Structural Analysis III

Structural Analysis Laboratories

2008/9

Dr. Colin Caprani,

Contents

1. Introduction

1.1 Outline

The ability to 'see' and interpret structural behaviour is a core ability of a structural engineer. As is pointed out in the *Course Introduction* to *Structural Analysis III*, this ability reduces errors both in design practice but also whilst in college. These laboratories have the aim of improving the natural structural intuition you already have. This should:

- Enable you to practice better as a structural engineer;
- Quicken your ability to learn whilst in college, since you will already 'see' the answer and will therefore make fewer errors in calculations.

These labs will probably be the only time in your career that you will get to examine structural behaviour with clarity and good background explanation. Enjoy it!

Important!

It is unfortunate that this note is required, but here it is. The work that is submitted for these laboratories must be your own work. It cannot be copied from others (classmates or wider). Either intentionally, or unintentionally, passing off others' work as your own is plagiarism. Please read the DIT Policy on Plagiarism on the web at http://www.dit.ie/media/documents/campuslife/plagiarism.doc. In any case, it is in your own educational best interest to complete the requirements of these laboratories.

1.2 Programme

The laboratory programme is as follows:

Week	Date	Group(s)	Laboratory
1	22/9/08	All	Session 1 Commences
2	29/9/08	All	Session 1
3	6/10/08	All	Session 1 – Step 1 & 2 Deliverable at 4pm
4	13/10/08	All	Session 1 – Step 3 Deliverable at 4pm
5	20/10/08	A	Session 1 – Final Deliverable at 2pm Session 2
6	27/10/08		
7	3/11/08	B	Session 2
8	10/11/08	C	Session 2
9	17/11/08	D	Session 2
10	24/11/08	All	Session 3 Commences
11	1/12/08	All	
12	8/12/08	All	
13	15/12/08	All	Session 3 – Final Deliverable

1.3 Reading Material

Some good books on structural behaviour are:

- Brohn, D., *Understanding Structural Analysis*, 4th Edn., New Paradigm Solutions, 2005.
- Jennings, A., *Structures: from theory to practice*, Spon Press, 2004.
- Ji, T., and Bell, A., *Seeing and Touching Structural Concepts*, Taylor & Francis, 2008.
- Hilson, B., *Basic Structural Behaviour: Understanding Structures from Models*, Thomas Telford, 1993.
- Pippard, A.J.S., *The Experimental Study of Structures*, Edward Arnold & Co., London, 1947.
- I.Struct.E., *Qualitative Analysis of Structures*, London, 1989.

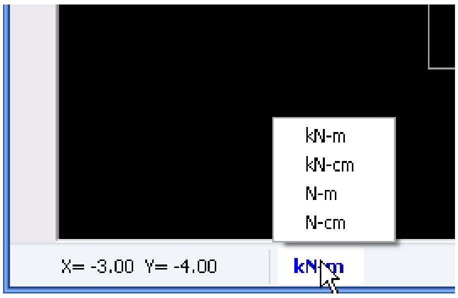
1.4 Software

You will be required to model the structures using a appropriate computer program. Most structural analysis programs today are extremely complex with many options and capabilities. This can often obscure the modelling process. An appropriate program (for a few reasons) is *LinPro* – freely available from www.line.co.ba. You should install *LinPro* on your own computer. Also, it is installed on the computers in Rm 392.

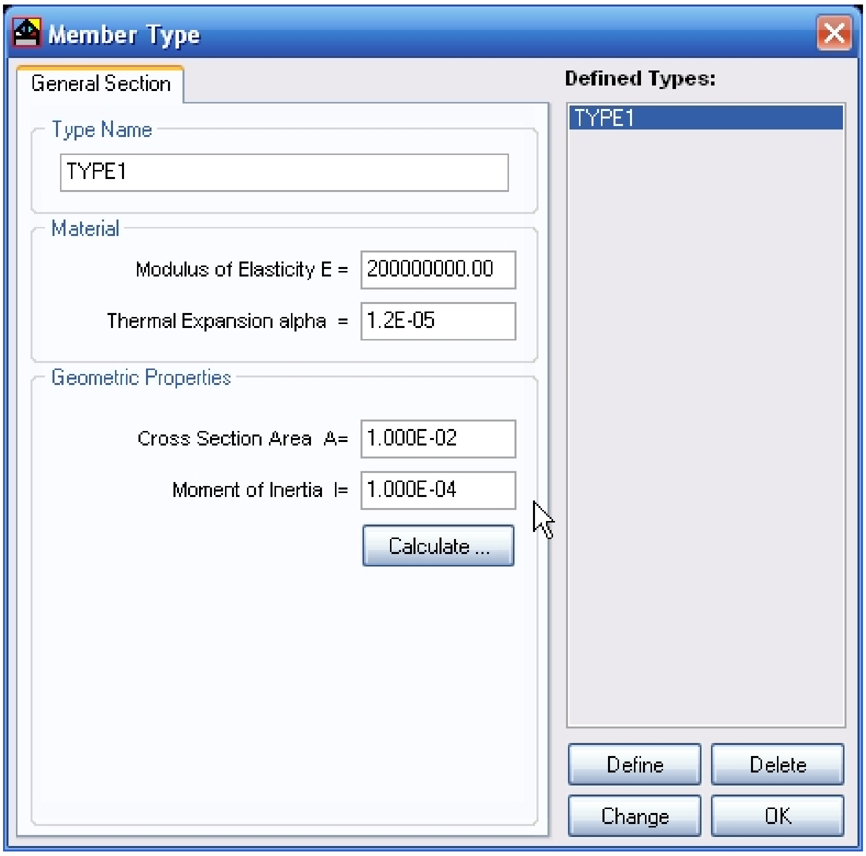
The program is intuitive to use and comes with a reasonable help file. If you have any difficulties using the program, please ask the lecturer.

A Note on Units

When using software you must be extremely careful with units. *LinPro* defaults to the units kN and m. Check it is set on these units at the bottom left of the *LinPro* screen, as shown here:



Once it is set on these units, you must consider the member properties in these units also. From the screen shot you can see the values *LinPro* defaults to:



Modulus of Elasticity, *E*:

Taking the material to be mild steel, we must calculate the value to enter into *LinPro* as follows:

$$200\ \text{kN/mm}^2 = 200\times10^6\ \text{kN/m}^2 = 200,000,000\ \text{kN/m}^2$$

and this is what appears above.

Cross Sectional Area, *A*:

The value above represents:

$$1.0\times10^{-2}\ \text{m}^2 = 0.02\ \text{m}^2 = 0.02\times10^6\ \text{mm}^2 = 20,000\ \text{mm}^2$$

Second Moment of Area, *I*:

The value above represents:

$$1.0\times10^{-4}\ \text{m}^4 = 1.0\times10^{-4}\times10^{12}\,\text{mm}^4 = 1\times10^8\ \text{mm}^4$$

In more usual units:

$$1\times10^8\ \text{mm}^4 = 1\times10^8 \div 10^4\ \text{cm}^4 = 1\times10^4\ \text{cm}^4 = 10,000\ \text{cm}^4$$

Flexural Rigidity, *EI*:

Often we want to achieve a certain value of *EI*, say $EI = 40\times10^3\ \text{kNm}^2$. It’s usually easiest to leave the *LinPro E*-value as it is. The default *EI* value of *LinPro* is:

$$\begin{aligned} EI &= 200\times10^6\ \text{kN/m}^2\ \times\ 1\times10^{-4}\ \text{m}^4 \\ &= 200\times10^2\ \text{kNm}^2 \\ &= 20\times10^3\ \text{kNm}^2 \end{aligned}$$

So to get our desired value of $EI = 40\times10^3\ \text{kNm}^2$, we will just double the *I*-value to $2\times10^{-4}\ \text{m}^4$. For any other value of *EI* we just scale the *I*-value similarly.

2. Session 1 - Qualitative Analysis

2.1 Introduction

This lab aims to develop structural intuition. We will examine a range of structures as follows:

1. We will analyse the structures 'by hand' and make notes on the solutions and the thought process that led to them;
2. We will construct physical models of the structures and examine their actual behaviour;
3. We will analyse the structures using *LinPro*;
4. We will compare the three sets of results, verifying that the computer and physical model agree, and using this to hone our intuition from the first step.

Important! Be honest about your first results and thought process for Step 1 above. This will better help you develop your abilities, since you will eliminate mis-understandings through the use of the model and computer. The marks for this lab are not awarded for 'getting everything right', but for demonstrating the development of your understanding through the use of the physical models and computer analysis.

This lab is run over four weeks. Each week you have a deliverable for sign off by the lecturer. This is to ensure an even workload across the four weeks, and the correct sequence of work.

Each week Rm 171 is available to work in. It is ideal for constructing your model. The computers in Rm 392 have *LinPro* and you can work on these. For groups/students requiring some help with the analyses, we can arrange a classroom. The lecturer will move between these locations.

2.2 Procedure

Step 1: Qualitatively analyse the structures (4pm Monday 6 October 2008)

Analyse each of the 20 structures 'by hand'. In order words, predict how the structure is going to behave, before you see a model of it. This must be completed by the date and time above. On this date, you are required to show your workings to the lecturer.

Step 2: Build your model (4pm Monday 13 October 2008)

Build the mode of the structure assigned to you. Have your model ready by the date and time shown and present your model to other students for them to investigate its behaviour. Take this opportunity to investigate models of the structures that you have had difficulty solving.

Step 3: Do the computer analysis (4pm Monday 13 October 2008)

Analyse the structures using *LinPro*. It is important that you do this last, since you will have a better expectation of the outcome and this means you're more likely to catch any errors you make. You must have the results of this analysis ready to show the lecturer on the date and time shown above.

Step 4: Prepare your report (2pm, Monday 20 October 2008)

Refer to the report guidelines further on for more details. The main aim here is for you to discuss your results paying particular attention to areas in which you may have erred and in which the physical and computer models helped you correct your thinking. Your report is due on the above date and time.

Note: Groups in the Soils lab on the above dates may show their workings at 2pm or 4pm for a quick sign-off.

2.3 Qualitative Analysis Guidelines

The following are some points that will help you carry out the analyses:

- To find a support reaction, remove the restraint offered by the reaction and draw the deflected shape of the resulting structure. Apply the support reaction in such to as to bring the structure back to where it should be.
- Use *Points of Certainty* – where you know the deflected position, for example at a support the deflection is zero, and usually the structure moves away from the applied load (though there are rare exceptions).
- Remember the basic moment = force × distance. Also recall the shapes of BMD and SFD under the different types of loading (rectangular, triangular, parabolic).
- Remember, fixed supports will have a moment reaction, pinned supports will not, though there may be an external moment applied at a pinned support.
- There is zero bending moment at a hinge.
- Keep in mind: deflections are always small and we neglect the self weight of the structures – only analyse for the loads shown.
- Rigid joints in frames must keep the same angle as they rotate.
- No transverse load or end shear force on a frame member means there is constant BM along the member (constant may equal zero).
- Remember: shear is rate of change of moment.
- For unbraced frames, only symmetrical such frames symmetrically loaded will not sway.
- Members with no bending moments remain straight, but may move.
- Deflected shapes are always very smooth curves, except at a hinge.

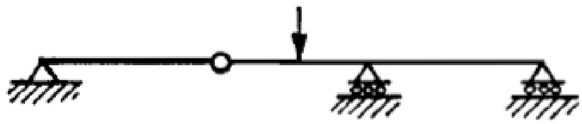
2.4 The Structures

Draw the Reactions, DSD, BMD, SFD and AFD for the following:

1

2

3



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See below for Structure 4

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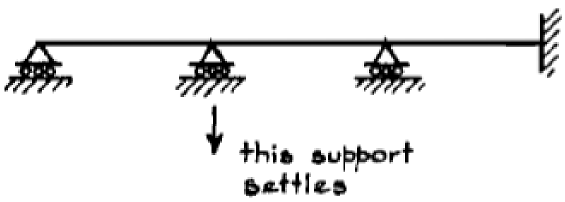

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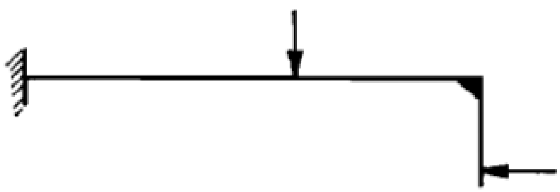

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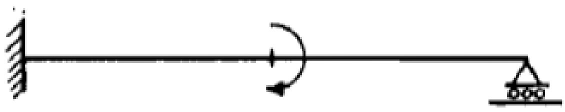

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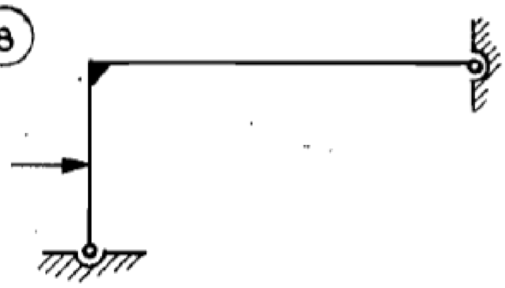

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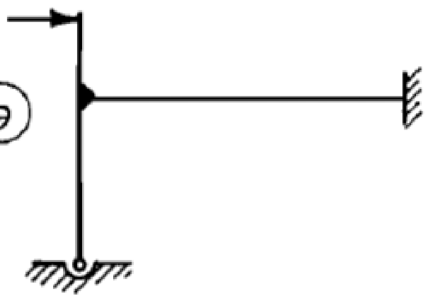

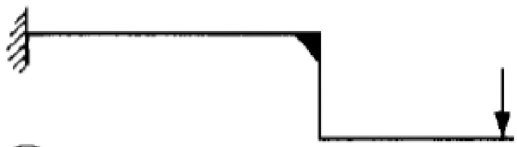

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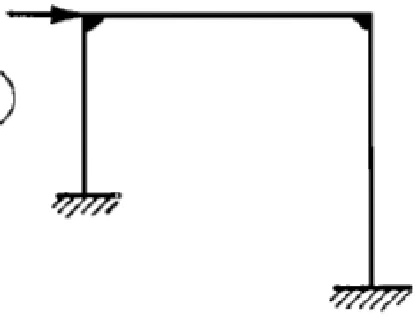

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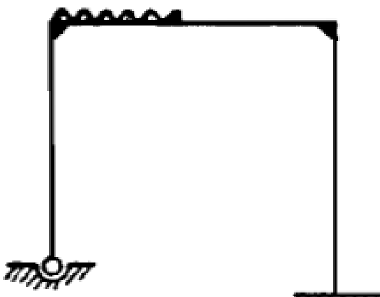

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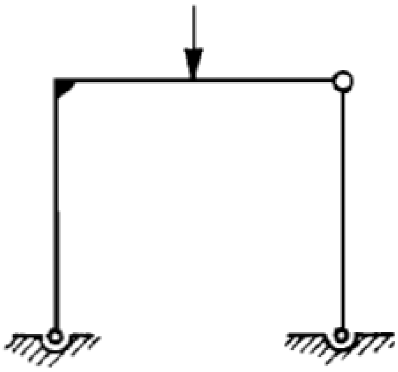

(14)

See below for Structure 14

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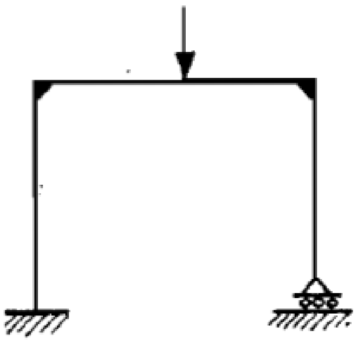
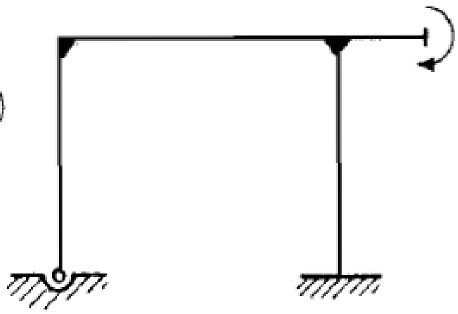


(16)

See below for Structure 16

(17)



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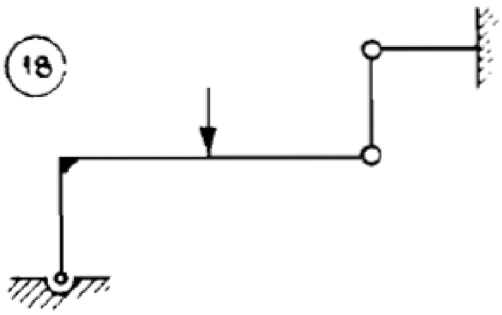

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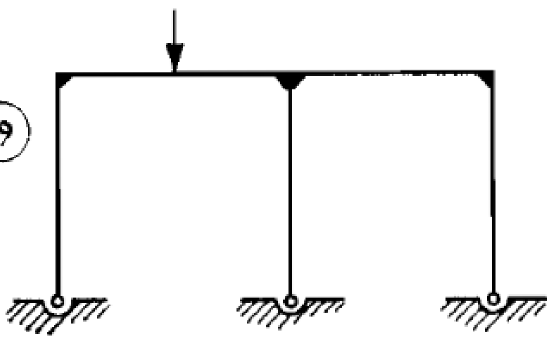

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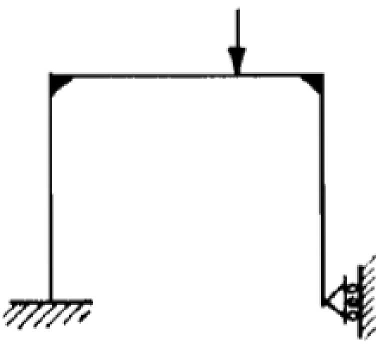
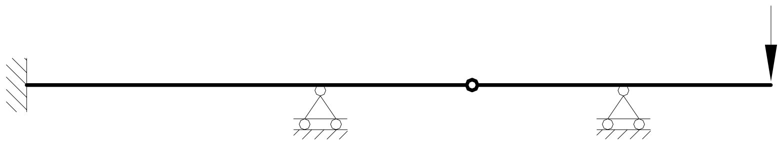
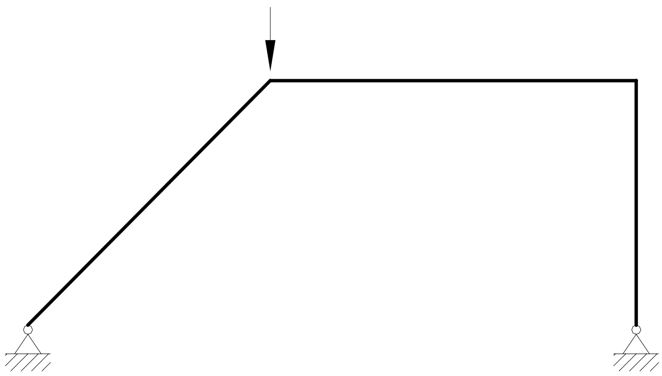
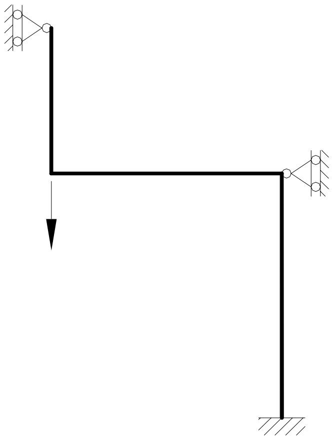




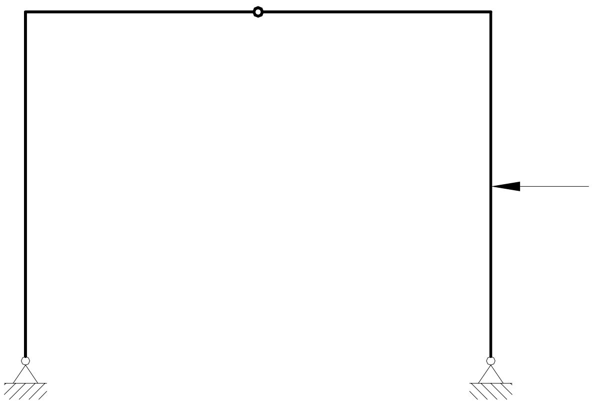
Structure 4



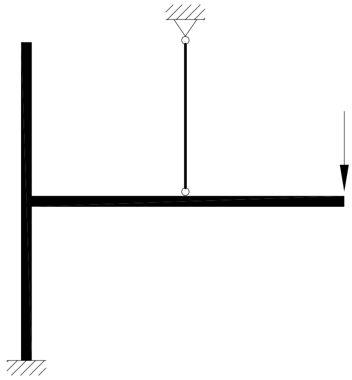
Structure 14



Structure 16

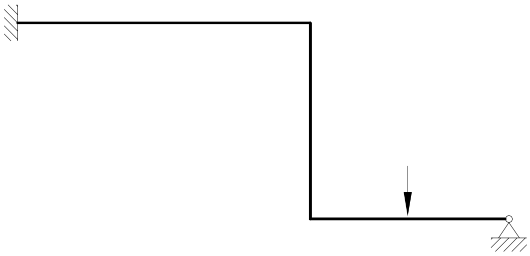


Structure 21



Structure 22

Structure 23



Structure 24

2.5 Physical Models

Requirements

You are required to construct a physical model of the structure assigned to you.

Your model must clearly demonstrate its structural behaviour by visibly deforming under 'finger load'.

In order to do this it:

- does not have to be pretty;
- must be of reasonable size;
- must have connections and supports as close as possible to their idealization;
- must be robust to withstand repeated use.

Some suggestions for materials are:

- Wardrobe fixings – these come in plastic, timber and aluminium strips which are ideal for working and model-building;
- Plastic strips and balsa wood are also useful, but may not be very robust;
- Press corners and hinges – to model rigid connections and hinge connections respectively;
- Small bolted connections with wing-nuts are useful for quick assembly and disassembly for transportation.
- Compression could be illustrated using sponge for example; tension by using an elastic band etc.

If you've any suggestions for connections/materials/supports please share them!

Assignments

The models will be built in groups of two. Each group is only required to construct a single model, as follows:

Group	Names		Structure
A	James Ashmore	Finn Courtney	1
	Killian Gallagher	Killian Mason	2
	Joseph Mears	Gavin Murphy	3
	Aidan Tighe	Peter Brady	4
	Fergal Kellett	Miriam Ryan	5
	Sean Bradley	Ian Crowley	6
B	Sean Harpur	Ciara Casserly	7
	Anthony Morris	Robert McAuliffe	8
	Thomas Vaughan	Neal Renehan	9
	Craig McDonnell	Matthew Fagan	10
	Kieran Convery	James Sutton	11
	John Breen	Kevin Doody	12
C	Jane Hennaghan	Fiach McDaid	13
	Joseph Muller	Keith Chapman	14
	Tom Nolan	Anne McKay	15
	Padraig Mullen	Oona Finn	16
	David Gibbons	Kevin O'Brien	17
	David Roche	Tommy O'Brien	18
D	Liam Corscadden	Erica Perris	19
	Oisin Doyle	Domhnall Keane	20
	Hugh McGuire	Enda Murphy	21
	David Sreenan	James Whelan	22
	Kevin Higgins	Aine McBride	23
	William Noonan	Evan Farrell	24
	Sarah Cooray	(with Noonan & Farrell)	24

2.6 Report and Model Submission

You will submit your report and model together, on the dates as per the lab schedule.

Your report will contain:

- A copy of your initial solutions to the structures;
- A brief description of your model and aspects about its behaviour that are interesting;
- A photograph of your model under load;
- Results of your computer analysis for each structure;
- A discussion on differences between your initial solutions and the physical models and computer analysis;
- A list of key points which you have learned from this lab.

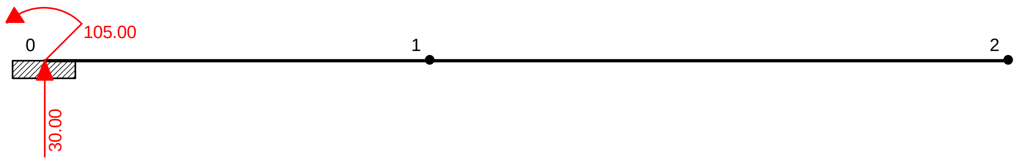
Your report is to be professionally presented. Poorly presented reports will be returned to the student to redo properly.

A sample of the results from the computer analysis follows.

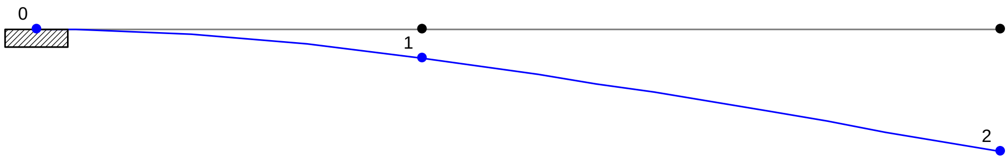
Computer Analysis – Sample Results

Note that tables of numbers are not wanted – only graphs etc – such as:

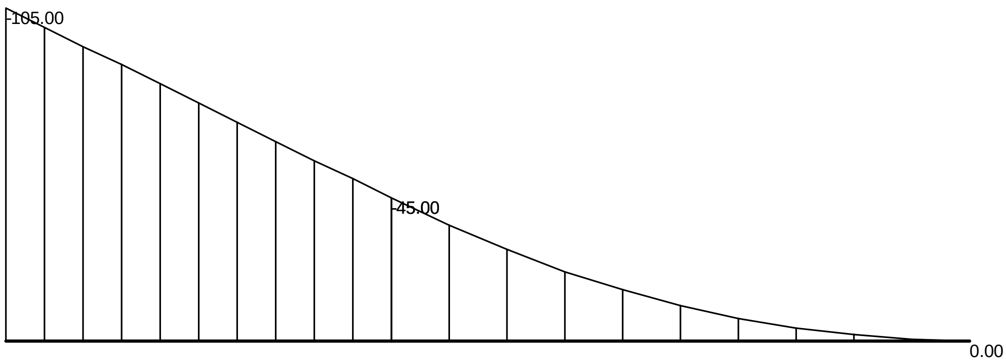
Beam and Loads



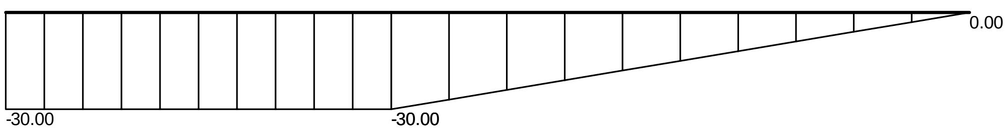
Reactions



Deflected Shape



Bending Moment Diagram



Shear Force Diagram

3. Session 2 – Deflection of Beams & Frames

3.1 Introduction

The aim of this lab is further develop your structural intuition and to link classroom activities to physical models in a quantitative way. By measuring the deflections on real structures and comparing these to theoretical calculations, it is hoped that you will begin to appreciate the limitations of our theories and also the true complexity of the real world - for it is in the real world that our structures must exist.

On a more practical note, comparison of measured deflections to both theoretical and computer-based approaches exercises the same 'muscles' as need for real-world design. It is never enough to perform one set of calculations – and by having repeated results from different sources a degree of confidence can be gained. Conversely, and of mush more benefit, is the cases where measurement and theory do not coincide. The resultant analysis of such cases usually provides far more information on the limitations of the theoretical models.

This lab is run over 4 weeks so that each group has sufficient time on the beams and frames to properly assess their behaviour.

3.2 Procedure

For this lab:

Stay with your partner for Laboratory 1

Step 1: Measure the deflections on the beams and frames

Each group has different loads and dimensions to work on. Take your time and understand the deflections of the models since you will not be able to return to them. Try to avoid the temptation to have one student call out numbers and another write them down without examining the structure. Make notes on the behaviour of the structure – for example, a support may not be quite pinned or fixed and this would affect the comparison with a theoretical model that neglects such effects.

Step 2: Calculate theoretical deflections

Calculate theoretical deflections by Mohr's Theorems and Macaulay's Method if required. Try to make the model as similar to the structural model..

Step 3: Calculate the deflections by computer analysis

Using LinPro (or equivalent) perform a computer analysis. Try to confirm your hand calculations and to approximate the actual structure – this might require two computer models.

Step 4: Compare the results and discuss

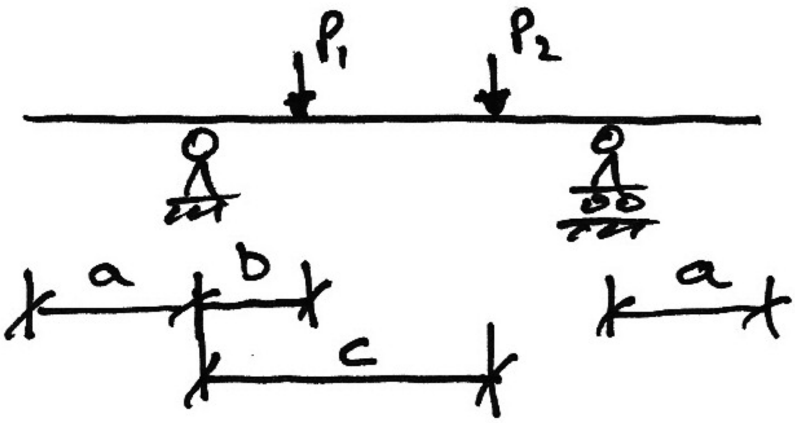
Outline the reasons for any differences between the three sources of results. Bear in mind that nature is never wrong (i.e. "the model was bad" is not a reason!). Assuming there is no mistake in the calculations or computer analysis, if results do not match it is because the model does not capture important aspects of the physical model's behaviour. You must identify these aspects – that is the job of a structural engineer.

3.3 The Structures

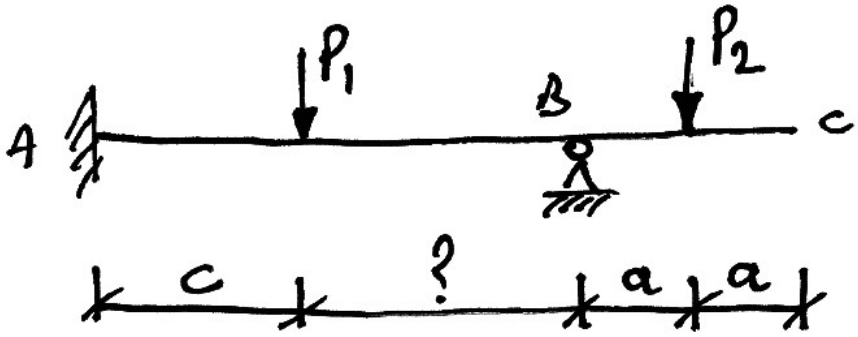
For each of the structures, determine:

- the deflection at all salient points;
- the position and magnitude of the maximum displacement (in the case of frames do this for each member);
- rotations at the ends of the members (by using deflections of overhangs);
- Sufficient measurements to verify that the load deflection curve is linear, up to the designated load;
- measurements along the members to check the validity of the hand calculations and computer model.

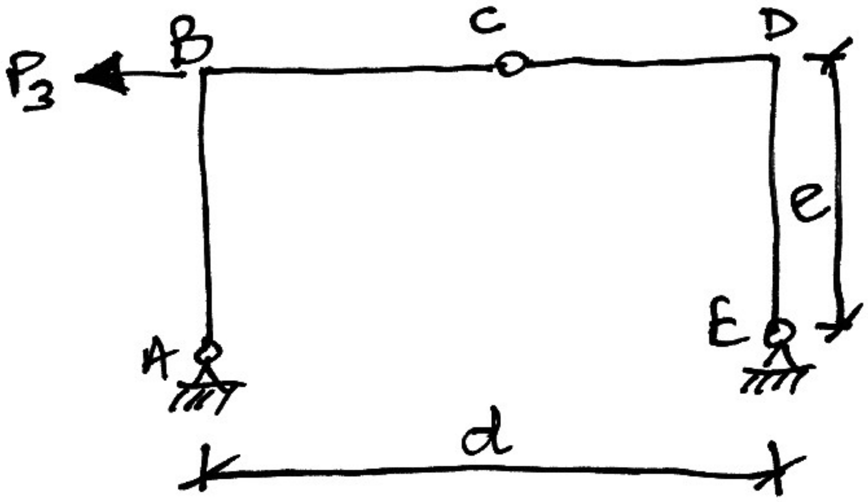
Structure 1 – Determinate Beam



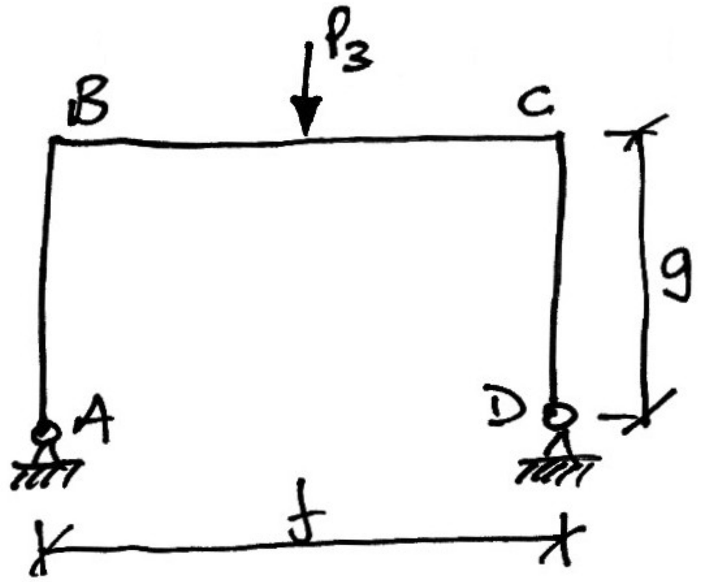
Structure 2 – Indeterminate Beam



Structure 3 – Determinate Frame



Structure 4 – Indeterminate Frame



3.4 The Variables

The loads and dimensions are varied for each group of two students as follows:

Group A

No.	**Initials**	P_1 g	P_2 g	P_3 g	a mm	b mm	c mm
1		200	0	800	100	50	250
2		250	100	750	100	60	240
3		300	200	700	100	70	230
4		350	300	650	100	80	220
5		400	400	600	100	90	210
6		450	0	550	100	110	200

Group B

No.	**Initials**	P_1 g	P_2 g	P_3 g	a mm	b mm	c mm
7		400	0	500	100	120	210
8		450	0	450	100	130	220
9		500	0	400	100	140	230
10		550	0	800	100	150	240
11		600	0	750	100	50	250
12		650	0	700	100	60	260

Group C

No.	**Initials**	P_1 g	P_2 g	P_3 g	a mm	b mm	c mm
13		200	200	650	100	70	270
14		250	300	600	100	80	280
15		300	400	550	100	90	290
16		350	0	500	100	110	300
17		400	100	450	100	120	310
18		450	200	400	100	130	320

Group D

No.	**Initials**	P_1 g	P_2 g	P_3 g	a mm	b mm	c mm
19		350	400	800	100	140	330
20		400	0	750	100	150	340
21		450	100	700	100	50	350
22		200	200	650	100	60	250
23		250	300	600	100	70	260
24		300	400	550	100	80	270
25		350	0	500	100	90	280
26		400	100	450	100	100	290
27		450	200	400	100	110	300

3.5 Report

Dates

You will submit a report of your work one week after your lab. Thus:

- Group A: Monday, 3 November, 2pm;
- Group B: Monday, 10 November, 2pm;
- Group C: Monday, 17 November, 2pm;
- Group D: Monday, 24 November, 2pm.

Report

The report will be concise and professionally presented. Poorly presented, incomplete or verbose reports will be returned to the student to redo. For each structure, your report will contain:

- A plot of the measured deflected profile;
- A plot showing the hand calculation profile;
- A plot showing the LinPro deflections;
- A plot showing the profiles for comparison;
- Your hand calculations;
- The computer analysis results;
- A discussion of the results.

A load deflection curve should also be drawn for each structure to check that its behaviour is linear, as is assumed in each of the hand and computer calculations.

Please include any other such comparison or calculation as may be appropriate to properly compare the theoretical and physical models.