

Structural Analysis III
Qualitative Analysis

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1. Introduction

1.1 Background

The ability to ‘see’ and interpret structural behaviour is a core ability of a structural engineer. At the initial stage of a structural scheme design, we are not interested in numbers, or amounts, only the sense of a load effect. Some examples of what we mean by sense are:

- Is there tension on the top or bottom of a beam?
- Does the tip of a cantilever deflect up or down?
- Is the moment reaction clockwise or anti-clockwise?

Getting this level of analysis right is not only the first step, but the most important step. If we don’t get this level right, then the answers to a more complicated analysis will be meaningless.

The ability to get the right answers to this level is called *Structural Intuition*. The better your structural intuition, the better you will be a designer. This ability reduces errors both in design practice but also whilst in college: since you will already ‘see’ the answer it is easier to catch errors in calculations.

1.2 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.

Due to its importance, the Ove Arup Foundation sponsored the report: *The Teaching of Structural Analysis* by Prof. Ian May and Dr. David Johnson. It is accessible here: <http://www.jbm.org.uk/uploads/StructuralAnalysiswithCover.pdf>.

A summarized version of the report appeared in *The Structural Engineer*, Vol.81, No.7, 2003, p.33-37, available at this link:

<http://www.istructe.org/thestructuralengineer/Abstract.asp?PID=7904>

1.3 Software

In developing your structural intuition, it is very helpful to model structures using an appropriate computer program – especially when the structure behaves counter-intuitively. Most structural analysis programs today are extremely complex with many options and capabilities and 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.

2. Methods in Qualitative Analysis

2.1 Main Points

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 a way 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 \times 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.

3. Problems

3.1 Introduction

There is no better way to learn qualitative analysis than by practice. So here follows a good variety of determinate and indeterminate structures for analysis.

For each of the following structures, determine the:

- Reactions;
- Bending moment diagram;
- Shear force diagram;
- Axial force diagram;
- Deflected shape.

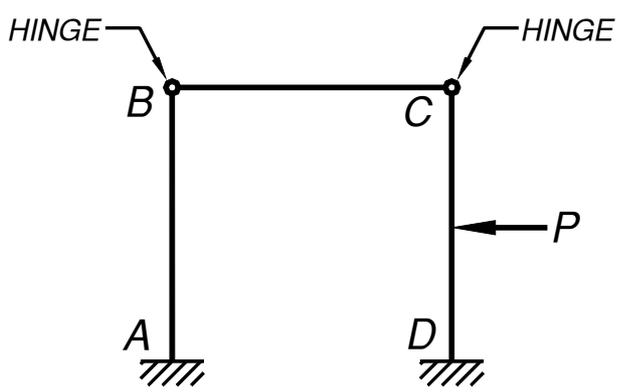
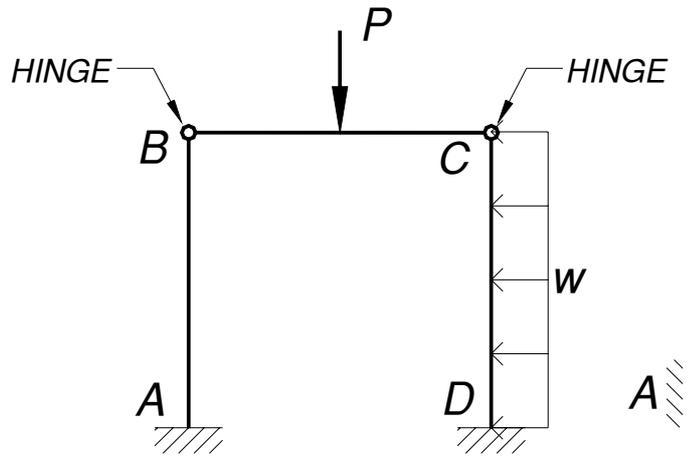
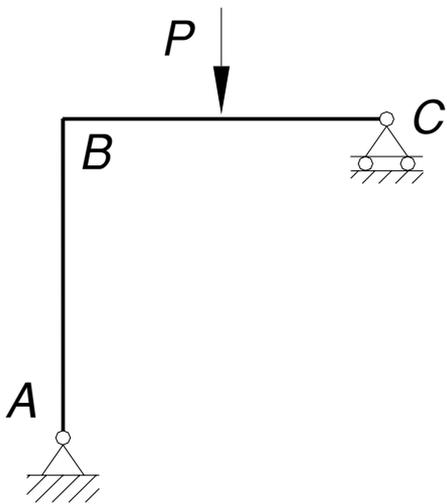
3.2 Statically Determine Beams

1	<p>Diagram 1: A beam with a fixed support at A, a hinge at B, a roller support at C, and a point load P at D.</p>
2	<p>Diagram 2: A beam with a pin support at A, a hinge at B, a roller support at C, and a pin support at D. A uniformly distributed load W is applied between A and B.</p>
3	<p>Diagram 3: A beam with a fixed support at A, a hinge at B, a roller support at C, and a clockwise moment M at D.</p>
4	<p>Diagram 4: A beam with a fixed support at A, a hinge at B, a roller support at C, and a point load P between B and C.</p>
5	<p>Diagram 5: A beam with a fixed support at A, hinges at B and D, roller supports at C and E, and a point load P at F.</p>
6	<p>Diagram 6: A beam with a fixed support at A, hinges at B and C, and a fixed support at D. A uniformly distributed load is applied between B and C.</p>
7	<p>Diagram 7: A beam with a fixed support at A, hinges at B and D, a roller support at C, a point load P between C and D, and a roller support at E.</p>

8	<p>Diagram 8: A beam with a pin support at A, a hinge at B, a roller support at C, and a roller support at D. A uniformly distributed load W is applied between A and C.</p>
9	<p>Diagram 9: A beam with a pin support at A, a roller support at B, a hinge at C, a roller support at D, and a pin support at E. A uniformly distributed load W is applied between A and C.</p>
10	<p>Diagram 10: A beam with a fixed support at A, a hinge at B, a roller support at C, and a free end at D. A concentrated moment M is applied at D.</p>
11	<p>Diagram 11: A beam with a fixed support at A, a hinge at B, and a roller support at C. A uniformly distributed load is applied between B and C.</p>

3.3 Statically Determinate Frames

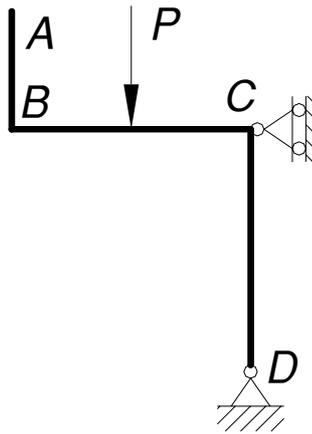
12	<p>Diagram 12: A frame structure with a fixed support at A. A vertical member AB is connected to a horizontal member BC at B. A hinge is located at B. A horizontal force P is applied at C, pointing to the left. A roller support is located at D, which is horizontally aligned with B. The label "HINGE" points to the joint at B.</p>
13	<p>Diagram 13: A frame structure with a roller support at A. A horizontal member AB is connected to a vertical member BC at B. A horizontal force P is applied at A, pointing to the right. A hinge is located at D on the vertical member BC. A fixed support is located at E at the bottom of the vertical member. The label "HINGE" points to the joint at D.</p>
14	<p>Diagram 14: A frame structure with a horizontal force P applied at A, pointing to the right. A vertical member AB is connected to a horizontal member BC at B. A roller support is located at C. A fixed support is located at D at the bottom of the vertical member CD.</p>

<p>15</p>	 <p>Diagram of a rectangular frame with hinges at joints B and C. The frame has fixed supports at joints A and D. A horizontal force P is applied to the right at joint C.</p>
<p>16</p>	 <p>Diagram of a rectangular frame with hinges at joints B and C. The frame has fixed supports at joints A and D. A vertical force P is applied downwards at joint C. A uniformly distributed horizontal load W is applied to the right along the entire length of the right vertical member CD.</p>
<p>17</p>	 <p>Diagram of an L-shaped frame with a pin support at joint A and a roller support at joint C. A vertical force P is applied downwards at joint B.</p>

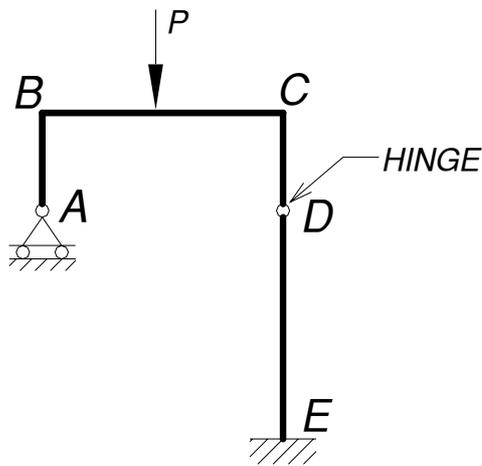
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<p>21</p>	<p>Diagram 21: A frame structure. It has a pin support at point A. A horizontal force P is applied at point A, pointing to the right. The structure consists of a vertical member AB, a horizontal member BC, and a roller support at point C.</p>
<p>22</p>	<p>Diagram 22: A frame structure. It has a pin support at point A. A horizontal force P is applied at point B, pointing to the left. A vertical force P is applied at point C, pointing downwards. The structure consists of a vertical member AB, a horizontal member BC, and a roller support at point D.</p>
<p>23</p>	<p>Diagram 23: A frame structure. It has a pin support at point A. A hinge is located at point B. A roller support is located at point C. A vertical force P is applied at point D, pointing downwards. The structure consists of a diagonal member AB, a horizontal member BC, and a horizontal member CD.</p>

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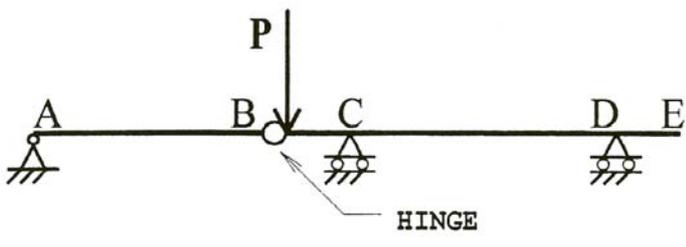
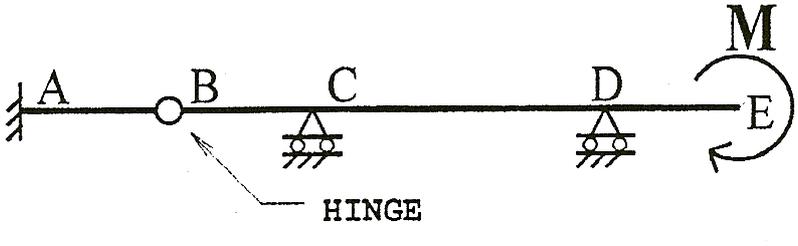


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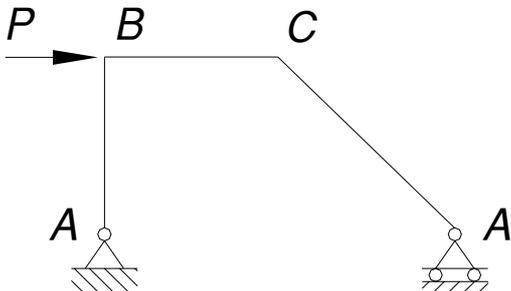
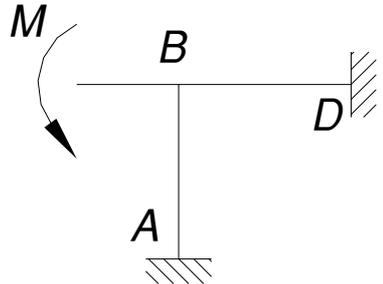
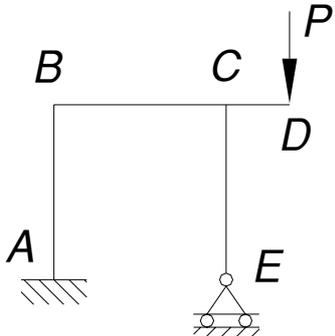
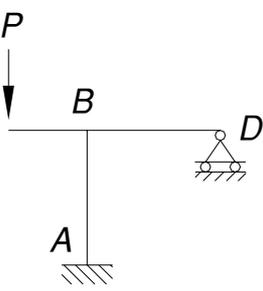


3.4 Statically Indeterminate Beams

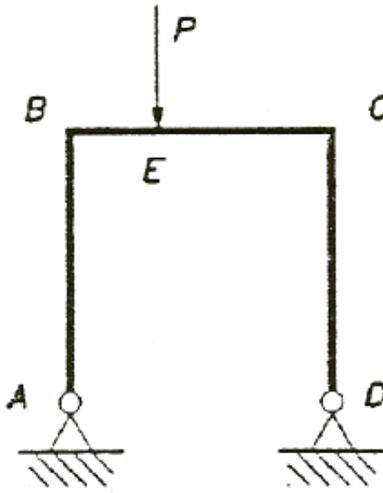
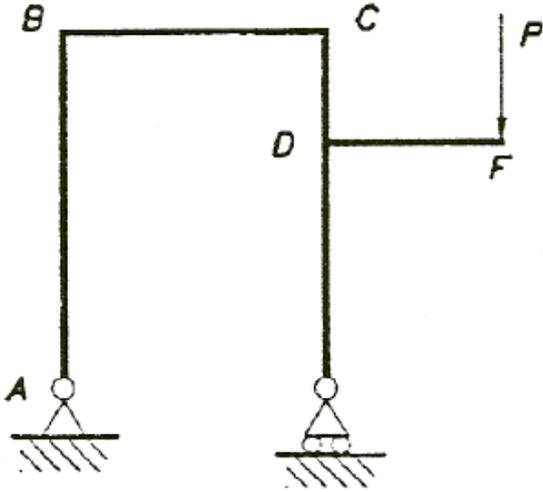
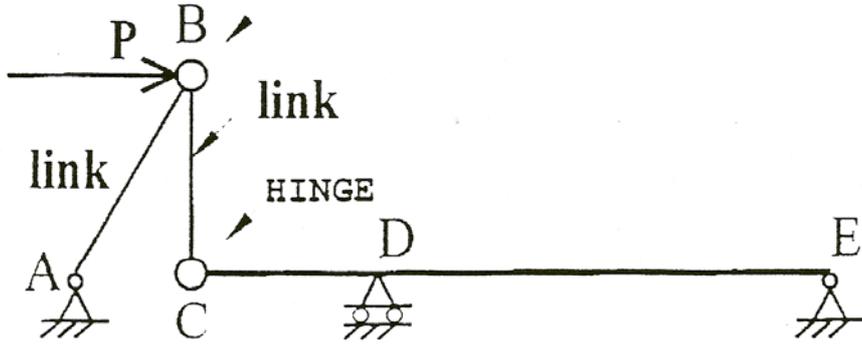
26	<p>Diagram 26: A beam with a fixed support at A, roller supports at B and C, a hinge at D, and a roller support at F. A downward point load P is applied at E.</p>
27	<p>Diagram 27: A beam with a fixed support at A, a hinge at B, a roller support at C, a downward point load P at D, a hinge at E, a roller support at F, and a free end at G.</p>
28	<p>Diagram 28: A beam with a fixed support at A, roller supports at B and C, and a downward point load P at D.</p>
29	<p>Diagram 29: A beam with a fixed support at A, roller supports at B and F, hinges at C and E, a downward point load P at D, and a roller support at G.</p>
30	<p>Diagram 30: A beam with a fixed support at A, a hinge at B, a roller support at C, a roller support at D, and a clockwise moment M at E.</p>

31	 <p>A horizontal beam is shown with points A, B, C, D, and E marked along its length. At point A, there is a fixed support. At point B, there is a hinge, and a downward vertical load P is applied. At point C, there is a roller support. At point D, there is another roller support. The end of the beam is at point E. An arrow points from the word "HINGE" to the hinge at point B.</p>
32	 <p>A horizontal beam is shown with points A, B, C, D, and E marked along its length. At point A, there is a fixed support. At point B, there is a hinge. At point C, there is a roller support. At point D, there is another roller support. At point E, there is a clockwise moment M applied. An arrow points from the word "HINGE" to the hinge at point B.</p>

3.5 Statically Indeterminate Frames

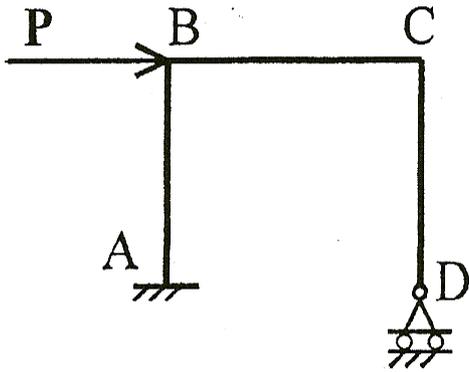
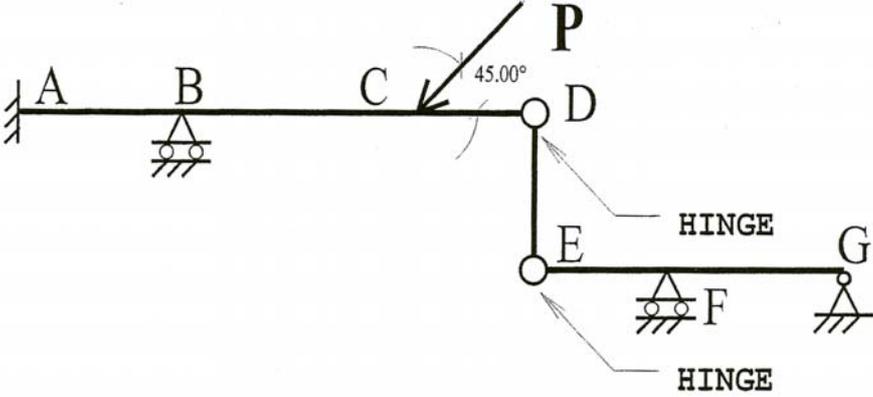
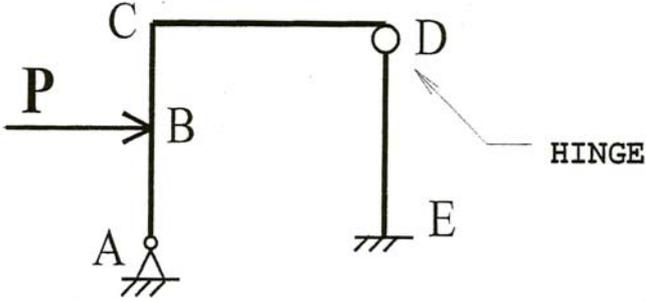
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<p>41</p>	 <p>A portal frame structure with pin supports at joints A and D. The frame consists of vertical members AB and CD, and a horizontal beam BC. A vertical load P is applied downwards at the midpoint E of the beam BC.</p>
<p>42</p>	 <p>A portal frame structure with pin supports at joints A and D. The frame consists of vertical members AB and CD, and a horizontal beam BC. A horizontal load F is applied to the right at joint D, with a vertical force P acting downwards at the same point.</p>
<p>43</p>	 <p>A mechanism consisting of three links: link AB, link BC, and link CD. Link AB is a diagonal member with a pin support at A and a roller support at B. Link BC is a vertical member with a pin support at C and a roller support at B. Link CD is a horizontal member with a roller support at D and a pin support at E. A horizontal force P is applied to the right at joint B. A hinge is located at joint D. The labels 'link' and 'HINGE' are used to identify the members and the joint respectively.</p>

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<p>47</p>	<p>The diagram shows a frame structure. It starts with a fixed support at point A. A vertical member AB goes up to point B. From B, a horizontal member BC goes to the right to point C. At point C, there is a hinge, indicated by a small circle and a dashed line labeled "HINGE". From C, a horizontal member CD goes to the right to point D. At point D, there is a vertical downward load P. From D, a horizontal member DE goes to the right to point E. At point E, there is a roller support. The label "HINGE" is written below the structure with a dashed line pointing to the hinge at C.</p>
<p>48</p>	<p>The diagram shows a frame structure. It starts with a roller support at point A. A vertical member AB goes up to point B. From B, a horizontal member BC goes to the right to point C. From C, a vertical member CE goes down to point E, which is a fixed support. From C, a horizontal member CD goes to the right to point D. At point D, there is a vertical downward load P.</p>
<p>49</p>	<p>The diagram shows a frame structure. It starts with a roller support at point A. A member AB goes up and to the right to point B. From B, a horizontal member BC goes to the right to point C. At point C, there is a vertical downward load P. From C, a horizontal member CD goes to the right to point D. At point D, there is a roller support.</p>

<p>50</p>	 <p>A frame structure consisting of a horizontal member BC and a vertical member CD. Support A is a fixed support at the bottom of member AB. Support D is a roller support at the bottom of member CD. A horizontal force P is applied at joint B, pointing to the right.</p>
<p>51</p>	 <p>A frame structure consisting of a horizontal member AD and a vertical member DE. Support A is a fixed support at the left end of member AD. Support B is a roller support on member AD. Support F is a roller support on member EG. Support G is a roller support at the right end of member EG. A force P is applied at joint D, acting at an angle of 45.00 degrees to the horizontal member AD. Hinges are located at joints D and E.</p>
<p>52</p>	 <p>A frame structure consisting of a vertical member AB, a horizontal member BC, and a vertical member CD. Support A is a fixed support at the bottom of member AB. Support E is a fixed support at the bottom of member CD. A horizontal force P is applied at joint B, pointing to the right. A hinge is located at joint D.</p>