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LIGHT TIMBER FRAMING CODES FOR DEVELOPING COUNTRIES*

Prepared by

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ABSTRACT

The features of timber frame construction, which merit its consideration as a building system for developing countries, are outlined. The purpose of a code for timber frame buildings is discussed and its main features listed. A procedure is suggested for formulating a timber frame code for developing countries.

CONTENTS

1. INTRODUCTION

(a) Definition of light timber frame construction

Light timber frame construction is the term commonly used to describe a building system using a frame constructed of relatively light, and relatively closely spaced, sawn timber members to support the cladding and lining materials. It is used mostly for housing and small industrial buildings but may also be used for in-fill panels and partitions in larger buildings.

(b) Structural characteristics

The relatively close spacings and plentiful fastenings ensure that a high degree of structural redundancy and load sharing exists within the structure. Weaker and less stiff members shed load (via crossing members and claddings) to the stronger and stiffer members so that the strength of the structure as a whole is related more to the average strength of the members than the minimum strength. Cladding and lining materials also contribute to the structural performance of the frame.

The close spacings mean lightly loaded bending members with high span/depth ratios, so that stiffness rather than strength generally determines the size of the members used in normal wind loading conditions. However, in the case of hurricane-resistant, light timber frames with full internal pressure, the size is governed by strength considerations. Thicker, more heavily loaded members are used to support wall and floor frames and span openings, and strength may govern in these cases. In some situations it may be necessary to use a larger member than is required by either strength or stiffness considerations simply in order to accommodate the fasteners.

(c) Advantages

Light timber frame construction is the traditional building method in a number of more industrialised countries, including Scandinavia, North America, Australia, and New Zealand, and has maintained its popularity for housing in the face of competition from other materials and building systems. It can be adapted economically to varying building styles and production methods. Both low and high cost timber framed housing performs well over a wide range of climatic conditions.

Production methods range from the one-man building firm, operating with hand tools and a truck, through to the capital-intensive, high-production, automated-frame manufacturing plant. These operations can coexist within the same economic environment.

Methods of assembly may be quite tolerant of dimensional innacuracy and timber shrinkage, so it is possible to build with green timber. This is easier to nail than dry timber and dries out in place under the restraint of surrounding structural members and finishing materials. Sawn timber may be used but planed timber is usual as the more accurate dimensions speed construction.

The load-sharing nature of the structure allows low grades of timber to be used safely and economically.

Preservative treatment of non-durable timber species, together with good detail design to control condensation and moisture entry, give the frame an indefinite service life against insect and fungal attack. Correct detail design also contributes to structural strength. Well constructed timber frame housing, in which members and frames are properly tied together, has a good record of resistance to high winds and earthquakes.

Light weight construction facilitates transport and lifting of the finished structure and reduces risk to life if failure does occur.

Properly managed forests constitute a renewable timber resource, from which sawlogs can be extracted with minimal impact on the environment. Compared with other building materials, timber requires relatively low inputs of energy for extraction and processing. No water is required on site for assembly of timber structures.

Timber frames do not rust and can be insulated to a high standard. The flexibility of timber frame construction allows repairs, alterations, extensions, and even relocation of the structure to be carried out with minimal difficulty and expense.

These advantages of timber frame construction commend it as a building system in any country where suitable materials are available.

2. PURPOSE AND SCOPE OF CODE

(a) Purpose

The purposes of codes in developed countries are first, and most importantly, to assist local authorities in ensuring safe and healthy building construction, and second to educate all involved in the design and building process. Timber frame building methods are taught through a combination of apprenticeships and courses in technical colleges. Text books and manuals, based on code requirements, are widely available.

In developing countries, where the method is not well known, the educational role probably comes first. As a result the code could appropriately resemble a manual in content and format.

(b) Scope

Rather than simply dealing with timber-related aspects of timber frame construction, it is better, and will increase the likelihood of obtaining a satisfactory building, if all constructional aspects of a timber frame building are dealt with in a single comprehensive code. For example, if concrete floors are a desired option, the construction details of these floors should be included in the code.

Including all possible structural options in a code would result in too big a document, consequently a selection of options will need to be made. This should be done on the basis of a careful study of local building forms, and cultural and climatic requirements. The availability of materials, fasteners, building equipment and tools, and the level of building expertise should all be ascertained before setting out the main framework of a code.

The implications of such an approach are that it is unlikely that a single code could be written that would be acceptable to all developing countries. Rather than writing a model code and introducing it and the timber frame construction system to a developing country, it is suggested that the exercise start with a study of that country's requirements and resources, so that a code can then be written around them.

What is required with this approach is not a model code itself but a set of guidelines for the production of a code. The following observations are based on the author's personal experience with the

New Zealand Code of Practice for Light Timber Frame Buildings (NZS 3604:1984, first published in 1978)[1] and on discussions with the authors of the equivalent Fiji code published in 1985[2]. It is hoped that these will prove useful guidelines for the production of codes in other countries. Excerpts from the above-mentioned codes are included to illustrate points made.

3. BASIC REQUIREMENTS OF A CODE

(a) Format

Codes suffer wear and tear from frequent reference so they need good quality paper and stout covers. For ease of use and ammendment, an A4 format in a 4 hole ring binder is recommended. Unfortunately this type of binding is not very durable as the punched holes wear and need reinforcing. Paper with a reinforced edge would be ideal if this can be obtained.

The A4 format is well suited to text with illustrations which should be placed close to the text to which they relate.

A contents list and an index which refer to clause numbers rather than page numbers is helpful.

(b) Contents - General

The choice of content of the code will be greatly influenced by the answers to two questions:

"What is the purpose of the code?"

"For whom is it written?"

Answers to the first question might be:

"To control the standard of building construction for the health and safety of occupants."

or "To inform builders about good building practice."

or "To instruct newcomers to the timber frame building system."

To the second question, answers might be:

"Building designers, draughtsmen, building inspectors."

or "Qualified builders, building designers, inspectors, and draughtsmen."

or "People with no previous construction experience wishing to build a timber frame house."

In developing countries it is likely that the last answers to the two questions are the most appropriate. If the code is written more as a manual catering to the lowest level of knowledge and experience it doesn't necessarily compromise its role as a regulatory document. In the New Zealand code, a conscious decision was made to move away from the austere legal document of the previous code to an illustrated manual type code with improved readability. This was done by adopting a "means of compliance" format in which the brief legal requirements were published separately in the form of broad performance statements. The code of practice then became a technical document written to inform people how to build timber frame structures complying with the legal requirements.

For timber frame to be successfully introduced to a country and become an accepted building method, structures must from the start be well built and free from major structural defects. If this is to happen, good communication is needed between the code writers and the reader, i.e., the message must get across.

Ideally the code should include plenty of good quality illustrations accompanied by a simply written text. As far as possible, non-legal and not too technical language should be used. Clarity and simplicity help to ensure that the regulatory process is not a source of abuse by officials.

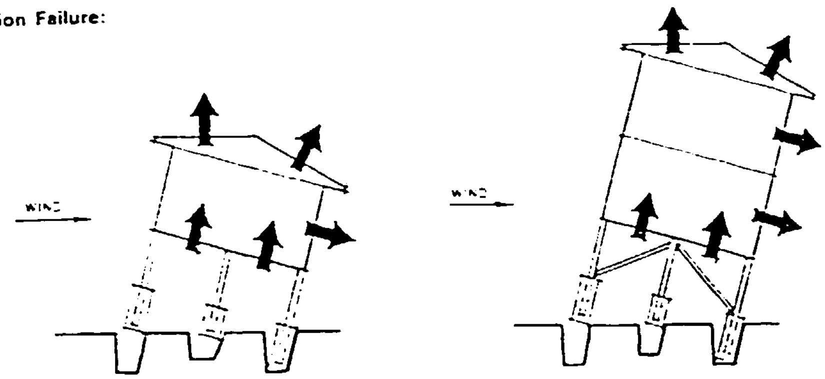
The broad areas to be covered in the content are:

1. The general form of the building.
2. Details of construction - particularly connections.
3. Span tables.

Illustrations should be used liberally to convey information in the first two sections. An understanding of how the structure works, and how the loads it is expected to withstand are resisted by members and connections, can be conveyed by diagrams of failure modes under loading (see Fig. 1). Including these, together with detailed diagrams of all vital structural connections, will improve the chances of obtaining a building free from major structural defects. Even in developed countries with a tradition of timber frame building, structural defects are not uncommon and usually arise as a result of lack of appreciation of what is needed, rather than through negligence.

Figure 1 - Example of failure mode diagram from Fiji Pine Code

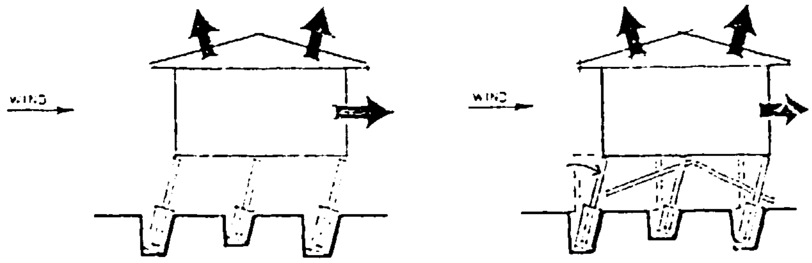
Foundation Failure:



FAILURE: 1. Pile foundations have inadequate depth and mass to resist uplift.

2. Pile foundations constructed in soft ground with inadequate shear friction resistance to prevent the pile from being pulled out of the ground.

REMEDY: Provide deep and heavy footings.



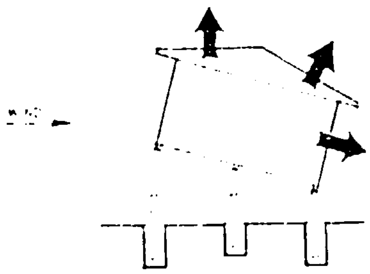
FAILURE: 1. Pile foundations at inadequate depth and width to resist overturning.

2. Pile foundations constructed in soft ground unable to resist overturning.

3. Pile height exceed code maximum for cantilevered piles and are overloaded.

4. Piles ex[illegible]ing 1.2 m. which are not laterally supported with diagonal braces.

REMEDY: Provide [illegible] and wide foundations with bracing as required by this code.



FAILURE: 1. Connections between bearers and piles fail.

2. Connections of braces to piles or sub-floor framing fail.

REMEDY: Provide adequate connections between bearers and piles and braces and piles.

Causes and Effects of Foundation Failures

Where light timber construction is introduced to a country with a tradition of building in heavy materials, it is vital that an appreciation of the wind uplift loads on the timber frame, and the need for clearly defined and well constructed load paths from roof to ground to resist these uplift forces, is conveyed. Similarly with lateral forces due to wind and earthquake. For lateral loads the paths are less easily defined so the diagrams will present a challenge to the illustrator.

Depending on the level of sophistication of the community into which the system is being introduced, it may be desirable to include illustrations and sample plans of complete houses built to the code. Cutaway views showing framing and connection details with references to the relevant pages of the code could be used to summarise the building system in a few pages (see Appendix).

(c) Contents - Specific

It is logical to structure the code so that specific subjects are discussed in the same order as they arise during the planning and building process itself. For example (a) the building system and its limitations, (b) materials and components, (c) requirements of a building site, (d) major structural components (from foundations to roof), and (e) finishing. Fastening systems are best dealt with along with the components to which they relate. Appendices may be used to describe different options and provide additional information.

With some minor variations, the New Zealand and Fiji framing codes follow the sequence of topics listed below:

1. Introduction
   - (a) Description of timber frame system and design options provided in the code.
   - (b) Limitations on loading, dimensions, number of stories.
   - (c) Definition of terms used. Diagram of structure with main components labelled.
   - (d) Use and interpretation of code.
2. Materials and components
   - (a) Timber and wood based products. Species, grade, sizes, finish, treatment, moisture content, type, specifications.

(b) Fasteners. Sizes and specifications for nails, screws, bolts, proprietary fasteners.

3. Site requirements

   Profile and stability, flooding, soil bearing strength, site preparation.

4. Foundations and subfloor framing
   (a) Structural action diagrams showing failure modes vertically and horizontally.
   (b) Systems to resist vertical loads.
   (c) Pile types and footings.
   (d) Systems to resist horizontal loads.
   (e) Bracing.
   (f) Bearers.
5. Floors
   (a) Structural action and failure diagrams.
   (b) Joists.
   (c) Flooring.
6. Walls
   (a) Structural action and failure diagrams
   (b) Systems to resist vertical loads
   (c) Wall framing. Studs, plates, lintels, intersections
   (d) Systems to resist horizontal loads
   (e) Wall bracing
7. Posts.
8. Exterior wall cladding.
9. Interior wall lining.
10. Roofs
    (a) Structural action and failure diagrams
    (b) Systems to resist vertical loads
    (c) Roof trusses
    (d) Framed roofs
    (e) Systems to resist horizontal loads
    (f) Roof bracing
    (g) Ceiling framing
    (h) Platforms (for water tanks) in the roof space
11. Roof coverings.

12. Ceiling lining.
13. Appendices
    (a) Sample plans covering a range of sizes and styles
    (b) Illustrations of completed houses

4. CALCULATION OF SPAN TABLES AND FASTENING REQUIREMENTS

With few exceptions, most users of the code would be likely to find numerical performance information of less interest than descriptions of the form of construction. Nevertheless, the successful introduction of the timber frame system depends on a correct specification of performance requirements. These figures need to be accessible to specialist groups, but not necessarily incorporated into the code, as this would make it bulky and less readable. The code itself should be a concise and practical document which enables builders to meet performance requirements economically.

For developing countries a specification type of code is more appropriate than a performance code, but it is important that the basis for the calculations be set out in an associated document so that future revisions or extensions of the code may be made knowing the basis for the original recommendations.

(a) Loading and deflection limitations

Where a loading code is available this may be used to establish wind, earthquake, snow, and occupancy loads. Otherwise loading codes from other countries may be used in association with local climatic and seismic data.

Deflection limitations are generally poorly dealt with in loading codes but as discussed in section 1(b) often dominate the construction of span tables for light timber framing. If local guidance is inadequate then other national codes and publications[3,4] may be helpful. Although the calculated stiffness of say two joisted floors under a given uniform loading may be the same, their performance may differ considerably under the more concentrated loads of normal use because of different amounts of load sharing. The different load sharing properties of different struc tures should be considered when formulating deflection limitations, as should any perceived local preferences for stiffer or more lively floors.

(b) Material properties

Knowledge of the timber available for construction may vary from crude density estimates through small clear specimen test data to detailed in-grade test data. A system of grading timber allows more efficient use of the resource and a more consistent standard of construction. Where in-grade data are not available then the classification system developed for the Standards Association of Australia[5] may be used to derive basic strength data for span table calculations. A similar grouping system has been developed for the derivation of fastening properties.

(c) Span tables

Span tables present the results of engineering calculations for defined structural components, material properties, and performance requirements. They are compromises between engineering efficiency, which demands large tables with small steps of the variables, and code usability, for which simpler, shorter, more easily read tables are required. For developing countries the compromise should be made more in favour of code usability. If possible, tables should be presented as finished answers in terms of member size or span without further calculation being required. Full documentation of the basis for their calculation should be available in supplementary reports. The ease with which a table can be used is dependent on the author, editor, graphic designer, and printer. The following guidelines have been found useful.

1. Table variables should be ordered so that an increase in member size results from going from top to bottom and/or left to right.
2. Rounding to 0.1 of a metre for span tables is generally sufficiently precise.
3. Where few variables are involved, such as in joist or rafter tables, the tables can give allowable member spans as the answer for given sizes and spacings. Where many variables are involved, such as in stud, plate and lintel tables, an allowable member size is the most appropriate tabulated answer.

4. Tables should relate to one another where appropriate. For example, tables of pile spacings should relate to bearer row spacings which should be covered in the joist span tables.

The calculation of span tables is invariably a computing job so that undue simplification of the number of loading cases or of other assumptions simply to ease the calculation load is unnecessary. Deflection (bending and shear) and strength calculations for dead, live, and dead-plus-live loads should all be included, with allowance for load sharing made where appropriate. Use of the more rational methods developed recently to account for partial composite action and lateral load redistribution[6] is probably not yet warranted.

Where timber is installed green and allowed to dry in place it is generally appropriate to use dry-strength values and shrunk sizes as this is the condition in which the members will be loaded for the greater part of their lives. Taking into account the large size effect which occurs with timber loaded in shear, the design of short span bending members, such as plates, need not be dominated by shear strength considerations. Deflection criteria for these members might in some circumstances be more appropriately expressed as absolute deflection limits rather than as proportions of the span. If there is a possibility of machine graded timber being available, some thought could be given to preparing stiffness based span tables for mixed species as proposed by Kennedy[7].

(d) Fastening recommendations

Fastening systems should be simple, easily inspected, where possible based on locally available materials, skills and tools, and clearly illustrated in the code alongside the components to which they relate. Nails and light-gauge metal strap, through which nails may be driven, meet these criteria and have been specified extensively in the Fiji Pine framing code. Fatigue testing of these strapped connections has demonstrated their resistance to simulated cyclone loading although their load capacity is reduced somewhat where a twist in the strap is necessary to align the strap with members crossing at right angles.

Member sizes may be determined by fastening requirements rather than strength, e.g., timber braces, and where this is so, the member tables should reflect this constraint.

Where extreme uplift loads exist as a result of high wind loadings, it is probably safest to standardise on fastening details. For instance, all vertically loaded joints with nails in end grain are strapped using the same detail, even though calculation may show that some of the straps are unnecessary. Where heavy materials have been used in the traditional building methods, it is important that the code should clearly convey the message that the structural performance of timber frame building systems depends on well constructed, clearly traceable load paths, through members and fastenings, to resist uplift loads and horizontal loads imposed by wind and earthquake. Clear diagrams of forces and failure modes are a good way of doing this.

5. SUGGESTED PROCEDURE FOR FORMULATING A CODE

(a) Prerequisites

1. An economic source of sawn, durable, graded timber to which some strength figures may be assigned.
2. A knowledge of the likely wind and earthquake loadings.
3. Ready availability of fasteners, cladding, roofing, and, if desired, lining material.

(b) Preparation of a design brief for the code

Visits should be made by architects and engineers to determine the size, shape, and cost of houses in relation to the needs, lifestyles, and aspirations of the local people. Questions that should be asked are: should a code be aimed at the top or middle of the market, or both? If the last, should it be printed in a single volume or two separate volumes? What marketing strategy should be employed? The best building system and code in the world may still not find favour with the intended users if it fails to recognise cultural needs and aspirations as well as those of basic shelter.

Sketch plans and structural details should be drawn up and discussed with informed locals. When satisfactory designs and details have been determined, the designs should be tested in actual building; the scope and limitations within which the code will be written can then be defined. The results of these investigations are written up as the design brief for the code.

(c) Draft for comment

Based on the design brief, a draft code and range of plans can then be prepared for wider discussion within the community.

(d) Publication and presentation

After suggestions have been collated, the draft can be revised in the light of comments received and the final code prepared. Ideally its launch should be made in association with the construction of an exhibition village of real buildings and publication of a variety of plans. The phased introduction of a building system will require careful planning, first to ensure an adequate supply of materials, and second to provide basic training for builders. The regulatory function should be kept to a minimum consistent with achieving desired objectives.

Initial impressions and performance can make or break a new product, so it is particularly important in the early stages that problems are sorted out quickly and the details are followed carefully.

6. LIST OF REFERENCES

1. Standards Association of New Zealand 1984: Code of practice for light timber frame buildings not requiring specific design. NZS3604:1984.
2. Ministry of Forests - Fiji 1985: Fiji pine code of practice for light timber frame building not requiring specific design.
3. Building Research Association of New Zealand 1983: Lintels and beams supporting light timber frame construction. Technical Recommendation No. 2.
4. Reardon, G.F. and Kloot, N.H. 1978: Low rise domestic and similar framed structures. Part 1. Design Criteria (Revised). CSIRO, Division of Building Research Special Report.
5. Standards Association of Australia 1979: Report on strength grouping of timbers. MP45.

6. Forest Products Research Society 1983: Wall and floor systems. Design and performance of light-frame structures. Proceedings 7317.

7. Kennedy, D.E. 1969: A new look at mechanical lumber grading. Forest Products Journal 19(6).

ACKNOWLEDGEMENTS

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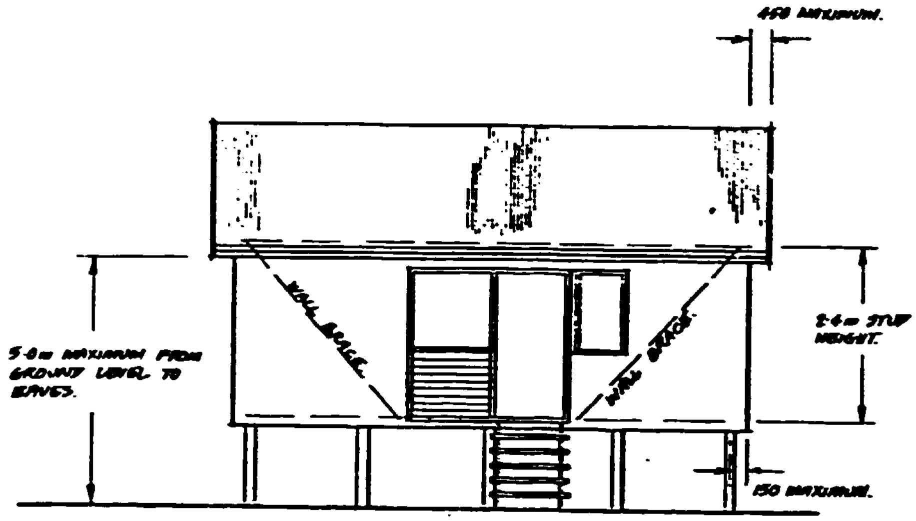
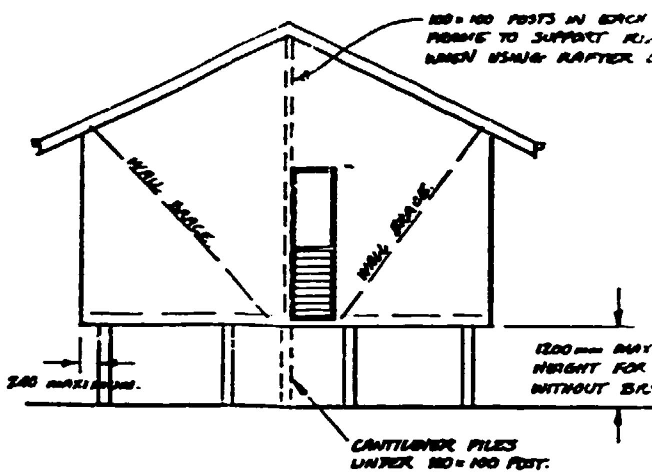
APPENDIX

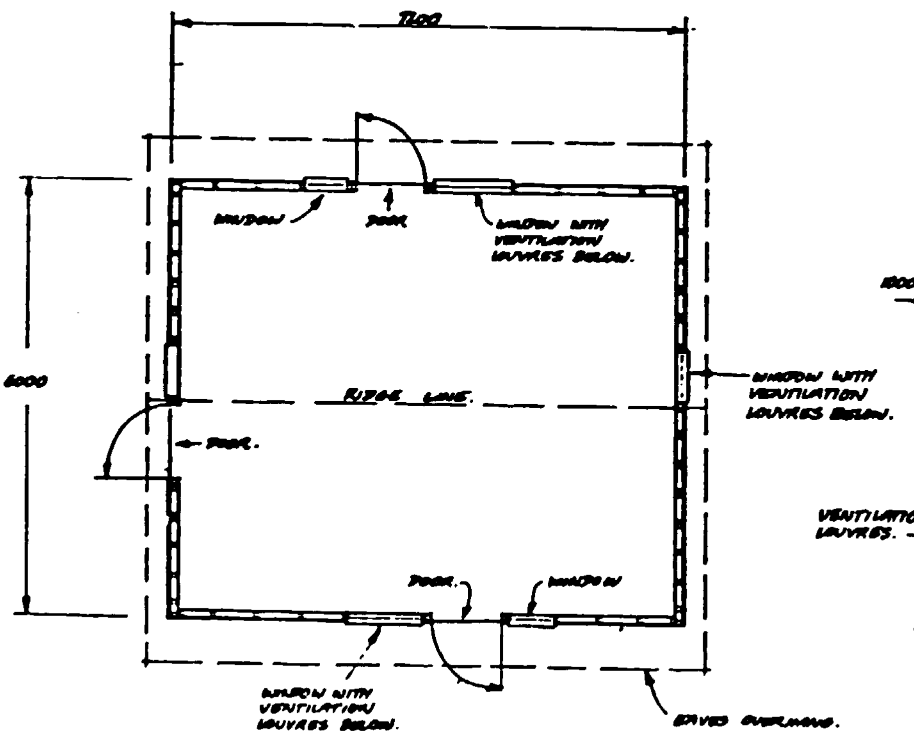
EXCERPTS FROM CONSTRUCTION GUIDELINES FOR SINGLE ROOM DWELLING

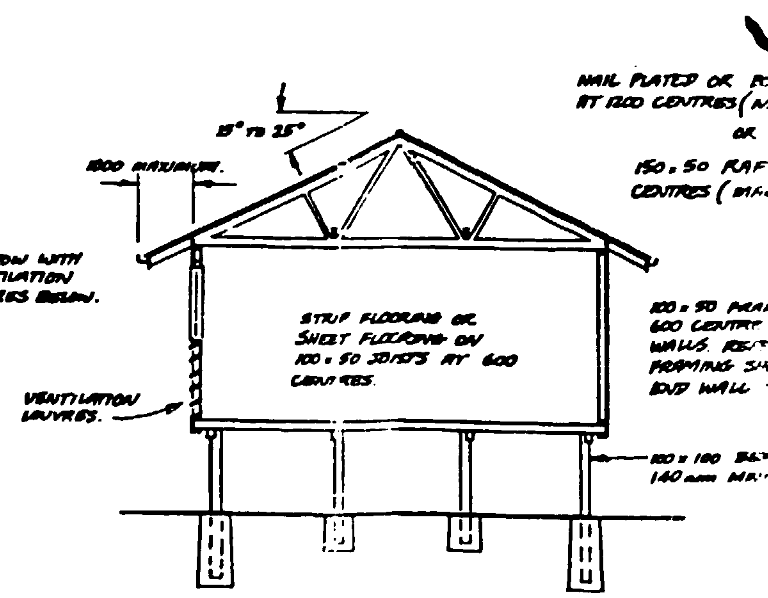




SIDE ELEVATION.

END EL

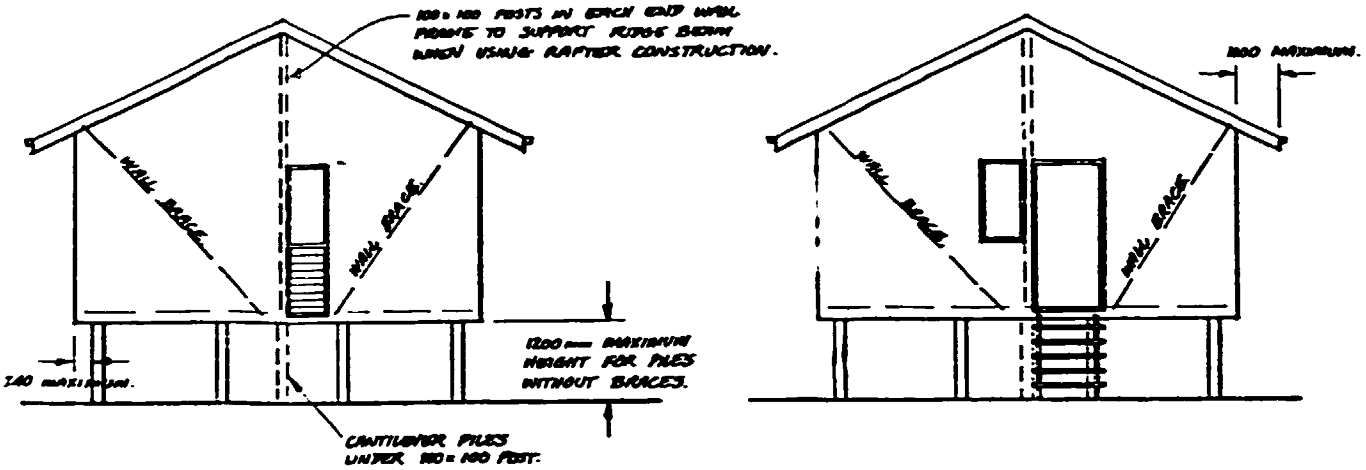




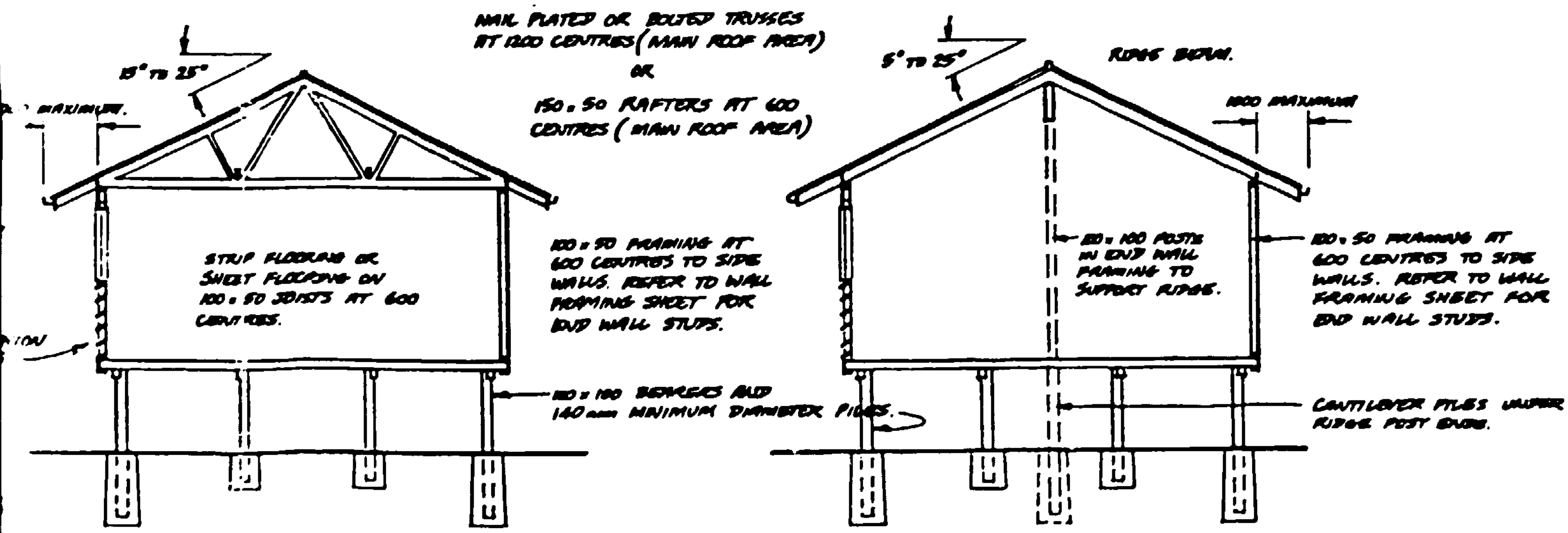
PLAN VIEW.

TYPICAL CR

SECTION 1



END ELEVATIONS.

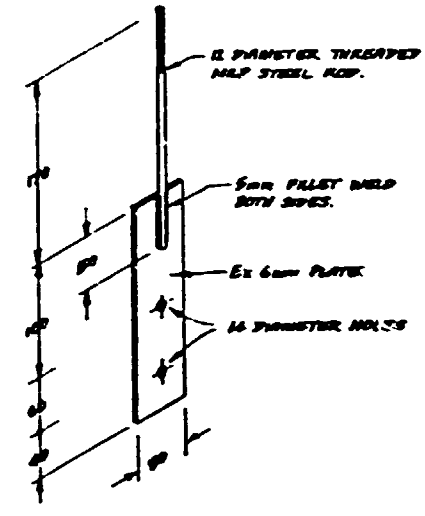


TYPICAL CROSS SECTIONS.

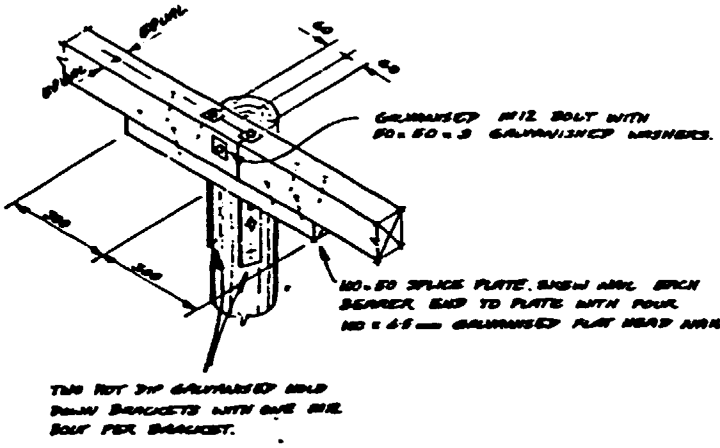
SECTION 2

CONSTRUCTION GUIDELINE
FOR SINGLE ROOM DWELLING.

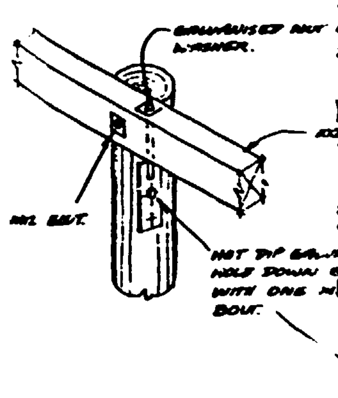
PAGE 1 : THE 7.2m x 6.0m SMALL BUILDING.



DETAILS OF SUB-FLOOR HOLD DOWN BRACKET. HOT DIP GALVANISE AFTER FABRICATION.

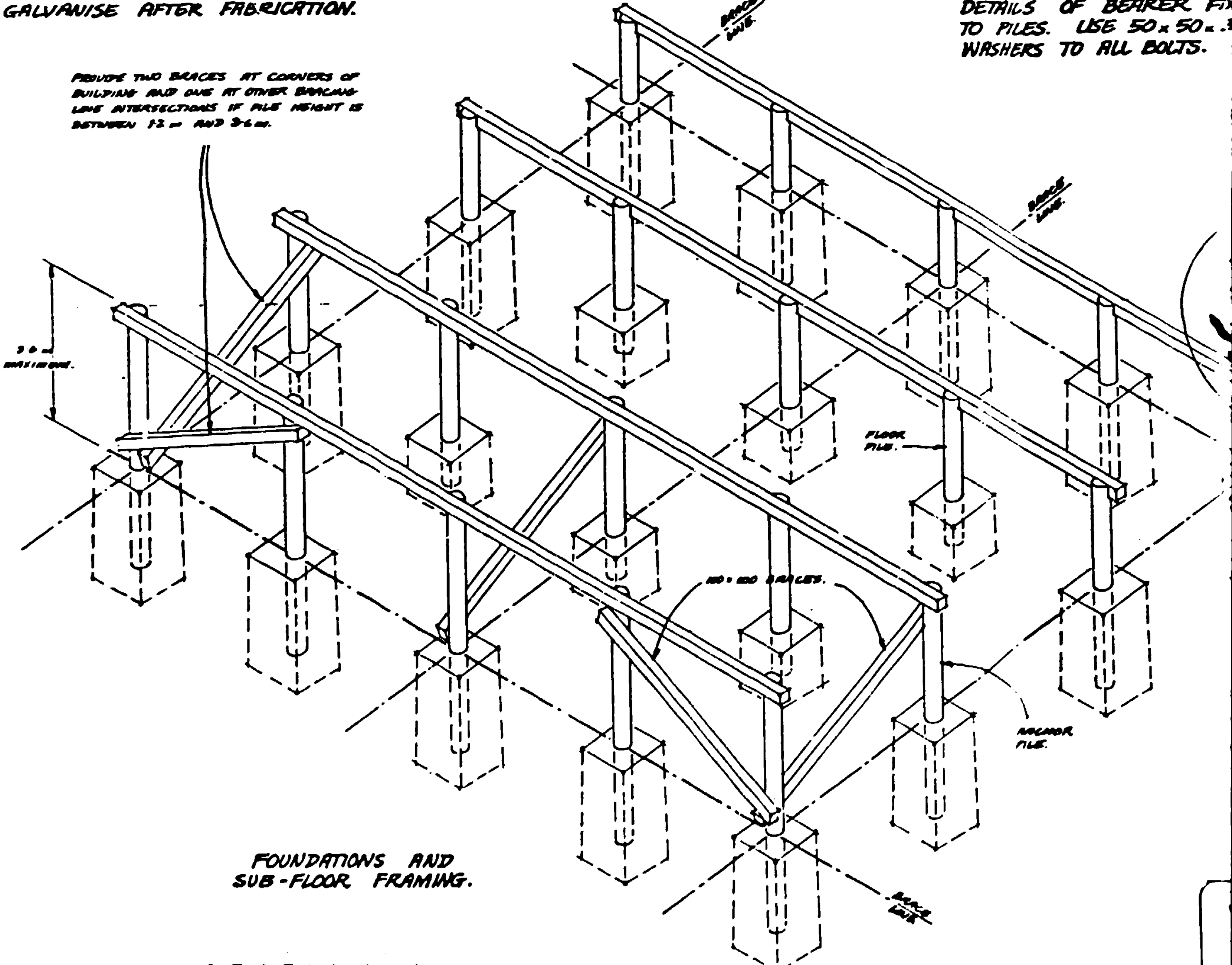


BEARER SPLICE DETAILS.



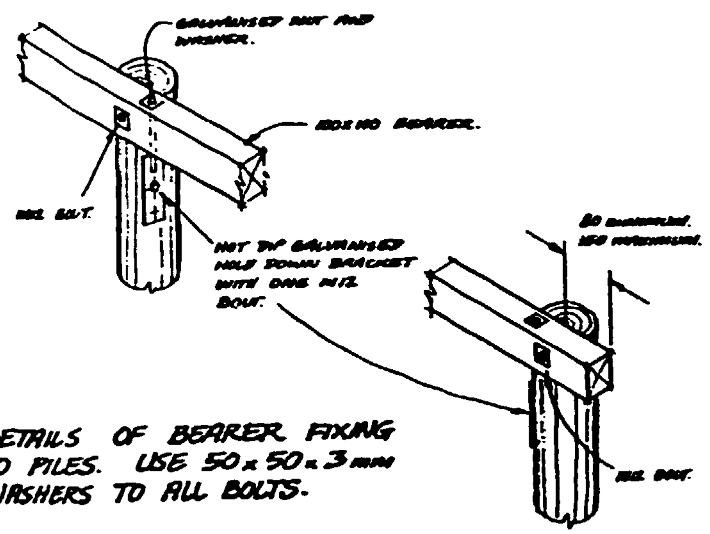
DETAILS OF BEARER FI
TO PILES. USE 50 x 50 x .
WASHERS TO ALL BOLTS.

PROVIDE TWO BRACES AT CORNERS OF BUILDING AND ONE AT OTHER BRACING LINE INTERSECTIONS IF PILE HEIGHT IS BETWEEN 1.2 m AND 3.6 m.

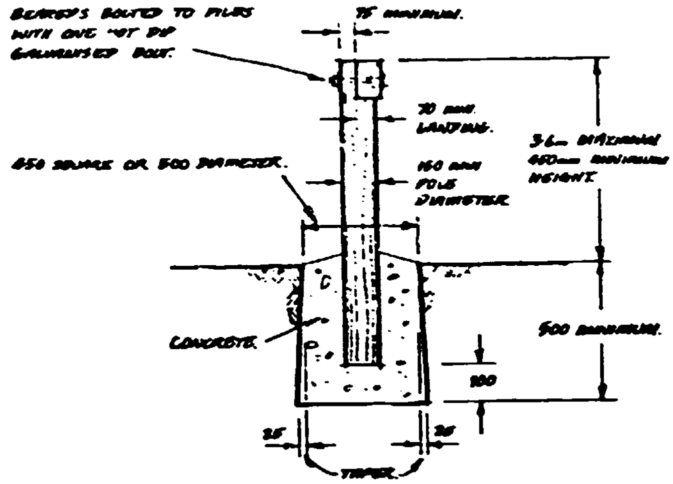


FOUNDATIONS AND SUB-FLOOR FRAMING.

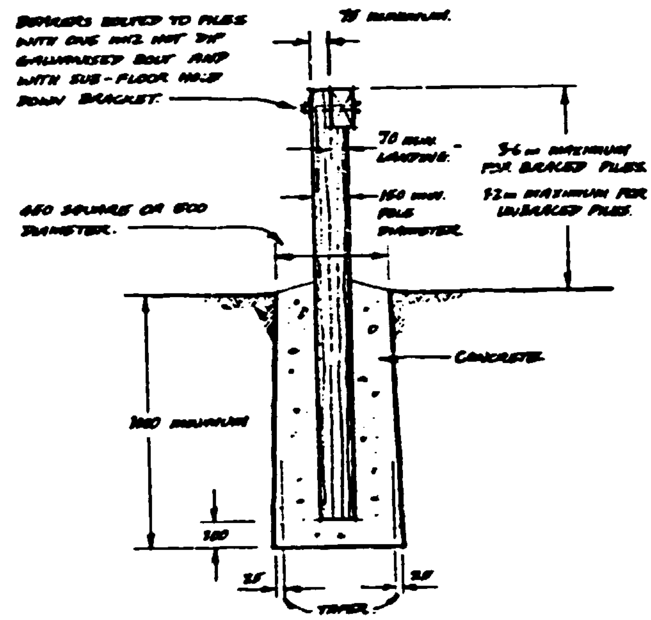
SECTION 1



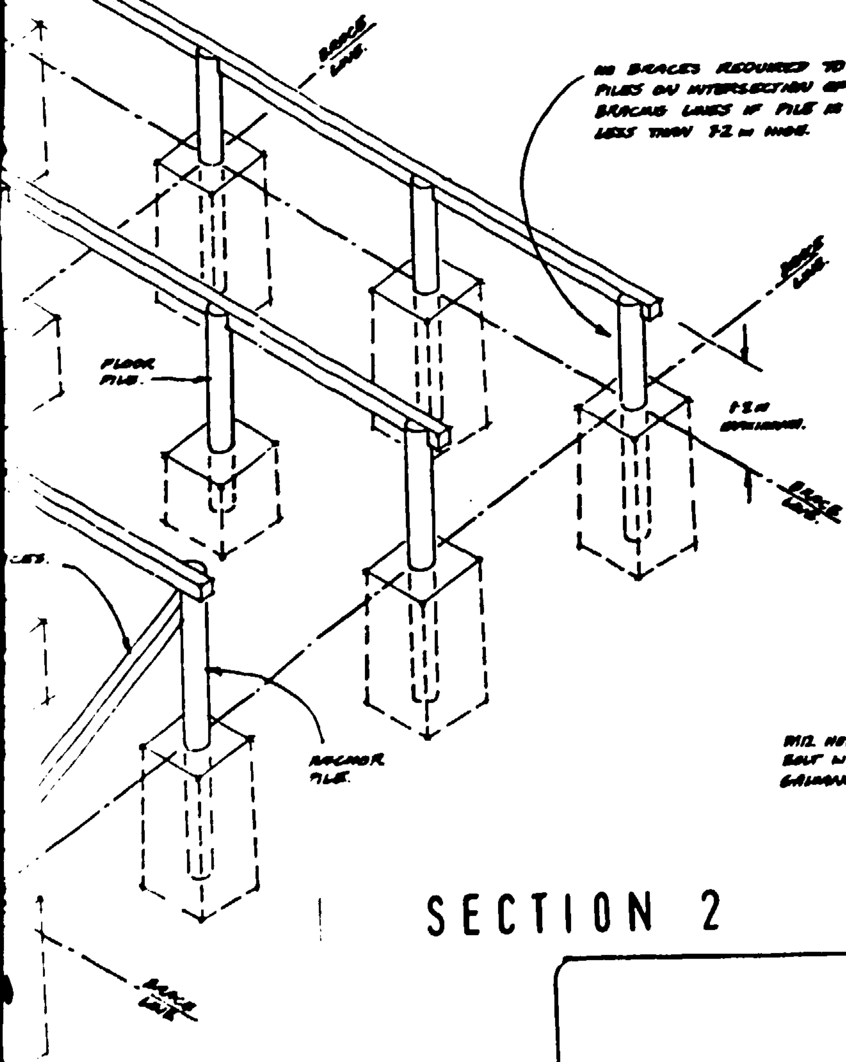
DETAILS OF BEARER FIXING TO PILES. USE 50 x 50 x 3 mm WASHERS TO ALL BOLTS.

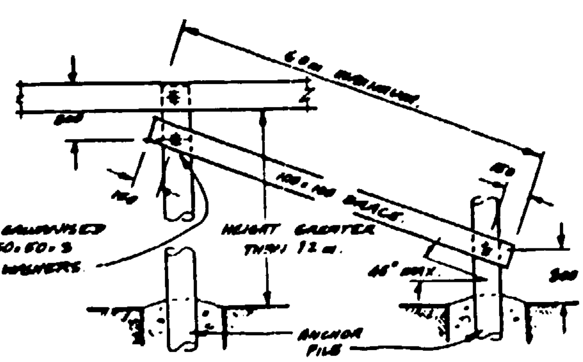


FLOOR PILES TO SUPPORT FLOOR ONLY.



ANCHOR PILES TO SUPPORT ALL LOADBEARING WALLS AND ATTACHED ROOF STRUCTURES.



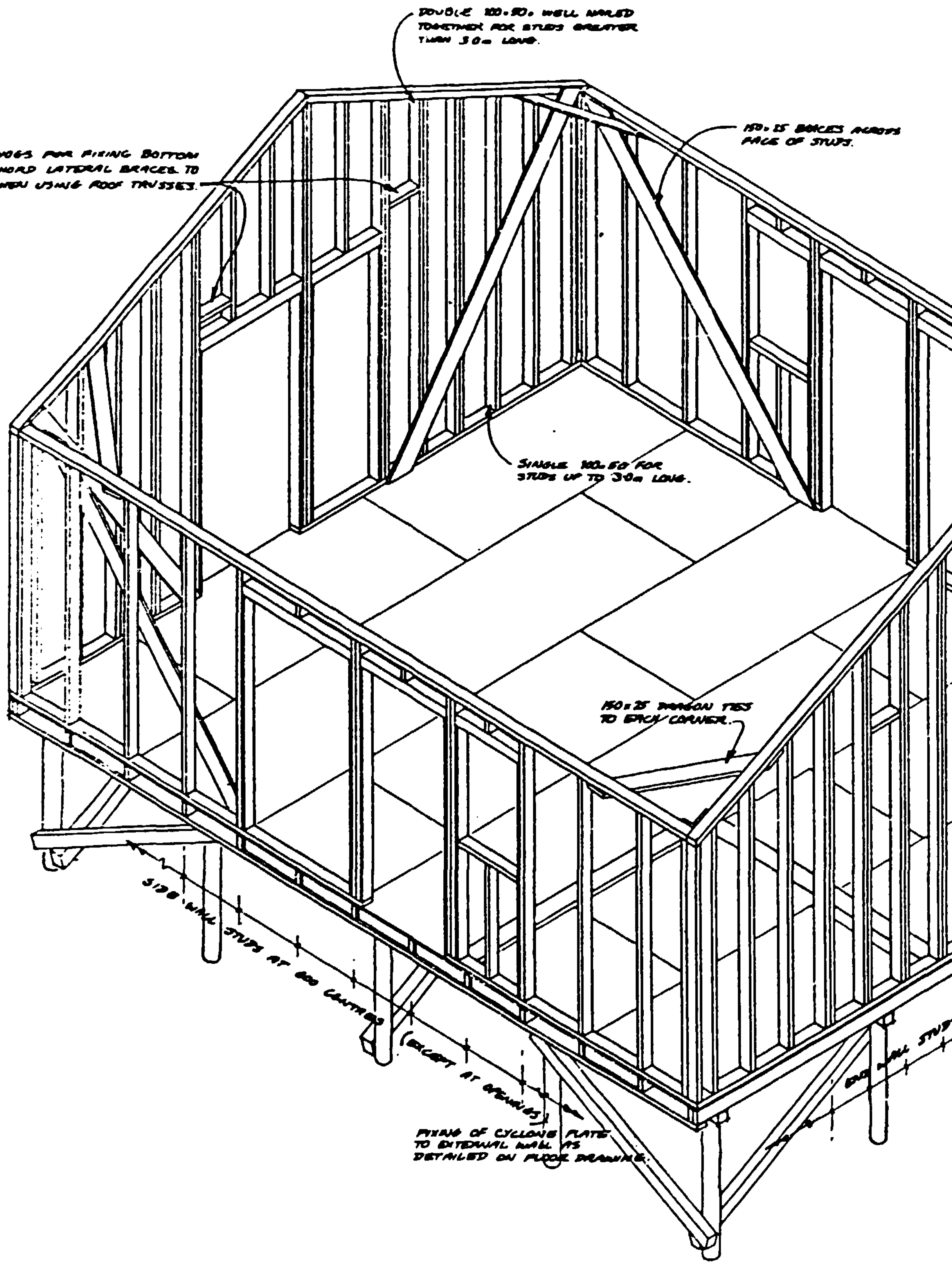


SECTION 2

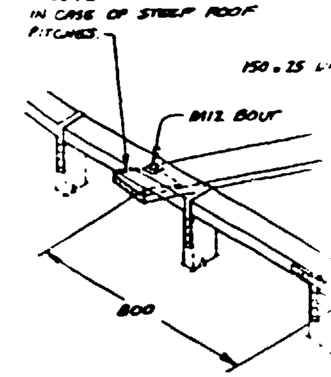
BRACES TO SUB-FLOOR STRUCTURE.

CONSTRUCTION GUIDELINE FOR SINGLE ROOM DWELLING.

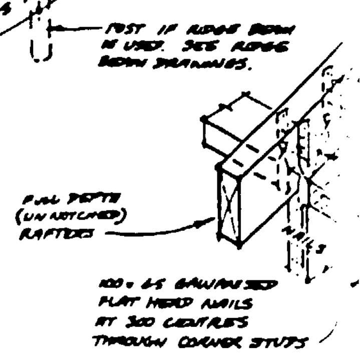
PAGE 2 : FOUNDATIONS AND SUB-FLOOR FRAMING.



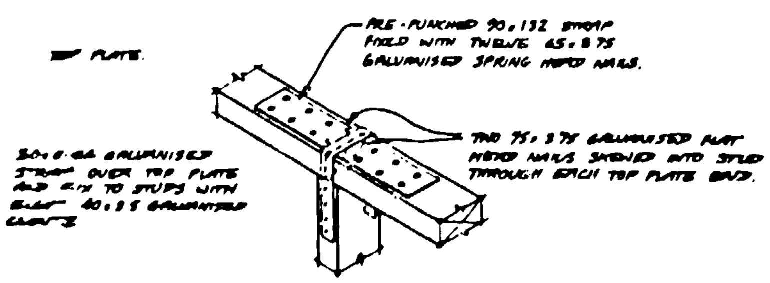
WALL FRAMING.



DETAIL OF
CONNE

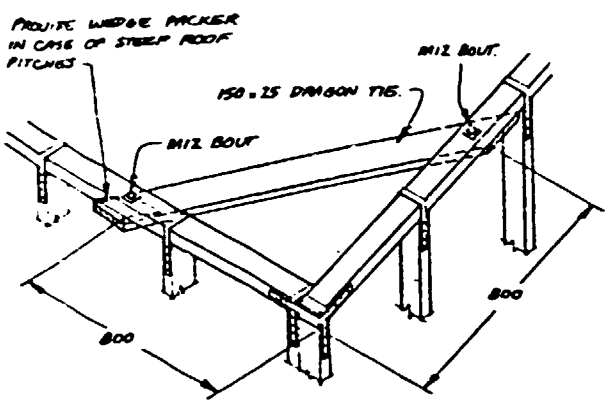


FIXING OF GABLE
WALLS AT TOP

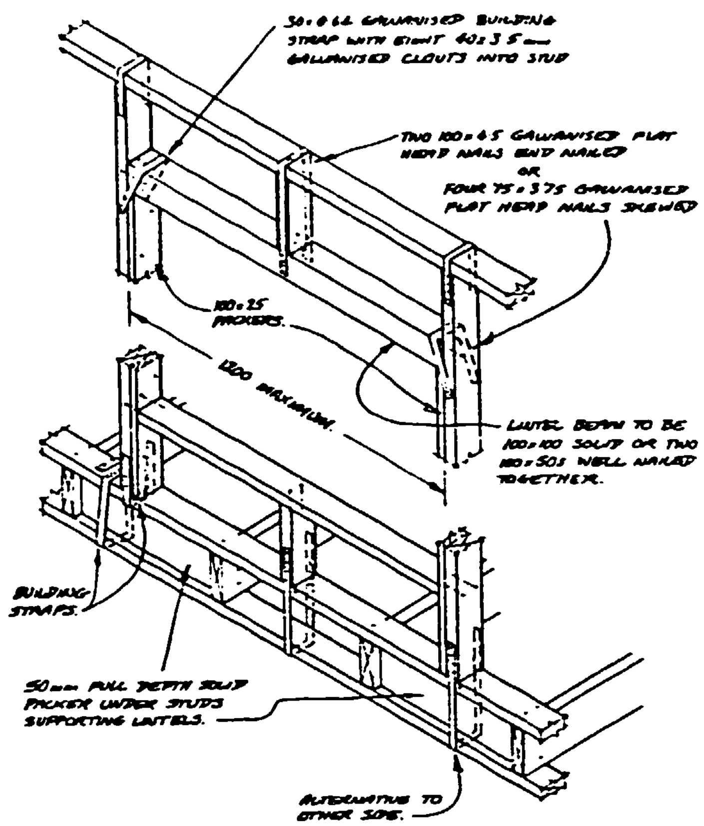


JOINTS IN TOP PLATES.

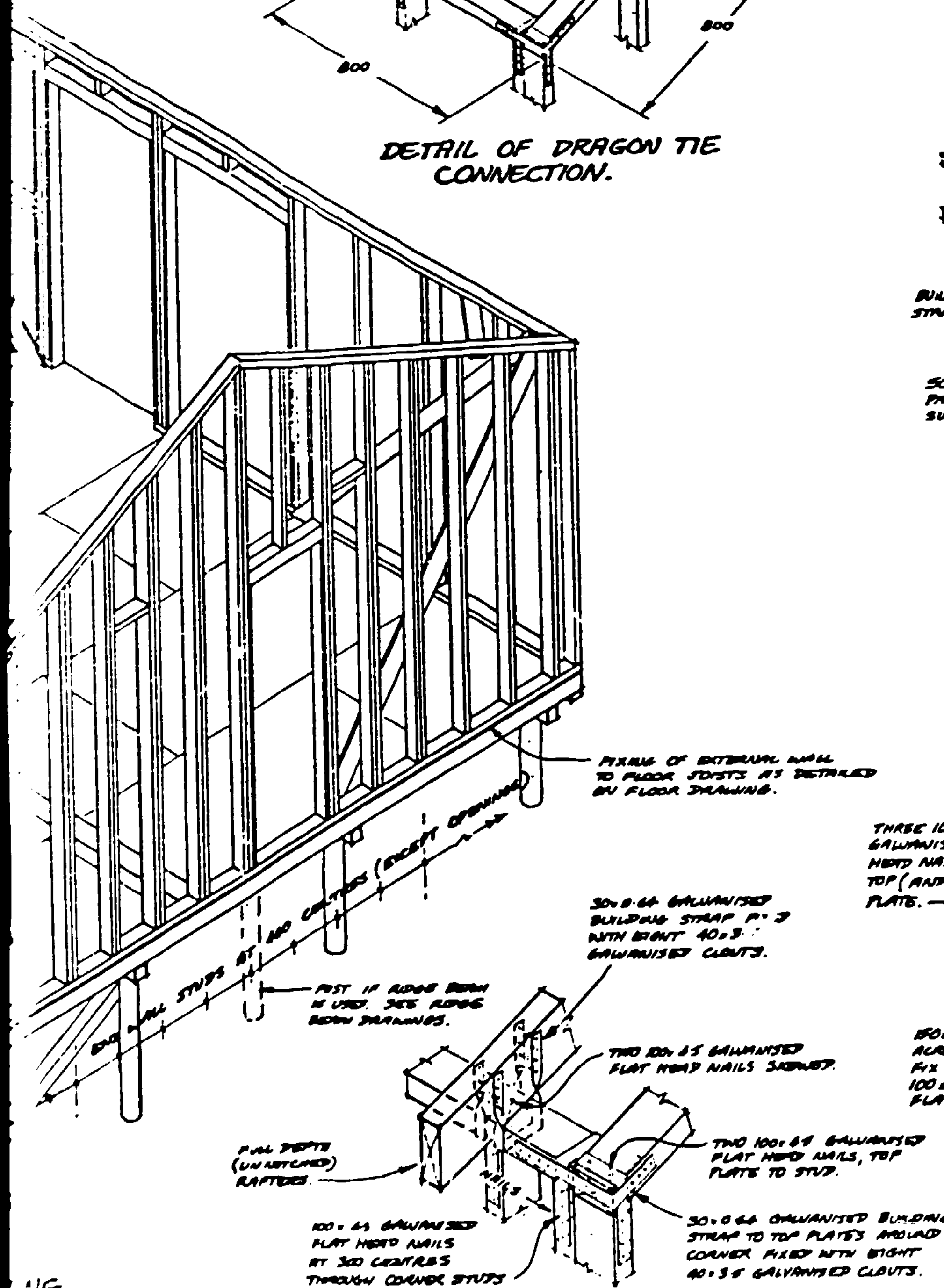
SECTION 1



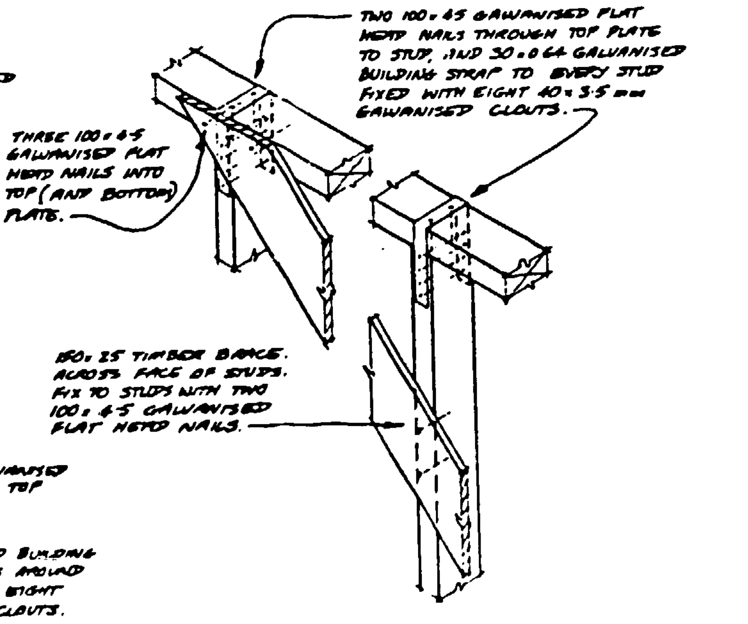
DETAIL OF DRAGON TIE CONNECTION.



LINTELS.



FIXING OF GABLE END WALLS TO SIDE WALLS AT TOP PLATE LEVEL.



WALL BRACES.

SECTION 2

CONSTRUCTION GUIDELINE FOR SINGLE ROOM DWELLING.

PAGE 4 WALL FRAMING.