THE USE OF ENCASEP TIMEBER BEAMS AS

ALTERNATIVE TO REINFORCED CONCRETE BEAMS.

BY

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DEPATMENF OF CIVIL ENGINEERING, FACULTY OF ENGINEERING, AHMADU BELLO UNIVERSITY, ZARIA, NIGERIA.

JUNE, 1997

DECLARATION

I hereby declare that this dissertation has been prepared by myself and it is a record of my research work. It has not been accepted in any previous application for a higher degree. All sources of information are specifically acknowledged by means of references.

GBENGA A. OJO

DEDICATION

I dedicate this project to all the members of my family, and also to the knowledge of God, his mercies and love for mankind.

CERTIFICATION

This Thesis entitled "The use of Encased timber beams as alternative to Reinforced Concrete beams " by Ojo, G.A. Meets the regulations governing the award of the degree of Master of Science (Structural Engineering) of Ahmadu Bello University, Zaria and is approved for its contribution to knowledge and literary presentation.

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Ojo Gbenga A.

ABSTRACT

The project investigates the possibility of adopting a composite beam consisting of concrete and timber, and consequently comparing the structural performance and the economical implications of this beam to a normal reinforced concrete beam.

The idea to do this is borne out of the need to discover alternative(s) to reinforced concrete beams which are otherwise expensive and therefore unaffordable to the majority of our people.

To achieve these objectives, two beams are designed (one as reinforced concrete and the other as timber encased in concrete) to satisfy the same conditions of loading and serviceability requirements, the prototype beams so obtained are modelled down mathematically to smaller and manageable sizes, which are tested in flexure till failure while observing and recording their respective deflections, strains, crack developments, mode of failure and failure loads.

The cost comparative analysis is a very important aspect of this research, this is based on the actual (prototype) beams. It includes the production as well as materials cost of each beam. Finally, the experimental data obtained are analysed and the following conclusions made.

i) That there was a 10% decrease in the production cost of the encased timber beam.

ii) There is also a 40% increase in collapse load for the encased timber beam over that for the reinforced concrete beam.

iii) The reinforced concrete beam being more rigid deflected far less in comparison with encased timber beam.

iv) The encased timber is viable for spans not exceeding 6m. Beyond this the encased timber beam ceases to be economical as the timber section required to satisfy the deflection clause would be too large.

v) The slope of the load-deflection graph of the plain timber beam tested (timber without concrete encasement) showed a greater deflection per load compared to the encased timber beam, indicating that a composite action does occur and that the concrete contributes to the stiffness of the encased timber beam.

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NOTATIONS

E.T = Encased Timber beam

R.C = Reinforced Concrete beam

d = depth of beam

g_k = dead load

q_k = Imposed load

W = design load

M = moment

f_m = characteristic strength of concrete

Z = lever area

A_s = Area of reinforcement

v = shear stress

V = applied shear force

L = lenght of beam

v_c = design shear stress

A_{sv} = Area of shear reinforcement

S_v = Spacing of links

Z_l = section modulus

l_q = shear per unit length of beam

f_{bapar} = stress in bending applied parallel

$\triangle$ = defection

E = Youngs modulus

A_c = Area of concrete

A_t = Area of timber

λ = Scale factor

l_m = Length of model

l_p = Length of prototype

CHAPTER 1

INTRODUCTION

1.1.0 ENCASED TIMBER

Encased timber refers to a composite structural member consisting mainly of concrete and timber, with the concrete enclosing the timber section. It is similar to enclosed steel sections, in that a composite action develops between the two materials. In steel concrete composite for instance, the steel is the structural member while the concrete encasement might also contribute in this aspect, its primary function is to satisfy the serviceability requirements such as fire and corrosion protection. Thus the two materials are mutually beneficial to each other during service.

The encased timber beam proposed in this research will be such that the timber is the designed load bearing structural member while the concrete encasement contributes to the beam's stiffness thus, reducing it's deflection under load. Most importantly the concrete provides a protective covering for the beam particularly against fire. The combination of these two materials (timber and concrete) thus results in a higher order of structural effectiveness.

There is one scepticism about the combination of timber and concrete as a composite member. One of the reasons advance is that the two materials lack the natural ability to bond together, hence composite action cannot be possible between the two. The bond between timber and concrete has been investigated (Adeyemi, 1990) and found to be substantial and adequate for structural purposes.

Furthermore, early mud houses built by reinforcing mud with timber to form elements such as slabs, and walls which have proven to be very durable. Consequently one wonders why concrete which is of higher strength and durability cannot be made to achieve same with timber.

Examples of modern day structures which are based on timber - concrete composites are:-

a) The construction of bridge decks using "timber - concrete composite slabs". In this system, timber planks are set on edge to produce the form for a reinforced concrete slab as well as acting compositely with the reinforced concrete slab .

b) Tee - beam construction, where timber stringer stems are attached to concrete slab flanges.

c) Encased timber columns have been researched and found to be satisfactory both structurally and economically (Adeyemi, 1990).

1.2.0 ENCASED TIMBER BEAM COMPONENT

As stated above, the main components of encased timber beams are concrete and timber. Nominal steel reinforcement is included for construction purposes only i.e. to hold the concrete casing together preventing spalling due to vibration and impact loading. A description of the two materials are discussed below.

1.2.1 TIMBER

Timber is one of the first construction materials known to man, and of all the materials used for construction, timber is unique by virtue of it being entirely natural. Timber as a material can be defined as a low density, cellular polymeric composite and as such does not fall conveniently into any particular class of material rather tending to overlap a number of classes (Desch, H. E 1977).

With the advent of new construction materials such as high grade steel, aluminium and plastics, it was thought that by the middle of the twentieth century, timber would have been completely replaced by these high strength materials but instead there has been a renewed use of timber in diverse forms. The use of timber is usually related to economical considerations and aesthetics, and is usually employed structurally in two forms.

i) Timber forming the entire structure i.e. the supporting structure as well as the suspended slab and the roof structure.

ii) Timber is used as a structural component or element of the entire structure e.g timber roof or suspended slab on a concrete or steel structure. An overwhelming percentage of building structure in this country falls into this category (i.e. concrete and block work structure with timber roof members). In countries like the United States and Canada, timber is used more than any other structural materials for the construction of buildings (Breyer D.E, 1980)

The following are the advantages of using timber as a construction material.

1. The Simplicity of working timber by hand or machine .
2. Tooling costs are low compared to concrete and steel.
3. Excellent thermal insulation and fire resistant properties.
4. Reasonable savings in cost compared to steel or concrete section of equivalent structural ability.
5. The aesthetic potential of finished timber.
6. The ability of timber to withstand large overloads of short duration without failure.
7. When properly treated timber can be very durable.

1.2.2 FACTORS AFFECTING THE USE OF TIMBER

The strength properties of timber apart from varying with the timber species also varies with certain conditions, hence the strength of timber cannot be accurately determined as in the case of other materials.

i) Direction of grain: The strength properties of timber varies with the direction of the direction of grain. For example timber is weak in tension perpendicular to grain but very strong in tension parallel to grain. Slopping grain which is a condition arising from careless conversion resulting in grain having a district angle to the surface of the piece of wood results in the significant loss in strength of timber. Desch (1977) found that there is reduction of about 4 percent in strength when the slope of the grain is 1 : 25 and with a slope of 1 : 20 the reduction was 7 percent.

ii) Moisture content: The presence of moisture has a great influence on the properties of timber. It is said that at moisture content below 20 percent most timber species will not decay. Generally the strength properties of wood tend to increase with decreasing moisture content. However, moisture contents in excess of the fibre saturation point (F. S. P) have no influence on the strength of timber (Breyer D. E. 1980).

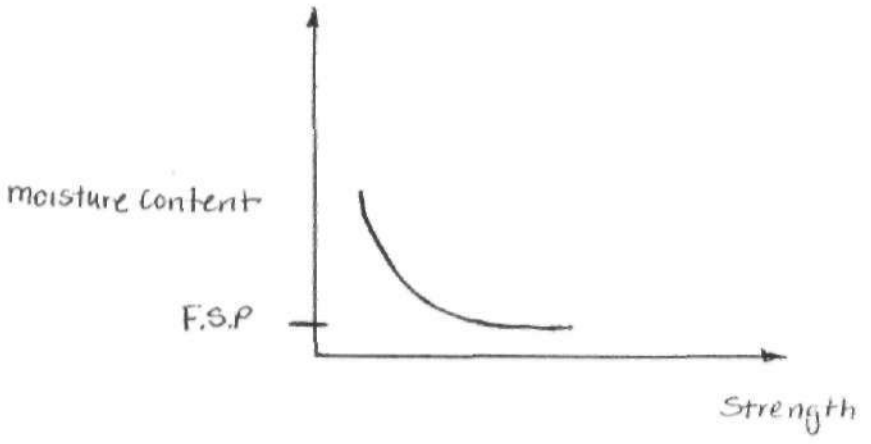


Fig 1.1 Timber strength - moisture content relationship

In using timber as beams creep is attached by moisture. The drier the member the less one creep effect. It is therefore important that moisture is reduced to the bearest minimum. The process of reducing the moisture content in timber is termed seasoning.

iii) Defects: the presence of defects in timber reduces its structural abilities. Defects may be natural e.g. knots, wane and resin pockets. They may also result from conversion and seasoning e.g. warping, splits and checks.

Knots are significant when they occur in positions of high tensile stresses, such as the bottom parts of beams, but are less significant for compression members such as columns. Warping is bending resulting from differential

drying during seasoning. It reduces the strength of timber as well as rendering it unsuitable for structural applications, because of its twisted nature. Splits and checks are rupture of timber tissues. They greatly reduce the shear resistance of structural timbers.

1.2.3 CONCRETE

Concrete is produced by mixing proportions of cement, coarse and fine aggregates with water. The cement is the compound with the adhesive and cohesive properties making it capable of binding the concrete constituents together. Admixtures may be added to the mixture to enhance certain desired characteristics such as acceleration, retardation and plasticisation of concrete. Concrete is most conditions will not corrode or decay, it is also not susceptible to attack by vermin, ferrites and rodents. It is made up of materials that will not burn and can therefore withstand prolonged heat and fire. It is also the only structural material that is in a plastic and mouldable state.

The strength and the durability of concrete is marred by the presence of voids and capillaries in the hardened concrete. This is brought about by incomplete compaction and excessive water cement ratio mix. Concrete has high strength in compression but is weak in tension, this explains the reason why concrete lends itself easily to composite action with other structural materials with high tensile strength.

1.3.0 PROBLEM STATEMENT

Reinforced concrete elements have been in use in the construction industry for a considerable number of years and has consequently undergone substantial positive developments resulting from research work into it's best possible use. The fact that it has survived and shall continue into the distant future is a testimony of it's outstanding performance with respect to other materials of construction.

The question therefore is, "why encased timber beams, when it obviously cannot be expected to compete with reinforced concrete beams in structural ability"?. The reason for this is not far fetched, - there is the need for reduction in the cost of construction of buildings in general and the production cost of reinforced concrete elements in particular.

In Nigeria today, the cost of production of reinforced concrete elements is high and of the reach of the majority of our people. The problem is therefore finding a solution, which inevitably means finding means of reducing the quantity of cement and steel by the injection of locally available and cheaper materials of construction.

By the consideration of encased timber beam it is hoped that the introduction of the structural hardwood timber into concrete beam would achieve the following:-

a) The timber is expected to replace an equivalent volume of concrete thereby replacing concrete by a cheaper material.

b) The structural attribute of the timber would necessitate a reduction or outright replacement of the quantity of steel reinforcement necessary for structural safety.

1.4.0 THE RESEARCH OBJECTIVE

The aim of this research is to investigate the possibility of using encased timber beams as a suitable alternative to normal reinforced concrete beams. In doing this two objectives would have to be achieved.

a) The encased timber beam designed to satisfy the same conditions of ultimate and serviceability limit states as the reinforced concrete beam, when tested would perform as satisfactorily.

b) The encased timber beam in question will have a total cost of production less than that of the reinforced concrete beam.

1.5.0 THE SCOPE OF WORK

The study will be centred on three major areas:

i) The theoretical design and modelling of beams.

ii) The practical tests and analysis of results.

iii) The cost comparison analysis between reinforced concrete and encased timber beam.

1.5.1 THEORETICAL DESIGN AND MODELLING

This will be done in order to achieve a basis for comparing the reinforced concrete and encased timber beams, designed for the same conditions of ultimate and serviceability limit states.

Only residential buildings will be considered because they are characterised by relatively smaller loads and shorter spans, the beam widths are restricted to 230mm which is the width of sandcrete blocks. Having completed the design, the prototype beams so obtained are modelled down to smaller and more manageable sizes.

1.5.2 PRACTICAL TESTS AND RESULT ANALYSIS

The main test involves loading the beams flexurally unto failure, while recording deflection and horizontal strain across the beam for every load increment. The load is read by means of a load cell placed under the loading jack, while deflection is read from dial gauges placed at the two loading points and at the beam centre. The strain along the beam length is measured by a special device consisting of a dial gauge called DEMEC. This DEMEC enables the determination of the position of the beam's neutral axis and its consequent moments during loading.

A control specimen will also be tested as above, this is the timber beam without the enclosing concrete. This enables us determine if at all or by what extent the concrete encasement contributes to the structural attributes of the encased timber beam.

Cube crushing tests are also conducted to determine the compressive strength of the concrete used in the beams.

1.5.3 COST ANALYSIS

The cost analysis is based on the production (material and labour) cost of the two beams obtained from the structural design. A cost comparison analysis can then be made between the two beam types. See Appendix II.

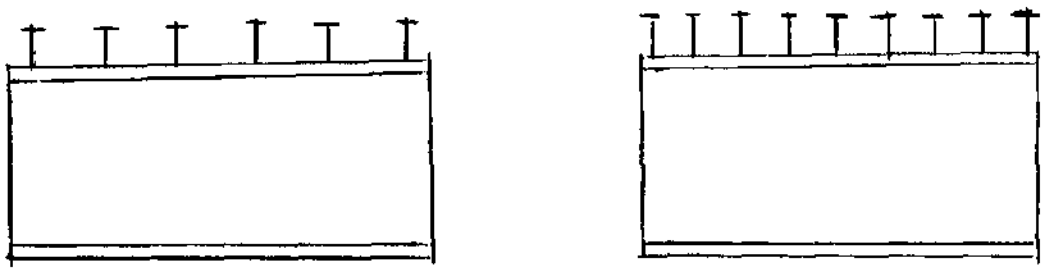
CHAPTER 2

LITERATURE REVIEW

2.1.0 CONCRETE FLEXURAL COMPOSITES

Composite action may be described as the interaction of different structural elements and may be developed using either different or similar structural materials (Sabris G. M, 1979). It involves utilising the most desirable attributes of several materials to their best advantage so that the combination may result in a higher order of structural efficiency and cost effectiveness (Cook G. P, 1977). Composites include steel - concrete beams and columns whether fully or partially encased or even held together by means of suitable connectors. Other examples are wood - concrete beams; layered wood system; sandwich beam construction etc.

Generally, composites can be devided into partial and complete composites (Cook G. P, 1977). In partial composites some degree of slip is anticipated between the materials while in complete composites, very little or no slip is anticipated between the two materials and are both expected to act in unison in resisting the induced stresses. An example of partial composite can be found in encased steel sections, where the steel is the structural member while the concrete encasement is intended for fire protection and possible for aesthetic purposes. A good example of complete composite is the 'T'- beam configuration between a reinforces concrete slab and a universal beam steel section. In this arrangement the concrete slab forms the flange while the steel section forms the web. Partial and complete composites are often indicated in the actual structure by the number and spacing of the shear connectors as show below for a 'I' section to be casted into concrete.



Partial composite Complete composite

Fig 2.1 Partial and complete composites

2.1.1 STEEL - CONCRETE COMPOSITES

The report by an ASCE (1974) subcommittee discussed many types of steel - concrete composites. They include: encased steel columns and frames; concrete filled steel tubes; concrete slabs with permanent steel formwork; ferrocements with steel plates at top and bottom with or without shear connectors etc. Generally in steel concrete composites the steel is introduced primarily to resist tensile stresses induced in the member while the concrete resists compressive stresses.

2.1.2 TIMBER - CONCRETE COMPOSITES

There is the misconception that no substantial bond exists between concrete and timber hence no composite action can occur between them. This is not necessarily true, as the degree of bond between concrete and any other material depends not only on the affinity for natural adhesion between the two but also on the surface condition of the material to be bonded with concrete. In this respect the bond between concrete and steel bars is further enhanced by using steel bars with deformed surfaces. Furthermore, when concrete is cast around a non-compressible material, the concrete contracts as hydration takes places, thus clamping the material and thereby improving the bond between the two. The use of shear connectors can also be employed to enhance bond between concrete and other materials.

Timber and concrete actually do posses some degree of naturally adhesion as shown by pull-out tests conducted by (Adeyemi, 1990) for plain mahogany timbers of various sizes. This resulted in an average bond strength value of 1-95N/mm^2 for a concrete characteristic strength of 22.5N/mm^2. Results indicated that greater bond strength is achievable with higher concrete strength.

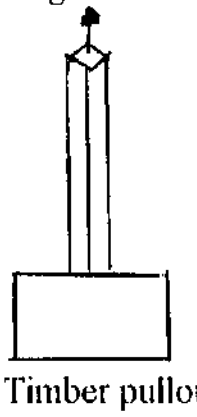


Fig 2.2 Timber pullout test

Furthermore, timber and concrete work well together as each has a great deal to contribute to the union. Timber has an inherent flexibility and the capability to absorb large overloads of short duration without failure, therefore most codes do not require the use of impact loads when designing timber members. Concrete on the other hand has good compressive strength and wearing characteristics and together they have elastic modulus values of the same order of magnitude (Cook G. P,1977). Another factor in their favour is their creep characteristics. In steel concrete composites, creep will cause a shift in the neutral axis and consequently in the stress distribution under long term loading. Whereas timber and concrete have creep and stress relaxation characteristics in the same order of magnitude, there is therefore very little change in the location of the neutral axis while the member is in service (Cook G. P, 1977).

Generally timber - concrete composites combine concrete and timber in such a way that the concrete is in compression and the wood in tension when stressed in flexure. For continuous spans in which negative bending moment exists over the supports, stresses are reversed. The wood acts in compression, and tension reinforcement is necessary in the concrete portion of the section. Temperature reinforcement is also placed in both transverse and lateral directions of the concrete portion. It is important that timber for this construction is well treated to guarantee a long service life.

2.1.3 AVAILABLE FORMS OF TIMBER - CONCRETE COMPOSITES

a) Composites 'T' beams: This consists of a timber beam (web) connected to a reinforced concrete slab (flange) by means of shear connectors. Where large sections of timber are required probably because of the large span, the laminated members may be used. It is important that well treated timber is used because of the exposure and constant contact with concrete. It is important therefore that the structure is designed in such a way that the neutral axis is very close to the junction of beam and slab, so that most of the timber remains in tension and the entire slab in compression.

b) Timber concrete composite slab: Timber - concrete composite slab consists of planks set on edge and spiked or dowelled together to receive a reinforced concrete slab. Once the timber deck is placed, it provides a platform for the workmen and also acts as bottom form for the concrete. There is economy as no formwork is required.

This type of structure lends itself well to a series of short span decks. It also provides a good looking bridge because of the slender thickness of the deck and the solid appearance seen from below. The reinforcing steel in the deck provides shrinkage and temperature reinforcement, and it also provides for the negative bending moments over the interior supports.

Many slab decks of composite timber - concrete composite have been built throughout North America. They are used for bridges, wharves, docks and buildings. Initial development and full scale test were made in 1933 by the service bureau of the American wood preserves institute and other similar institute. A good example is the Elkhorn bridge San Benito country California U. S. A. (Cook, 1977).

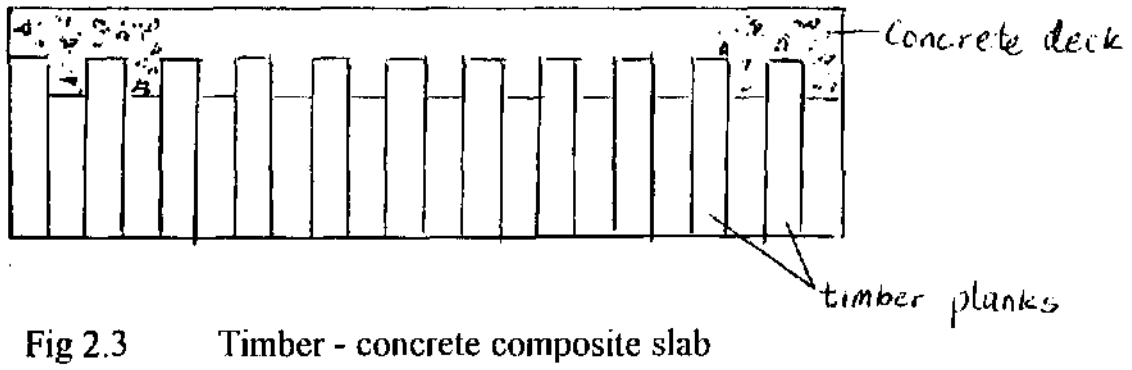


Fig 2.3 Timber - concrete composite slab

2.2.0 SHEAR CONNECTORS FOR TIMBER - CONCRETE COMPOSITES

The function of shear connectors is to enhance the bond between two separate members by preventing slip and enabling them to act as a unit. To accomplish this the shear connectors must do two things.

a) It must resist the horizontal force tending to shear the two members apart.

b) It should hold the two members together hence preventing uplifting of any of the members.

The composite action in timber structural systems depends to a large measure on the type of connection existing between the various components. Generally, the horizontal shear occurring at the junction between the components is used to design the shear connections at that point.

$$q = \frac{V A Y}{I}$$

where q = shear per unit length of the beam

V = Vertical shear force

A = Transformed area of the concrete above the interface

Y = Distance between the centre Area A and the neutral axis

I = Moment of inertia of the transformed composite section about the neutral axis.

The above equation indicates that for a beam subjected to uniformly distributed load, the spacing of shear connectors should be closer near the supports. Where shear is maximum .

In timber - concrete composites notching (fig 2.4) provides good shear connection between the two members as the beam projections prevents interlayer slip.

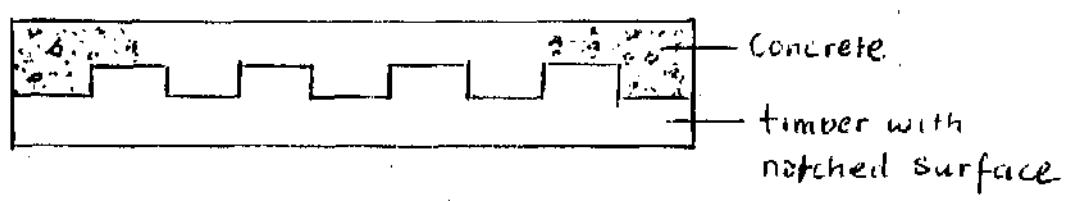


Fig 2.4 Notched timber beam surface

Notching however, reduces the effective depth of the timber section in question thereby causing a reduction in strength of the timber beam. Mechanical connectors may also be used as shear connectors, examples are shear developer plates, bolts, mails etc. as shown (fig 2.4).

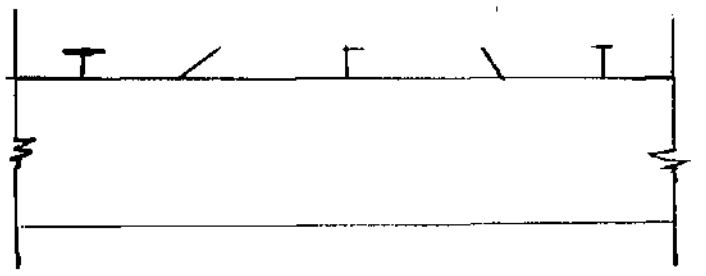


Fig 2.5 Mechanical shear Connectors

2.2.1 GLUED JOINTS AS ALTERNATIVE TO MECHANICAL SHEAR CONNECTORS.

When the joint between two members in a simple composite beam is subjected to horizontal shear, no slip between the members can be achieved by surfacing the sections and making the joint a glue joint thus obtaining full composite action (Ozelton and Baird, 1976).

Furthermore the position of NCP2 1973 is that the strength of a glued joint can be assumed to be equal to the full strength of the timber in both shearing parallel to grain and tension perpendicular to grain.

2.2.2 STEEL - TIMBER COMPOSITES

The low modulus of elasticity value for timber in comparison to other construction materials especially steel, implies that a large timber section in comparison to a

small steel section is required to sustain the same load. Secondly and particularly with beams in excess of 4m length, after satisfying the ultimate limit state requirements, the timber beam section still has to be increased substantially to satisfy the serviceability limit state of deflection. In situations such as these, it might be more economical to introduce some steel into the timber section.

The introduction of steel can be achieved in two ways. One is to attach using bolts flat steel sections to the timber beam. It is important that the steel will be of maximum benefit at the position of maximum tension. This method is shown below.

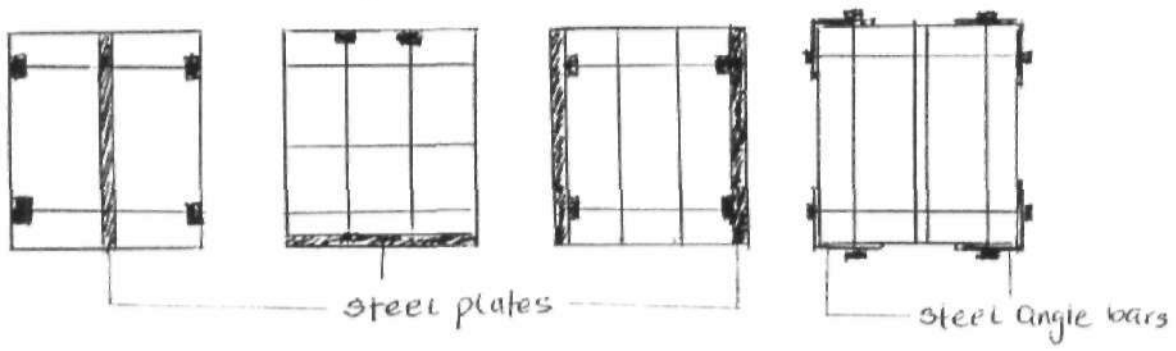


Fig 2.6 Steel - timber composites

The second system involves the use of the good adhesion of epoxy based potting compounds to timber and steel. Developed by V. Schniko at the Novosibirsk Civil engineering institute. (G Karslen and Yu Sliskonhov, 1989). This method entails making slots in the timber beam with the aid of a milling machine to receive reinforcement bars. The slots may be semicircular or square in section and between 1 - 5mm large than the bar diameter. He recommended that the percentage reinforcement should not exceed 3 - 4% of the timber cross sectional area.

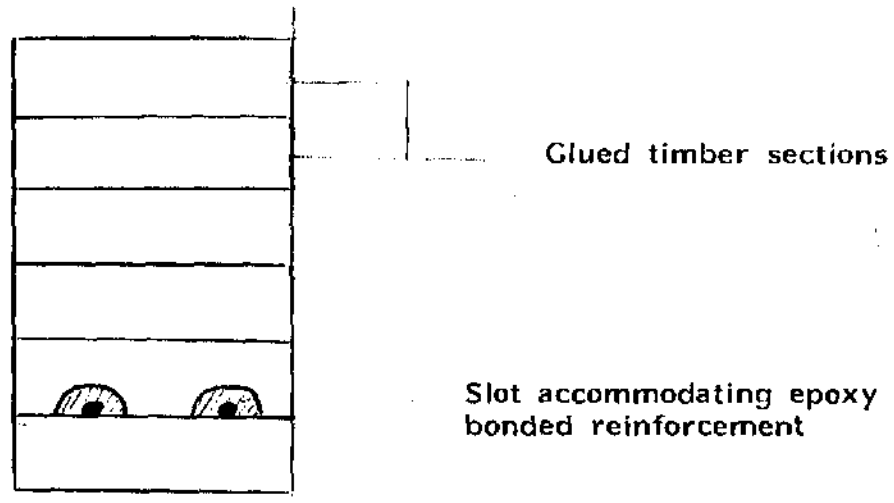


Fig 2.7 Steel Rod - timber composite beam.

CHAPTER 3

3.1.0 DESIGN OF REINFORCED CONCRETE BEAM

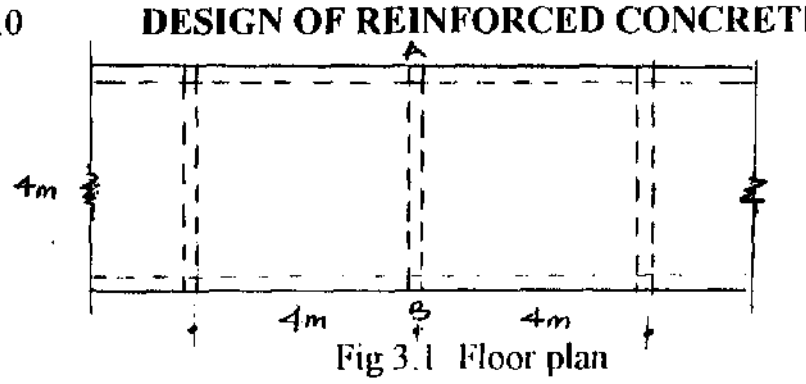


Fig 3.1 Floor plan

Consider beam A - B in the plan above.

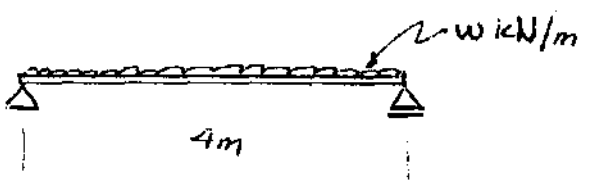


Fig 3.2 Loaded beam

CASE 1: A - B AS R. C BEAM

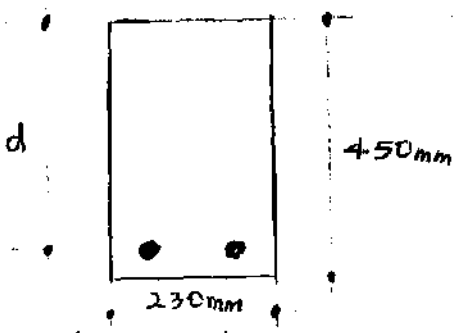


Fig 3.3 R.C beam section

d = 450 - (20 + 12 + 16/2)

d = 410mm

LOAD COMPUTATION

R.C slab wt $= 0.15 * 24 * 4 = 14.4$

Partitioning blockwall $= 0.55 * 4 = 2.2$

Self wt. of beam $= 0.23 * 0.45 * 24 = 2.5$

dead load $g_k = 19.1 KN/m$

imposed load, $q_k = 1.5 * 4 = 6 kN/m$

design load, $w = 1.4\ q_k + 1.6\ g_k = 36.34 KN/m$

MOMENTS

$$M = \frac{WL^2}{8} = \frac{36.34 * 4^2}{8} = 72.68\ KN/m$$

$$K = \frac{M}{bd^2 f_{cu}} \leq 0.156$$

BS 8110 for singly reinforced beam

$$K = \frac{72.68 * 10^6}{230 * 410^2 * 30} = 0.063 < 0.156$$

Therefore section O.K as singly reinforced beam

$$Z = d\left[0.5 + \sqrt{(0.25 - k/0.9)}\right] < 0.95d$$

$Z = 0.92d < 0.95d$

AREA OF STEEL REINFORCEMENT

$$As = \frac{M}{0.87 f_y Z} = \frac{72.68 * 10^6}{0.87 * 460 * 377.2}$$

$As = 540mm^2$ (use bott. 3Y16 $\underline{603mm^2}$)

PERCENTAGE OF REINFORCEMENT

$$\frac{100A_s}{bd} < 4\%$$

$$\frac{100 * 603}{230 * 410} = 0.64\% < 4\% \text{ O.K}$$

SHEAR REINFORCEMENT

$$v = \frac{V}{bd}$$

$$\text{but } V = \frac{WL}{2} = \frac{36.34 * 4}{2}$$

$V = 72.68$ KN

$$v = \frac{72.68 * 10^3}{230 * 410} = 0.77 \text{ N/mm}^2$$

$100\ A_s/bd = \frac{100 * 603}{230 * 410} = 0.64$

from tab 3.9 BS 8110 part 1

$v_c = 0.54\ N/mm^2$

$A_{sv} \geq \frac{0.4.b.S_v}{0.87 f_{yv}}$

but $S_v > 0.75d = 307.5mm$

take $S_v = 250mm$

$A_{sv} \geq \frac{0.4 * 230 * 250}{0.87 * 250}$

$A_{sv} \geq 105.75mm^2$

use 2 legs R12 mm rod [$113mm^2$] @ 250mm c/c

CHECK DEFLECTION

span/eff depth > 20 (simply supported beam)

therefore $\frac{4000}{410} = 9.75 < 20$

deflection O.K

3.2.0 CASE 2 ENCASED TIMBER BEAM

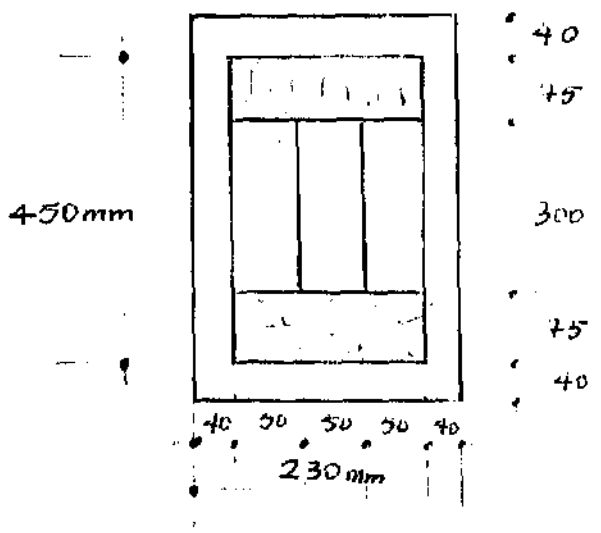


Fig 3.4 Encased timber beam section

LOADING:

Slab wt = 0.15 * 24 * 4 = 14.4 kN/m

partition = 0.55 * 4 = 2.2 kN/m

Beam self wt. = (timber wt + concrete wt.)

$$\text{timber wt} = 6.72\ \text{kN/m}^3 \left[\frac{150 * 450}{10^6} - \frac{50 * 300}{10^6} \right]$$

$$= 0.45\ \text{kN/m}$$

$$\text{Concrete wt} = 24\text{kN/m}^3 \left[\frac{230 * 530}{10^6} - \frac{150 * 450}{10^6} \right]$$

Dead load $g_k = [\ 14.4 + 2.2 + 0.45 + 1.30]$

$= 18.35$ kN/m

Imposed load, $q_k = 1.5 * 4 = 6$kN/m

design load, $w = 1.4\ g_k + 1.6q_k$

$= 1.4\ *\ 18.35 + 1.6\ *\ 6$

$= \underline{35.11\ \text{kN/m}}$

MOMENT:

$$M = \frac{WL^2}{8} = \frac{35.11 * 4^2}{8} = 70.22\ \text{kNm}$$

DESIGN FOR BENDING

$Z_1 = [150 * 450^2 - 50 * 300^2]\ 1/6$

$Z_1 = 4312500\text{mm}^3$

Stress in bending applied parallel, $f_{bapar} = \frac{M}{Z}$

$$= \frac{70.22 * 10^6}{4312500}$$

$= 16.28 < 18\text{N/mm}^2$

[bending stress O.K for Mahogany N3]

DESIGN FOR SHEAR

The maximum shearing stress parallel to grain occurs at the neutral axis

$$q = \frac{V.a.y}{I.b}$$

$$= \frac{[70.22 * 10^3 (75 * 150 * 187.5 + 2 * 50 * 150 * 75)]}{1026562500 * 100}$$

$$= 2.21 \text{ N/mm}^2 < 2.24 \text{ N/mm}^2$$

[Ok for mahogany N3]

CHECK FOR DEFLECTION

$$\Delta = \frac{5WL^4}{384\,E.I} + \frac{19.2M}{A.E}$$

The concrete casing section will be converted to an equivalent timber area. This is done since it is apparent that the encasement increases the rigidity of the beam and thus aid in resisting the induced deflection

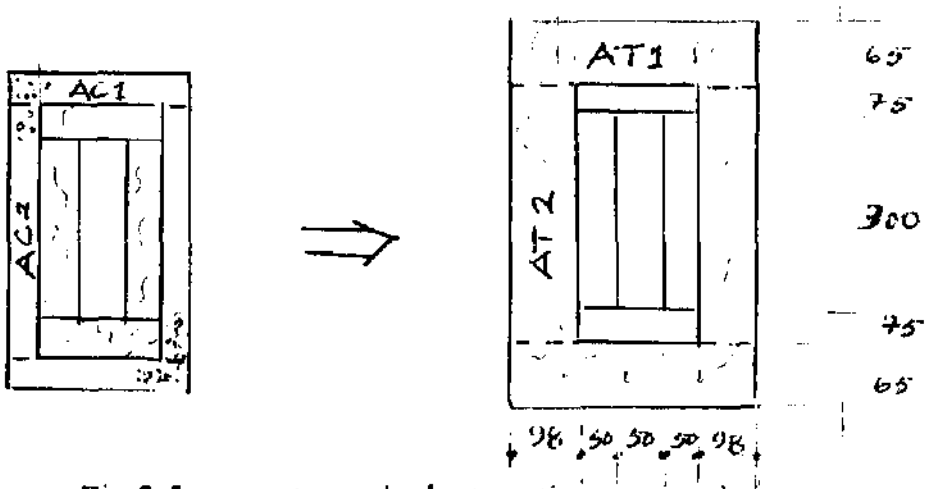


Fig 3.5 concrete equivalent section conversion

$$AT\ 1 = AC\ 1 * \frac{E_C}{E_T} = \frac{(40 * 230 * 26000)}{10600}$$

$$AT\ 1 = 22566mm^2$$

$$AT\ 2 = AC\ 2 * \frac{E_C}{E_T} = \frac{(450 * 40 * 26000)}{10600}$$

$$AT\ 2 = 44150.94mm^2$$

FOR THE CONVERTED SECTION

$$I = bh^{3}/_{12}$$

$$I = [346 * 580^{3}/_{12} - 50 * 300^{3}/_{12}]$$

$$I = 5513229333mm^4$$

$$\triangle = \frac{5WL^4}{384\ E.I} + \frac{19.2M}{A.E}$$

$$\triangle = \frac{5 * 35.11 * 4000^4}{384 * 10600 * 551322933} + \frac{19.2 * 70.22 * 10^6}{185680 + 10600}$$

$$\triangle = 2.0 + 0.69$$

$$\triangle = 2.69 < 0.0031 = 12mm$$

[deflection O.K]

DETERMINATION OF HORIZONTAL SHEAR TO DESIGN WEB AND FLANGE CONNECTION

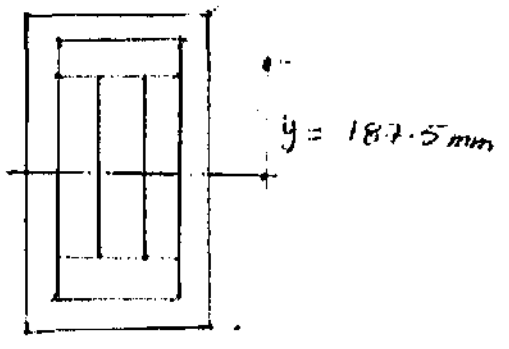


Fig 3.6 horizontal shear between web and flange

$$q = \frac{V.a.y}{I.b}$$

$$= \frac{70.22 * 10^3}{102562500 * 100}(75 * 150 * 187.5)$$

$$= 1.44\ N/mm^2 < 2.24\ N/mm^2$$

The strength of a glue joint is assumed to be equal to the shear strength of the timber. This is explained in detail in section 2.2.1

3.3.0 MODELLING

It has been found desirable for economic and other reasons to study the mechanical behaviour of the two beams by means of models. Modelling involves the

determination of the suitable scale laws relating the deflections and stresses in such a model to the prototype.

The scale factor, λ is derived from

$$\lambda \cdot L_p \cdot E_p = L_m \cdot E_m$$

$$\text{therefore, } \lambda = \frac{L_m \cdot E_m}{L_p \cdot E_p}$$

$$\text{and if } E_m = E_p$$

$$\text{then } \lambda = \frac{L_m}{L_p}$$

Where L_m and L_p represent any linear dimension on the model and prototype respectively. Similarly, other sectional properties of the model are derived from the relationships below.

$$A_m = \lambda^2 A_p$$

$$Z_m = \lambda^3 Z_p$$

$$I_m = \lambda^4 I_p$$

since $L_p = 4m$

let $L_m = 2m$

$$\lambda = \frac{L_m}{L_p} = 2/4 = 0.5$$

similarly, $h_m = 0.5 * 450 = 225mm$

$b_m = 0.5 * 230 = 115mm$

$A_{sm} = 0.5^2 A_{sp}$

PROTOTYPE

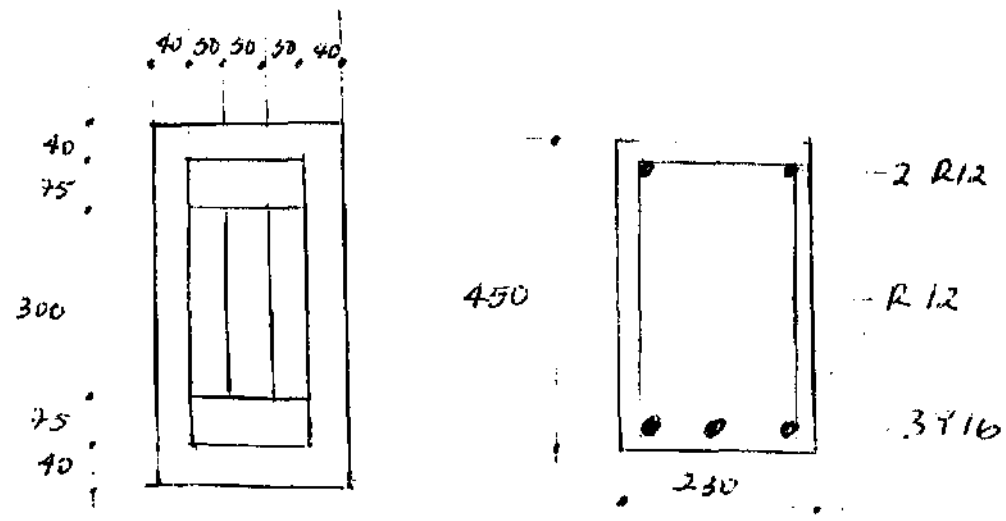


Fig 3.7 E.T and R.C Prototype dimensions

MODEL

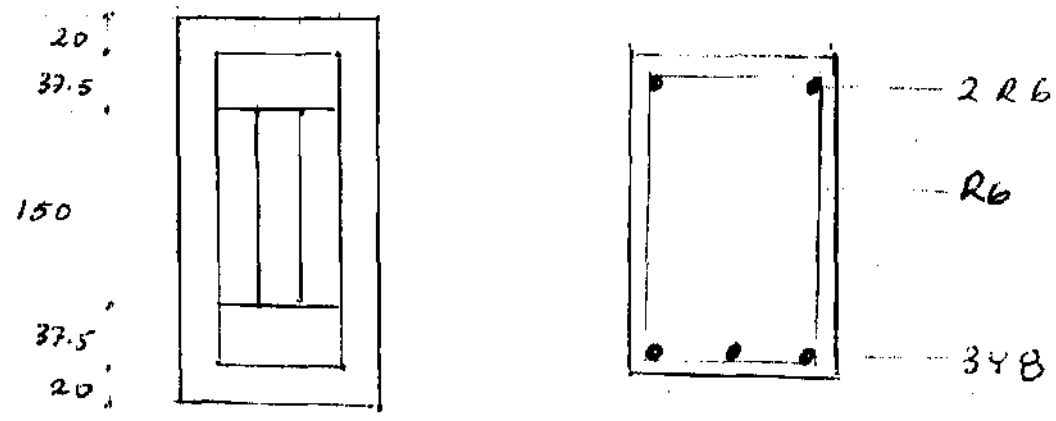


Fig 3.8 E.T and R.C model dimensions

There is also the need to establish the relationship between the load, moment, deflection and other properties between the model and the prototype.

If the stresses in the prototype is equal to the stresses in the model, then.

$$W_m = \lambda\ W_p$$

$$M_m = \lambda^3\ M_p$$

$$Y_m = \lambda\ Y_p$$

Where W, M, Y represent the load, moment and deflection respectively.

3.4.0 EXPERIMENTAL PROCEDURES

3.4.1 SOURCING OF MATERIALS

TIMBER: The choice of the specie timber was informed by the following factors: the strength of the timber; its availability; cost and durability. On consideration of these, mahogany of the dry zone (Khaya) type N3 according to NCP 2 (1973) classification was selected. It is true that other stronger and more durable timber exist such as Iroko, Teak and Opepe, but other considerations such as costs and easy availability informed the choice of mahogany.

CONCRETE: The Concrete was designed for a characteristic cube strength of 30N/mm^2. To ensure that this was what was achieved, three cube samples were casted from the concrete used for each beam. These cubes where later crushed and their crushing strength noted.

Preliminary investigations revealed that adequate strength of concrete is required particularly in the encased timber beam given the thin thickness of the concrete encasement. Secondly, the coarse aggregate used in casting the encased timber beam had to be reduced to a maximum thickness of 10mm because of the reduced thickness of the modelled section, in order to ensure absence of voids.

REINFORCEMENT: Reinforcement rods of various sizes both of high yield and mild steel are available in the markets. The problem was in obtaining a 3mm diameter rod for the construction reinforcement of the modelled encased timber beam. This was solved by using 3mm diameter bars employed in the manufacture of 3mm diameter BRC mesh.

3.4.2 DESCRIPTION OF EXPERIMENTS

The beams were tested under a two point loading system as shown below. The system is preferred to the central point loading system as its bending moment diagram bears a closer resemblance to that of a uniformly distributed load, thus giving a better representation of what happens in practice.

The dial gauges and DEMEC buttons are positioned as shown below.

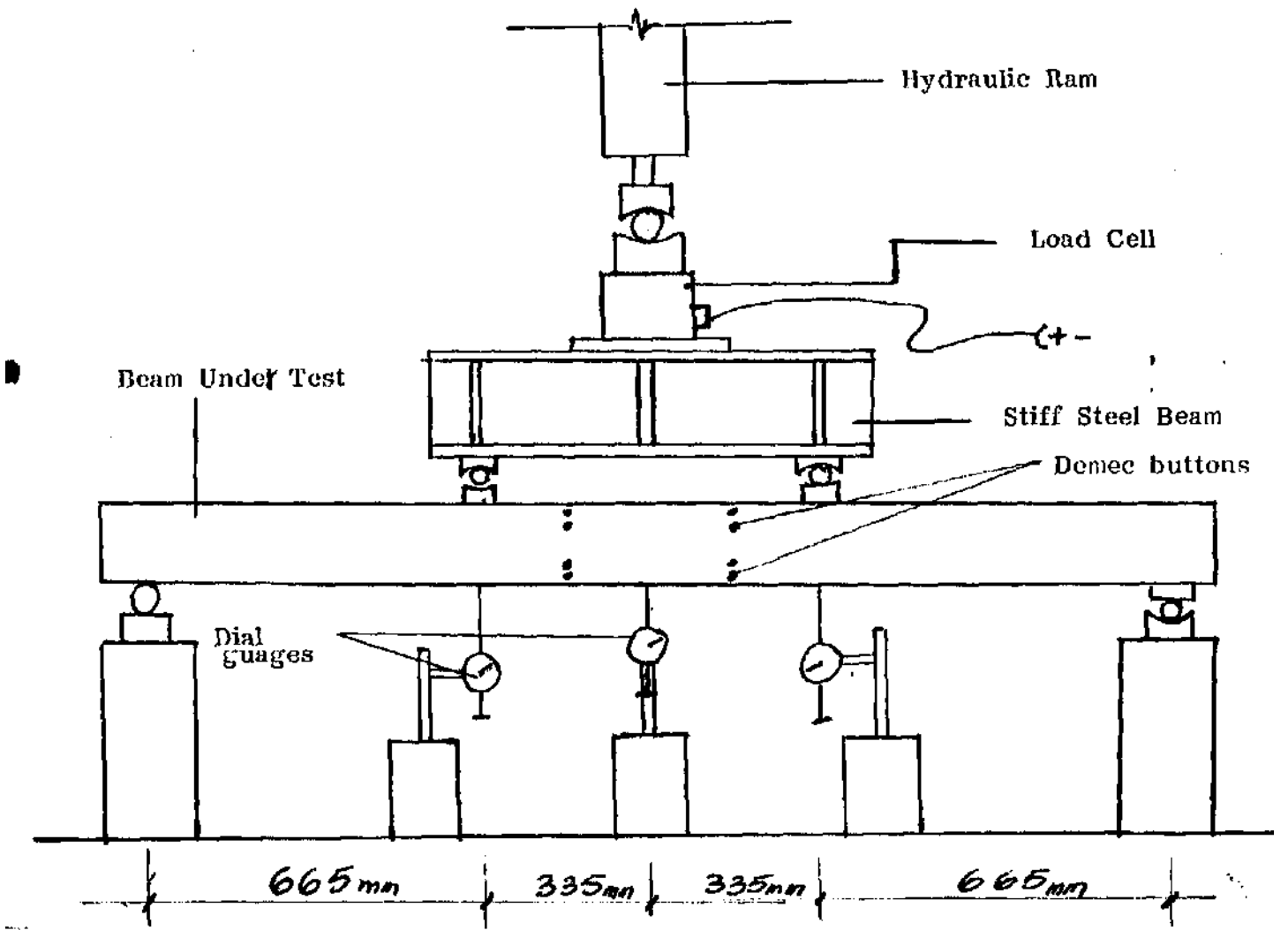
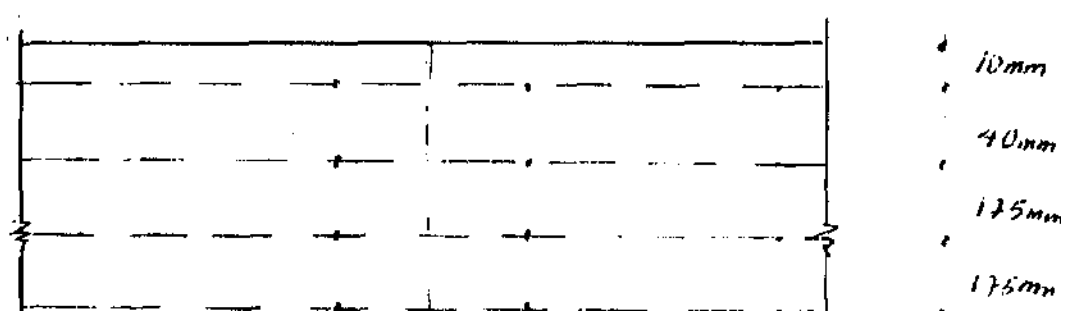


Fig 3.9 flexural test arrangement

3.4.2.1 DEMEC READINGS

A simple beam under loading is subjected to compressive stresses above the neu axis and tensile stresses below the neutral axis. Therefore, there is a shrinkage in upper and a corresponding elongation in the lower parts of the beam respectiv The DEMEC apparatus consists of the buttons position a shown below and a gauge which enables the measurement of the successive shrinkage and elongatic before and after every load increment.

The measurements of the shrinkage and elongation (or the strains) across the b enables the determination of the position of the neutral axis and its conseq movement with each load increment. This is important since the suddenne failure and the resisting ability of a beam is dependent on the movement o neutral axis.



3.4.2.2 DEFLECTION READINGS

Three deflection readings are to be taken, two at the load points and one at the centre of the beams, where deflection is maximum and of paramount importance. The relationship between the deflection at load points and that at the centre is derived below.

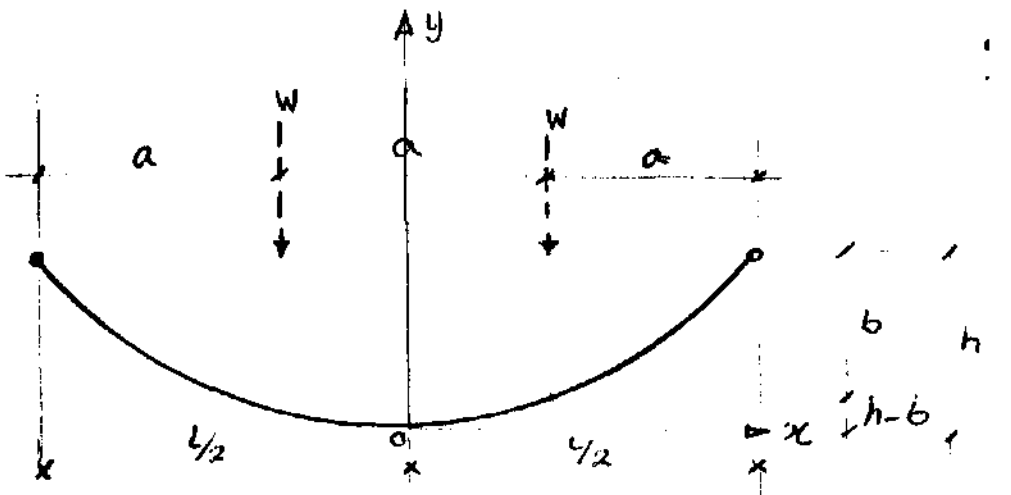


Fig 3.11 Deflection points

The simply supported beam loaded with two point loads at third points has the deflected shape AOB shown above (exaggerated). The deflection at the centre is h, and at the load points is b, which are at distances a from the supports.

The parabolic equation is given by

$$y = mx^2$$

$$(h - b) = m\,(l/2 - a)^2$$

at $a = 0,\ b = 0$

$$\therefore \quad h = ml^2/4$$

$$m = 4h/l^2$$

$$(h - b) = \frac{4h}{l^2}(l/2 - a)^2$$

$$(h - b) = \frac{4h}{l^2}(l/2 - \frac{2la}{2} + a^2)$$

$$(h - b) = h - \frac{4ah}{l} + \frac{4a^2h}{l^2}$$

$$b = \frac{4ah}{l^2}(l-a)$$

but $a = l/3$

$$b = \frac{4h}{3l}(^2/_3\, l)$$

$$b = \frac{8h}{9}$$

or $h = \frac{9}{8} b$

3.4.3 AVERAGE DEFLECTION

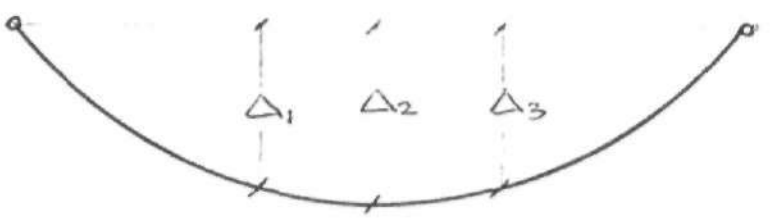


fig 3.12 Average deflection

The deflection at the centre of the beam is of interest and since it is possible to determine the deflection at the centre of the beam from the deflection at any known point along the beam length, then the average deflection at the centre could be computed from the average of the three deflection readings as shown below.

From above.

$\Delta_2 = {}^9/_8\ \Delta_1 = {}^9/_8\ \Delta_3$

let ${}^9/_8\ \Delta_1 - \Delta_{1\text{-}2}$ and ${}^9/_8\ \Delta_3 = \Delta_{3\text{-}2}$

Average deflection, $\Delta_A = {}^1/_3\ (\Delta_{1\text{-}2} + \Delta_2 + \Delta_{3\text{-}2})$

Δ_A is the average deflection used in the load deflection graphs.



PLATE 1: **REINFORCEMENT CONCRETE AND ENCASED TIMBER BEAMS READY FOR CASTING.**

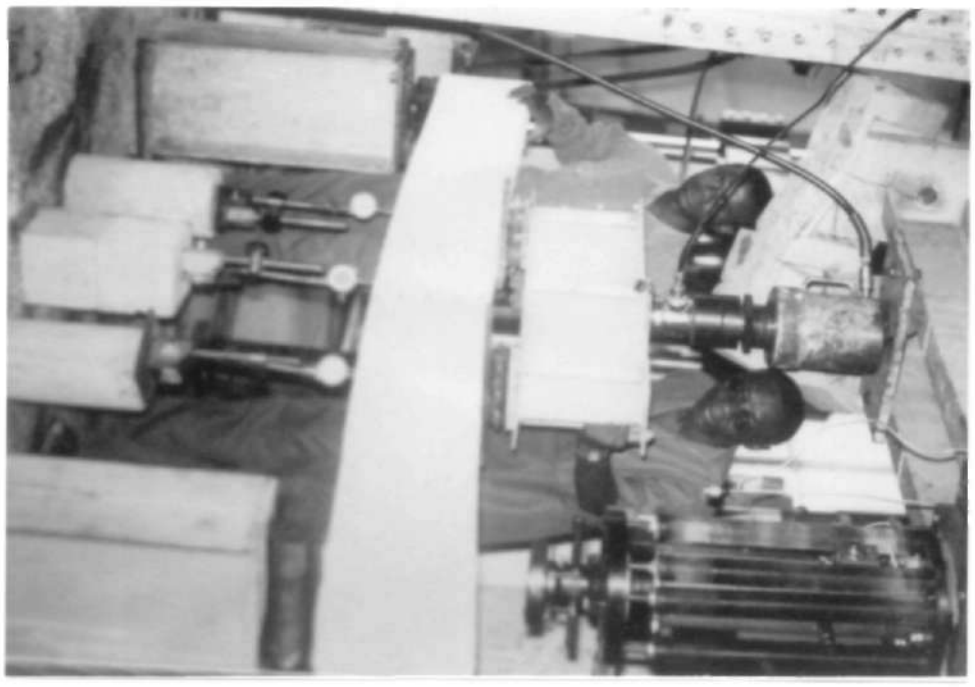


PLATE 2: **FLEXURAL TEST ARRANGEMENT**

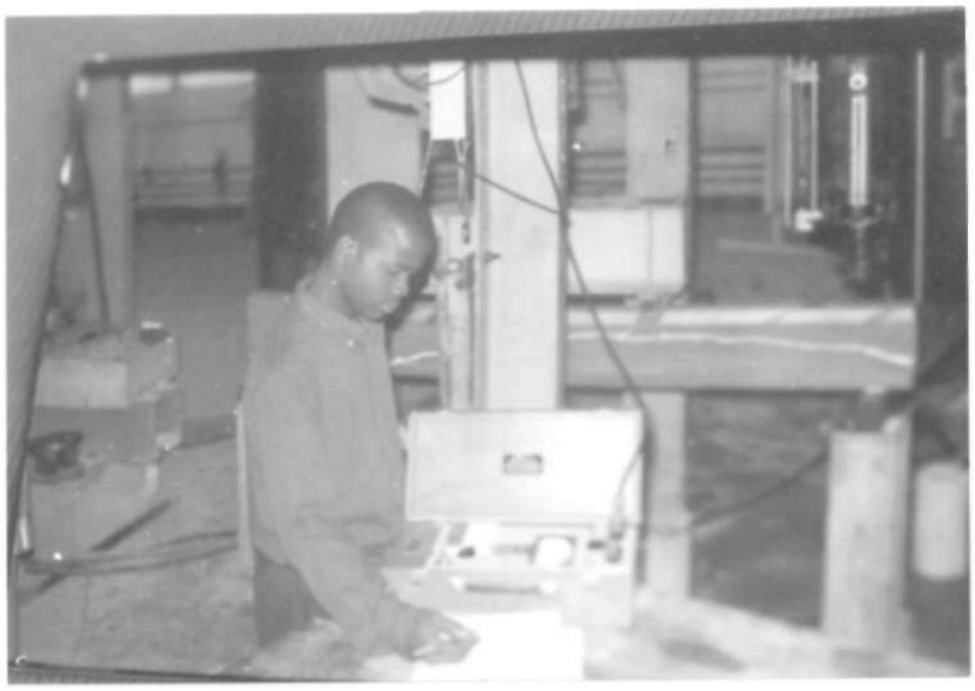


PLATE 3: RECORDING LOAD CELL READINGS

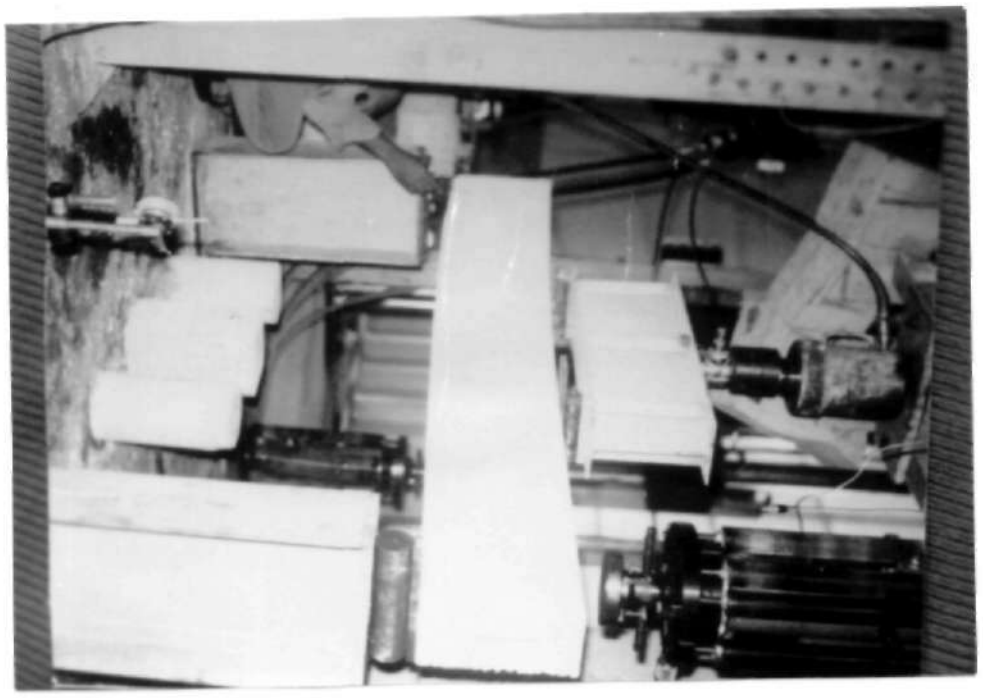


PLATE 4: INSPECTION OF CRACK DEVELOPMENTS FOR BEAM UNDER LOADING.

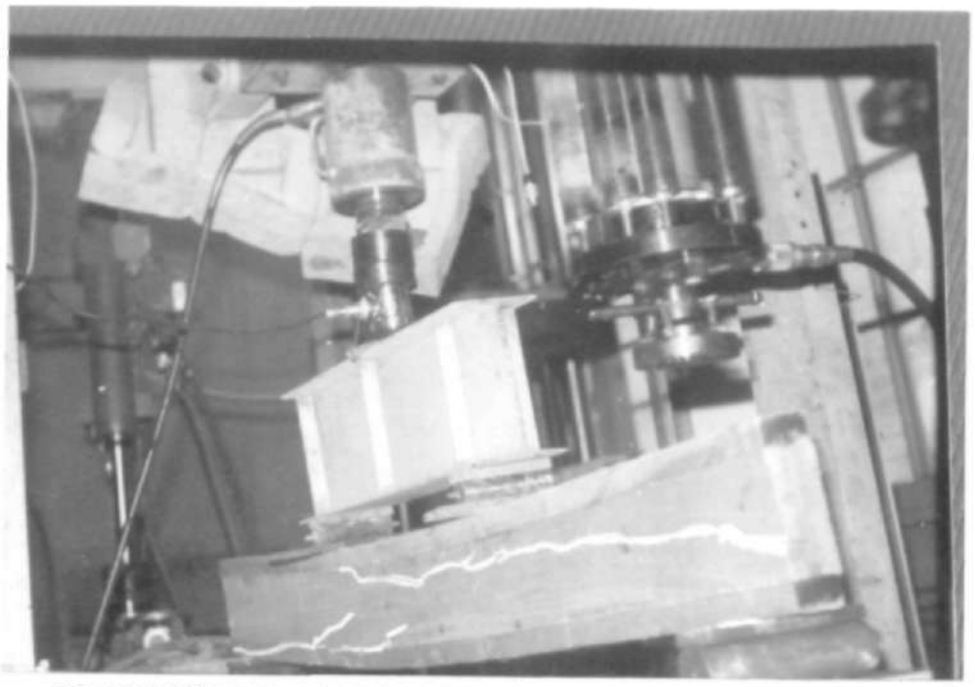


PLATE 5: PLAIN TIMBER BEAM UNDER LOADING WITH CRACKS HIGHLIGHTED

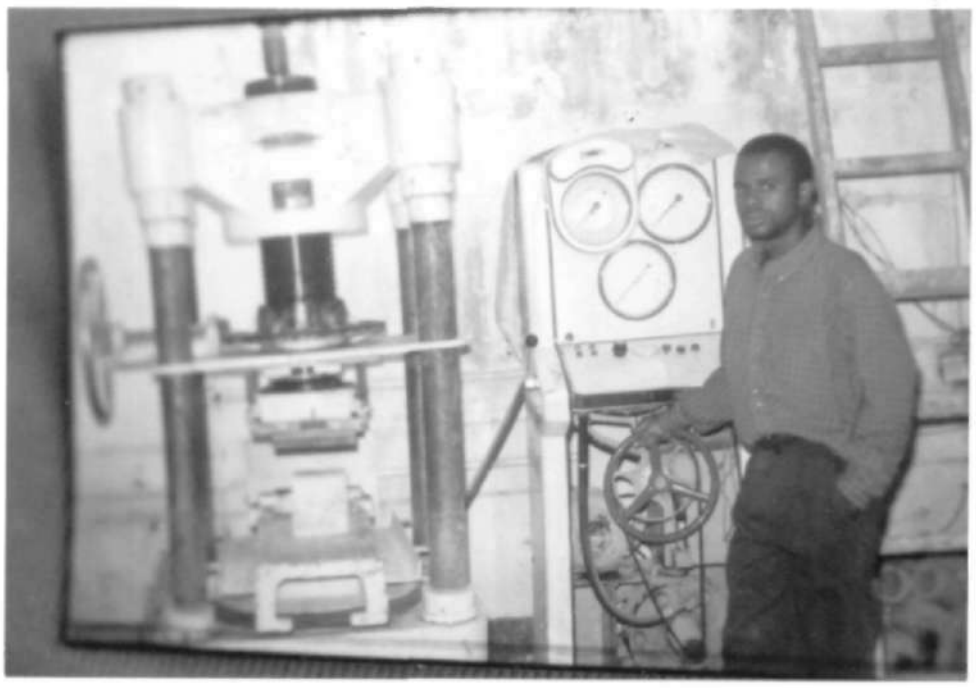


PLATE 6: OPERATING CONCRETE CUBE CRUSHING MACHINE

CHAPTER 4

RESULTS ANALYSIS AND DISCUSSION

4.1.0 DEDUCTIONS FROM STRAIN AND LOADING DEFLECTION CHARACTERISTICS

It is important to point out that the strain readings from the DEMEC buttons are susceptible to errors as soon as wide cracks begin to occur in the beams (fig G8-G13) and secondly when there is a shift in the position of the DEMEC buttons. The movement of the DEMEC buttons is prevented by using high strength adhesive and given adequate drying time. This however does not prevent slight movements due to accidents. The cracks on the other hand cannot be controlled and when a vertical crack passes between DEMEC buttons on the same plane then the reading at this point rises astronomically while a corresponding increase will not be recorded at other DEMEC locations where such cracks are absent. In this regard such readings are neglected.

At the commencement of loading up to 8kN (per jack) the neutral axis lies approximately at the centre for both beams (fig G8 - G13) This implies that points of equal distances from either sides of the beam centre suffer equal amount of strain. On the average, the strain at loads up to 4kN (per jack) is higher in the reinforced concrete beams (RC) compared to the encased timber beams (ET), this is the only situation when this is so. This is most likely explained by the fact that since concrete is weak in tension, cracks would normally occur in the concrete before the steel

reinforcement can come into play. Thus there is an initial deflection before stabilisation. The cracks at this point are not yet visible.

Beyond the 8kN load the strain at the lower (tensile) portion of the two beams increases more significantly in comparison to the strain at the upper (compression) portion of the beam. Thus the neutral axis travels upwards rapidly up to the 12kN load where it does not increase significantly till failure finally occurs.

Cracks become visible in the ET beams particularly at the tension face beyond the 12kN load and thus the strain at the lower (tensile) portion of the ET beam exceeds that of the R.C beam. Hence the position of the neutral axis in the E.T beam is higher than that of the R.C beam at and beyond this load point. Cracks in the R.C beam are noticeable at loads close to the design load and they increase in width as the load increases until failure occurs. From the load - deflection graphs (Figs G1 - G7) it can be seen that the E.T beam is more elastic than the R.C beam. Meaning that it deflects more but can withstand far more over loads than the R.C beam.

The two beams adequately satisfy (with enough room for the effect of creep) the BS 8110 requirement of span: deflection ratio < 250 at the design load. The plain timber specimen (without concrete encasement) was not able to satisfy this requirement, thus confirming the earlier suspicion that the encasement has the added advantage of increasing the rigidity of the E.T beam and thus reducing its deflection under load as earlier suggested.

The load deflection graph of the E.T beam is almost a straight line (linear) graph, while that of the R.C beam displays a parabolic curve with the curve more pronounced as failure is approached (about 26 kN load on the average)
(Figs G1 - G7). Failure of the E.T beam occurs around the 36 kN load
(Figs G1 - G7) and the failure is marked by spalling of the encasing concrete in protest to the high deflection of the beam and finally by the cracking of the timber itself.

It was noted during the conduction of the flexural test that the E.T beams as well as the plain timber beam achieved almost complete recovery on removal of the load. Whereas the R.C beams maintain permanent deformation after failure. The plain timber beam failed at 44kN, showing that the early failure in the E.T beam was as a result of the failure of the encasing concrete.

4.20 MATHEMATICAL MODELLING

The uniformly distributed design load is equivalent in value to the bending moment of a two point load of 20kN per jack, the deflection of the beams at this load has been recorded. The regression equations for each load - deflection curve of each beam has been computed by means of a computer program GRAPHER. The differential of this equation gives the stiffness equation for the beams.

When the deflection values at 20kN load per jack are substituted into the stiffness equation it gives the value of the beam's stiffness at this load point. This is done since the load deflection curves for the beams are not linear, it is therefore necessary

to define the stiffness (or slope of the curve) of the beam at a particular load point. The design load was then taken.

TABLE 1

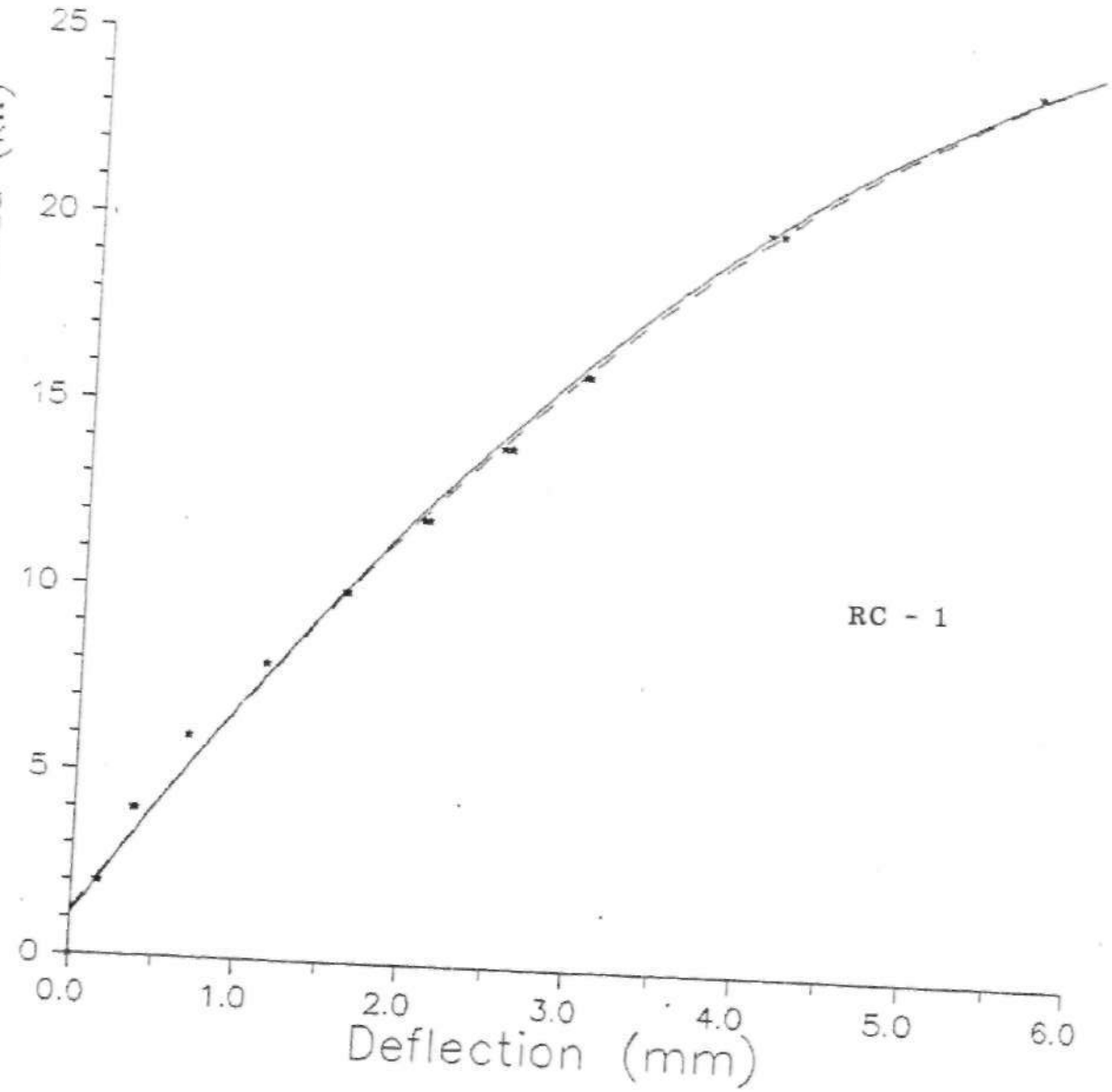
BEAMS	d(mm) corresponding deflection	REGRESSION EQUATION (P=) LOAD (kN)	= (dp/dd)	STIFFNESS
R.C 1	4.2mm	$1.20 + 6.08d - 0.36d^2$	$6.08 - 0.72d$	3.06
E.T 1	5.5mm	$0.32 + 4.06d - 0.12d^2$	$4.06 - 0.24d$	2.74
R.C 2	5.4mm	$2.34 + 4.96d - 0.16d^2$	$4.96 - 0.32d$	3.20
E.T 2	6.2mm	$-0.22 + 3.85d - 0.07d^2$	$3.85 - 0.14d$	2.98
R.C 3	4.5mm	$0.20 + 5.35d - 0.10d^2$	$9.35 - 0.20$	4.45
E.T 3	6.5mm	$-1.07 + 4.27d - 0.12d^2$	$4.27 - 0.24d$	2.71
P.T	10.0mm	$-0.47 + 2.10d$	2.10	2.10

Average stiffness of Reinforced concrete beam $= \frac{3.06 + 3.20 + 4.45}{3} = 3.57$

Average stiffness of Encased timber beam $= \frac{2.74 + 2.98 + 2.71}{3} = 2.81$

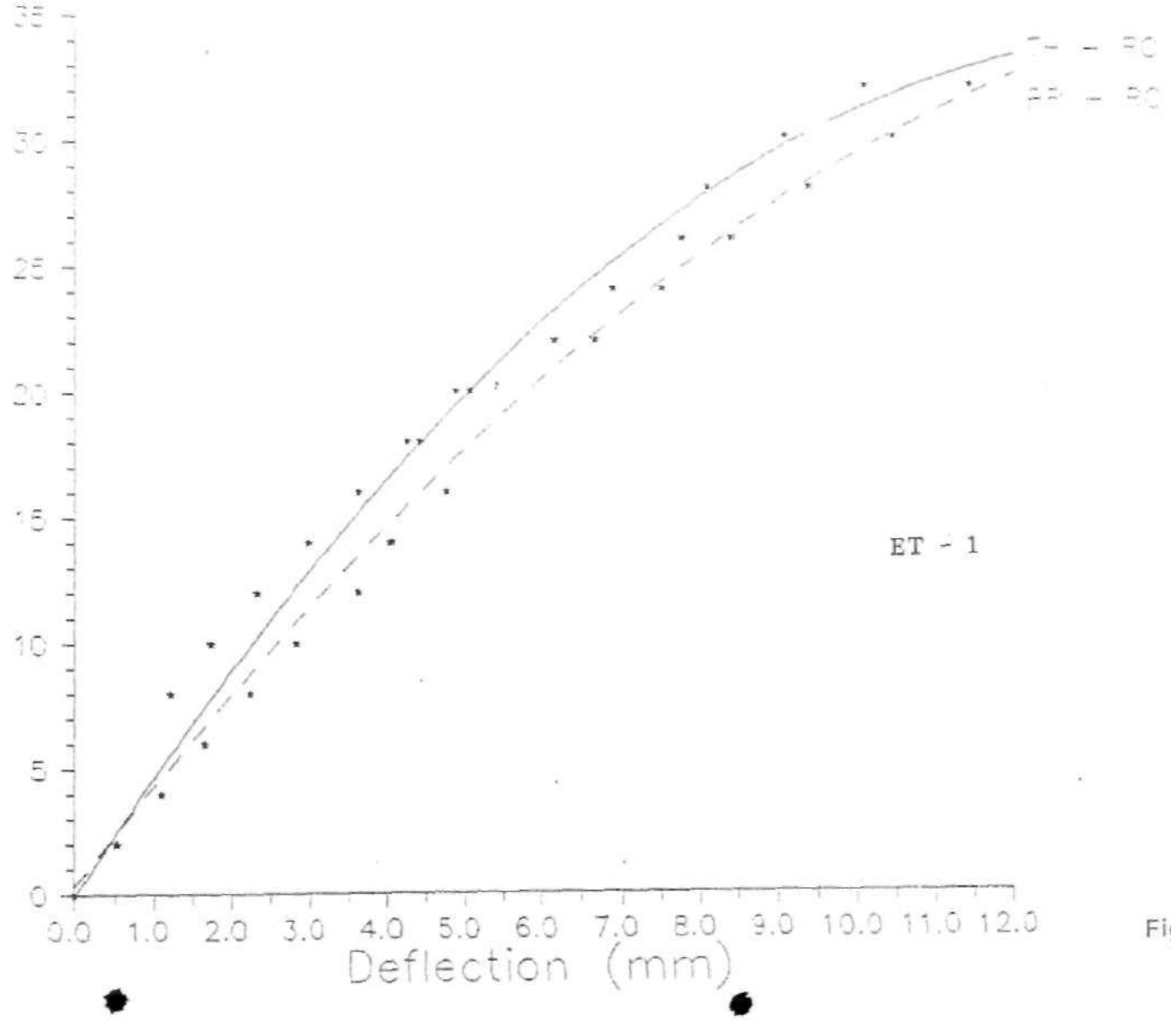
Stiffness of Plain Timber beam $= 2.10$

4.30 LOAD - DEFLECTION GRAPHS



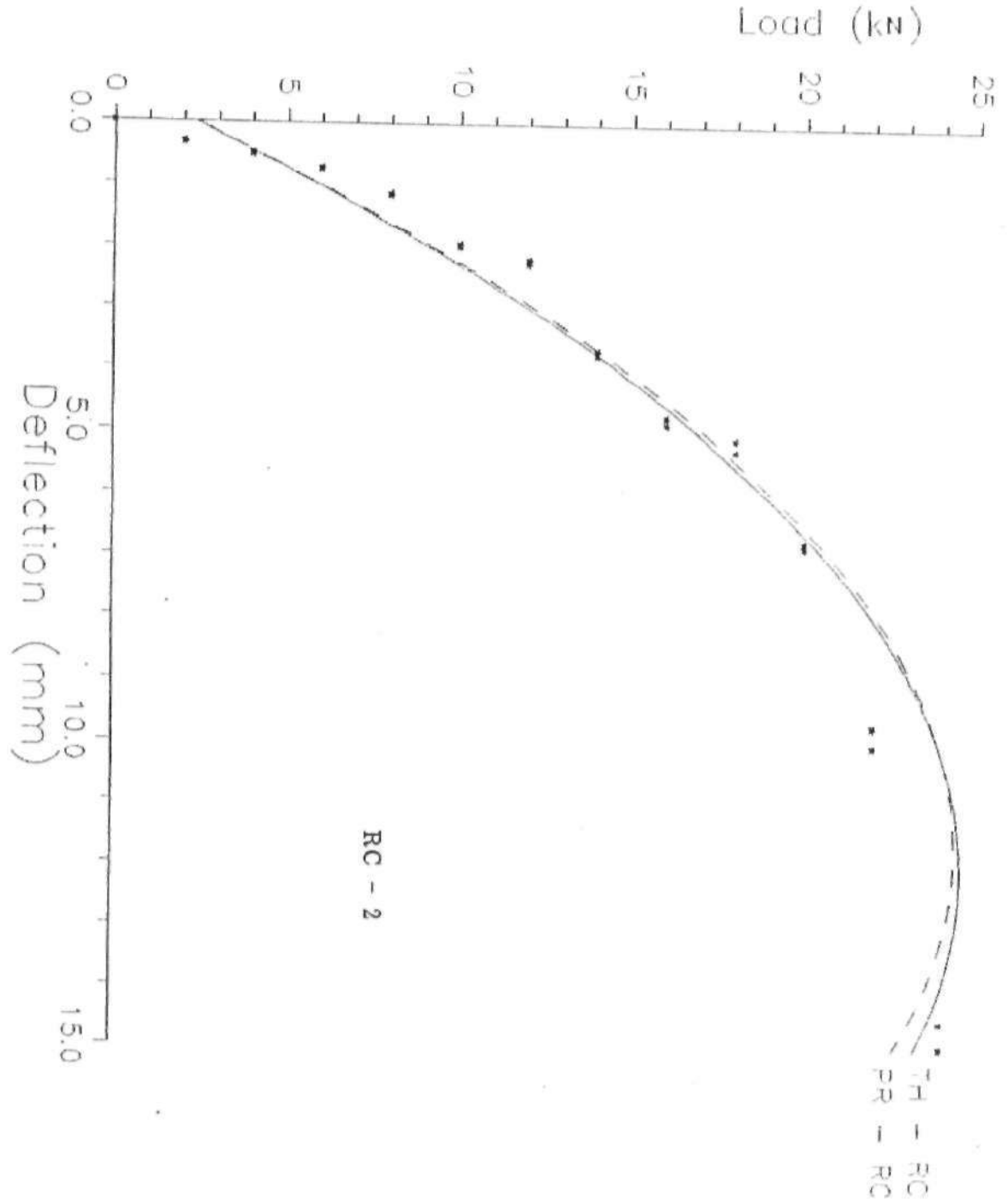
RC - 1

Fig. G.1


Load (kN)
0
5
10
15
0.0 1.0 2.0 3.0 4.0 5.0 6.0 7.0 8.0 9.0 10.0 11.0 12.0
Deflection (mm)

ET - 1

Fig. G.2



RC - 2

Fig. G.3

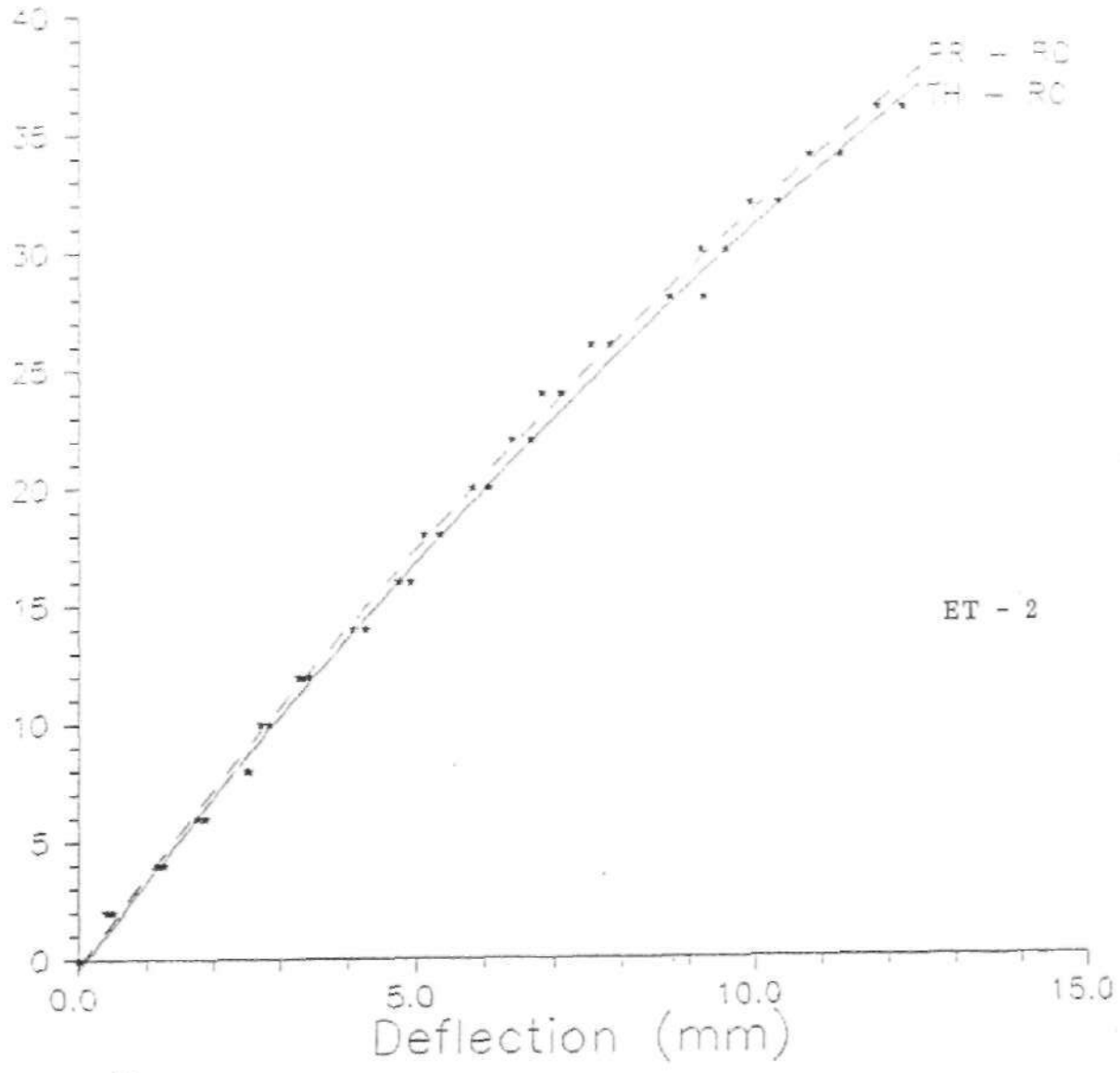


Fig. G4

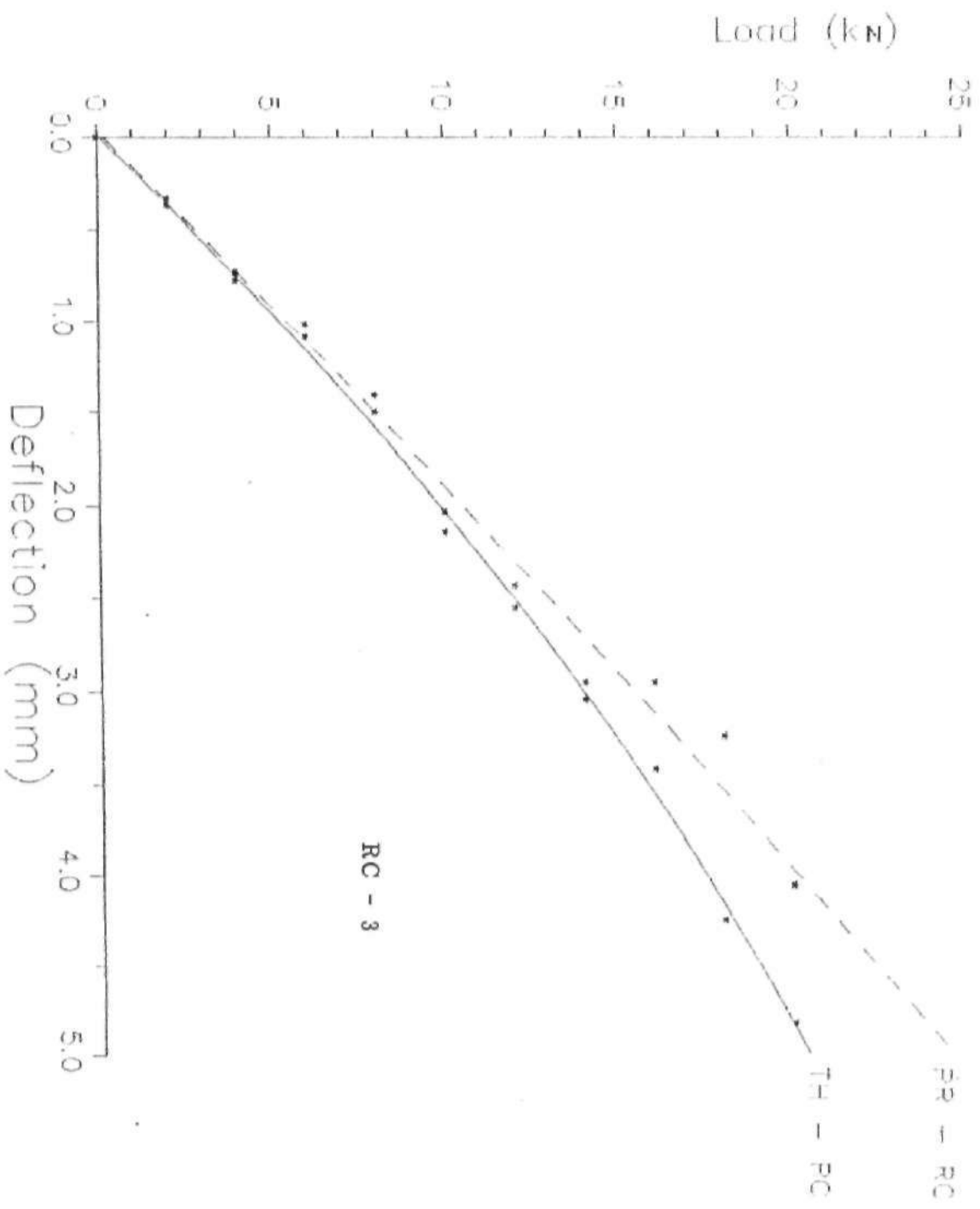

Load (kN)
0
5
10
15
20
25
0.0
1.0
2.0
3.0
4.0
5.0
Deflection (mm)
RC - 3
TR - RC
TL - RC

Fig. G.5

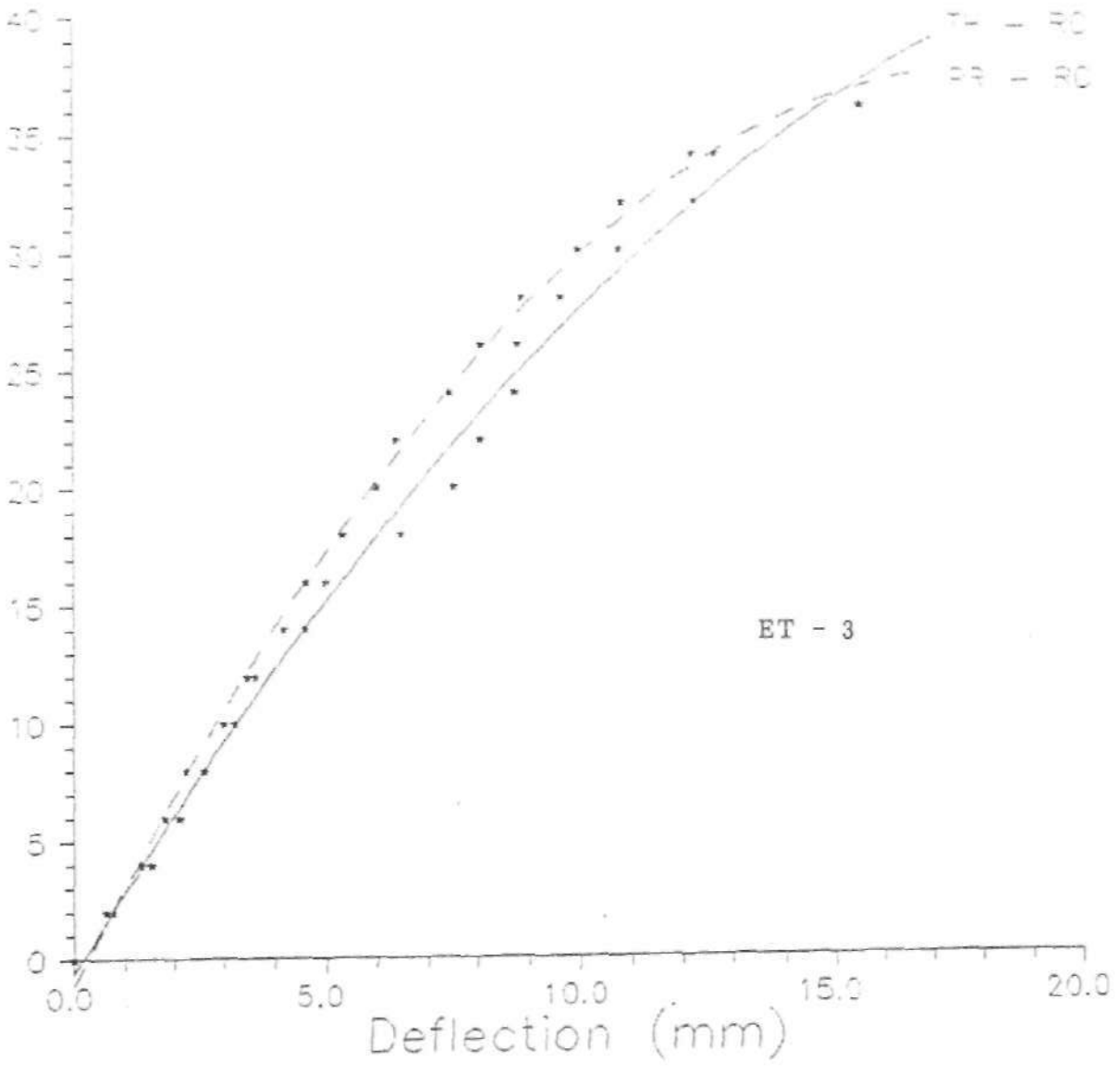
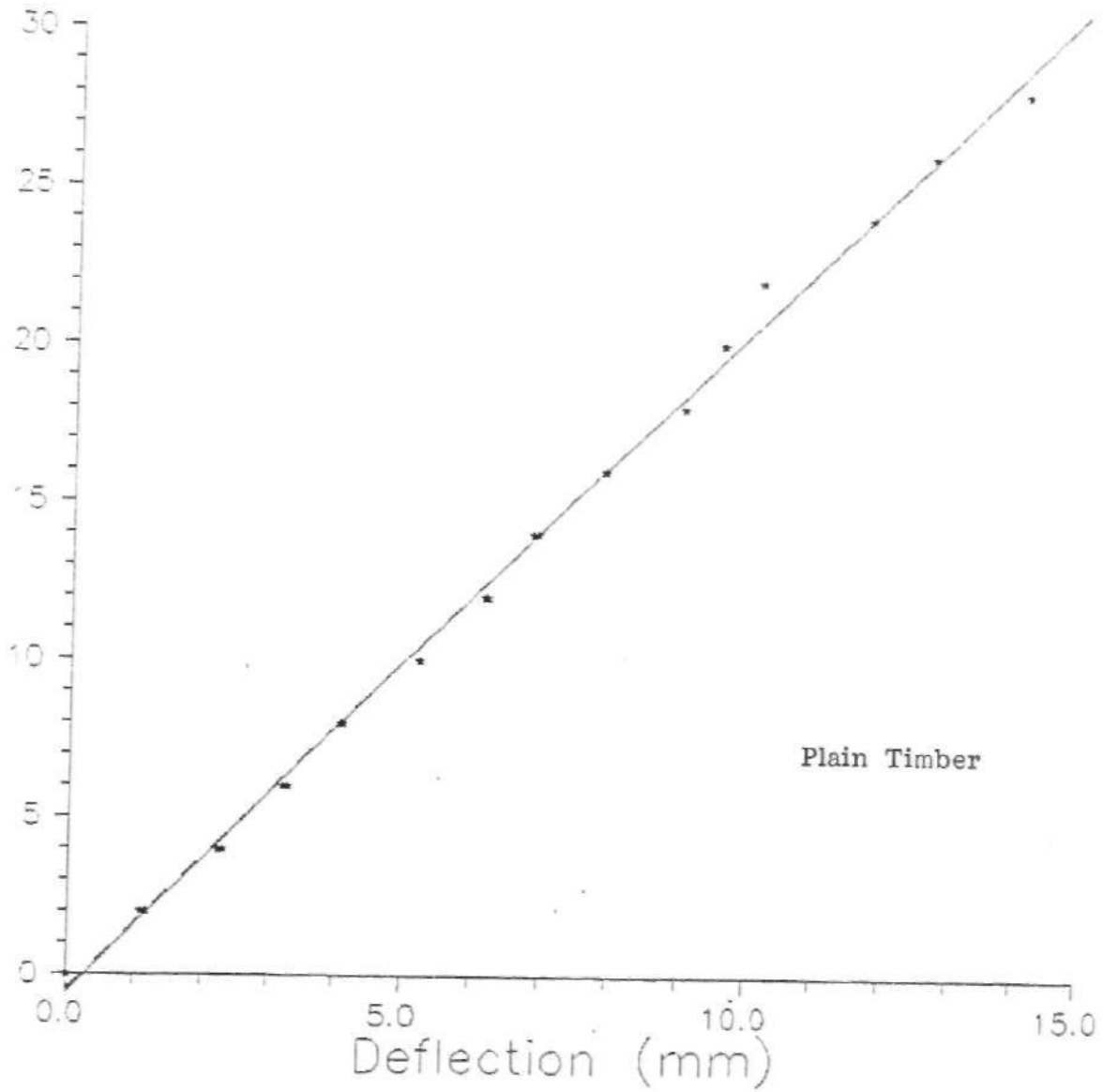


Fig. G.6



Plain Timber

Fig. G.7

4.40 STRAIN DIAGRAMS

R.C.1

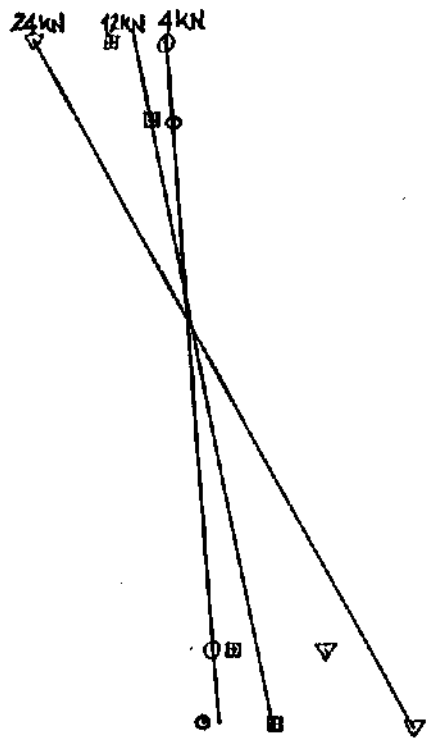


Fig. G.8

E.T.1

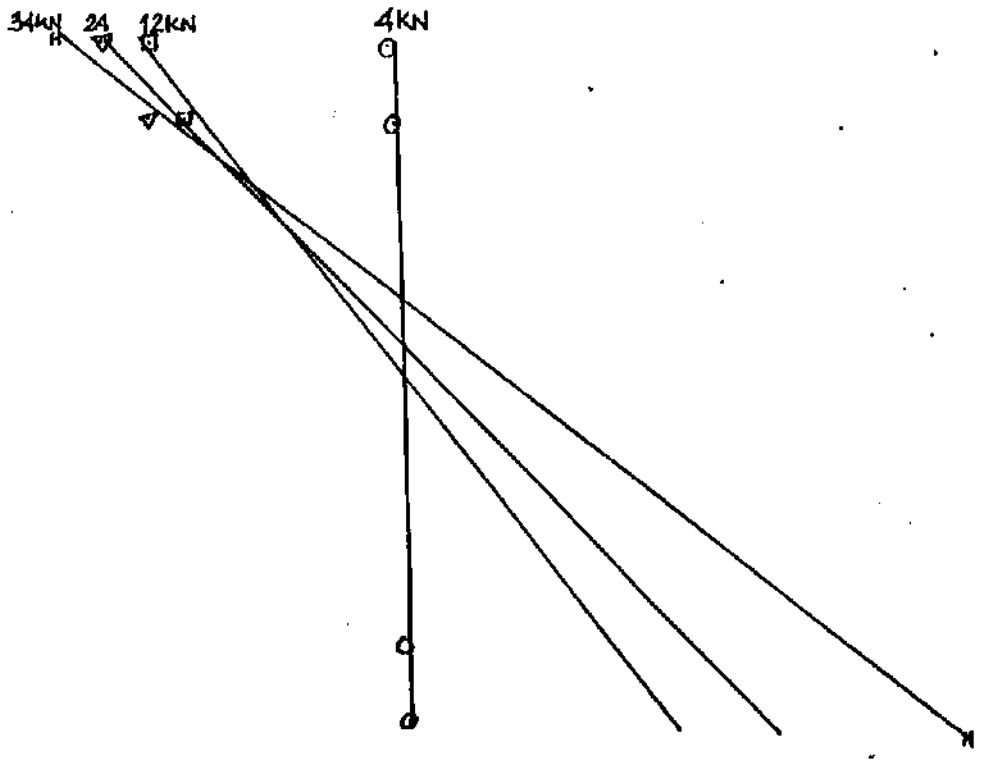


Fig. G.9

R.C.2

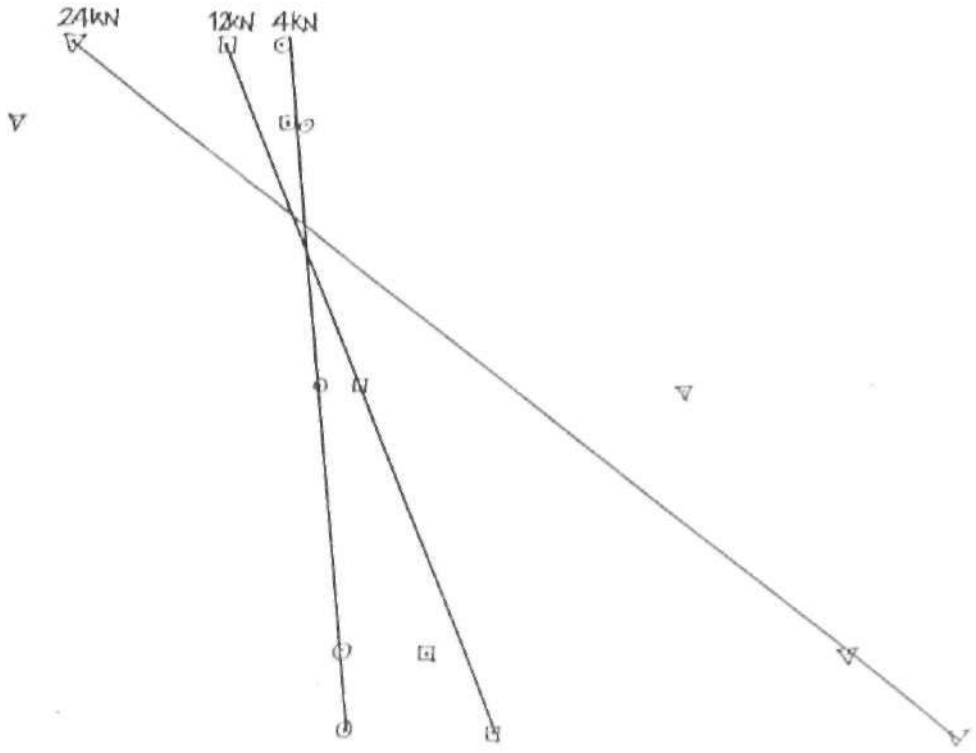
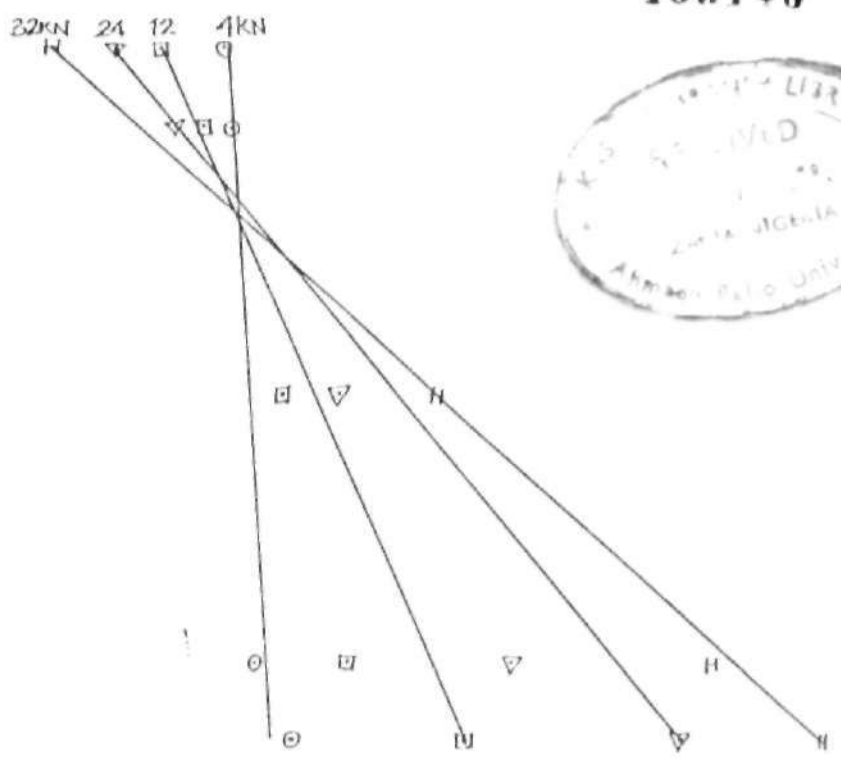


Fig. G.12

E.T.2

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Fig. G.13

R.C.3

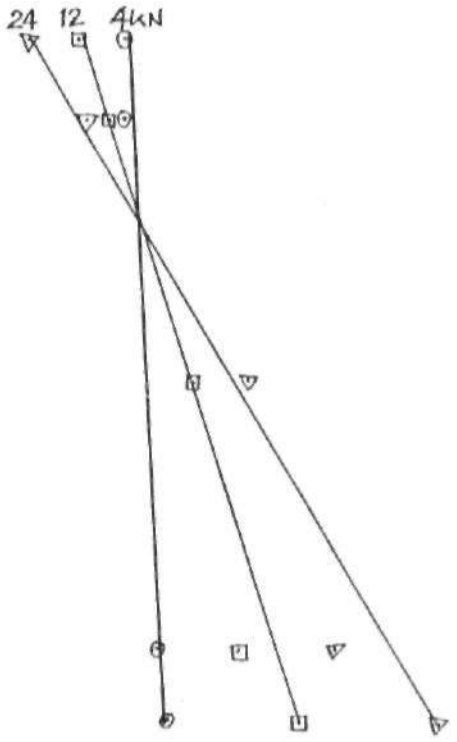


Fig. G.10

E.T.3

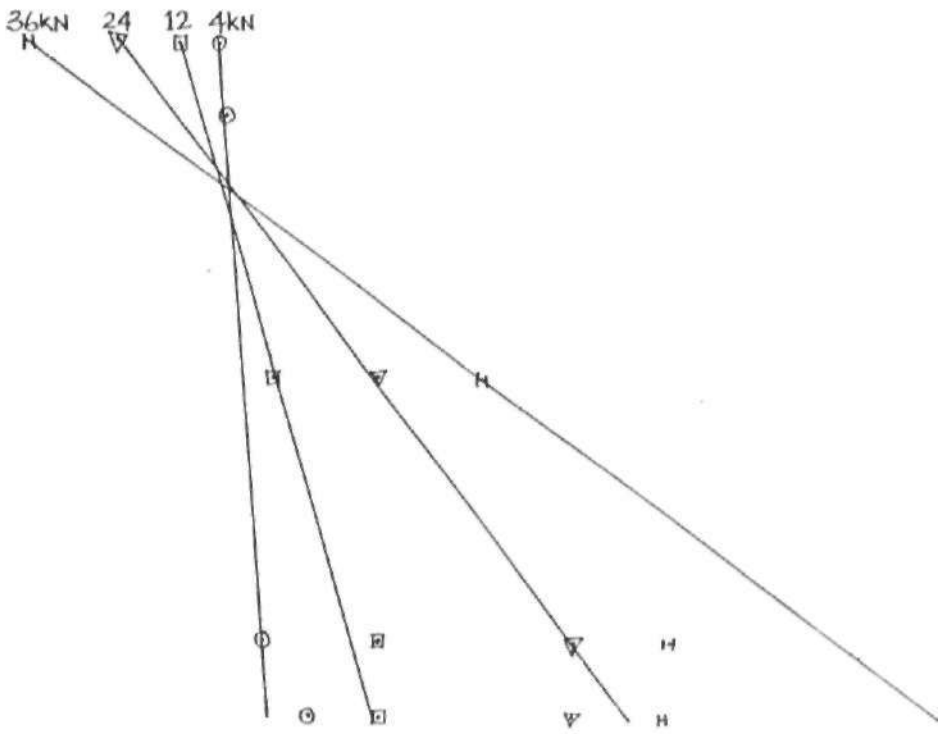


Fig. G.11

CHAPTER 5

CONCLUSION & RECOMMENDATIONS

5.10 CONCLUSIONS

Following the conclusion of experiments with encased timber beams and reinforced concrete beams the following conclusions were arrived at.

1. The concrete encasement present in the encased timber beam enhances its rigidity as predicted in the design (3.25) there was an average stiffness of 2.81 for encased timber against 2.10 for the plain timber beams as shown by their load-deflection graphs.

2. It was discovered that the concrete encasement does not really contribute to the overall load carrying ability of the encased timber beam, this is because deflection beyond 30kN load would have been so large as to result in spalling of the concrete encasement. At this point, only the timber section is present to resist the applied load.

3. The reinforced concrete beam load-deflection graph has an average stiffness of 3.57 compared to 2.81 for the encased timber beam. This indicates that the reinforced concrete beam is more rigid (stiffer).
   However, this changes around the 20kN load when the load-deflection curve for the reinforced concrete beam is within the plastic region i.e., substantial deflection for slight increments in load. Failure occurs soon after (about 24kN average), while the load deflection curve for the encased timber beam

remains uniform at this stage. The failure of the encased timber beams occurs at 38kN average and does so gradually without the suddenness of that for reinforcement concrete beam.

4. A lot can be deduced from the loads deflection curve of a beam. While the load deflection curve for the plain timber beam is almost linear, that for the reinforced concrete beam is close to parabolic and that for the encased timber beam lying in between. The implication is that the plain timber beam is the most elastic followed by the encased timber beam. An elastic beam has the advantage of withstanding large overloads of short duration, with significant recovery when the load is removed.
This is reflected in the failure loads of the beams, with the plain timber beam recording the highest value of 44kN.

5. Most importantly the encased timber beam was found to be structurally efficient in addition to a 10% reduction in production cost in comparison to the reinforced concrete beam. This however, is not a general statement as it is expected that for large loads and spans the encased timber beam would not be a viable option to the reinforced concrete beam. This is so because the heavy load and the resulting deflection would necessitate a large timber section. This means increased cost as well as aesthetics and headroom restrictions.

5.20 RECOMMENDATIONS

1. The encased timber beam (E.T) is very suitable and highly recommended for use as precast concrete beams to hasten construction for two reasons. Firstly, it is less than half the weight of a reinforced concrete beam (R.C) of equivalent strength, thus reducing hoisting problems on site and at the workshop. Secondly, E.T beams being a relatively new concept and also the fact that it combines three materials compared to the R.C beams two, requires more control which is best achieved in the workshop rather than insitu on site.

2. It was observed in the course of the experiments that, well before the failure of the E.T beams there is first the cracking of the concrete encasement followed by failure of the reinforcing steel. This is then followed by noticeable deflection in the E.T beam. It is safe therefore to suggest an increment in the area (particularly a reduction in spacing) of the construction reinforcement and also the use of a higher grade concrete. This would increase the failure load as well as reducing the deflection under load of the E.T beam.

3. Based on the finding that the E.T beam failed at a much higher load in comparison to the R.C beam but suffering greater deflection in the process. It is therefore recommended that the E.T beam be used in situations where overloads may occur but where deflection does not pose a serious problem to

the integrity of the structure, e.g. beams which run over walls could be an example.

4. Encased timber beams (E.T) are well protected (by the encasement) against fire outbreak, impact forces and fungi attack. It is therefore highly recommended for use in aggressive environments as against plain timber beams.

APPENDIX I

Table 1 EXPERIMENTAL RESULTS

	CONCRETE CUBE STRENGHT AT 30 DAYS	
R.C I	FAILURE LOAD (KN)	STRENGHT OF CONCRETE (N/mm)
1	720	32
2	680	30.22
3	710	31.55
	AVERAGE CUBE STENGTH = 31.26N/mm	

DEMIC(STRAIN) READINGS R.C I					BEAMS DEFLECTION		
DEMEC No / Load (kN)	1	2	3	4	$\triangle^1$	$\triangle^2$	$\triangle^3$
0	11.065	11.31	11.44	11.22	1.62	7.79	2.38
2	10.99	11.23	11.1	11.485	1.75	7.64	2.53
4	10.91	11.20	11.535	11.22	1.94	7.44	2.72
6	10.825	11.22	11.44	11.3.5	2.21	7.11	3.0
8	10.805	11.15	11.525	11.405	2.60	6.66	3.405
10	10.645	11.03	11.56	11.48	2.995	6.19	3.82
12	10.635	11.11	11.62	11.63	3.405	5.71	4.245
14	10.62	11.235	11.78	11.74	3.755	5.24	4.665
16	10.465	11.115	11.88	11.88	4.20	4.79	5.09
20	10.34	11.095	12.025	12.015	5.12	3.67	6.06
24	10.23	11.15	12.14	12.4.	6.415	2.17	7.58
27.5	FAILURE LOAD						

Table 2

	CONCRETE CUBE STRENGHT AT 36 DAYS	
E.T 1	FAILURE LOAD (KN)	STRENGHT OF CONCRETE (N/mm^2)
1	640	28.44
2	620	27.55
3	610	27.11
	AVERAGE CUBE STENGTH = 27.70N/mm^2	

	DEMIC(STRAIN) READINGS R.C 1				BEAMS DEFLECTION		
Load (kN) \ DEMEC No.	1	2	3	4	Δ 1	Δ 2	Δ 3
0	11.04	14.38	11.34	11.12	0.975	8.02	3.91
2	11.07	14.34	11.35	11.13	1.45	7.49	4.41
4	10.975	13.85	11.335	11.15	1.925	6.915	4.935
6	9.91	13.335	11.33	11.125	2.40	6.37	5.44
8	9.84	13.30	11.325	11.13	2.92	6.80	5.925
10	9.795	13.29	11.32	11.84	2.45	5.20	5.51
12	9.74	13.26	11.31	11.235	3.00	4.405	6.055
14	9.70	13.23	11.31	11.13	3.55	3.98	6.63
16	9.61	13.23	11.325	11.14	4.125	3.38	3.28
18	9.58	13.30	11.35	11.14	4.68	3.62	7.75
20	9.51	13.21	11.33	11.15	5.24	2.97	8.32
22	9.52	13.22	11.31	11.23	5.87	1.375	9.93
24	9.95	13.06	11.315	11.135	6.53	0.52	10.59
26	9.44	13.01	11.34	11.13	7.32	19.63	11.35
28	9.39	12.95	11.32	11.16	8.14	18.64	11.12
30	9.385	12.93	11.35	11.135	8.98	17.60	12.04
32	9.36	12.83	11.33	11.14	9.85	16.60	12.94
34	9.36	12.83	11.33	12.20	-	-	-
36	9.35	12.79	11.325	11.135	-	-	-
39.4	FAILURE LOAD						

Table 3

	CONCRETE CUBE STRENGHT AT 32 DAYS	
R.C 2	FAILURE LOAD (KN)	STRENGHT OF CONCRETE (N/mm^2)
1	720	32
2	710	31.55
3	740	32.89
	AVERAGE CUBE STENGTH = 32.15N/mm^2	

DEMIC(STRAIN) READINGS R.C 2					BEAMS DEFLECTION		
DEMEC NO. / Load (KN)	1	2	3	4	Δ 1	Δ 2	Δ 3
0	11.835	16.73	12.54	22.36	7.02	17.13	1.94
2	11.63	16.71	12.58	22.46	7.31	16.81	2.225
4	11.57	16.81	12.63	22.52	7.45	16.63	2.36
6	11.53	16.67	12.81	22.64	7.69	16.40	2.59
8	11.44	16.68	12.84	22.84	8.07	15.99	2.95
10	11.36	16.13	13.05	23.17	8.82	15.18	3.67
12	11.31	16.66	13.12	23.26	9.08	14.93	3.89
14	11.24	16.70	13.42	23.71	10.40	13.45	5.23
16	11.12	16.81	13.63	24.06	11.47	12.39	6.12
18	11.08	16.74	13.71	24.16	11.78	12.05	6.51
20	10.93	15.93	14.01	24.7	13.25	10.39	7.85
22	10.83	15.86	4.48	0.33	16.21	7.11	10.00
24	10.49	15.12	16.32	-	20.62	2.60	14.92
26	FAILURE LOAD						

Table 4

E.T 2	CONCRETE CUBE STRENGHT AT 36 DAYS FAILURE LOAD (KN)	STRENGHT OF CONCRETE (N/mm^2)
1	620	29.33
2	640	28.44
3	680	20.22
	MEAN CUBE STENGTH = 29.33N/mm	

DEMEC(STRAIN) READINGS E.T 2					BEAM DEFLECTION		
Load (kN) \ DEMEC No.	1	2	3	4	Δ 1	Δ 2	Δ 3
0	8.67	14.61	21.31	21.63	4.76	1.87	0.78
2	8.59	14.57	21.31	21.71	5.27	1.47	1.21
4	8.52	14.52	21.33	21.87	6.02	0.71	1.81
6	8.40	14.44	21.43	22.18	6.57	0.09	2.43
8	8.34	14.37	21.54	22.37	7.07	19.34	2.95
10	8.30	14.41	21.67	22.55	7.45	19.15	3.31
12	8.22	14.33	21.83	22.80	7.94	18.58	3.78
14	8.20	14.33	22.04	23.18	8.75	17.80	4.53
16	8.15	14.31	22.08	22.23	9.32	17.13	5.10
18	8.08	14.29	22.36	23.57	9.74	16.75	5.51
20	8.03	14.29	22.55	23.76	10.41	16.05	6.15
22	7.95	14.29	22.65	23.87	10.93	15.45	6.72
24	7.93	14.23	22.69	23.91	11.34	15.03	7.10
26	7.81	14.23	22.85	24.13	11.98	14.31	7.79
28	7.81	14.23	23.00	24.23	12.62	12.62	8.43
30	7.74	14.26	23.25	24.45	13.57	12.65	9.37
32	7.70	14.28	23.34	24.54	14.25	11.91	10.06
34	7.65	14.33	23.53	24.68	15.08	11.05	10.89
36	7.61	14.33	23.74	24.65	15.74	10.03	11.90
38	FAILURE LOAD						

27.5 FAILURE

Table 5

	CONCRETE CUBE STRENGHT AT 30 DAYS	
R.C 3	FAILURE LOAD (KN)	STRENGHT OF CONCRETE (N/mm^2)
1	760	33.78
2	710	31.56
3	730	32.44
	AVERAGE CUBE STENGTH = 32.59N/mm	

DEMIC(STRAIN) READINGS R.C 3					BEAMS DEFLECTION		
Load (kN) \ DEMEC No.	1	2	3	4	Δ 1	Δ 2	Δ 3
0	16.21	11.88	19.93	23.87	1.83	2.17	2.44
2	16.15	11.74	19.93	23.89	2.14	1.84	2.78
4	16.08	11.67	19.94	23.98	2.52	1.44	3.12
6	16.05	11.67	20.02	24.14	2.79	1.15	3.42
8	15.92	11.64	20.23	24.29	3.14	0.76	3.79
10	15.90	11.64	20.29	24.63	3.71	0.14	4.36
12	15.84	11.63	20.43	24.67	4.07	19.74	4.74
14	15.72	11.63	20.54	24.86	4.51	19.21	5.18
16	15.70	11.60	20.64	0.02	4.85	18.92	5.51
18	15.63	11.59	20.93	0.33	5.57	18.11	6.25
20	15.55	11.59	20.99	0.37	6.10	17.60	6.74
24	FAILURE LOAD						

Table 7

DEFLECTION (Plain timber)			
LOAD (KN)	1	2	3
0	3.85	5.11	3.53
2	4.90	4.00	4.65
4	5.91	2.87	5.62
6	6.81	1.88	6.47
8	7.50	1.04	7.17
10	8.50	19.90	8.17
12	9.38	18.95	9.02
14	9.92	18.18	9.58
16	10.89	17.15	10.52
18	11.89	16.02	11.05
20	12.40	15.45	12.02
22	12.89	14.91	12.50
24	14.33	13.27	13.93
26	15.10	12.38	14.71
28	16.18	11.15	15.78
44KN	FAILURE LOAD		

COST ANALYSIS
(As at June 1995)

Table 9

DESCRIPTION	UNIT	QUANTITTY	RATE	AMOUNT
Reinforced Concrete Beam				
A. 0.23 x 0.45 x 4m Concrete of grade 30,allowing for waste and bulking 50%	m3	0.626	2,200.00	1,377.20
B. Y16 bars (main reinforcement)	kg	26.22	31.20	818.06
C. R12 bars (Stirrups)	kg	10.48	22.72	238.21
D. Y12 (Norminal bars)	kg	7.89	28.00	220.92
				2654.39
E. Add 20% labour Cost of production				530.88
TOTAL COST				3185.27
Encased Timber Beam				
A. Grade 30 concrete allowing 50% for waste and bulking	m3	0.326	2,200.00	718.08
B. R6 (construction reinforcement)	kg	797	22.32	177.89
C. 3" x 6" mahogany timber (air dried) length 4m		2 No.	200.00	400.00
D. 2" x 12" mahogany timber (air dried) length 4m		2 No.	350.00	700.00
E. 'cascamite' glue (W.B.P)	Litres	4	60.00	240.00
				2,235.97
F. Add 30% labour cost				670.79
TOTAL COST				2,906.76

$$\% \text{ Cost savings} = \frac{(3185.27 - 2906.76)}{2906.76} \times 100\%$$

$$= \frac{278.51}{290.76} \times 100\%$$

$$= \underline{\underline{9.58\%}}$$

There is therefore a Cost reduction of 9.58% for the prototype Encased timber beam against that for the prototype Reinforced Concrete beam.

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