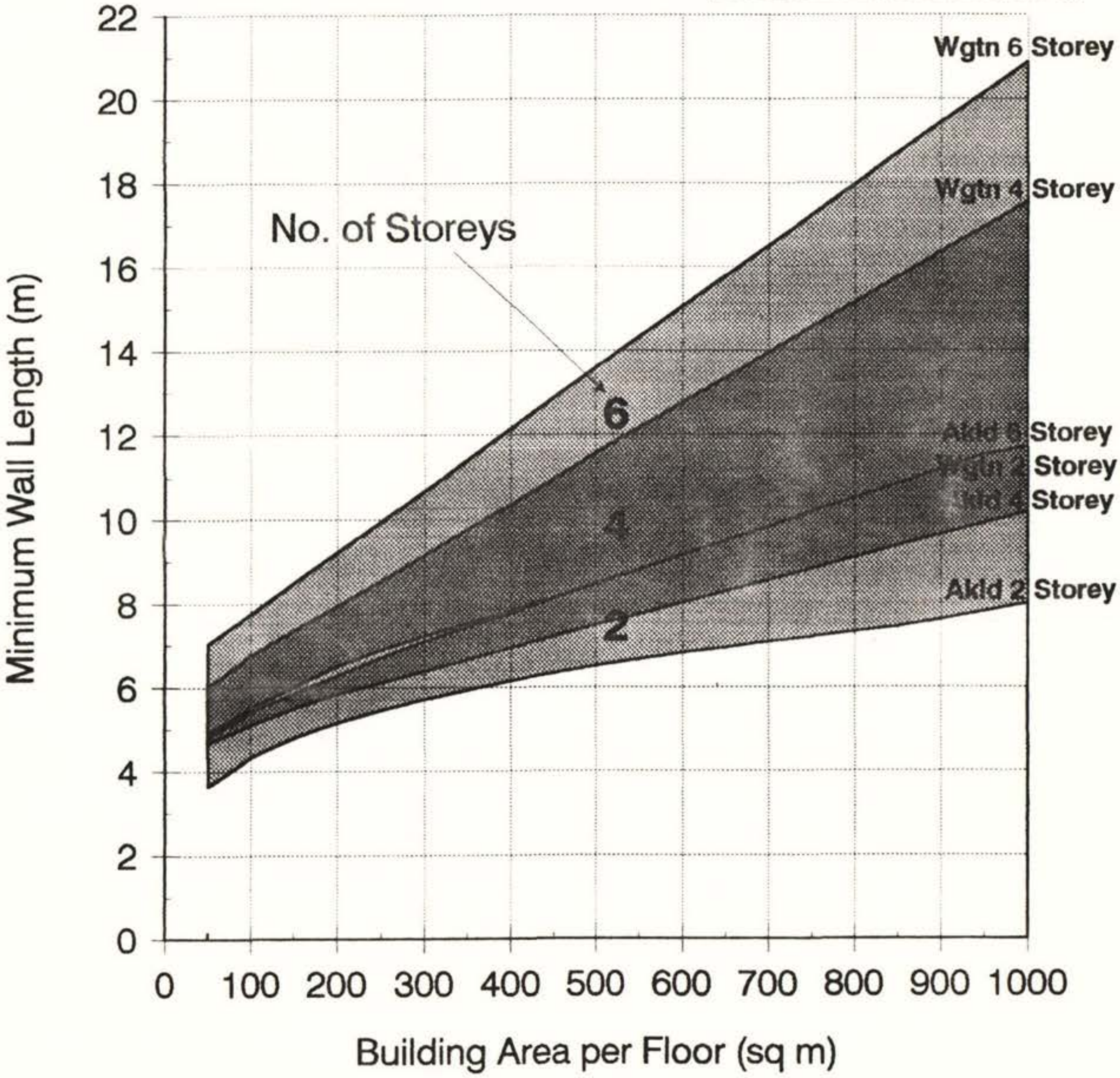
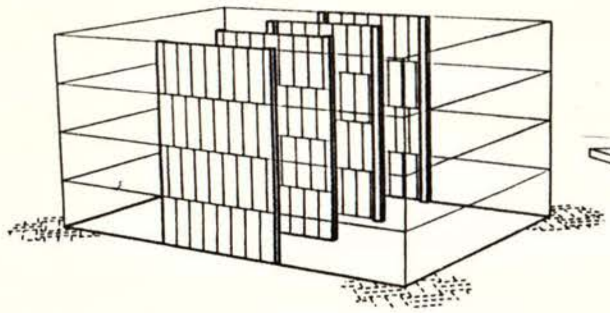


Fig. 4.8 Timber walls: Minimum wall length for various numbers of storeys with two walls: seismic loads.



BUILDING DATA

Floor Construction : Light
Wall Cladding : Light
Partitions : Light
Roof Construction : Light
Interstorey Height : 3.5m
Occupancy Class : Office
Classification : 4
Foundations : Ordinary

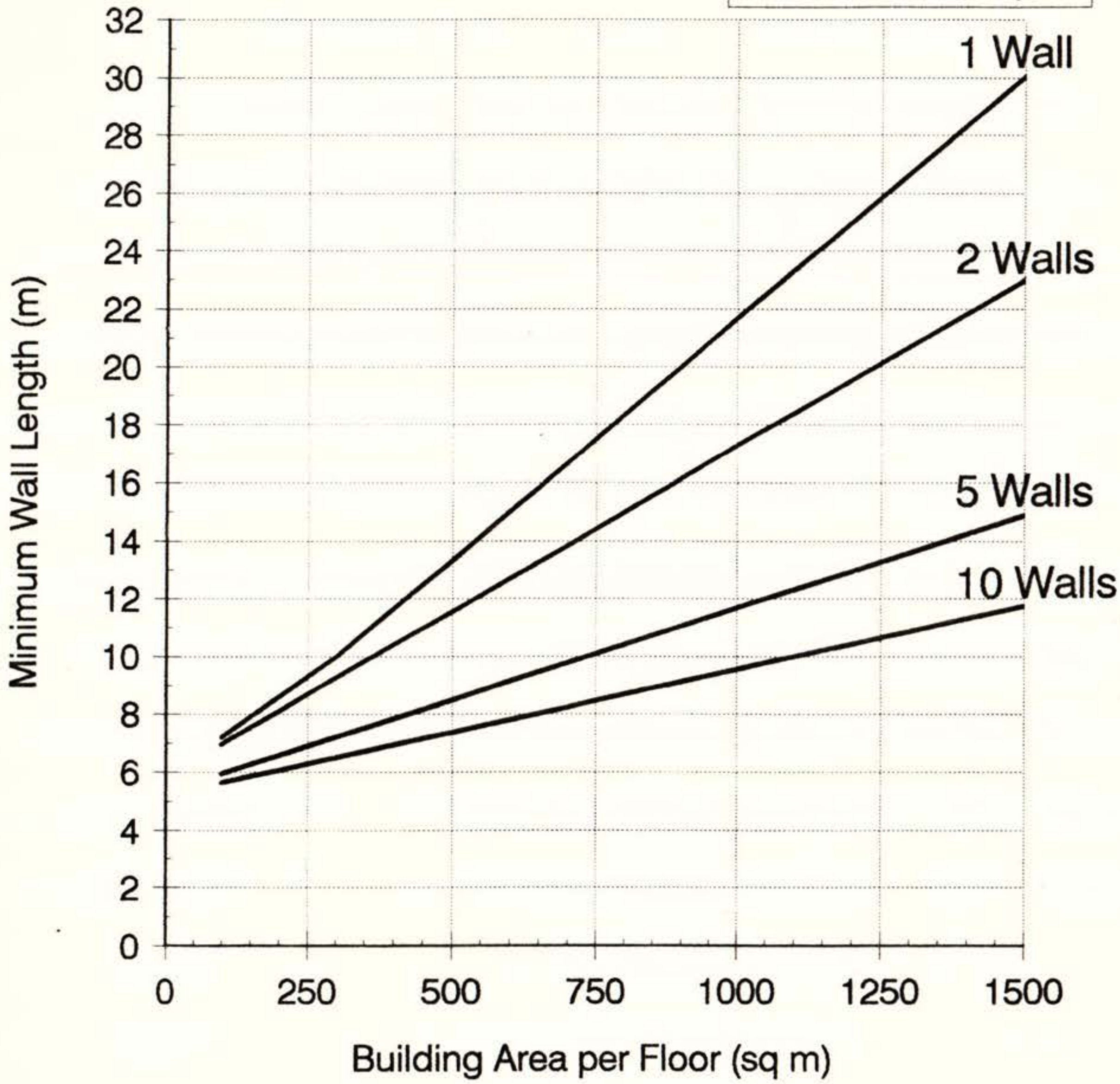
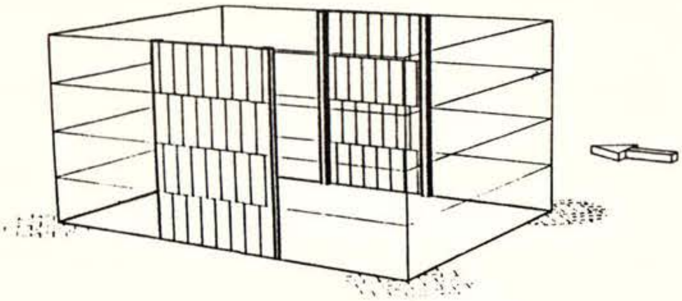


Fig. 4.9 Timber walls. Minimum wall lengths for a four storey building with various numbers of walls: seismic loads, Wellington.



BUILDING DATA

Terrain Classification : City Centre
No Topographical Factors
No Channelling Factors
No Lee Effects
Interstorey Height : 3.5m
Roof Height : 0m
Foundations : Ordinary

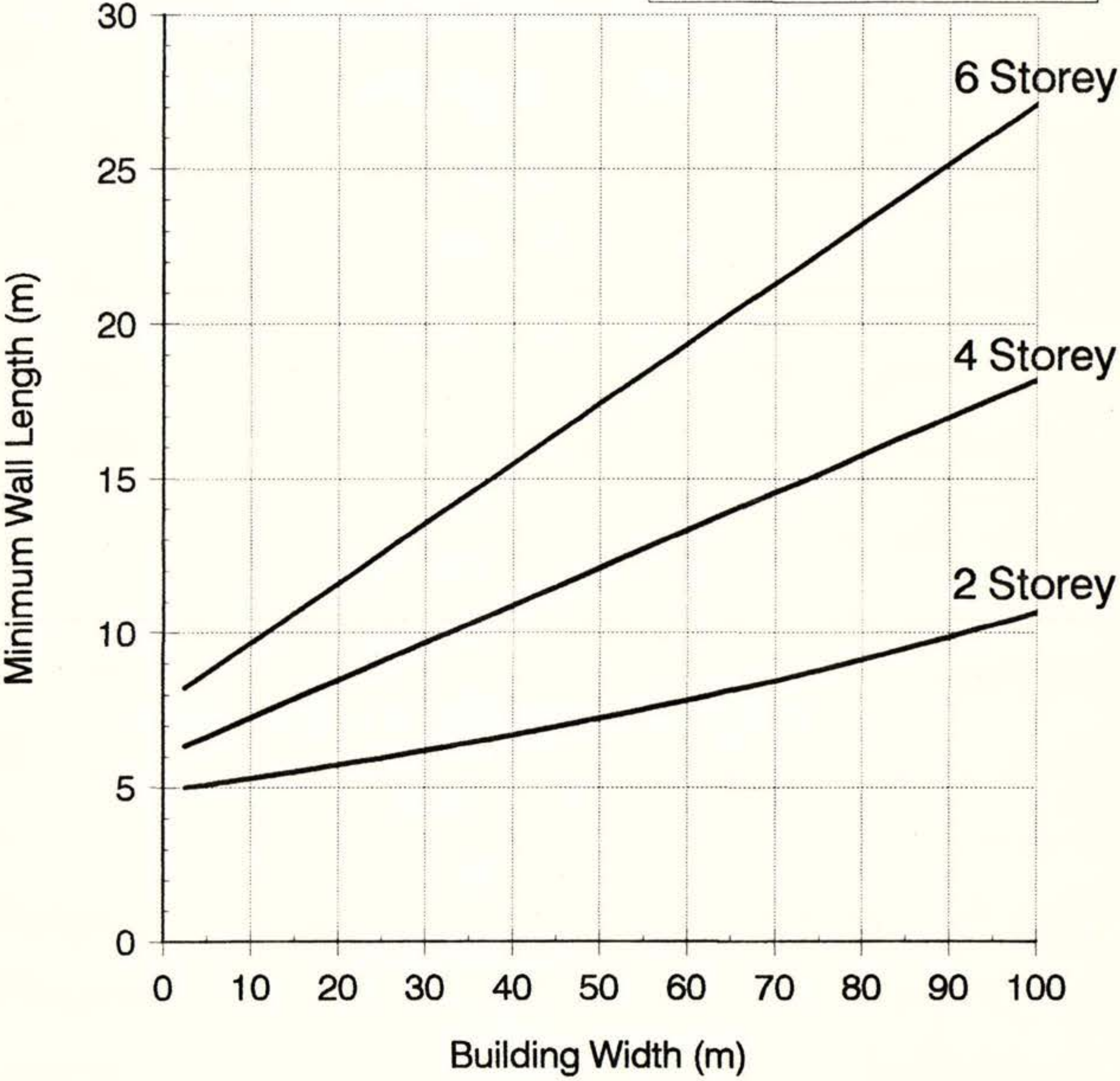
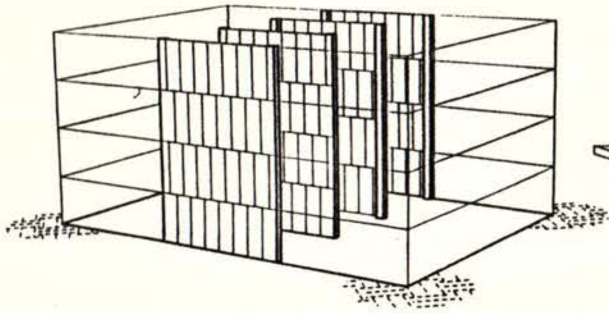


Fig. 4.10 Timber walls. Minimum wall lengths for various numbers of storeys with two walls: wind loads.



BUILDING DATA

Terrain Classification : City Centre
No Topographical Factors
No Channelling Factors
No Lee Effects
Number of Storeys : 4
Interstorey Height : 3.5m
Roof Height : 0m
Foundations : Ordinary

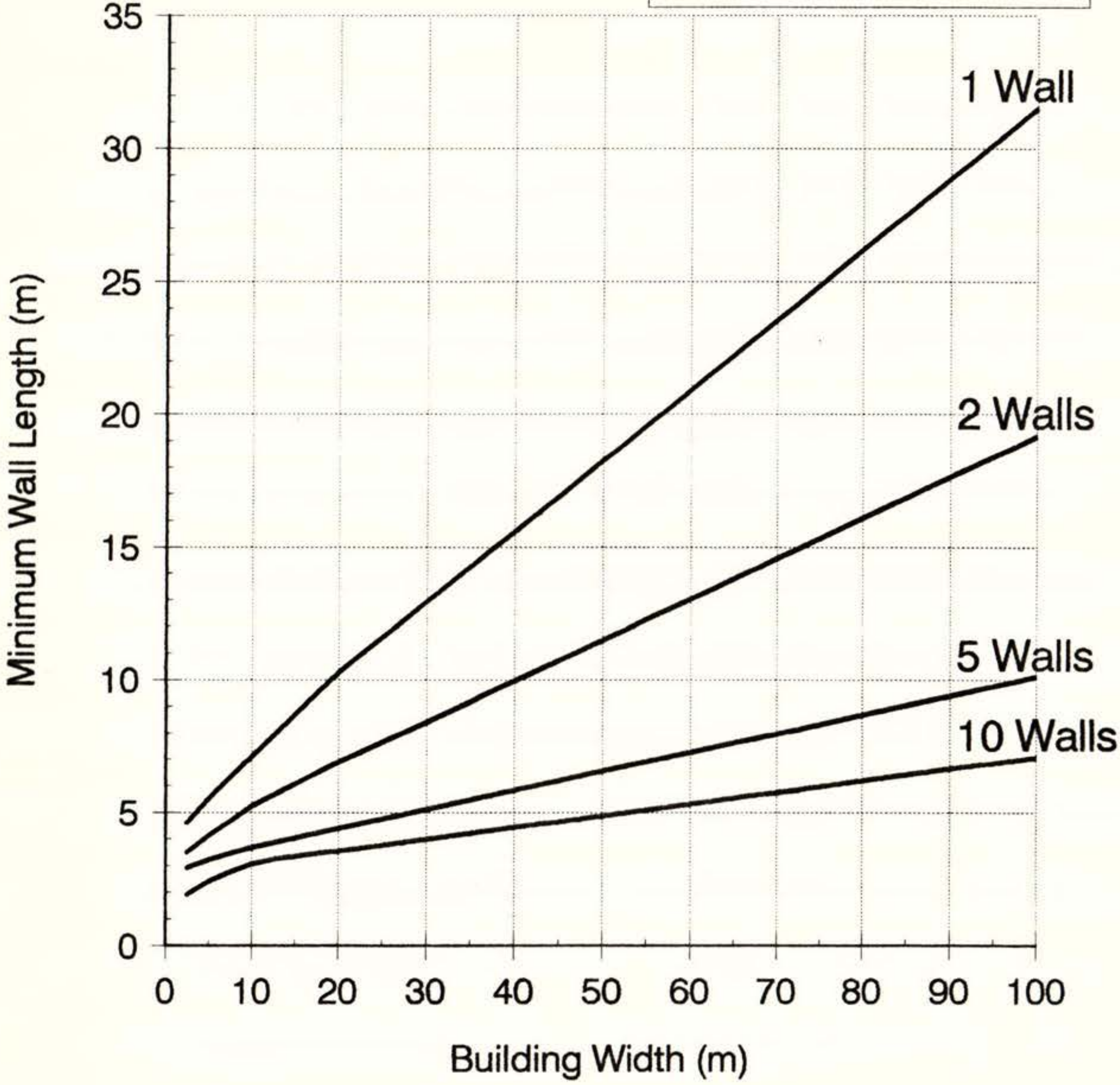


Fig 4.11 Timber walls. Minimum wall lengths for a four storey building with various numbers of walls: wind loads.

4.3 Moment Resisting Frames

REINFORCED CONCRETE

Seismic loads

Before consideration of frame structural requirements some comments on the type and number of design options should be made. RESIST requires designers to decide on the values of six factors, including the number of frame lines and number of bays in each line. The distance between columns defines beam lengths which affects building flexibility. Generally, increasing this value will increase frame flexibility and hence deflections. Column depth has an even more significant influence on frame stiffness. The width of flooring supported by the beam is significant where the beam span is long. In this case beam bending and shear strength might become critical. Foundation type, the final factor, is most significant for short frames, consisting of, say two or three columns.

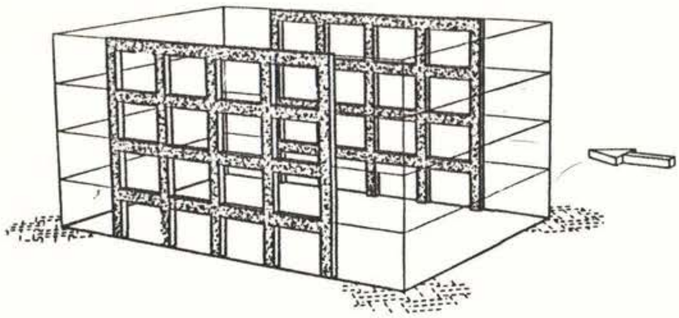
In all frames, the distance between column centre-lines is taken as 6 m.

For any one building there are many design options that may be considered. RESIST can examine a large number of these but for the purposes of publishing design information it is only possible to consider a limited number of configurations. This section is restricted to buildings which firstly, have all walls and floors of heavy construction, and secondly have the roof of medium construction.

Requirements for reinforced concrete frames have been investigated from a number of different perspectives and information is presented in Figs 4.12 to 4.15.

In Fig. 4.12 minimum frame depths for a range of floor areas is given for two parallel frames in buildings of different heights, with four bays per frame. Frame member depths are determined by deflection considerations. Use of lighter construction materials would reduce member sizes significantly.

Fig. 4.13 examines a Wellington four storey building by varying the numbers of frames. As for reinforced concrete walls, the fewer the structural elements, the less structural material is required. In Fig. 4.14 the influence on member size of variation in numbers of bays per frame is shown for four storey buildings in Wellington.



BUILDING DATA

Floor Construction : Heavy
Wall Cladding : Heavy
Partitions: Heavy
Roof Cladding : Medium
Interstorey Height : 3.5m
Occupancy Class : Office
Classification : 4
Foundations : Ordinary

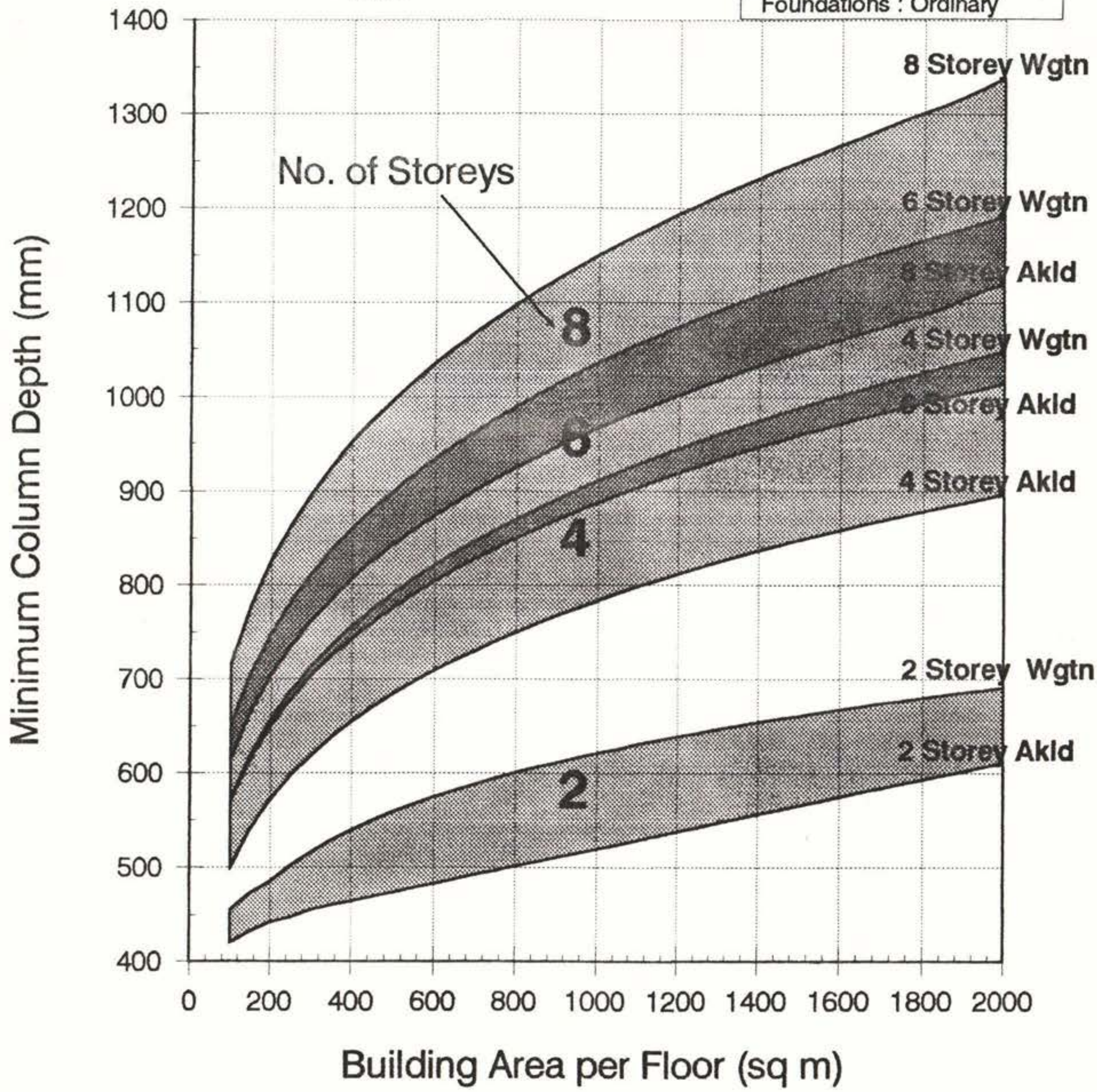
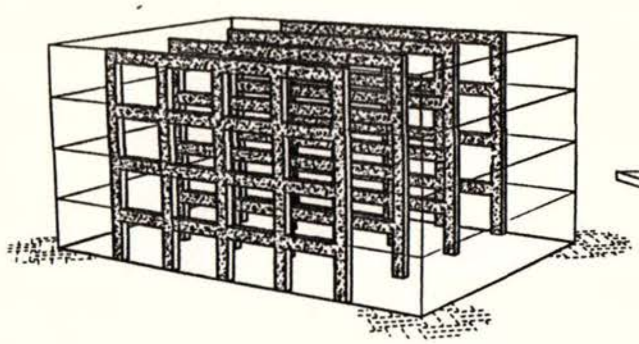


Fig. 4.12 Reinforced concrete frames. Minimum column depths required for various numbers of storeys with two frames, each of four bays: seismic loads.



BUILDING DATA

Floor Construction : Heavy
Wall Claddding : Heavy
Partitions : Heavy
Roof Cladding : Medium
Interstorey Height : 3.5m
Occupancy Class : Office
Classification : 4
Foundations : Ordinary

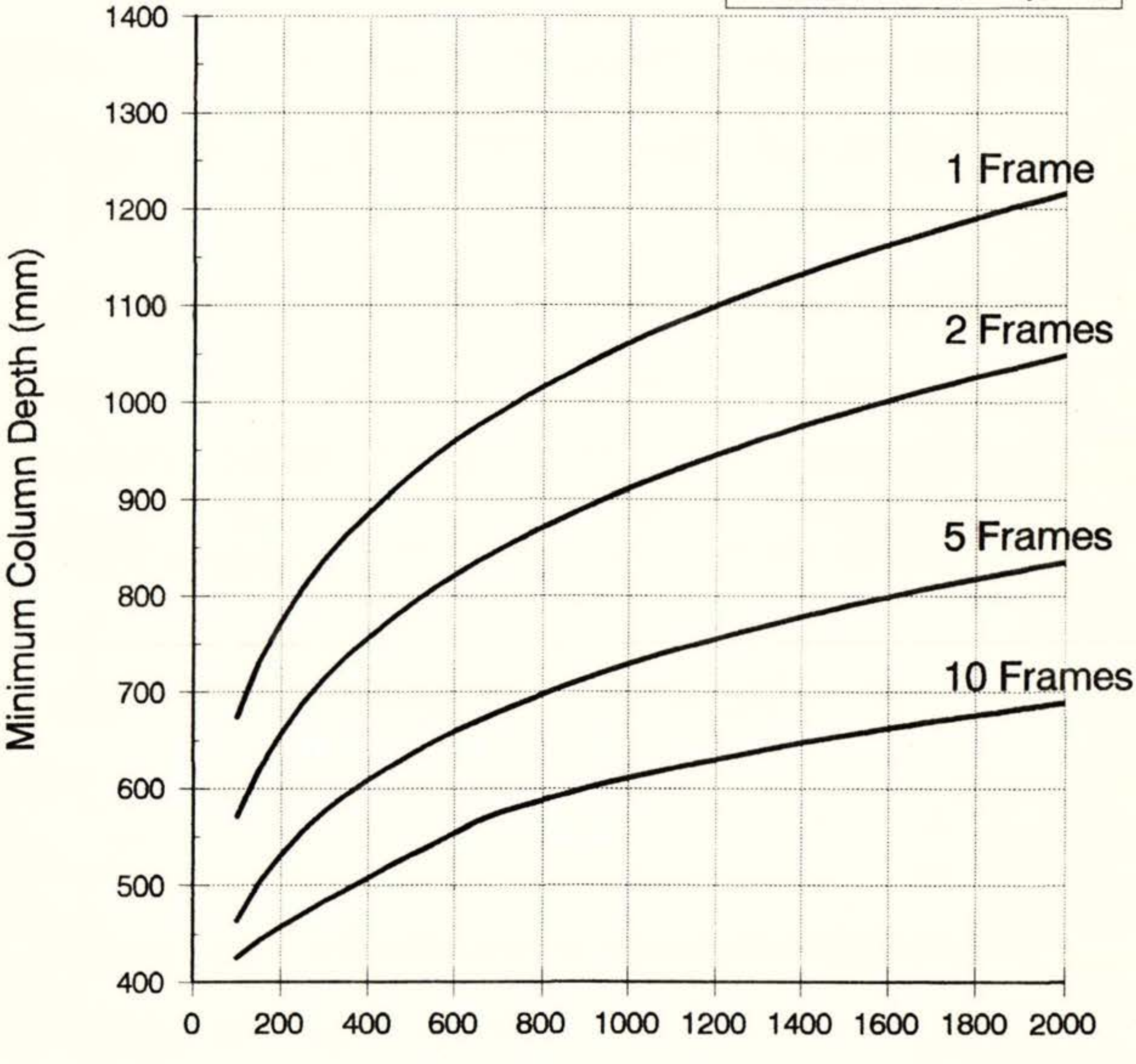
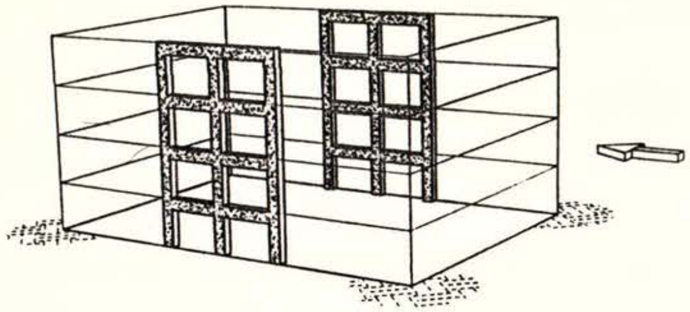


Fig. 4.13 Reinforced concrete frames. Minimum column depths required for a four storey building with four bays per frame for various numbers of frames: seismic loads, Wellington.



BUILDING DATA

Floor Construction : Heavy
Wall Cladding : Heavy
Partitions : Heavy
Roof Cladding : Medium
Interstorey Height : 3.5m
Occupancy Class : Office
Classification : 4
Foundations : Very Extensive

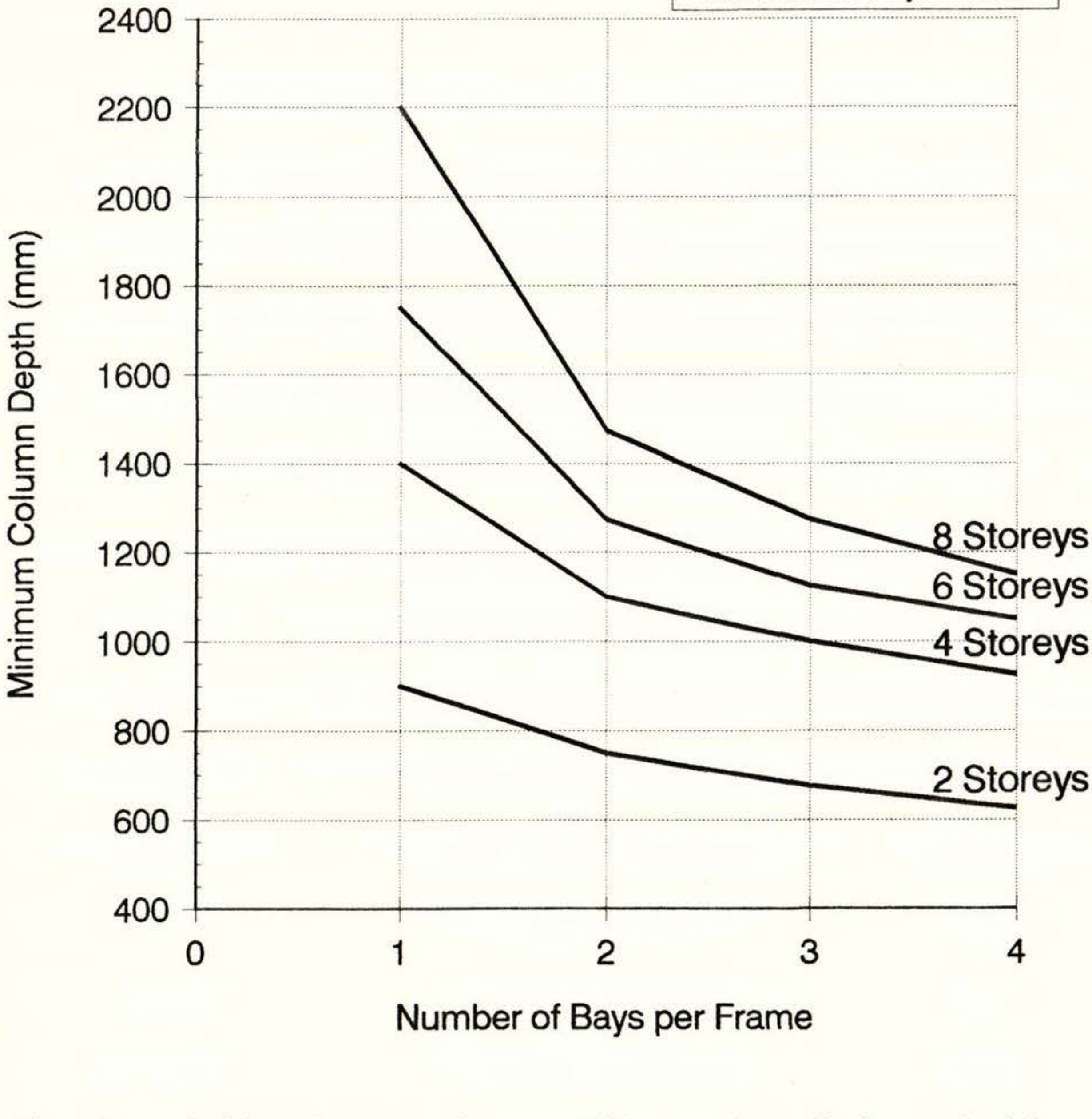
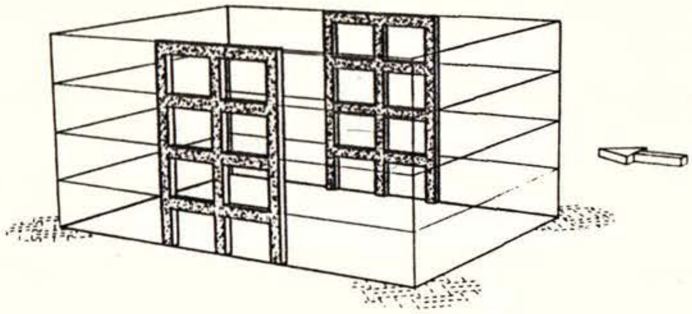


Fig. 4.14 Reinforced concrete frames. Minimum column depths required for various numbers of storeys with two frames and various numbers of bays per frame: seismic loads, Wellington.



BUILDING DATA

Floor Construction : Heavy
Wall Cladding : Heavy
Partitions : Heavy
Roof Cladding : Medium
Interstorey Height : 3.5m
Occupancy Class : Office
Classification : 4
Foundations : Ordinary

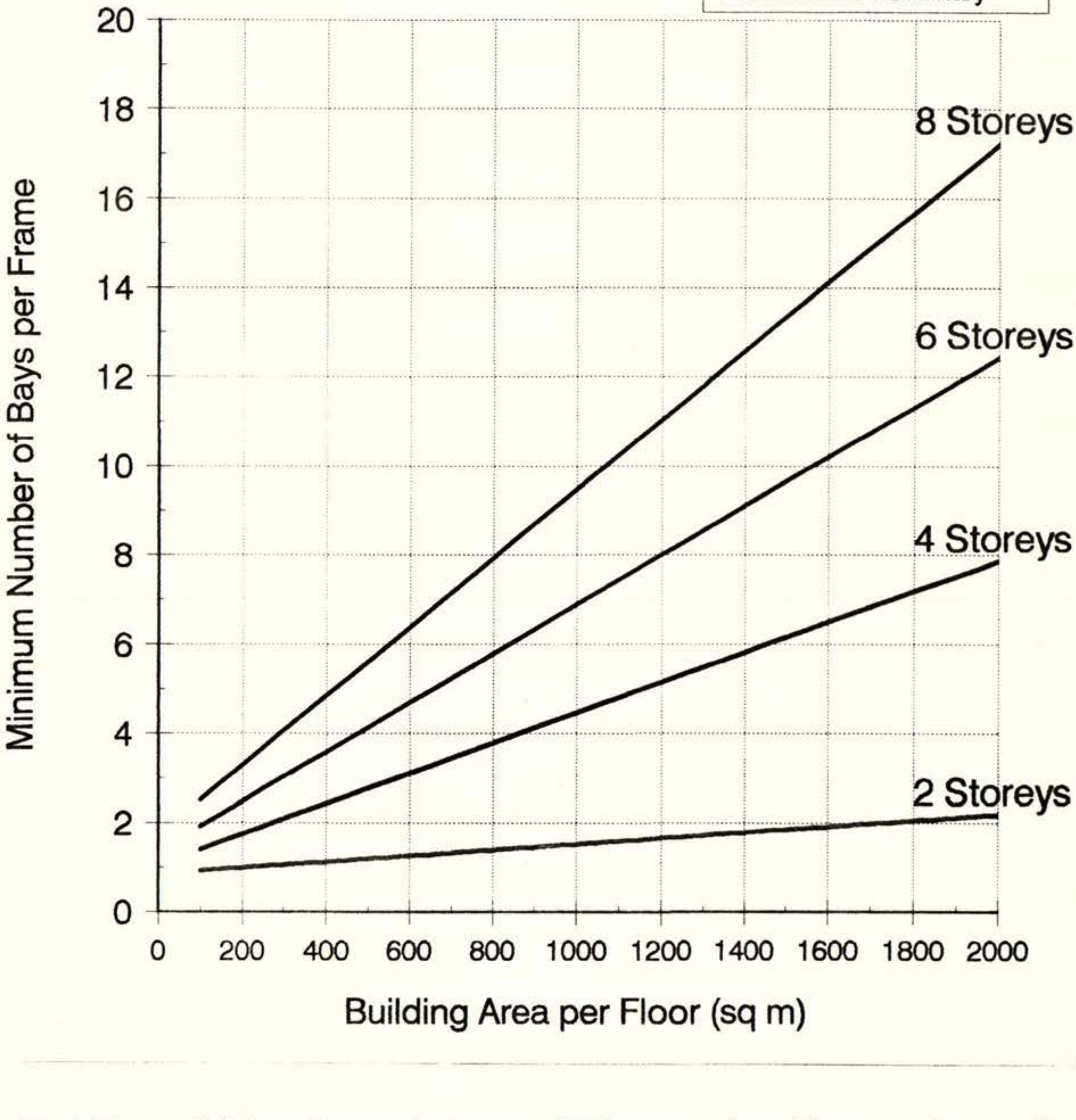


Fig 4.15 Reinforced concrete frames. Minimum number of bays per frame with two frames of 900 mm deep columns for various numbers of storeys: seismic loads, Wellington.

With reference to Fig. 4.14 it is important to note the significance of foundation type. As previously mentioned, with few columns, lateral load overturning moments generate high levels of axial load in end columns. This may lead to considerable foundation vertical deformations, resulting in large horizontal deflections.

Fig. 4.15 investigates the number of columns necessary to maintain a constant column depth of 900 mm.

Wind Loads

Wind loads are not likely to be the critical load case for reinforced concrete buildings. For a four storey building, square in plan, column numbers and sizes are given for buildings of various widths. Column sizes are small when compared to those required to resist seismic loads. (Fig. 4.16)

STRUCTURAL STEEL FRAMES

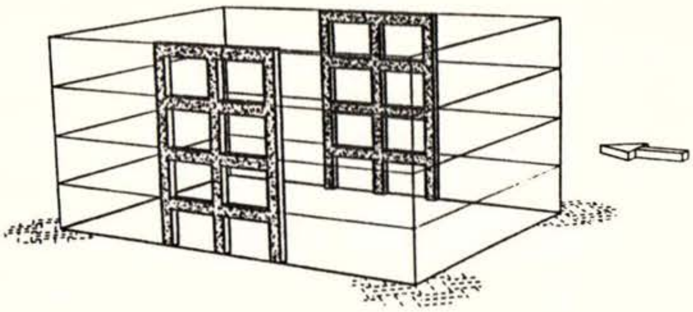
Seismic loads

Requirements for structural steel moment resisting frames are presented in Figs. 4.17 to 4.20. In all cases construction components are of medium weight construction. Two parallel frames have been assumed to resist seismic lateral loads. Column spacing is 6.0 m.

In Fig. 4.17 minimum column depth is given for a range of floor areas and buildings of different heights situated in Wellington and Auckland. Two parallel frames with four bays per frame resist lateral loads. The graph indicates a gradual increase in column depth as building area and number of storeys increase. Column dimensions are seen not to be very sensitive to number of storeys or building location. Designers should note that beam depths are somewhat greater than column depths as explained in Section 3. These beam dimensions may be obtained directly from RESIST's "other results" screen.

As for reinforced concrete, it is found that structural efficiency improves with fewer frames. This is shown in Fig. 4.18 where for a four storey building in Wellington with four bays per frame, the minimum column depth is presented for various numbers of frames. Fig. 4.19 indicates that use of fewer bays has the same effect. Minimum column depth is not sensitive to number of bays when there are over five per frame.

In Fig. 4.20 column depth has been kept constant at 400 mm, and, with the assumption of two parallel frames, the minimum number of bays per frame is calculated. In all cases of seismic load, performance is governed by axial load and bending strength in interior columns, rather than by deflection.



BUILDING DATA

Floor Construction : Heavy
Wall Cladding : Heavy
Partitions : Heavy
Roof Cladding : Medium
Interstorey Height : 3.5m
Occupancy Class : Office
Classification : 4
Foundations : Ordinary

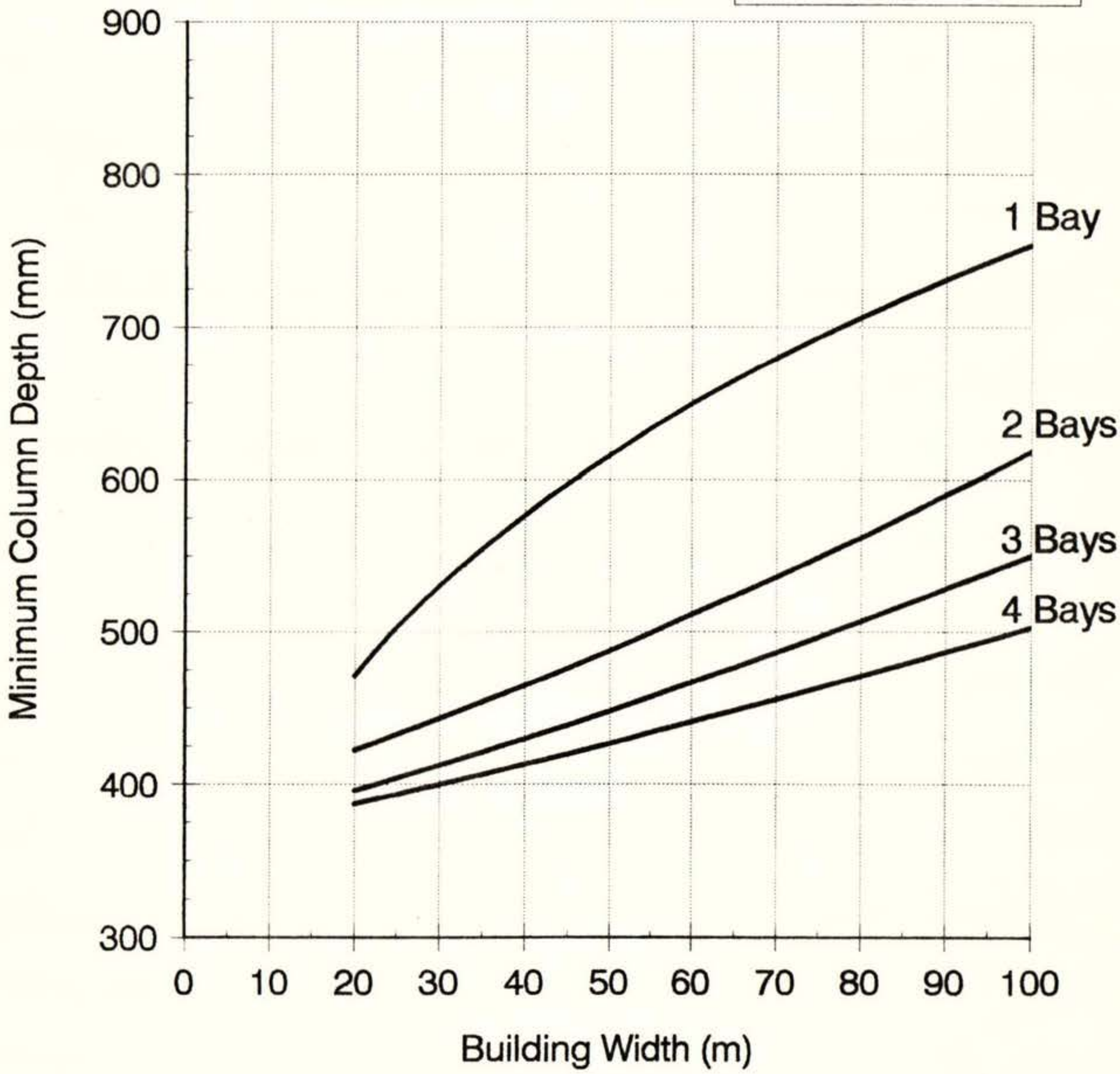
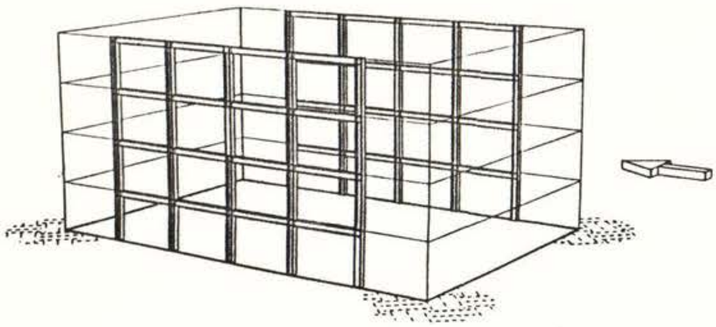


Fig. 4.16 Reinforced concrete frames: minimum column depth for a four storey building with two frames and various numbers of bays per frame and various building widths: wind loads.



BUILDING DATA

Floor Construvtion : Medium
Wall Cladding : Medium
Partitions : Medium
Roof Cladding : Medium
Interstorey Height : 3.5m
Occupancy Class : Office
Classification : 4
Foundations : Ordinary

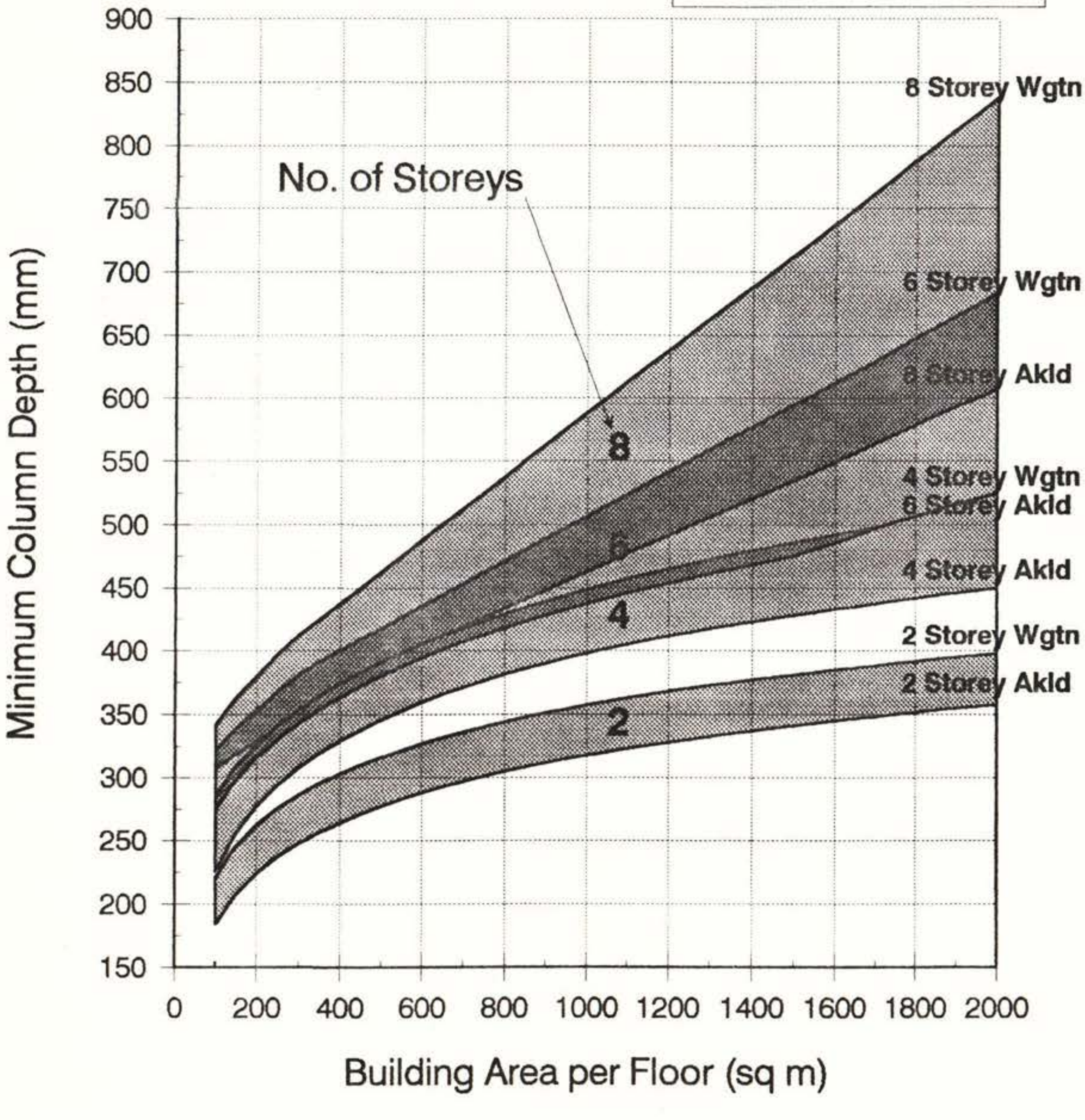
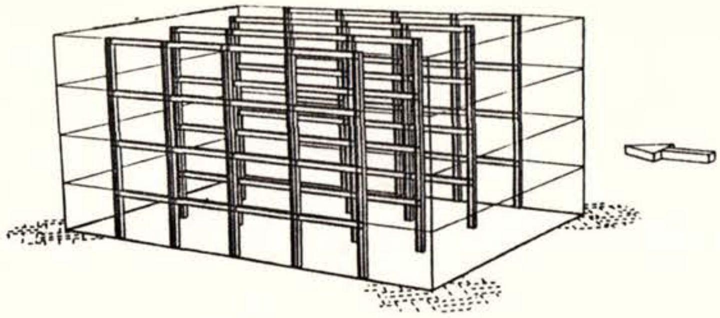


Fig. 4.17 Steel frames. Minimum column depth for two frames with 4 bays per frame for various numbers of storeys: seismic loads.



BUILDING DATA

Floor Construction : Medium
Wall Cladding : Medium
Partitions : Medium
Roof Cladding : Medium
Interstorey Height : 3.5m
Occupancy Class : Office
Classification : 4
Foundations : Ordinary

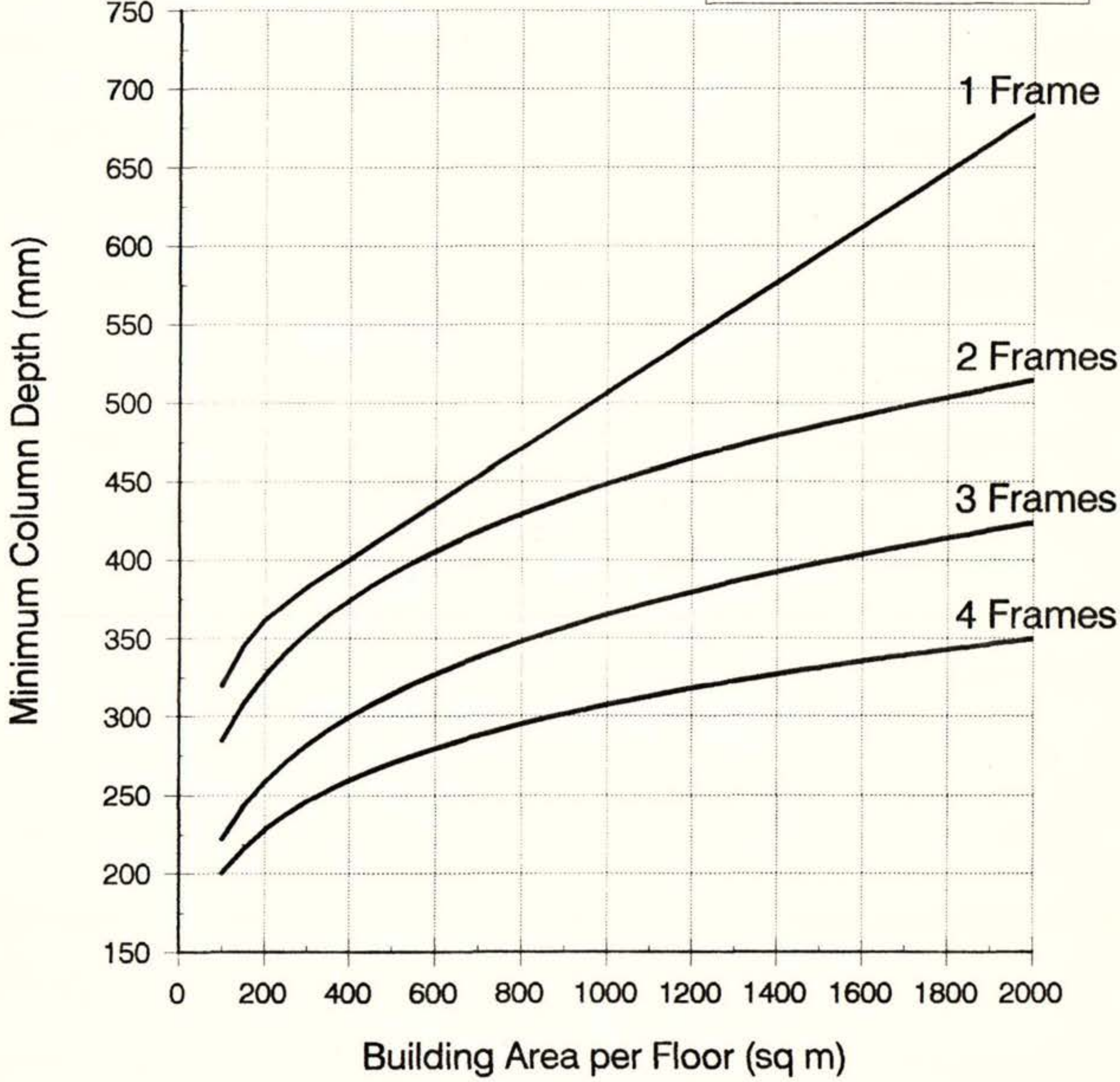
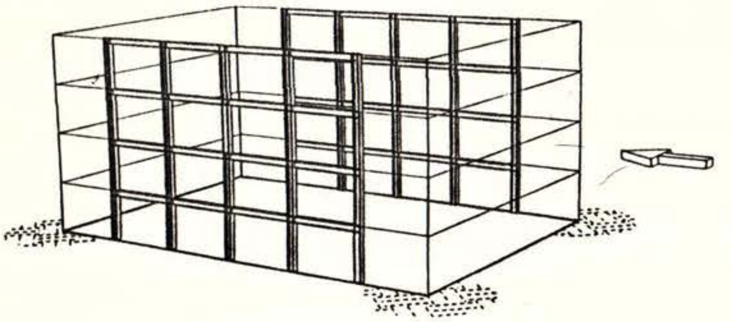


Fig. 4.18 Steel frames. Minimum column depth for a four storey building with 4 bays per frame with various numbers of frames: seismic loads, Wellington.



BUILDING DATA

Floor Construction : Medium
Wall Cladding : Medium
Partitions : Medium
Roof Cladding : Medium
Interstorey Height : 3.5m
Occupancy Class : Office
Classification : 4
Foundations : Ordinary

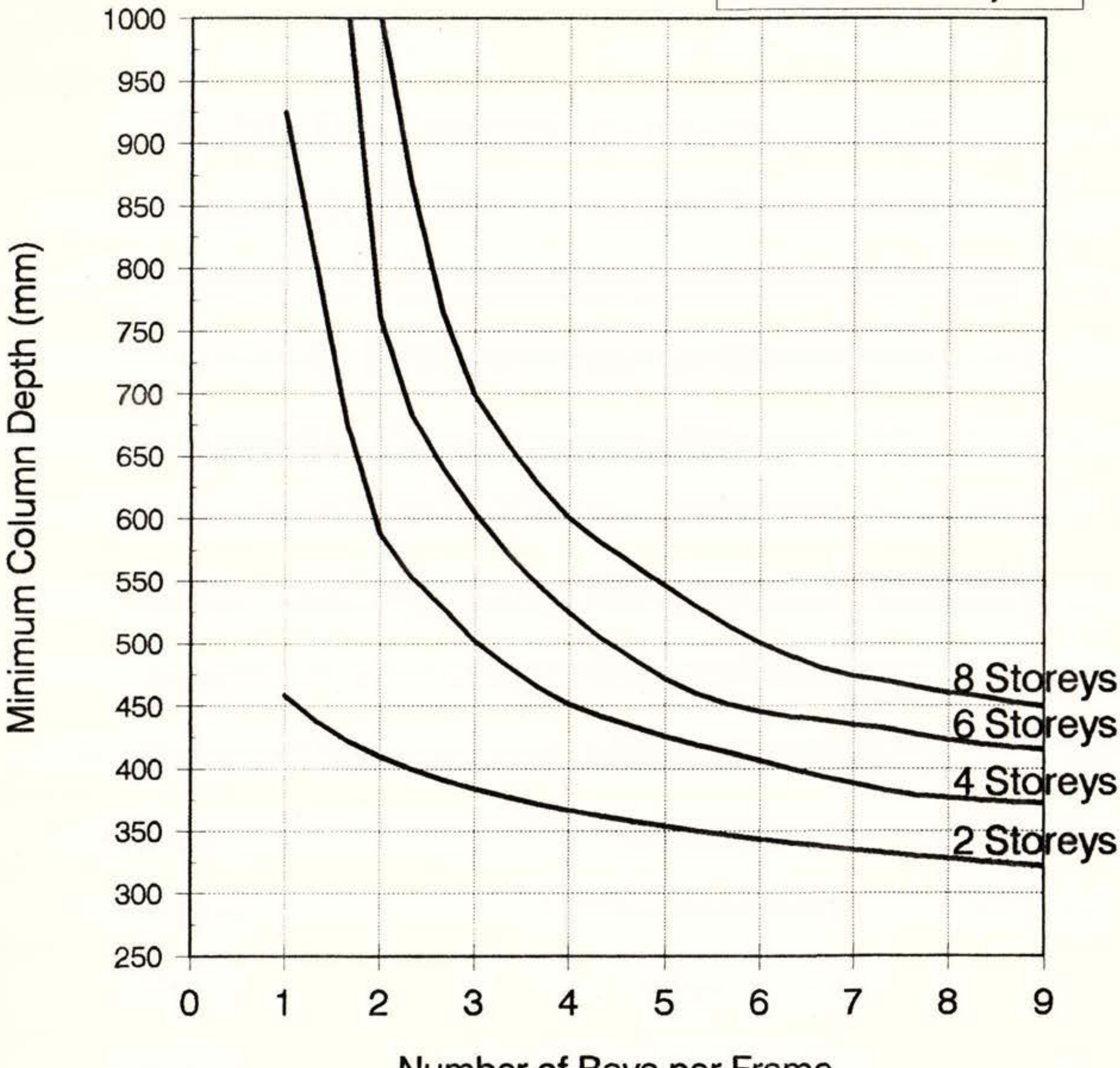
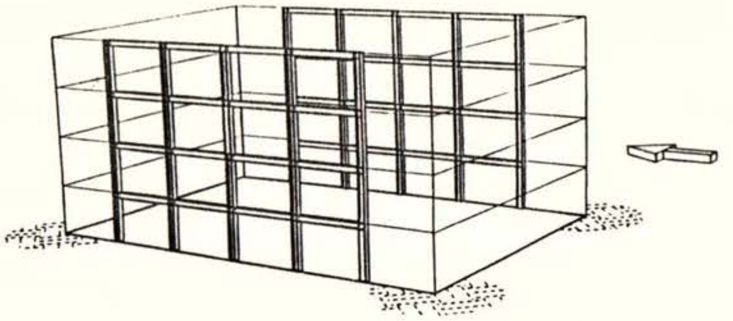


Fig. 4.19 Steel frames. Minimum number of bays per frame with two frames of 400 mm deep columns for various numbers of storeys: seismic loads, Wellington.



BUILDING DATA

Floor Construction : Medium
Wall Cladding : Medium
Partitions : Medium
Roof Cladding : Medium
Interstorey Height : 3.5m
Occupancy Class : Office
Classification : 4
Foundations : Ordinary

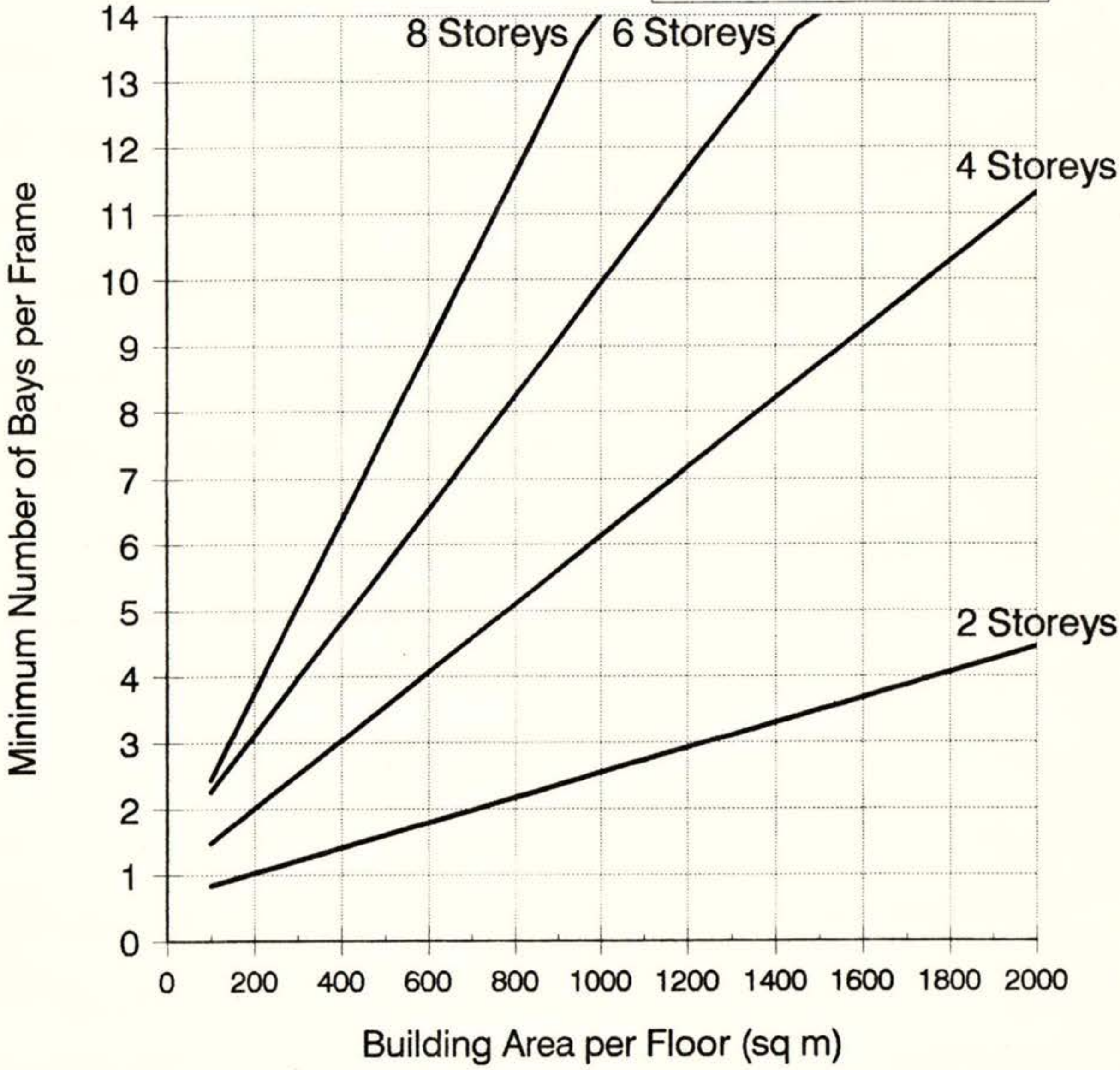
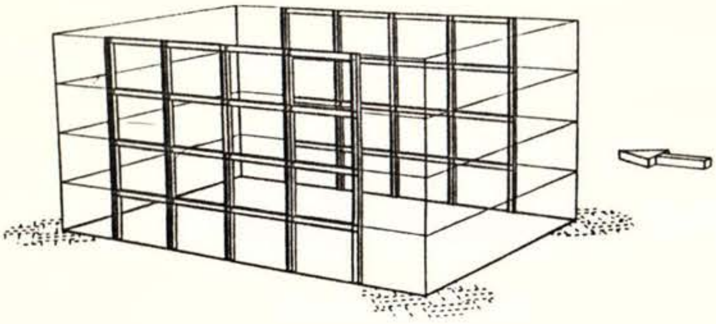


Fig. 4.20 Steel frames. Minimum number of bays per frame with two frames of 400 mm deep columns for various numbers of storeys: seismic loads, Wellington.



BUILDING DATA

Terrain Classification : City Centre
No Topographical Factors
No Channelling Factors
No Lee Effects
Number of Storeys : 4
Interstorey Height : 3.5m
Roof Height : 0m
Foundations : Ordinary

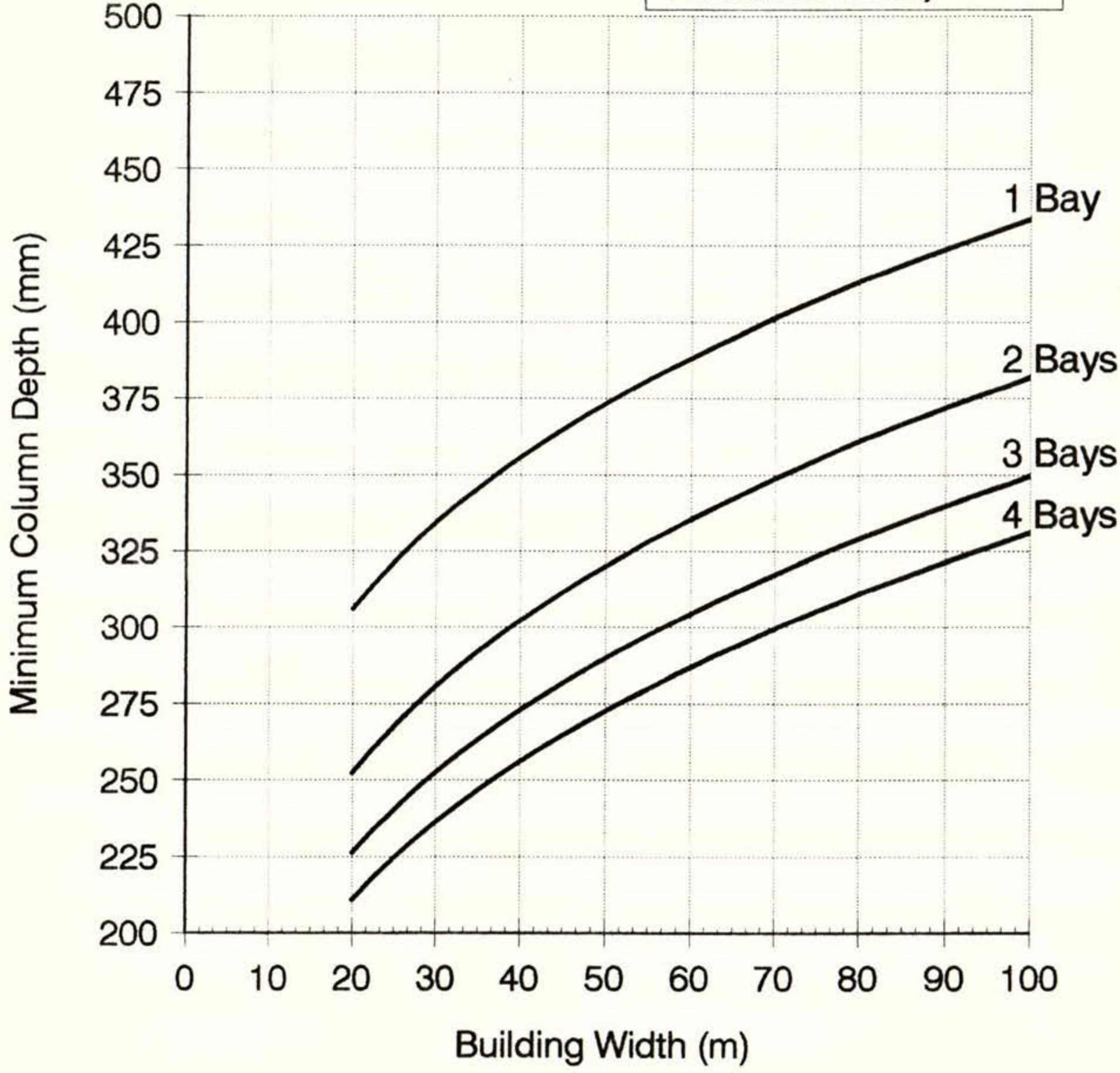


Fig. 4.21 Steel frames. Minimum column depth of a four storey building with two frames and for various numbers of bays: wind loads.

Wind Loads

Information on structure to resist wind load is shown in Fig. 4.21. The building is assumed to be on a sheltered site so additional structure will be necessary for more exposed conditions. Structural requirements are low when compared to seismic loads. For example, a four storey building with a floor area of 1000 m^2 needs two frames with two bays of 275 mm deep columns for wind loads. For seismic loads in Wellington and Auckland with 400 mm deep columns, (Fig. 4.19) seven and four bays respectively are required. Minimum structure for wind loads is dictated by horizontal deflection criteria.

TIMBER FRAMES

Seismic Loads

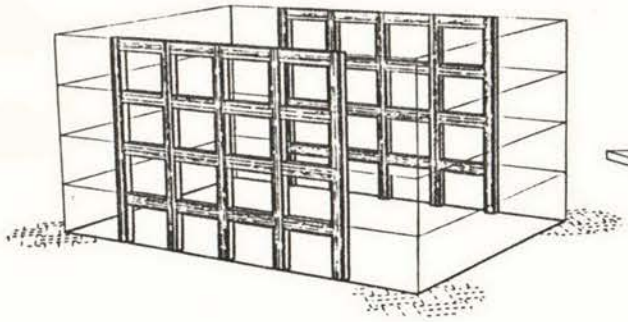
Figs. 4.22 to 4.25 provide information on timber moment resisting frames to resist seismic loads. The graphs consider the same variables as for reinforced concrete and steel frames. Again it has been assumed that the frame columns are spaced at 6.0 m. Construction is lightweight, consistent with timber flooring and timber framed exterior and interior walls.

In general, the main features are similar to those of other structural materials. It is interesting to note that the column depths for timber members and light construction are slightly less than those for reinforced concrete columns and heavy construction.

No one structural action dominated the structural performances, but shear in columns was a commonly a critical factor. If the column cross section were made more square, column depth would be less likely to be governed by shear.

Wind Loads

Structure for wind is given in Fig. 4.26. Unless the building has a high depth to width ratio in plan, or is in an exposed location, it is unlikely wind will govern the design. Deflection was usually the critical performance criterion.



BUILDING DATA

Floor Construction : Light
Wall Cladding : Light
Partitions : Light
Roof Cladding : Light
Interstorey Height : 3.5m
Occupancy Class : Office
Classification : 4
Foundations : Ordinary

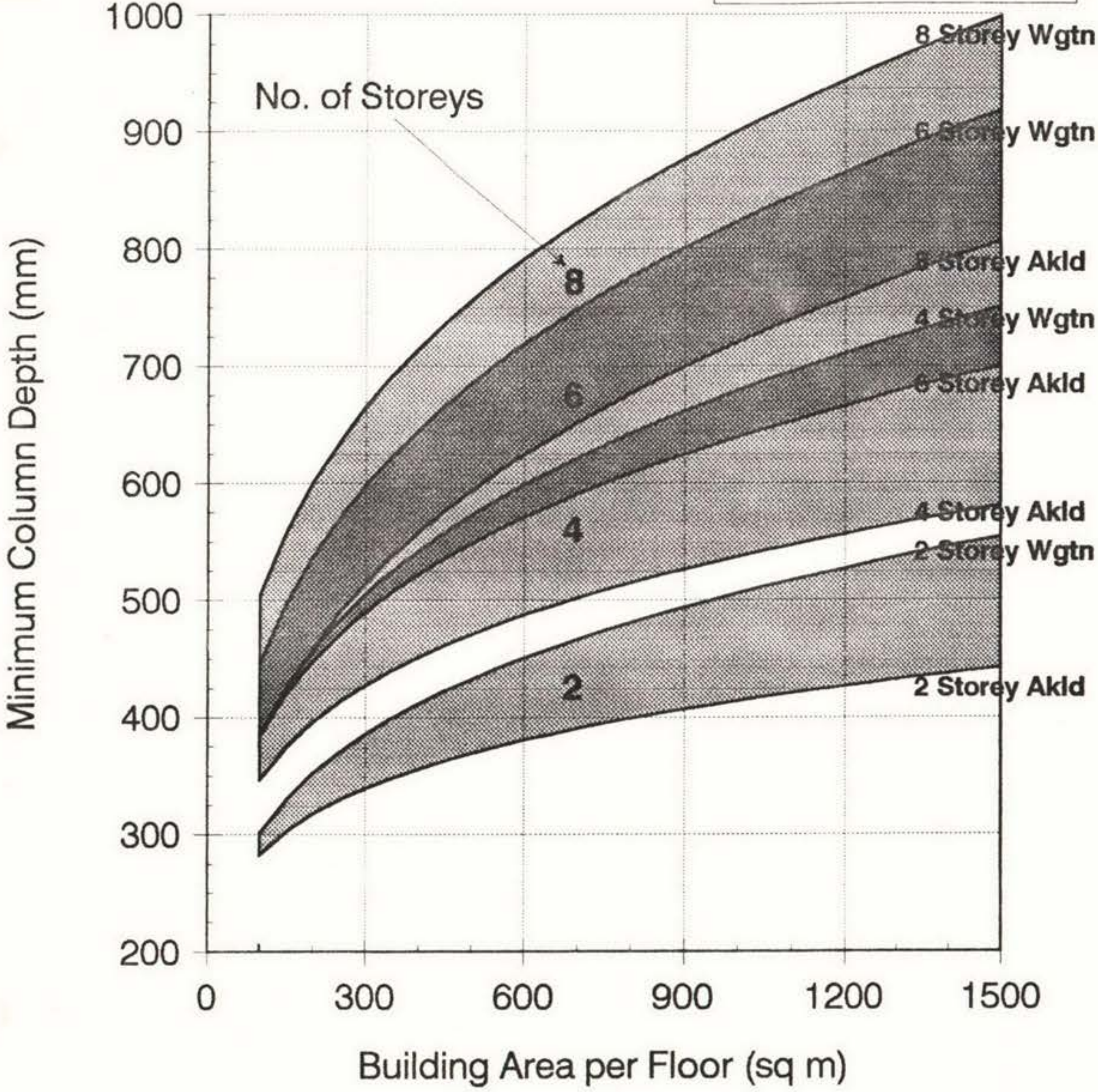


Fig. 4.22 Timber frames. Minimum column depth for two frames with 4 bays per frame for various numbers of storeys: seismic loads.

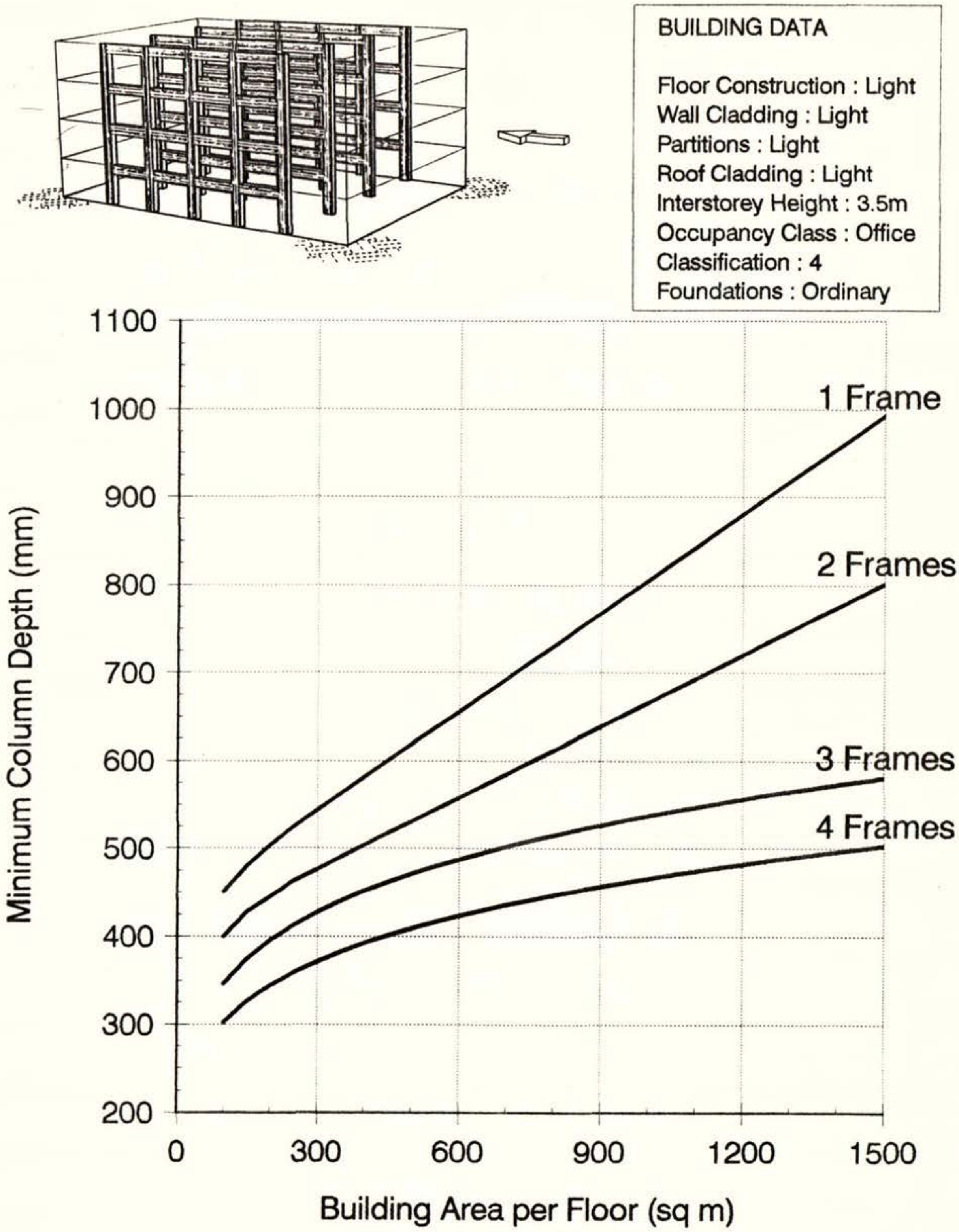
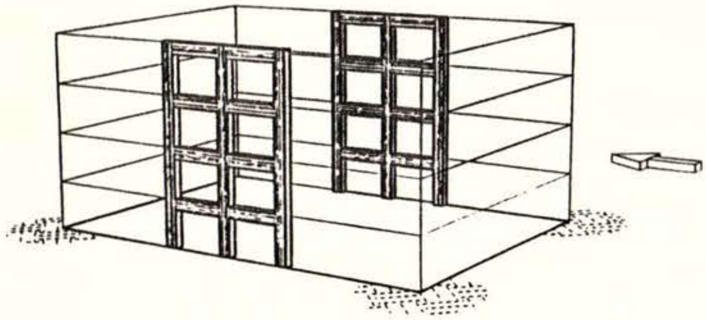


Fig. 4.23 Timber frames. Minimum frame depth for a four storey building with 4 bays per frame with various numbers of frames: seismic loads, Wellington.



BUILDING DATA

Floor Construction : Light
Wall Cladding : Light
Partitions : Light
Roof Cladding : Light
Interstorey Height : 3.5m
Occupancy Class : Office
Classification : 4
Foundations : Ordinary

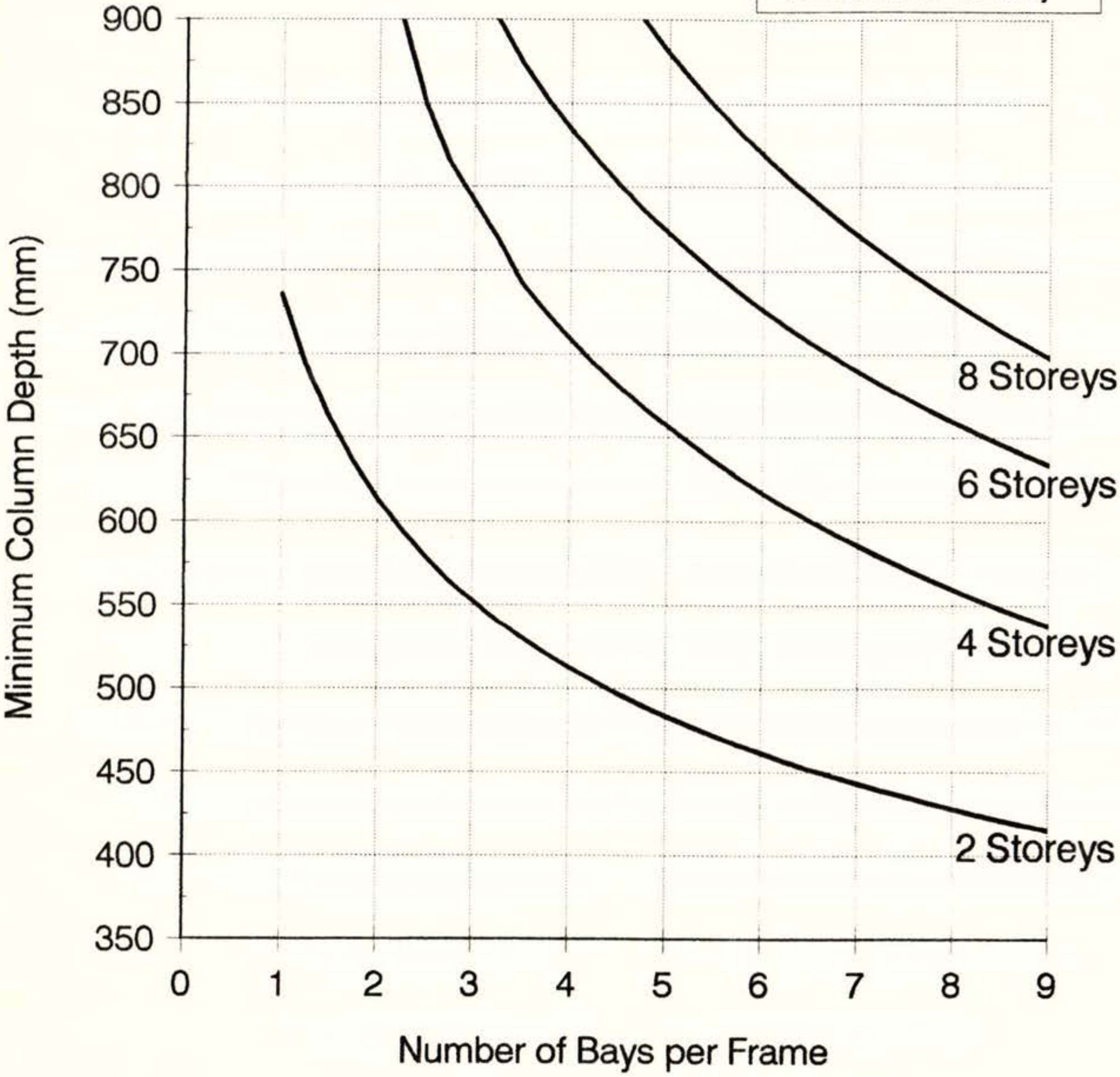
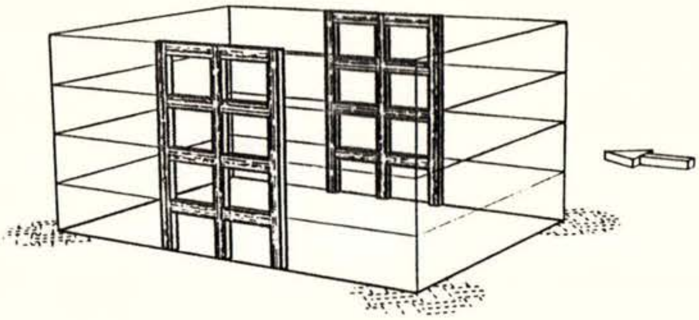


Fig. 4.24 Timber frames. Minimum number of bays per frame with two frames of 400 mm deep columns for various numbers of storeys: seismic loads, Wellington.



BUILDING DATA

Floor Construction : Light
Wall Cladding : Light
Partitions : Light
Roof Cladding : Light
Interstorey Height : 3.5m
Occupancy Class : Office
Classification : 4
Foundations : Ordinary

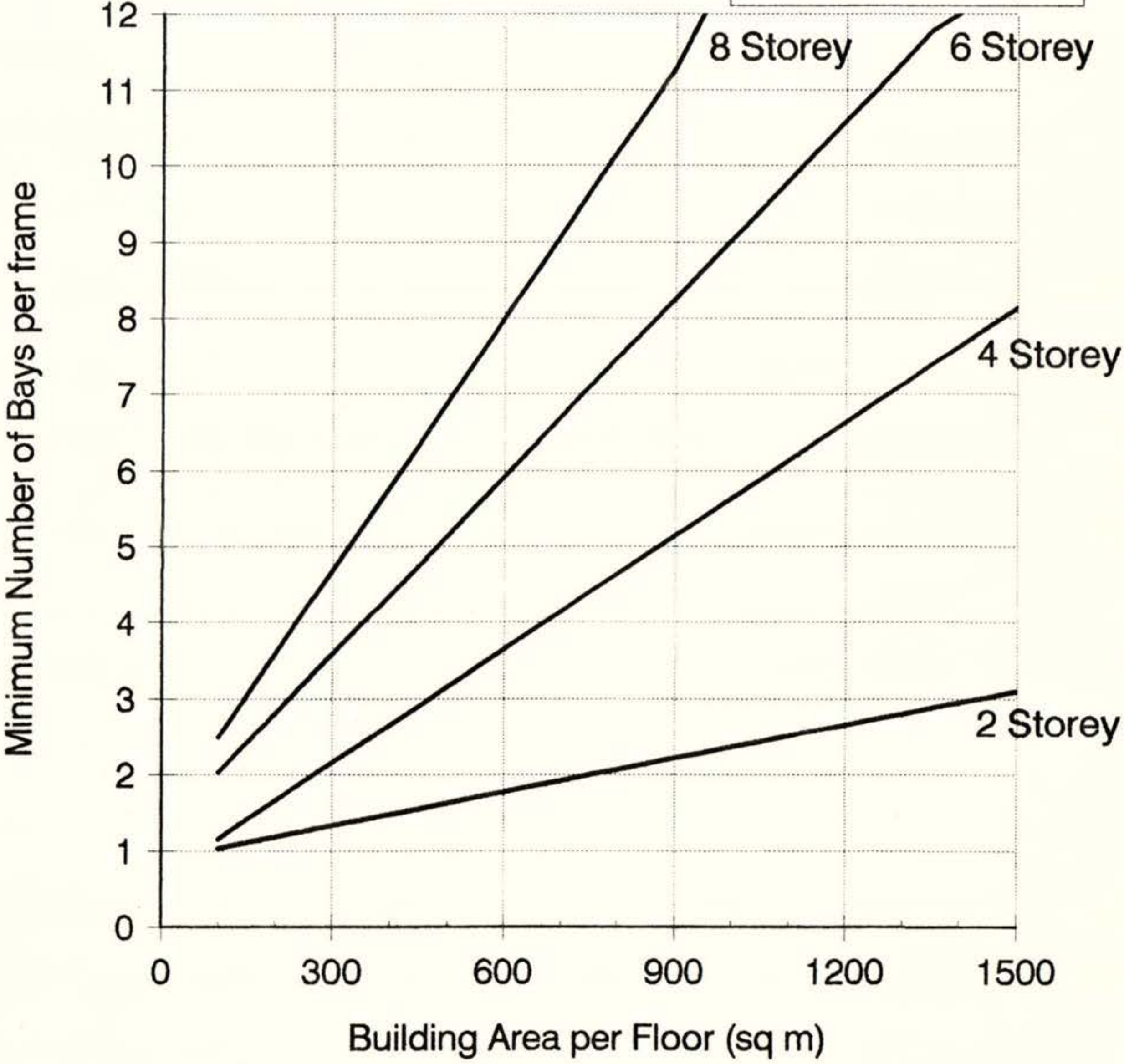
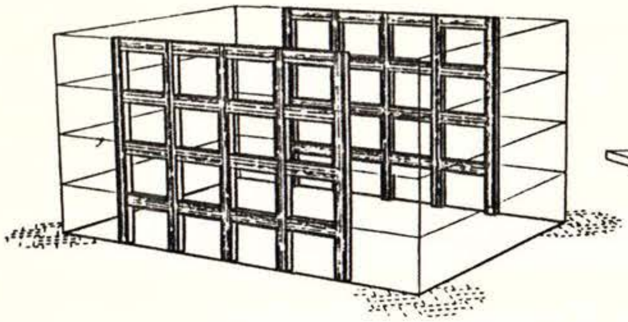


Fig. 4.25 Timber frames. Minimum number of bays per frame with two frames of 400 mm deep columns for various numbers of storeys: seismic loads, Wellington.



BUILDING DATA

Terrain Classification : City Centre
No Topographical Factors
No Channelling Factors
No Lee Effects
Number of Storeys : 4
Interstorey Height : 3.5m
Roof Height : 0m
Foundations : Ordinary

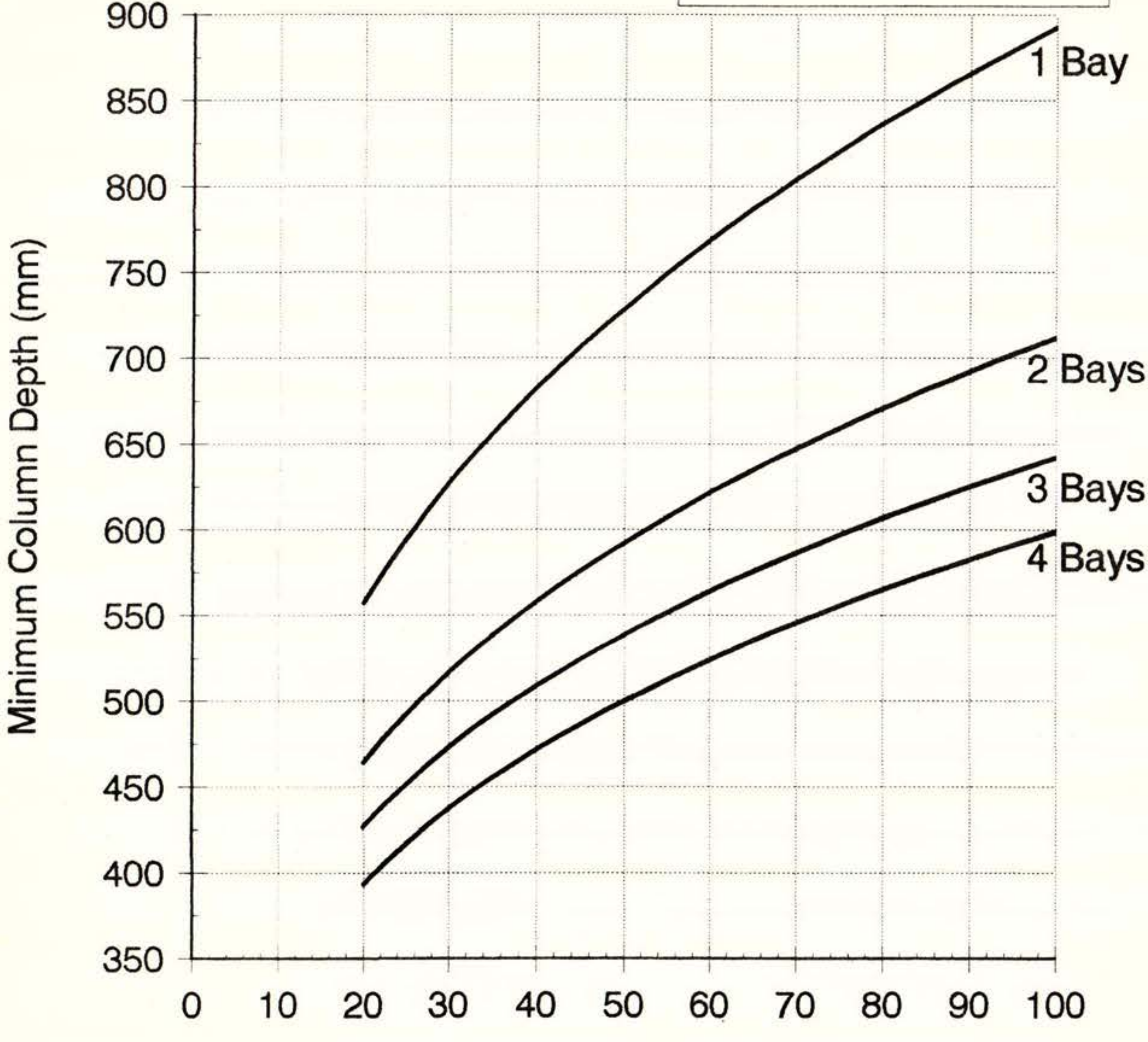


Fig. 4.26 Timber frames. Minimum column depth of a four storey building with two frames and for various numbers of bays: wind loads.

4.4 Braced Frames

STRUCTURAL STEEL

Compression/Tension Bracing

Only limited information is presented for braced frames as the architectural implications of a change in brace depth are not usually significant. Details of minimum brace depth for various storey heights and floor areas are shown in Fig. 4.27. A Wellington location is assumed. Concentrically braced compression/tension frames with two bracing lines and two braced bays adjacent to each other are assumed. Brace performance governs the design, but for fewer bays adjacent to each other, deflections may be the limiting factor. The dimensions of chords (columns) at the end of bracing bays are provided by RESIST output.

Concentric K-bracing has very similar dimensions to X-bracing and is not graphed. Tension only bracing is more slender than other bracing types as members are assumed to be solid steel rods.

Eccentrically Braced Frames

As this system is significantly more ductile than other bracing forms smaller brace sizes are required. However, deflection performance is not as good for the following two reasons. First, foundation deformations are significantly increased by the large ductility factor (μ=6), and secondly, there may be a considerable increase in lateral load and deflection due to P-Delta effects. Deflection performance can only be improved significantly by enlarging foundations.

Fig. 4.28 gives minimum brace depths for buildings in Wellington. A foundation type factor of 4, representing extensive foundations has been used for the structural calculations. Additional braced bays are required to control deflections, but the size of bracing members is small when compared to concentrically braced frames.

As for other structural systems, wind loads are not expected to dominate. It was found that for buildings up to 100 m wide and 8 storeys high, two bracing lines, each with two adjacent bays will usually be adequate. Brace depths or diameters are not expected to exceed 150 mm.

TIMBER BRACED FRAMES

Minimum sizes of timber seismic compression and tension braces for a Wellington building are presented in Fig. 4.29. In this figure, square section braces have been used. Buildings are of light construction and normal foundations have been used. Two bracing lines, each with two adjacently braced bays are assumed. The feature of this figure is the small difference in bracing requirements between four and six storied buildings. This is due to the increased natural period of vibration reducing lateral load to an extent that almost compensates for the additional inertial mass from extra floors. Although brace size is not very sensitive to building height there is a larger variation in the braced frame chord sizes, provided by RESIST output.

For timber braced frames RESIST also provides information on the number of bolts required at the heaviest loaded bracing joint. Bolt diameter is sized relative to brace dimensions.

Brace sizes for resisting wind loads on buildings of different heights and widths are shown in Fig. 4.30. For buildings not higher than six storeys and narrower than 60 m, two bracing lines and two adjacently braced bays are sufficient, given the mild exposure conditions of a central city location.

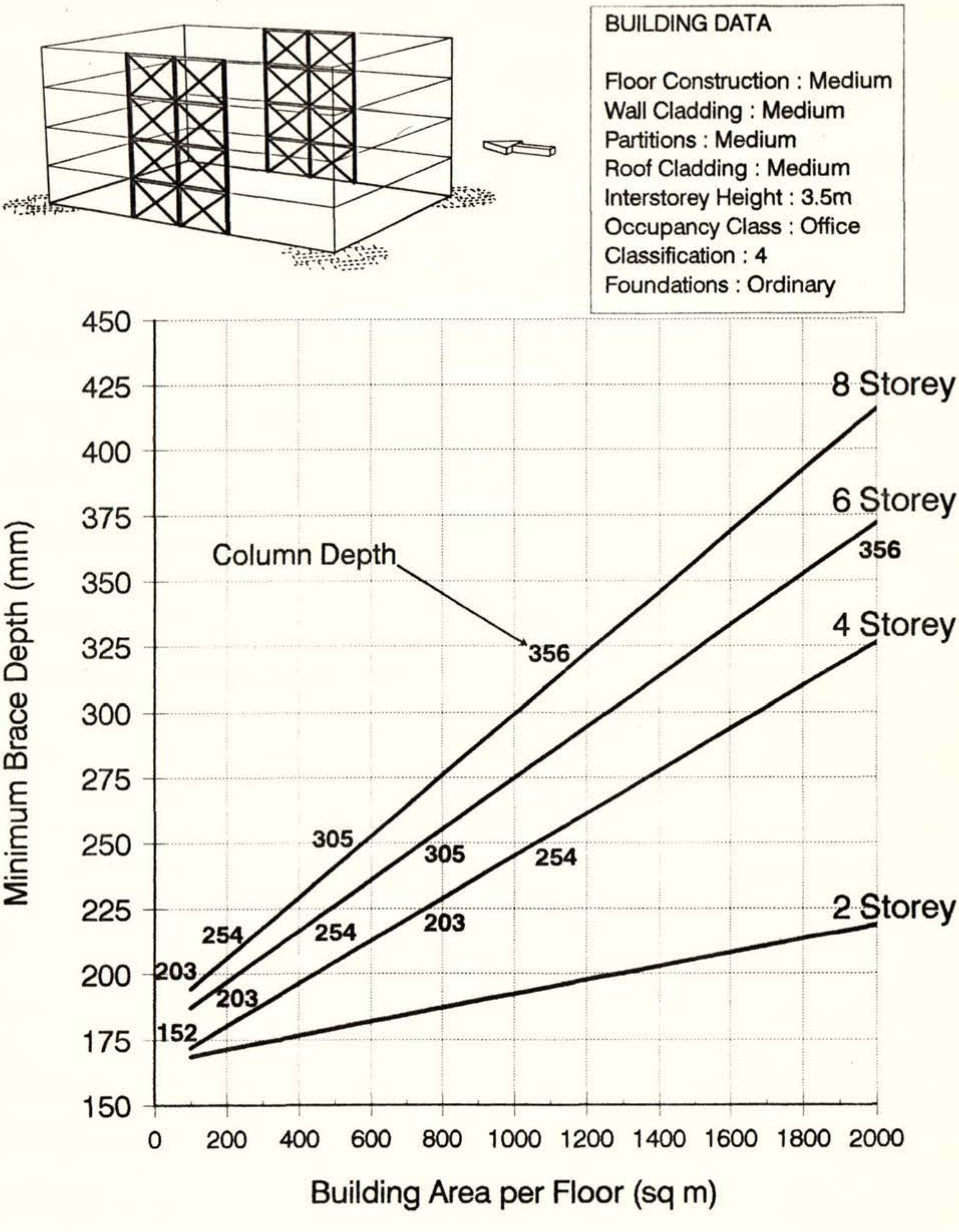
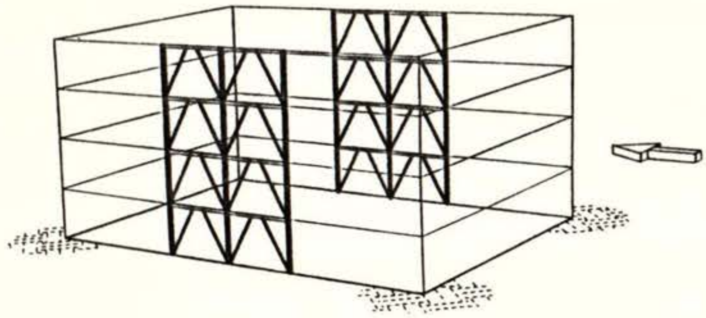


Fig. 4.27 Steel concentrically braced frames. Minimum brace depths for two bracing lines and two adjacent braced bays: various heights of building: seismic loads, Wellington.



BUILDING DATA

Floor Construction : Medium
Wall Cladding : Medium
Partitions : Medium
Roof Cladding : Medium
Interstorey Height : 3.5m
Occupancy Class : Office
Classification : 4
Foundations : Very Extensive

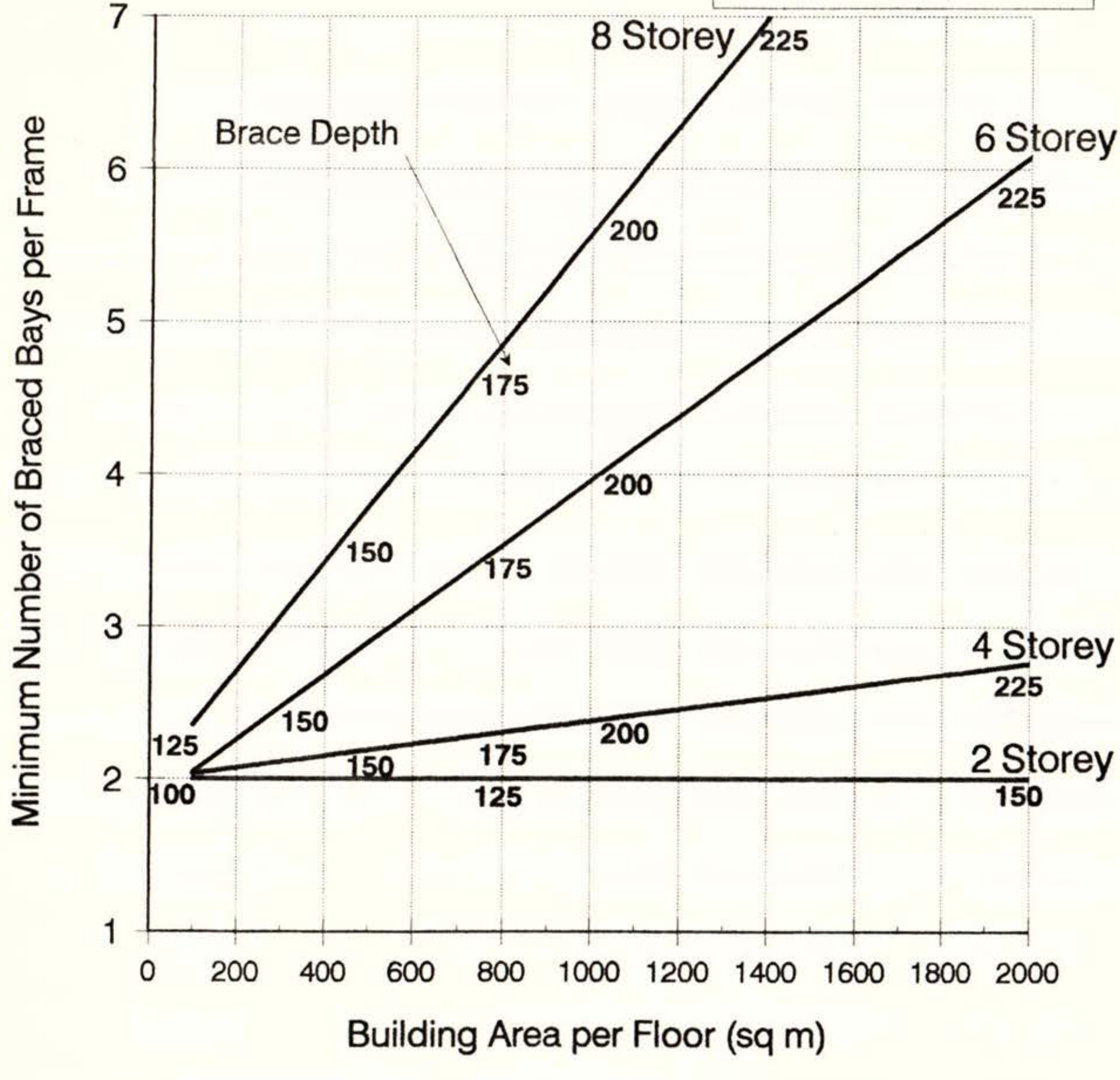
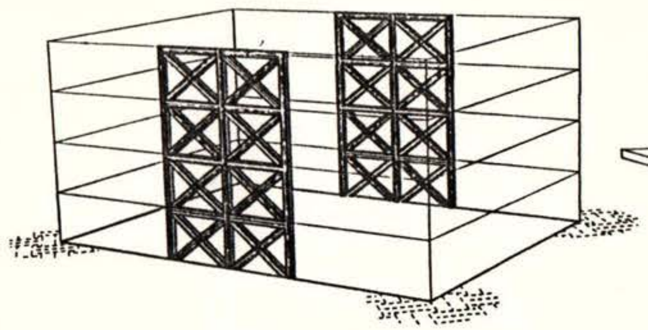


Fig. 4.28 Steel eccentrically braced frames. Minimum number of braced bays for two bracing lines: various numbers of storeys: seismic loads, Wellington.



BUILDING DATA

Floor Construction : Light
Wall Cladding : Light
Partitions : Light
Roof Cladding : Light
Interstorey Height : 3.5m
Occupancy Class : Office
Classification : 4
Foundations : Ordinary

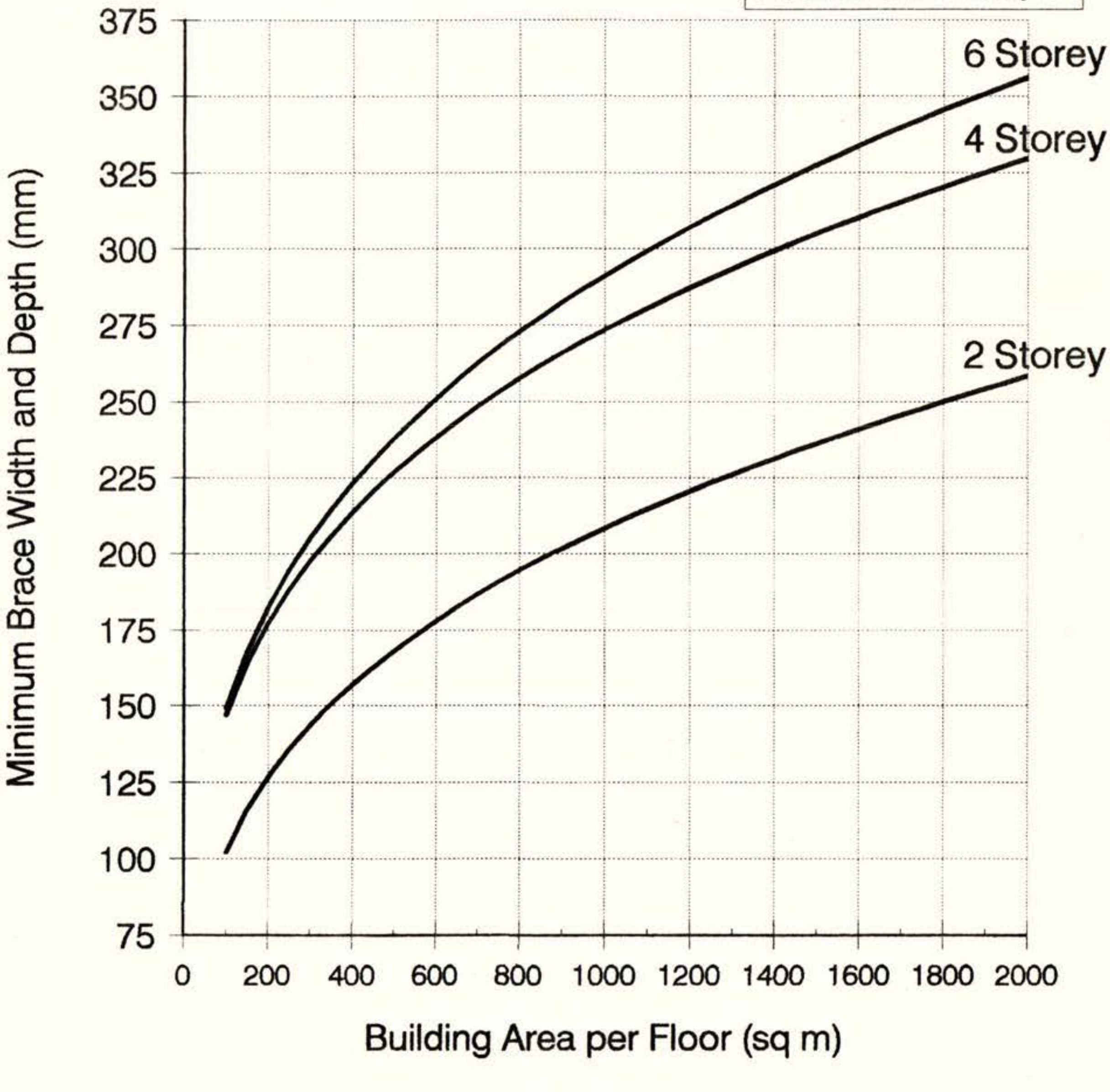
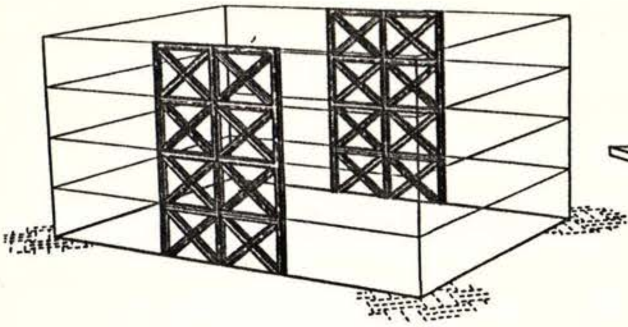


Fig. 4.29 Timber braced frames. Minimum brace depths for two bracing lines and two adjacent braced bays: various number of storeys seismic loads, Wellington.



BUILDING DATA

Terrain Classification : City Centre
No Topographical Factors
No Channelling Factors
No Lee Effects
Interstorey Height : 3.5m
Roof Height : 0m
Foundations : Ordinary

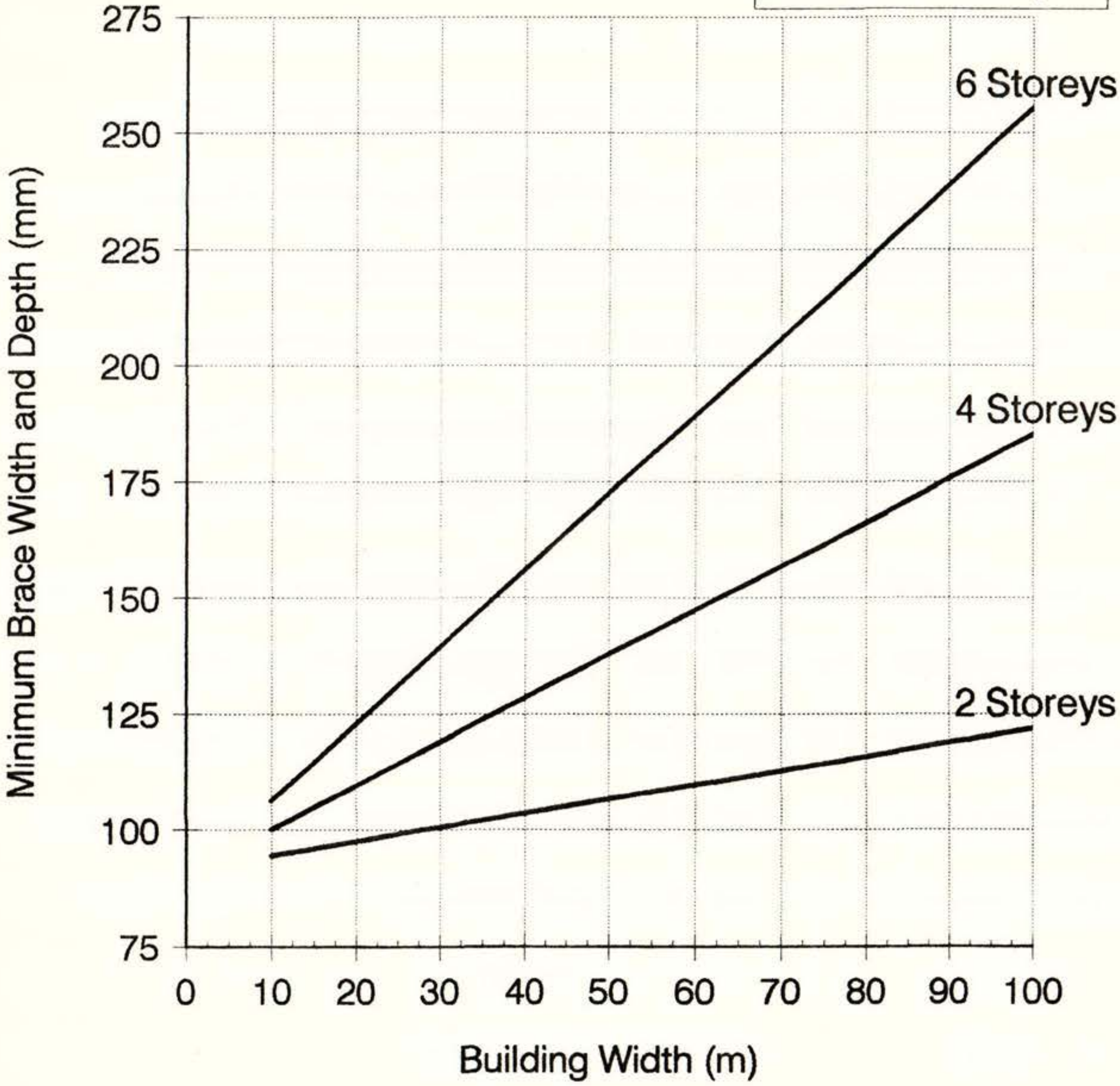


Fig. 4.30 Timber braced frames. Minimum brace depths for two bracing lines and two adjacent braced bays: various numbers of storeys: wind loads.

5. RECOMMENDATIONS AND CONCLUSIONS

5.1 Recommendations

The following recommendations are made:-

(a) The design guides and RESIST be made accessible to designers as widely as possible. The cost of RESIST should be minimised to achieve this objective.

(b) User feedback on RESIST be encouraged so that the program can be improved, as much as possible, to meet the needs of architectural designers. Future enhancements of RESIST will be in response to user comment.

5.2 Conclusion

The objectives of this research project were as follows:-

- To produce design guides which can be used by architects to assist with the preliminary design of vertical lateral load resisting elements.

- To produce a computer program which will provide architects with design information on the requirements of vertical lateral load resisting systems for a particular building.

It is concluded that these objectives have been met. Design guides have been published and a very user-friendly computer program has been developed for use by architects.

7. REFERENCES

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APPENDIX

RESIST MANUAL

Release 1.00 June 1992

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Victoria University of Wellington
PO Box 600
WELLINGTON

Licence Agreement

1. RESIST, including the manual, which has been developed with the assistance of a grant from the New Zealand Earthquake and War Damage Commission may be copied and given or loaned to another person.

2. Every effort has been made to ensure the program gives the correct results, but the responsibility for its use in design rests with the user. The author shall not be liable for any direct or indirect loss or damages arising from the use of RESIST.

3. The author welcomes suggestions for improvements to RESIST.

Acknowledgements

The assistance of the following organisations and people is acknowledged:

- The New Zealand Earthquake and War Damage Commission for its financial assistance to the program development.

- Andrew Vere-Jones and Cranko and Thomson, Architects and Engineers, Wellington for compiling the program and enhancing its user friendliness.

- To all staff and students of the School of Architecture for their constructive comments.

<u>Contents</u>

Chapter 1

Introduction

RESIST is intended to be used by architects and other designers to determine at a preliminary stage in the design how much vertical structure is required to resist horizontal loads from wind and earthquake.

Users are required to input building data and a structural scheme which is then evaluated by the program in terms of compliance with New Zealand Codes of Practice and current structural engineering practice. Results are presented mainly in graphical form.

Designers have the choice of three structural systems; structural walls, moment resisting frames and braced frames. Structural steel, reinforced concrete, reinforced concrete masonry and timber are the structural materials that may be used for appropriate structural systems.

RESIST is completely menu driven and has extensive context-sensitive information available to the user.

RESIST can print the input data and results to provide a written record for later reference. It can also save copies of input data on disk and retrieve them for later re-use or modification.

Chapter 2

Experienced Users Start-up and Quick-start

Who Should Read this Chapter

This chapter is intended for those users familiar with installing and using programs on personal computers using MS DOS. A hard disk, and at least 512K RAM are assumed.

2.1 *Installation*

Make a new subdirectory (named RESIST or whatever).

Copy the two 5¼" floppy disks (or the one 3½" disk) to the new directory.

If you have a HERCULES display adapter, type MSHERC to allow graphs to be displayed. (if you have both a HERCULES monochrome card and a colour video card, type MSHERC /H).

Type RESIST to start the program.

2.2 *Quick-start*

Proceed through the pull down menus starting from the left (except FILE submenu), from TERRAIN to CONFIGURATION to reach each input screen. Press F1 for a context sensitive screen of further information on any topic.

Enter your answer for each question. Note that all questions can be answered by entering a simple number, or the first letter of the listed choices (shown in brackets).

Note that your responses to some questions can affect whether certain later questions and/or input screens appear. For this reason, you must choose each menu item in the order in which they appear.

Choose RESULTS from the main menu. RESIST displays a graph to show the performance of structural elements. This is followed by a screen displaying other miscellaneous construction data relevant to the user.

Save the data you entered to a new data file, with a new filename. Do not save to the filename RESIST.RES - this is a file containing the data the program contains on start up.

PRINT the input data and results if you require a written record of the output.

EXIT the program when finished.

Type RESIST from the DOS command line to restart. GET a previously saved file or start again with the default data file.

Chapter 3

Ordinary Users Start-up

Who Should Read this Chapter

Ordinary Users Start-up is designed for ordinary (rather than experienced) users of personal computers and programs. It describes in detail the procedures that you must complete before you can use RESIST.

3.1 Disks

Your RESIST package should contain one of the following sets of disks, depending on the type of disks your computer uses: two 5¼" disks or one 3½" disk.

5¼" Disks

RUN Disk:

This disk contains the following files:

RESIST.BAT	A small file that starts the program when the user types RESIST.
RUN.EXE	A large file that runs the program and data files. This file is copyright to Baler Software Corporation.
MSHERC.COM	This program "initialises" the computer system to be ready to display graphs on a HERCULES monitor. If you have a HERCULES monitor, you must run this program before starting RESIST. This file is copywrite to Baler Software Corporation.

RESIST Disk:

This disk contains the following files:

RESIST.RES:	A data file that contains the start-up settings for starting a new RESIST session. Do not overwrite this file with data for a job, unless you want that data to appear every time you start RESIST. Type a new filename when saving data to avoid this.

RESIST.HLP	A file containing the additional INFO screens obtained when F1 is pressed while in RESIST.
RESIST.OVR	This file contains those parts of RESIST which do not contain user input data.

3½" Disks

RESIST Disk

This contains the contents of both 5¼" disks. See above for description of contents.

3.2 Hardware Requirements

To use RESIST you must have the following hardware:

An IBM PC or 100% compatible personal computer;

A hard disk and at least one floppy diskette drive OR two diskette drives, one of which must be at least 720 kB.

A keyboard;

A printer (if you wish to print your output).

One of the following types of video display adapters (must be capable of displaying graphics): CGA, EGA, VGA, MONOCHROME or HERCULES. If your video display adapter does not have enough video memory, you will not be able to display the graph part of the results properly. (If you have a HERCULES display adapter, you must run the program MSHERC.COM before each session of RESIST);

RESIST will also use a math coprocessor if one is present. If one is not present, RESIST will be slower in running and calculating results.

3.3 Memory Requirements

To use RESIST your computer must have:

EITHER

A minimum of 512 kilobytes (KB)of conventional memory and a hard disk;

OR

A minimum of 640 KB of conventional memory and two diskette drives, one of which must be at least 720 kB;

OR

A minimum of 512 kB conventional memory and 384kB expanded memory (to EMS LIM v3.2 or later) and two diskette drives.

NOTE: *RESIST supports conventional memory, expanded memory (EMS LIM v3.2 or later), if this memory is available, and virtual memory (free disk space). If RESIST reports an "Out of Memory" error, try removing any device drivers and resident programs from conventional memory (see your DOS manual about these), then try making more disk space available, rather than installing extra expanded memory (unless you have extended memory that can easily be converted into expanded memory). Unless expanded memory is available, RESIST will need about 250kB of free disk space on the disk with the file RUN.EXE on it.*

3.4 Operating System Requirements

You must have version 2.10 of the operating system MS-DOS (or PC-DOS) or higher.

RESIST may conflict with some memory-resident software programs. It is a good idea not to use such programs without thorough testing. If RESIST does not work on your computer, try removing any device drivers and memory resident programs from the system. These are most likely to be called up in your AUTOEXEC.BAT or CONFIG.SYS files.

3.5 Starting Your Computer

Follow the instructions in this section to start either a hard-disk or two-diskette system:

* If you have a hard-disk system, these instructions assume you have installed DOS on your hard disk and that your hard disk is called drive C. If this is not the case, substitute the correct drive letter wherever appropriate in the steps that follow. If you are not sure, ask your computer dealer or technical resource person for assistance.

* If you have a two-diskette system, these instructions assume that your diskette drives are A and drive B. If this is not the case, substitute the correct drive letter wherever appropriate in the steps that follow. If you are not sure, ask your computer dealer or technical resource person for assistance.

If you have a two-diskette system (ie no hard drive), insert your DOS disk in drive A and close the door. If you have a hard drive system, continue to the next item.

Turn on the computer.

If DOS asks you to do so, type the date (mm-dd-yy) and press ENTER.

If DOS asks you to do so, type the time in 24-hour format (hh:mm) and press ENTER.

NOTE: *Computers that have an internal clock set the date and time for you and will not prompt you to enter any information.*

If you enter the date or time incorrectly, DOS lets you try again. Once the date and time are correct, the operating system prompt appears. Each computer's operating system prompt may look different depending on how the computer is configured and the name of the drive from which you started DOS. For example, your prompt might look like any of the following:

A>
A:>
C:\>
C:\>Mon 11-03-1992 (the current date)
D:\>13.50.21> (the current time)

Proceed to the next section.

3.6 Hard-disk Systems: Copying RESIST to a Hard Disk

If you have a hard-disk system, you probably want to copy the RESIST program files onto your hard disk so that you can start the program quickly, without changing disks. You can also store data files you create with RESIST on the hard disk.

Follow the instructions in this section to copy RESIST to a hard disk. These instructions assume that your hard disk is called drive C, your diskette drive is drive A, and the directory you create for RESIST is named RESIST. If this is not the case, substitute the correct drive letter and/or directory name wherever appropriate in the steps that follow. If you are not sure, ask your computer dealer or technical resource person for assistance.

Before you proceed, read the following section if you need to learn about directories, subdirectories, and paths.

About Directories, Subdirectories, and Paths

Directories are subdivisions of the hard disk inside your computer. You use them to keep the files on your hard disk organized. For example, an architect might keep files about one client in one directory and files about another client in a separate directory. To differentiate between directories, you name them. It is a good idea to give a directory a name that relates to the type of files it contains.

Directories can contain other directories, as well as files. Directories inside directories are called subdirectories.

A path identifies the location of the file by showing the disk drive, directory, and subdirectories the file is in. For example, if the file JOB1.RES is located in a subdirectory named RESIST on drive C, the path is C:\RESIST\ and the pathname is C:\RESIST\JOB1.RES.

Creating a RESIST Directory

Directories let you organize files on your hard disk in groups. It is a good idea to have a directory that contains only the RESIST program files and to make sure that you copy the contents of all the RESIST program disks into this directory.

Follow the instructions below to create a directory on your hard disk for the RESIST program files. These instructions name the directory RESIST, but you can give your directory any name.

> At the C:\> (or equivalent) prompt, type MD \RESIST and press ENTER to create a directory for your RESIST program files.
>
> Type CD \RESIST and press ENTER to make RESIST the current directory.

NOTE: *If you are using MS-DOS 2.11 and you have trouble changing to the RESIST directory, type CD C:\RESIST and press ENTER.*

> Proceed to the next section, "Copying the program disks to the RESIST directory".

Copying the Program Disks to the RESIST Directory

Once you create a directory for RESIST you must copy the contents of all the RESIST program disks into that directory.

Follow the instructions below to copy the contents of the RESIST program disks into the directory you created.

Type CD \RESIST and press ENTER to make the RESIST program directory the current directory.

Insert one of the RESIST program disks in drive A and close the door.

Type COPY A:*.* and press ENTER.

The light next to the drive door goes on and DOS lists the files it is copying. When it is finished copying files, the light goes out and DOS displays a message telling you the number of files it copied.

Remove the RESIST program disk from drive A and store it in a safe place.

Repeat the last three steps to copy the other disk (if you are using 5¼" disks).

When you are finished copying disks, proceed to the final section of this chapter: "Starting the program".

3.7 Two-diskette Systems: Backing up the RESIST Disks

A backup disk is a copy of an original disk. You make backup copies of the RESIST program disks so you can use the backup program disks when you work with RESIST instead of using the original disks. Then if anything happens to one of the backup program disks you are using, you can make another copy from the original RESIST disk.

Follow the instructions in this section to make a backup disk from each of the original RESIST program disks.

These instructions assume that your diskette drives are named drive A and drive B. If this is not the case, substitute the correct drive letter(s) wherever appropriate in the steps that follow. If you are not sure, ask your computer dealer or technical resource person for assistance.

Formatting Blank Disks

You must prepare, or format, blank disks so that they can hold information. You should format only blank disks or disks that contain files you do not want.

You will format a blank disk for each of the original RESIST program disks.

These instructions assume both your disk drives are of the same type (size and density). If they are not, you will have to format a disk of each size and density to match your disk drives. The exact commands to use will depend on the size, density and drive letter names of each disk drive. See your DOS manual to ensure each disk is formatted correctly. Note that RESIST requires one disk drive to be at least 720kB, unless you have a hard disk or expanded memory.

* If you have high density disk drives, you will need high density disks. If a drive is not high density, it is double density, and you will need double density disks.

* If you are using 5¼" RESIST program disks, you should have 2 blank 5¼" disks available.

* If you are using 3½" RESIST program disks, you should have still have 2 blank 3½" disks because you will have to copy some of the RESIST files to each disk, to be able to use both disk drives..

Follow the instructions below to format the blank disks:

Make sure your computer is turned on and the operating system prompt is displayed.

Insert the DOS disk in drive A and close the door.

At the DOS prompt, type A: and press ENTER to make drive A the current drive.

Insert one of the blank disks in drive B and close the door.

Type FORMAT B: and press ENTER to format the blank disk.

DOS will display a message saying "Insert new diskette for drive B: and strike any key when ready".

Press ENTER to begin the formatting.

The message "Formatting ..." appears on the screen and the lights next to the drive doors go on. Formatting can take as long as a minute. When the process is finished, the lights go out, and the message "Format complete" appears. DOS displays some information about the disk and asks "Format another (Y/N)?"

Type Y to format the other disk. Type N if when you have formatted both disks.

Remove the formatted disk from drive B.

Attach a label to the disk so you know you formatted it.

Repeat the last four steps to format the other disk if needed.

After you have formatted the last disk, type N to stop formatting.

NOTE: With some versions of DOS, you must press ENTER after you type N.

Remove the DOS disk from drive A.

Proceed to the next section, "Making the backup program disks".

Making the Backup Program Disks

Follow the instructions below to backup the RESIST program disks. These instructions assume your disk drives are of the same size and density. If they are not, make sure you copy the RUN disk onto the disk with higher capacity. You may need to check the COPY command in your DOS manual to ensure you copy from and to the correct drives.

Insert the RESIST program disk in drive A and close the door:

Type A: and press ENTER to make drive A the current drive.

Insert one of the formatted blank disks in drive B and close the door.

Type COPY RESIST.* B: and press ENTER to copy all the files with names starting with "RESIST" to the backup disk.

The lights next to the drive doors go on and DOS lists the files it is copying. When it is finished copying the files, the lights go out and DOS displays a message telling you the number of files it has copied.

Remove the backup disk from drive B and label it.

Name the disk "RESIST disk: Backup". Include the release number in the lower corner of the label. This will help you avoid mixing disks from different releases of RESIST.

If you have 5¼" disks, remove the original RESIST program disk from drive A and store it in a safe place. Insert the RUN disk in drive A: and close the door.

Insert one of the formatted blank disks in drive B and close the door.

Type COPY RUN.EXE B: and press ENTER to copy that file to the backup disk. Then type COPY RESIST B: and COPY MSHERC.COM B: to copy those files too.

Remove the backup disk from drive B and label it.

Name the disk "RUN disk: Backup". Include the release number in the lower corner of the label. This will help you avoid mixing disks from different releases of RESIST.

From now on, you will use the backup copy you made of each program disk when you need to use a RESIST disk. Keep the original disks stored in a safe place. If anything happens to one of the backup program disks you are using, you can make another copy from the original RESIST disk. Remove original and store in safe place.

Starting the Program

Hard-drive Systems

Type CD \RESIST (assuming the subdirectory in which you placed copies of the RESIST program files was named RESIST) and press ENTER to make RESIST the current directory.

If you have a HERCULES display adaptor (for some single colour screens), type MSHERC and press ENTER to "initialise" the display to show graphs.

If you don't know what type of display adaptor you have, try running RESIST without typing MSHERC. If, when you select RESULTS from the main menu, you get an error message rather than a graph, QUIT from RESIST, run MSHERC, and the try running RESIST again. If you have a colour screen, you do not have a HERCULES display adaptor. (If you have both a HERCULES monochrome card and a colour video card, type MSHERC /H)

Type RESIST and press ENTER to start the program.

These instructions assume drive A is the same or higher capacity than drive B. If this is not the case, swap drives A and B in the following sections.

Two-floppy drive systems:

To run RESIST on a 2-floppy system, do the following:

Insert the RUN disk in drive A and close the door.

Insert the RESIST disk in drive B and close the door.

Type A: and press ENTER to make A the current drive.

If you have a HERCULES display adaptor (for some single colour screens), type MSHERC and press ENTER to "initialise" the display to show graphs.

If you don't know what type of display adaptor you have, try running RESIST without typing MSHERC. If, when you select RESULTS from the main menu, you get an error message rather than a graph, QUIT from RESIST, type MSHERC, and the try running RESIST again. If you have a colour screen, you do not have a HERCULES display adaptor. (If you have both a HERCULES monochrome card and a colour video card, type MSHERC /H)

Type RUN B:\RESIST and press ENTER to start the program.

Chapter 4

Using RESIST

4.1 Menus

To use RESIST, select each item from the menus by pressing the highlighted letter, or by positioning the cursor over the item and pressing ENTER.

Press ESCAPE or select the last option (usually a menu name) when in a submenu to return to the previous menu.

4.2 Answering Questions

RESIST will display screens containing questions needed to define the configuration of the building and lateral load resisting structure to work out wind and earthquake performance of structural elements. All questions can be simply answered with a single letter (for example y for Yes) or a number (for example 13.4 (metres)). To use RESIST correctly, you must answer all the questions on every screen that appears under every menu heading.

There are some areas where your answer to a previous question will affect whether you are required to fill out later screens or questions. RESIST will automatically send you to all the required screens and questions as long as you answer them in the correct order (ie the order in which they appear).

To answer the questions, type your response in the space provided. Press ENTER or an arrow key to move on to the next question.

Your response to each question must be one of the letters given as a prompt, usually the first letter of each possible choice (usually in round brackets).

If you require more information from RESIST before answering any question, position the cursor in the space for the answer to the question and press F1 to obtain one or more screens of further information. Press ESCAPE to quit from the INFO system, or PAGE UP and PAGE DOWN to get to the previous or next screen of INFO on that topic (if they exist).

The INFO screens (accessed by pressing F1) are also linked by a menu system which can be accessed by pressing ENTER from any INFO screen.

After you have answered all the questions on a screen, press ENTER or ESCAPE to continue on to the next screen (if there is one which is needed) or back to the main menu, to allow you to choose the next item.

4.3 Using RESIST - Steps

Enter Data

Select TERRAIN (the first option except for the FILE utilities) from the main menu. Answer all the questions on that screen. Press ENTER or ESCAPE to continue. Depending on your answers to the questions on **topography** and **lee effects**, RESIST will continue either to one of up to two more screens of terrain questions or back to the main menu.

Answer all the questions on all the terrain screens required, pressing ENTER or ESCAPE after each screen to continue.

When you return to the main menu, select BUILDING to get to the building information submenu. Select WIND REQUIREMENTS and answer all the questions on that screen, pressing ENTER or ESCAPE to return to the submenu when finished.

Then choose EQ REQUIREMENTS and answer all the questions on the resulting two screens. When you return to the submenu, select MAIN MENU or press ESCAPE to return to the main menu.

Similarly answer questions on STRUCTURE (1 or 2 screens) and CONFIGURATION.

The CONFIGURATION screen is different dependant on the **Structural System** you chose, and some of the questions on these screens are different depending on the **Material**. To ensure you answer the right set of questions, it is important to select each screen from the menu in the order in which they appear.

For more information on each of the questions, press F1 for INFO about the question that the cursor is on.

Calculate the Results

Select RESULTS from the main menu to calculate the performance of the building structural elements under the design wind and earthquake loads.

RESIST will perform the required calculations (which may take up to two minutes or so), then display a graph. This shows the performance of the structural elements expressed as a percentage of that allowed by current good practice.

This information shows the suitability of the structural system given its configuration for that building.

Press any key to continue to the next screen, which shows other miscellaneous results and dimensions required for the structural system chosen. When you have read this, press any key to return to the main menu.

Printing the Data and Results

Select PRINT from the main menu to make a printout of the data you entered, and the results you calculated. On the screen which appears, select which of the two pages (or both) you wish to print.

Also enter the number of lines of text which will fit onto a page (the page length). See your printer manual for more information on this, or simply try different values until you manage to align the text at the top of the page, for both pages. Fairly common values are :

59	Sheet feeder using A4
66	Sheet feeder using B4
70	Tractor feeder on A4

Some printers allow you to set the page length in the printer. See your printer manual if you want to do this.

Enter a Transmission Delay Time. This causes RESIST to pause between sending blocks of text to the printer, for the number of seconds specified. This is needed for some printers to "reset" themselves after receiving a block of text.

Try a value of two seconds, or more if this does not work. Quite a high value is good (say 180 seconds) if your printer is unable to hold all the information to be printed at one time.

Saving and Getting Data from the Disk

Select SAVE from the FILE menu to save your data and results for later re-use. Choose a filename from those displayed in the current directory, or type a filename directly. You can also use the ESCAPE, BACKSPACE and ENTER keys to page through the directory system to find a filename.

By default, RESIST files will have a filename extension of .RES.

If you select the name of a file which already exists on the disk, RESIST will replace the file with the current data being saved. Do not save to an existing filename unless you do not want the data in the copy of the file already on the disk.

Select GET from the FILE menu to get a previously saved document. Follow the instructions for SAVE above to select the filename. RESIST filenames have a default extension of .RES.

GETting a file causes the current data to be replaced with the data retrieved from the disk. Remember to SAVE the current data before GETting another file if you will need the data again.

Exiting from RESIST

Select EXIT from the FILE submenu to finish your session on RESIST and return to the operating system. Remember to SAVE your work if you will need it again later. RESIST does not automatically save when EXITting.

Printer and Disk Errors

If RESIST reports an error with the printer or disk, simply press ENTER or ESCAPE as necessary to clear the error. RESIST should return you to the main menu, where you can try the operation again after fixing the cause of the error.

← **Disk**


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June 1992
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