BUILDING AND STRUCTURAL CONSTRUCTION

N6

Building and Structural Construction

Lecturer Guide

EAY Ebrahim

Additional resource material for this title includes:

- **Electronic Lecturer Guide**
- **Exemplar examination paper memos**
- **PowerPoint presentation**
- **Past exam papers**

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Dedication

This book is dedicated to my four grandchildren as well as all the students who have attended my classes.

Acknowledgements

A very special thanks to Danny Mitchell – for your friendship, guidance and assistance during my early years of teaching. Without you, I would never have been able to teach this subject.

A very special thanks to Alfred Ramahlape – for your assistance in some of the difficult parts, for the encouragement and calculations. You remain a sincere and good friend.

Contents

Introduction

This syllabus is specifically designed for the TVET college system. It is a continuation of the N5 system and concludes the building sciences regarding the design of reinforced concrete structural elements.

This syllabus is also the culmination of all the work between N1 to N3 Building Science, N4 and N5 Building and Structural Construction and some elements from N3 Building Drawing where reinforced steel was introduced.

Students will be pleased to know that the final examination and class tests will all be open-book exams. They will be allowed into the exam room with their subject files and notes, as well as all the required Codes of Practices for referencing. A BOE8/2 Hot-rolled structural steel section red book will be issued to them. However, NO past question papers and marking guidelines (memos) will be allowed in the exam room.

Students should not be fooled by an open-book exam – it could become very confusing to write the exam while searching through their notes.

Here are some solutions:

- Encourage your learners to prepare from day one, ie. the beginning of the semester.
- I suggest using a well-organised lever arch file.
- They should neatly rewrite all exercises on single-sided exam pad pages – one exercise at a time, and then number the pages and clip them together. They should keep all the same types of exercises together, eg. all concrete beams, then the slabs, then the columns, etc.
- With the final examination being an open-book exam and class test, they should create a column on the right-hand side of their exam pad page to write their OWN personal notes, eg. how to use the calculator when doing tricky calculations or anything of significance. This will be less time-consuming as they only have FOUR hours to sit for the exam.
- Students should copy ALL the relevant tables and keep it at the front of their files.

Always remember that as an educator, you are the students' main source of information and they will draw on your knowledge and experience. The Student Book remains a learning resource for them and does not replace a lecturer.

You are encouraged to work through the calculations yourself and ensure that you understand the answers so that you can explain these processes to your classes.

We wish you well and trust that you will enjoy teaching this course and guiding your students to success.

EAY Ebrahim

Lecturer Guidance

1. General aims

To provide students with knowledge and skills that is used for structural design in the construction industry.

2. Specific aims

2.1 Students should obtain thorough background knowledge of the theory and methodology as applied in Building and Structural Construction.

2.2 The teaching of this subject is aimed at introducing the student to the application of technological principles and practices in the building and structural construction industry.

3. Prerequisites

The student must have a N5 certificate in Civil Engineering.

4. Duration

Full-time: 7.5 hours per week. This instructional offering may also be offered part-time.

5. Evaluation

5.1 Evaluation is conducted continuously by means of two formal tests at college level. Learner must obtain a minimum ICASS mark of at least 40% in order to qualify to write the final examination and a mark will be calculated together in a ratio of 40:60 to derive the promotion mark. The learner must obtain at least 40% on the final examination.
The promotion mark will be calculated as follows:
Promotion mark = **40%** of (ICASS mark) **+ 60%** of (exam mark)

5.2 Examination
The open-book examination in N6 Building and Structural Construction (Engineering Studies – Report 191) will be conducted as follows:
Modules 1 to 3:
Marks: 100
Duration: 4 hours

Items permitted in the open-book examination are as follows:

- Students' subject files/notes may be brought into the exam room (**No past question papers and marking guidelines are allowed**)
- A normal A4 answer book MUST be provided to students.
- Non-programmable scientific calculators may be used.
- The following addenda:
  - Schedule A: Cross-sectional area of reinforced rods for beams and columns
  - Schedule B: Cross-sectional area of reinforced rods per metre width for slabs and staircases
  - Schedule C: Isometric black hexagonal bolts and nuts
- Students are allowed to bring the following Codes of Practices for referencing into the exam room.
  - SABS 0100-1:1992
  - SABS 0100–2:1992
  - SABS 0162-1:1993
  - SABS 0144:1995
  - SABS 0162–3 1984
  - SABS 0144-1978
  - SANS 10100-1:2000
- For steel design work, the recognised tables may be used by making reference to the BOE8/2 Hot-rolled Structural Steel Sections as issued by National Examinations.

5.3 Weighting

The following weights are consequently awarded to each category:

Knowledge and understanding	Application	Analysis/synthesis and evaluation
5–10%	10–20%	10–80%

6. Learning content

THEORETICAL BACKGROUND

It is essential that this subject introduces students to basic principles applicable to different sections of building and structural construction before working through a typical design.

TECHNICAL BACKGROUND

It is essential that this subject should be illustrated and evaluated within the context of concrete and steel structural design work.

Note

Lecturers MUST make references to the following:

- Standard Building Regulation (Act 103 of 1977) as printed from Government Gazette and all amendments made to date;
- Codes of Practices when teaching:
    - SABS 0100-1:1992
    - SABS 0100–2:1992
    - SABS 0162-1:1993
    - SABS 0144:1995
    - SABS 0162–3 1984
    - SABS 0144-1978
    - SANS 10100-1:2000;
  - The following schedules:
    - Schedule A: Cross-Sectional area of reinforced rods for beams and columns
    - Schedule B: Cross-Sectional area of reinforced rods per metre width for slabs and staircases
    - Schedule C: Isometric black hexagonal bolts and nuts for steel roof truss calculations;
  - BOE8/2 Hot-rolled Structural Steel Sections (red book) for steel design work.

7. Mark allocation and weighted value of modules

MODULES	WEIGHTING (%)
1. Concrete	50
2. The bending schedule	5
3. Iron and steel	45
Total	**100**

8. Work schedule

Week	Topic	Content	Exercises	Hours
1–5	**Module 1** Concrete	1.1 Concrete materials 1.2 Reinforced concrete beam design 1.3 Rectangular reinforced concrete beam design 1.4 One-way or unidirectional reinforced concrete slabs 1.5 Flanged T-beams of reinforced concrete 1.6 Flanged L-beams of reinforced concrete 1.7 Reinforced concrete column design 1.8 Reinforced concrete staircases	Exercise 1.1 Exercise 1.2 Exercise 1.3 Exercise 1.4 Exercise 1.5 Exercise 1.6 Exercise 1.7 Exercise 1.8	50 hours
6	**Module 2** The bending schedule	2.1 Structural detailing	Exercise 2.1	5 hours
6–10	**Module 3** Iron and steel	3.1 Materials 3.2 Binding joints 3.3 Roof frame connection joints 3.4 Welding connections 3.5 Steel beams 3.6 Steel columns 3.7 Eccentric-loaded beam connections	Exercise 3.1 Exercise 3.2 Exercise 3.3 Exercise 3.4 Exercise 3.5 Exercise 3.6 Exercise 3.7 Exercise 3.8 Exercise 3.9	45 hours
TOTAL				**±100 hours**

9. Lesson plan template

Subject and level	N6 Building and Structural Construction
Prescribed textbook (Title and author)	*N6 Building and Structural Construction* by EAY Ebrahim

<table>
<tr><th colspan="7">WEEK 1</th></tr>
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WEEK 5

Content/outcomes to be covered this week	**List of examples to be done in class by the lecturer to explain the outcome/concept**	**Facilitation method (Please tick)**		**Teaching resources/aids (Please tick)**		**Student activity (exercise in textbook/additional supporting tasks) to be done this week**
		Lecture		White board/OHP		
		Group work		Models		
		Demonstration		Handouts		
		Simulation		Multimedia		
		Introduction to lessons				
		Recapping/reinforcement				

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WEEK 6

Content/outcomes to be covered this week	**List of examples to be done in class by the lecturer to explain the outcome/concept**	**Facilitation method (Please tick)**		**Teaching resources/aids (Please tick)**		**Student activity (exercise in textbook/additional supporting tasks) to be done this week**
		Lecture	☐	White board/OHP	☐	
		Group work	☐	Models	☐	
		Demonstration	☐	Handouts	☐	
		Simulation	☐	Multimedia	☐	
		Introduction to lessons				
		Recapping/reinforcement				

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		Lecture		White board/OHP		
		Group work		Models		
		Demonstration		Handouts		
		Simulation		Multimedia		
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WEEK 10

Content/outcomes to be covered this week	**List of examples to be done in class by the lecturer to explain the outcome/ concept**	**Facilitation method (Please tick)**		**Teaching resources/ aids (Please tick)**		**Student activity (exercise in textbook/additional supporting tasks) to be done this week**
		Lecture		White board/OHP		
		Group work		Models		
		Demonstration		Handouts		
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MODULE

1 Concrete

By the end of this module, students should be able to:

Concrete materials

- define *concrete* by listing and explaining the materials that are used to mix concrete;
- determine by means of calculation the relation between the quantity of mixing water and the amount of cement in a concrete mix known as the water-cement ratio;
- explain the importance of curing using the following curing methods:
  - wet/damp sand
  - sawdust
  - hessian
  - polythene sheeting
  - curing compound
  - pounding
  - water sprinkling; and
  - curing by leaving the formwork in place or unremoved.
- explain and distinguish between the following tests that are done in concrete:
  - slump test
  - cube test
  - bending test
  - water permeability test
  - concrete abrasion test;

Reinforced concrete beam design

- determine the following, by means of calculation, on a simply supported reinforced concrete beam with effective depth and suitable reinforcement (live- and point loads):
  - the effective span if not given
  - the maximum bending moment due to imposed load
  - the effective depth
  - the overall depth
  - the dead load
  - the maximum bending moment due to dead load
  - the total bending moment

  - the value of ‘k’
  - the distance of lever arm (Z)
  - the tension reinforcement
  - check the minimum reinforcement
  - check the maximum area of reinforcement
  - check the shear stress (v)
  - the maximum design shear stress
  - the shear reinforcement
  - the anchorage for links;
- determine the following, by means of calculation, on a simply supported reinforced concrete beam with a maximum distributed load (tension and compression reinforcement):
  - the area of steel in tension
  - check the minimum reinforcing
  - the distance of the lever arm (Z)
  - the maximum moment of resistance in tension
  - the area of steel in compression
  - check the minimum reinforcing
  - the maximum moment of resistance in compression
  - the total load
  - the dead load
  - the maximum imposed load;
- determine the following, by means of calculation, on a simply supported reinforced concrete beam with maximum distributed load (tension reinforcement)
  - the area of steel in tension
  - check the minimum reinforcement
  - check the maximum reinforcement
  - the distance of the lever arm (Z)
  - the maximum moment of resistance
  - the total load
  - the dead lead
  - the maximum imposed load;
- determine the following, by means of calculation, on a simply supported reinforced concrete beam (given uniformly distributed live load and a point load):
  - the design loads for the given beam
  - the reactions RL and RR
  - the shear force and bending moment diagram
  - the value of ‘K’;

Rectangular reinforced concrete beam design

- determine the following, by means of calculation, on a simply supported rectangular reinforced concrete beam:
  - the effective depth of the reinforced concrete beam
  - the suitable tension reinforcement for the reinforced concrete beam
  - the minimum and maximum required main reinforcement;

One-way or unidirectional reinforced concrete slabs

- determine the following, by means of calculation, on a simply supported reinforced concrete slab with maximum distributed load per-square meter:
  - the area of steel
  - the distance of lever arm (Z)
  - the maximum moment of resistance
  - the total load
  - the dead load
  - the imposed load
  - the maximum area of reinforcement
  - the check the shear stress (v)
  - the maximum design shear stress
  - the shear reinforcement
  - the anchorage for links
- determine the suitable tension and secondary reinforcement for a one-directional simple supported reinforced concrete slab using the following specifications:
  - the span
  - the live load
  - the concrete grade
  - the density of concrete
  - the main reinforcement
  - the secondary reinforcement
  - the self weight of the slab included/ not included;
- determine the following specifications, by means of calculation, on a simply supported reinforced concrete slab:
  - the effective span
  - the length of the slab
  - the overall depth
  - the density of concrete
  - the supported by I-profile parallel flange beams;
- calculate :
  - the total design dead load of the slab

  - the suitable I-parallel flange steel beam to support the slab;

Flanged reinforced concrete T-beams

- determine, by means of calculation, $x < hf$ of the neutral axis lies within the flange, using the following specification:
  - the lever arm (Z)
  - the neutral axis (x)
  - the total design load
  - the maximum bending moment
  - the tension reinforcement
  - the minimum distance between bars
  - the minimum reinforcing
  - the maximum area of reinforcements
  - the check the shear stress (v)
  - the maximum design shear stress
  - the maximum spacing (0,75d)
  - the anchorage for links
- determine, by means of calculation, the required tension reinforcement if the neutral axis is within the flange of the flanged beam;

Flanged reinforced concrete L-beams

- determine by means of calculation the required tension reinforcement if the neutral axis is within the flange;
- use Clause 4.3.1.5 to calculate width 'X' of the L-beam;
- determine, by means of calculation, the suitable tension reinforcement for a simply supported L-beam given the following specifications:
  - the effective span if not given
  - the imposed load
  - the dead load
  - the maximum bending moment
  - the value of 'K'
  - the distance of the lever arm (Z)
  - the tension reinforcement
  - the minimum distance between bars
  - check the minimum reinforcing;

Reinforced concrete columns

- determine by means of calculation a square, rectangular and round axially loaded column the following:
  - the required number and diameter of the longitudinal bars
  - the maximum and minimum percentage of the steel reinforcement
  - the diameter and pitch of the helical binder

  - the net area of the concrete
  - the axial load the column can withstand
  - the required diameter and spacing of the binders;
- determine by means of calculation the size and suitable reinforcement of pad foundation using the following:
  - the imposed load
  - the dead load
  - the self-weight
  - the given bearing pressure on the ground; and

Reinforced concrete stairs

- calculate the following using the relevant code references where necessary:
  - the total design, dead and imposed loads
  - the maximum bending moment
  - the value of the constant 'K'
  - the size and spacing of suitable main and secondary reinforcements.

Concrete is one of the most used materials in most types of buildings structures. Concrete is a composite material composed of fine and coarse aggregate bonded together with a fluid cement that hardens over time. Concrete is the second most-used substance in the world after water, and is the most widely used for building material.

Concrete is produced by mixing aggregate and cement. The addition of enough water allows the mixture to set and gain strength. Concrete gains strength over time, as long it is given the time to cure.

Exercise 1.1

SB page 36

The following exercise focuses on single beams.

1.

All references taken from SANS 10100-1 (2000)	
Fcu = 20 MPa	Table 2 (4.1.5.1)
Fy = 250 MPa	Table 3 (4.1.5.2)
Span = 7,00 m	Table 3 (4.1.5.2)
Density of reinforced concrete	2 400 kg/m^3

1.1

Determine the effective depth of the slab Effective depth = span / 16 Effective depth = 7 000 / 16 Effective depth = 437,5 mm	Table 10 (Cl 4.3.6.2.1)	
Determine the overall depth Assume R20 main steel, R8 binders and 25 mm cover. Overall depth = 437,5 + 10 + 8 + 25 Overall depth = 480,5 mm (Use overall depth = 500 mm)		
Determine the design dead loads of the beam Design dead load = Volume × density × $9{,}81 \times 10^{-3}$ × 1,2 Gn DDL = $0{,}50 \times 0{,}32 \times 1 \times 2\,400\ \text{kg/m}^3 \times 9{,}81 \times 10^{-3} \times 1{,}2$ Gn Design dead load = 4,52 kNm Design imposed UDL = 7 kNm × 1,6Qn = 11,2 kNm Design imposed point load = 12 kN × 1,6Qn = 19,2 kN	Cl 4.2.2.1 Cl 4.2.2.1	
Calculate the maximum bending moment $BM_{max} = \frac{WL^2}{8} + \frac{WL^2}{8} + \frac{WL}{4}$ $BM_{max} = \frac{4{,}52 \times 7^2}{8} + \frac{11{,}2 \times 7^2}{8} + \frac{19{,}2 \times 7}{4}$ $= 27{,}69 + 68{,}6 + 33{,}6$ $BM_{max} = 129{,}89$ kNm		
Calculate the value for 'K' $K = \frac{BM}{fcu\ b\ d^2}$ $K = \frac{129{,}89 \times 10^6}{20 \times 320 \times 437{,}5^2}$ $K = 0{,}106 < K^1 = 0{,}156$ Provide tension reinforcement only.	(Cl 4.3.3.4.1)	
Calculate the distance of the lever arm (Z) $Z = d\left\{0{,}5 + \sqrt{0{,}25 - \frac{k}{0{,}9}}\right\} \leq 0{,}95d$ $Z = 437{,}5\left\{0{,}5 + \sqrt{0{,}25 - \frac{0{,}106}{0{,}9}}\right\} \leq 0{,}95 \times 437{,}5$ $Z = 437{,}5\ \{0{,}864\} \leq 415{,}63$ $Z = 377{,}84\ \text{mm} < 415{,}63\ \text{mm}$	(Cl 4.3.3.4.1)	(2)

1.2

Calculate the tension reinforcement $As = \frac{M}{0,87 \times fy \times z}$ $As = \frac{129,89 \times 10^6}{0,87 \times 250 \times 377,84}$ $As = 1\ 518,72\ mm^2$ Use 4R25 ($As = 1\ 964\ mm^2$)	(Cl 4.3.3.4.1)	(3)
Check for the minimum main reinforcement $\frac{100\ As}{Ac} = \frac{100 \times 1\ 964}{500 \times 320}$ $= 0,92$ $1,23 > 0,8$ The reinforcement is sufficient.	Table 23 (Cl 4.11.4)	
Check for the maximum area of reinforcement 4% of AC 4% × 500 × 320 $6\ 400\ mm^2$ $964 < 6\ 400$ The reinforcement is sufficient.	(Cl 4.11.5.1)	

2.

All references taken from SANS 10100-1 (2000).		
Fcu = 25 MPa Fy = 250 MPa Span = 6,7 m Density of reinforced concrete	Table 2 (4.1.5.1) Table 3 (4.1.5.2) Clause 4.3.1.2 $2\ 415\ kg/m^3$	
Determine steel in tension $As = 2 \times \frac{\pi d^2}{4}$ $As = 2 \times \frac{\pi 20^2}{4}$ $As = 628\ mm^2$		
Check the minimum area reinforcement $\frac{100\ As}{Ac}$ $\frac{100 \times 628}{220 \times 450} = 0,63 > 0,45$ OK Check the maximum area of reinforcement 4% of AC 4% × (220 × 450) = $3\ 960\ mm^2$ okay	Table 23 (Cl 4 11.5.4)	

Calculate the distance of lever arm (Z) $Z = d\left\{ 0{,}5+ \sqrt{0{,}25 - \frac{K^1}{0{,}9}} \right\}$ $Z = 400\left\{ 0{,}5+ \sqrt{0{,}25 - \frac{0{,}156}{0{,}9}} \right\}$ Z = 400 (0,777) Z = 310,8 mm	(Cl 4.3.3.4) Use effective depth ‘d’ = 400 mm. Where cover = 50 mm	
Determine the maximum moment of resistance in tension Where As = $\frac{M}{0{,}87\, fy\, z}$ Then: M = As × 0,87 × fy × z $M = 628\ mm^2 \times 0{,}87 \times 250\ N/mm^2 \times 310{,}8\ mm$ M = 42,45 kNm	(Cl 4.3.3.4)	
Determine the total load Where: Maximum bending moment = $\frac{WL}{4}$ $42{,}45 = \frac{w \times 6{,}70}{4}$ W = 42,45 × 4 / 6,70 W = 25,34 kN		
Determine the dead load Dead load = Volume × density × g a × 10^{-3} Dead load = 0,45 × 0,22 × 1 × 2 415 kg/m^3 × 9,81 × 10^{-3} Dead load = 2,35 kN		
Determine the maximum point load Total load = 1,2(Gn) + 1,6 (Qn) 25,53 kN = 1,2 (2,35) + 1,6 (Qn) 25,34 kN – 2,35 = 1,6(Qn) Qn = 22,99 / 1,6 Maximum point load = 14,37 kN	(Cl 4.2.2.1)	

3.	<u>All references taken from SANS 10100-1 (2000)</u> Fcu = 25 MPa Fy = 250 MPa Span = 5,5 m Density of reinforced concrete	Table 2 (4.1.5.1) Table 3 (4.1.5.2) Clause 4.3.1.2 2 400 kg/m3	

3.1	<u>Determine the effective depth of the slab</u> Effective depth = span / 16 Effective depth = 5 500 / 16 Effective depth = 343,75 mm	Table 10 (Cl 4.3.6.2.1)	
	<u>Determine the overall depth</u> Assume R20 main steel, R8 binders and 25 mm cover. Overall depth = 343,75 + 10 + 8 + 25 Overall depth = 386,75 mm (Use overall depth = 400 mm)	(SABS 0144 Cl 6.1 and SABS 0100–2 Cl 8.2)	
	<u>Determine the design dead loads of the beam</u> Design dead load = Volume × density × 9,81 × 10^{-3} × 1,2 Gn DDL = 0,40 × 0,27 × 1 × 2 400 kg/m^3 × 9,81 × 10^{-3} × 1,2 Gn Design dead load = 3,05 kNm Design imposed UDL = 3,5 kNm × 1,6Qn = 5,6 kNm	Cl 4.2.2.1 Cl 4.2.2.1	
	<u>Calculate the maximum bending moment</u> $BM_{max} = \frac{WL^2}{8} + \frac{WL^2}{8}$ $BM_{max} = \frac{3{,}05\ x\ 5{,}5^2}{8} + \frac{5{,}6\ x\ 5{,}5^2}{8}$ $= 11{,}53 + 21{,}175$ $BM_{max} = 32{,}71$ kNm		
	<u>Calculate the value for ‘K’</u> $K = \frac{BM}{fcu\ b\ d^2}$ $K = \frac{32{,}71 \times 10^6}{25 \times 270 \times 386{,}75^2}$ $K = 0{,}03 < K^1 = 0{,}156$ Provide tension reinforcement only.	(Cl 4.3.3.4.1)	

	Calculate the distance of the lever arm (Z) $Z = d\left\{0{,}5+\sqrt{0{,}25-\frac{k}{0{,}9}}\right\} \le 0{,}95\text{d}$ $Z = 386{,}75\left\{0{,}5+\sqrt{0{,}25-\frac{0{,}03}{0{,}9}}\right\} \le 0{,}95 \times 386{,}75$ $Z = 386{,}75\{0{,}965\} \ge 367{,}4$ $Z = 373{,}4 \text{ mm} > 367{,}4 \text{ mm}$	(Cl 4.3.3.4.1)	

3.2	Calculate the tension reinforcement $\text{As} = \frac{\text{M}}{0{,}87 \times fy \times z}$ $\text{As} = \frac{32{,}71 \times 10^6}{0{,}87 \times 250 \times 373{,}4}$ $\text{As} = 402{,}7 \text{ mm}^2$ Use 4R12 (As = 452 mm^2) (The minimum distance between bars is OK (Cl 11.4.8).	(Cl 4.3.3.4.1)	(2)

3.3	Check for the minimum main reinforcement $\frac{100 \text{ As}}{\text{Ac}} = \frac{100 \times 425}{400 \times 270}$ $= 0{,}39$ $0{,}39 > 0{,}8$ The minimum reinforcement is not sufficient.	Table 23 (Cl 4.11.4)	
	Check for the maximum area of reinforcement 4% of AC 4% × 400 × 270 5 120 mm^2 $425 < 4\ 320$ The max reinforcement is sufficient.	(Cl 4.11.5.1)	

Exercise 1.2

SB page 46

The following exercise focuses on double beams.

1.

All references taken from SANS 10100-1 (2000) Fcu = 25 MPa Fy = 450 MPa Span = 6,50 m Density of reinforced concrete	Table 2 (4.1.5.1) Table 3 (4.1.5.2) Cl 4.3.1.2 2 425 kg/m^3	
Determine the effective depth (d): 460 mm – 50 mm (cover) = 410 mm		
Loading of the beam Dead load = Volume × density × 9,81 × 10^{-3} = 0,46 × 0,22 × 1 × 2 425 kg/m^3 × 9,81 × 10^{-3} = 2,407 kN/m Design dead load = 2,407 × 1,2 Gn = 2,889 kNm Design imposed load = 18 kN/m × 1,6Qn = 28,8 kN/m		
Loading of the beam Dead load = Volume × density × 9,81 × 10^{-3} = 0,46 × 0,22 × 1 × 2 425 kg/m^3 × 9,81 × 10^{-3} = 2,407 kNm Design dead load = 2,407 × 1,2 Gn = 2,889 kNm Design imposed load = 18 kNm × 1,6Qn = 28,8 kNm	(Cl 4.2.2.1) (Cl 4.2.2.1)	
Calculate the maximum bending moment $BM_{max} = \frac{WL^2}{8} + \frac{WL^2}{8}$ $BM_{max} = \frac{2{,}889 \times 6{,}50^2}{8} + \frac{28{,}8 \times 6{,}50^2}{8}$ $BM_{max} = 15{,}26 + 152{,}10$ $BM_{max} = 167{,}36$ kNm		
Calculate the value for 'K' $K = \frac{BM}{fcu\, b\, d^2}$ $K = \frac{167{,}36 \times 10^6}{25 \times 220 \times 410^2}$ $K = 0{,}181 > K^1 = 0{,}156$ Tension and compression reinforcement required.	(CL 4.3.3.4.1)	

Determine the compression reinforcement $A's = \frac{(K - K^1)\, fcu\, b\, d^2}{fyc \times (d - d^1)}$ $A's = \frac{(0{,}181 - 0{,}156)\ 25 \times 220 \times 410^2}{327 \times (410 - 35)}$ $A's = \frac{23\ 113\ 750}{122\ 625}$ $A's = 188{,}49\ mm^2$ Use 2Y12 bars ($As = 226\ mm^2$)	(Cl 4.3.3.4) $Fyc = \frac{Fy}{1{,}15 + \frac{Fy}{2\ 000}}$ $Fyc = \frac{450}{1{,}15 + \frac{450}{2\ 000}}$ Fyc = 327 MPa	
Calculate the distance of the lever arm (Z) $Z = d\left\{0{,}5 + \sqrt{0{,}25 - \frac{K^1}{0{,}9}}\right\}$ $Z = 410\left\{0{,}5 + \sqrt{0{,}25 - \frac{0{,}156}{0{,}9}}\right\}$ $Z = 410(0{,}777)$ $Z = 318{,}6\ mm$	(Cl 4.3.3.4)	
Calculate the tension reinforcement $As = \frac{K^1\, fcu\, bd^2}{0{,}87\, fy\, Z} + \frac{A'S\, fyc\, bd^2}{0{,}87\, fy}$ $As = \frac{0{,}156 \times 25 \times 220 \times 410^2}{0{,}87 \times 450 \times 318{,}6} + \frac{226 \times 327}{0{,}87 \times 450}$ $As = \frac{144\ 229\ 800}{124\ 731{,}9} + \frac{73\ 902}{391{,}5}$ $As = 1\ 156{,}32 + 188{,}77$ $As = 1\ 345{,}09\ mm^2$ Use 3Y25 bars ($As = 1\ 473\ mm^2$)	(Cl 4.3.3.4.1)	
Check the minimum area of reinforcement $\frac{100\ AS}{AC}$ $\frac{100 \times 1\ 473}{460 \times 220} = 1{,}46 > 0{,}45$ okay Check maximum area of reinforcement 4% of AC $4\% \times (460 \times 220) = 4\ 048\ mm^2$ okay	Table 23 (Cl 4 11.5.4)	

2	All references taken from SANS 10100-1 (2000)		
	Fcu = 25 MPa	Table 2 (4.1.5.1)	
	Fy = 450 MPa	Table 3 (4.1.5.2)	
	Span = 8 m	Clause 4.3.1.2	
	Density of reinforced concrete	2 425 kg/m3	(2)

2.1	Determine the effective depth of the beam		
	Effective depth = span / 16		
	Effective depth = 8 000 / 16	Table 10	
	Effective depth = 500 mm	(4.3.6.2.1)	
	Determine the overall depth		
	Assume Y25 main steel and Y10 binders		
	Assume Cover of 25 mm.		
	Overall depth = 500 + $\frac{25}{2}$ + 10 + 25		
	Overall dept2h = 547,5 mm		
	(Use overall depth = 550 mm)		

2.2	Determine the design dead loads of the beam		
	Design dead load = Volume × density × 9,81 × 10^{-3} × 1,2 Gn	(Cl 4.2.2.1)	
	DDL = 0,55 × 0,33 × 1 × 2 425 kg/m^3 × 9,81 × 10^{-3} × 1,2 Gn		
	Design dead load = 5,18 kNm		
	Design imposed load = 36 kNm × 1,6Qn	(Cl 4.2.2.1)	
	Design imposed load = 57,6 kNm		
	Total design load = 5,18 + 57,6 = 62,78 kNm		

2.3	Calculate the maximum bending moment		
	$BM_{max} = \frac{WL^2}{8}$	(Cl 4.3.3.4.1)	
	$BM_{max} = \frac{62{,}78 \times 8{,}0^2}{8}$		
	BM_{max} = 502,25 kNm		

Calculate the value for 'K' $k = \frac{BM}{fcu\ b\ d^2}$ $k = \frac{502{,}25 \times 10^6}{25 \times 330 \times 500^{\ 2}}$ $k = 0{,}244 > K^1 = 0{,}156$ Tension and compression reinforcement required.		

2.4

Calculate the distance of the lever arm (Z) $Z = d\left\{0{,}5 + \sqrt{0{,}25 - \frac{k^1}{0{,}9}}\right\}$ $Z = 500\left\{0{,}5 + \sqrt{0{,}25 - \frac{0{,}156}{0{,}9}}\right\}$ $Z = 500\{0{,}777\}$ $Z = 388{,}50$ mm	(Cl 4.3.3.4.1)	

2.5

Determine the compression reinforcement $A's = \frac{(k - k^1)\ Fcu\ b\ d^2}{Fyc\ (d - d^1)}$ (Use $d^1 = 50$ mm) Where: $Fyc = \frac{Fy}{1{,}15 + \frac{Fy}{2\ 000}}$ $Fyc = \frac{450}{1{,}15 + \frac{450}{2\ 000}}$ Fyc = 327 Mpa $A's = \frac{(0{,}244 - 0{,}156)\ 25 \times 330 \times 500^2}{327\ (500 - 50)}$ $A's = 1\ 233{,}44\ mm^2$ Use 4Y20 (As = 1 257 mm^2)	(Cl 4.3.3.4.1) Figure 2 Ɣm = 1,15 (Cl 3.3.3.2)	
Check for the minimum compression reinforcement $\frac{100\ As}{Ac} = \frac{100 \times 1\ 257}{550 \times 330}$ $= 1{,}06$ $0{,}69 > 0{,}24$ The reinforcement is sufficient.	Table 23 (Cl 4.11.4)	(1)

2.6	Determine the tension reinforcement $As = \frac{k^1\ Fcu\ b\ d^2}{0{,}87 \times fy \times z} + \frac{A's\ Fyc}{0{,}87 \times fy}$ $As = \frac{0{,}156 \times 25 \times 330 \times 500^2}{0{,}87 \times 450 \times 388{,}5} + \frac{1\ 257 \times 327}{0{,}87 \times 450}$ As = 2 115,42 + 1 049,91 As = 3 165,33 mm^2 Use 4y32 (As = 3 217 mm^2)	(Cl 4.3.3.4.2)	

2.7	Check for the minimum main reinforcement $\frac{100\ As}{Ac} = \frac{100 \times 3\ 217}{550 \times 330}$ $= 1{,}77$ $1{,}77 > 0{,}45$ The reinforcement is sufficient.	Table 23 (Cl 4.11.4)	
	Check for the maximum area of reinforcement 4% of AC 4% × 550 × 330 5 940 mm^2 $(3\ 217 + 1\ 257) < 7\ 260$ The reinforcement is sufficient.	(Cl 4.11.5.1)	

3.	All references taken from SANS 0100-1 (2000) Fcu = 30 MPa Fy = 450 MPa Maximum bending moment =160 kNm Effective depth = 350 mm	Table 2 (4.1.5.1) Table 3 (4.1.5.2)	
	Calculate the value for 'K' $K = \frac{BM}{fcu\ b\ d^2}$ $K = \frac{160 \times 10^6}{30 \times 230 \times 350^2}$ $K = 0{,}19 > K^1 = 0{,}156$ Tension and compression reinforcement required.	(Cl 4.3.3.4.1)	(2)

Calculate the compression reinforcement $A's = \frac{(k - k^1)\ Fcu\ b\ d^2}{Fyc\ (d - d^1)}$ Where: $Fyc = \frac{Fy}{1{,}15 + \frac{Fy}{2\,000}}$ $Fyc = \frac{450}{1{,}15 + \frac{450}{2\,000}}$ Fyc = 327 MPa $A's = \frac{(0{,}19 - 0{,}156)\ 30 \times 230 \times 350^2}{327\ (350 - 50)}$ $A's = 293\ mm^2$ Use 3Y12 (As = 339 mm^2)	(Cl 4.3.3.4.1) Figure 2 $\gamma m = 1{,}15$ (Cl 3.3.3.2) (Use $d^1 = 50$ mm)	(3)
Check for the minimum compression reinforcement $\frac{100\ As}{Ac} = 0{,}4$ $\frac{100 \times 339}{600 \times 300} = 0{,}19$ $0{,}19 < 0{,}4$ The reinforcement is not sufficient.	Table 23 (Cl 4.11.4)	(2)
Calculate the distance of the lever arm (Z) $Z = d\left\{0{,}5 + \sqrt{0{,}25 - \frac{k^1}{0{,}9}}\right\}$ $Z = 350\left\{0{,}5 + \sqrt{0{,}25 - \frac{0{,}156}{0{,}9}}\right\}$ $Z = 350\{0{,}777\}$ Z = 271,95 mm	(Cl 4.3.3.4.1)	(2)
Calculate the tension reinforcement $As = \frac{K^1\ fcu\ bd^2}{0{,}87\ fy\ Z} + \frac{A'S\ fyc\ bd^2}{0{,}87\ fy}$ $As = \frac{0{,}156 \times 30 \times 230 \times 350^2}{0{,}87 \times 450 \times 271{,}95} + \frac{339 \times 327}{0{,}87 \times 450}$ $As = \frac{131\,859\,000}{106\,468{,}425} + \frac{110\,944{,}53}{391{,}5}$ As = 1 238,48 + 283,15 $As = 1\,521{,}63\ mm^2$ Use 5Y20 bars (As = 1 571 mm^2)	(Cl 4.3.3.4.1)	(4)

Check for the minimum main reinforcement $\frac{100\text{ As}}{\text{Ac}} = 0{,}45$ $\frac{100 \times 1\ 571}{600 \times 300} = 0{,}87$ $0{,}45 < 0{,}87$ The reinforcement is sufficient.	Table 23 (Cl 4.11.4)	(2) [15]

4.

Determine the area of steel in tension: $\text{As} = 3 \times \frac{\pi 20^2}{4}$ As = 942 mm	CL 4.3.6.2.1 Table 10	
Check for the minimum main reinforcement $\frac{100\text{ As}}{\text{Ac}} = \frac{100 \times 942}{480 \times 270}$ $= 0{,}72$ $0{,}72 > 0{,}3$ The reinforcement is sufficient.	Table 23 (Cl 4.11.4)	
Calculate the distance of the lever arm (Z) $Z = d\left\{0{,}5 + \sqrt{0{,}25 - \frac{k^1}{0{,}9}}\right\}$ $Z = \left\{0{,}5 + \sqrt{0{,}25 - \frac{0{,}156}{0{,}9}}\right\}$ $Z = 430 \times 0{,}777$ Use Z = 334,11 mm	(Cl 4.3.3.4.1)	
The maximum moment of resistance in tension M = As 0,87 *fy z* $M = 942 \times 0{,}87 \times 450 \times 334{,}11$ M = 123,2 kNm	(Cl 4.3.3.4.1)	(2)
Determine the area of steel in compression $\text{A's} = 3 \times \frac{\pi 16^2}{4}$ A's = 603 mm	CL 4.3.6.2.1 Table 10	

Check for the minimum reinforcement $\frac{100\ As}{Ac} = \frac{100 \times 603}{480 \times 270}$ $= 0,31$ $0,47 > 0,2$ The reinforcement is sufficient.	Table 23 (Cl 4.11.4)	
The maximum moment of resistance in compression Substitute: $K = \frac{M}{b\,d^2\,fcu}$ into $A's = \frac{(K - K^1)}{fcu\,(d - d^1)}$ Then: Make M the subject of the formula: $M = A's\,f_{yc}\,(d - d_1)) + 0,156\,f_{cu}\,bd^2$ $M = 603 \times 327,27 \times (430 - 40) + 0,156 \times 25 \times 270 \times 430^2$ $M = 76\ 964\ 085,9 + 194\ 699\ 700$ M = 271, 66 kNm $f_{yc} = \frac{fy}{1,15+\frac{Fy}{2\ 000}}$ $f_{yc} = \frac{450}{1,15+\frac{450}{2\ 000}}$ Fyc =323,27 MPa	Cl 4.3.3.4.1 Cl 4.3.3.3	
Use the lesser of the two bending moments Maximum moment of resistance in tension = 123,2 kNm Maximum moment of resistance in compression = 271, 66 kNm Therefore: the lesser BM =123,2 kN		
Determine the total load $BM_{max} = \frac{w\,l^2}{8}$ $123,2 = \frac{w \times 7^2}{8}$ $w = \frac{123,2 \times 8}{7,^2}$ $w = 20,11$ kN m		
Determine the dead load Dead load = area × density × $9,81 \times 10^{-3}$ Dead load = $0,48 \times 0,27 \times 2\ 415$ kg/m^3 $\times 9,81 \times 10^{-3}$ Dead load = 3,07 kNm		

Determine the maximum imposed load Total load = 1,2 (Gn) + 1,6 (Qn) 20,11 = 1,2 (3,07) + 1,6 (Qn) 20,1 = 3,68 + 1,6 Qn Qn = 10,26 kNm	(4.2.2.1)	
The maximum imposed load ∴ Qn = 10,26 kNm^2		

Exercise 1.3

SB page 58

The following exercise focuses on rectangular beams.

1.1

All references taken from SANS 10100-1 (2000) Fcu = 25 MPa Fy = 450 MPa Effective Span = 6,0 m Density of reinforced concrete	 Table 2 (4.1.5.1) Table 3 (4.1.5.2) Clause 4.3.1.2 2 415 kg/m^3	
Determine the effective depth (d): 600 mm – 45 mm (cover) = 555 mm		
Loading of the beam Dead load = Volume × density × 9,81 × 10^{-3} × 1,2Gn = 0,6 × 0,3 × 2 415 kg/m^3 × 9,81 × 10^{-3} × 1,2Gn = 5,12 kN/m Design imposed load = 24 kNm × 1,6Qn = 38,4 kN/m	 (Cl 4.2.2.1) (Cl 4.2.2.1)	
Calculate the maximum bending moment $BM_{max} = \frac{WL^2}{8} + \frac{WL^2}{8}$ $BM_{max} = \frac{5,12 \times 6^2}{8} + \frac{38,4 \times 6^2}{8}$ $BM_{max} = 23,04 + 172,8$ $BM_{max} = 195,84$ kNm		(3)

Calculate the value for 'K' $K = \frac{BM}{fcu\ b\ d^2}$ $K = \frac{195,84 \times 10^6}{30 \times 300 \times 555^2}$ $K = 0,07 < K^1\ 0,156$ Use tension reinforcement only.	(Cl 4.3.3.4.1)	
Calculate the distance of the lever arm (Z) $Z = d\left\{0,5+\sqrt{0,25 - \frac{k}{0,9}}\right\} \le 0,95\ d$ $Z = 555\left\{0,5+\sqrt{0,25 - \frac{0,07}{0,9}}\right\} \le 0,95 \times 555$ $Z = 555\{0,91\} \le 527,25$ $Z = 505,05$ mm $< 527,25$ Use $Z = 505,05$ mm (least Z)	(Cl 4.3.3.4.1)	
Calculate the tension reinforcement $As = \frac{M}{fy \times 0,87 \times z}$ $As = \frac{195,84 \times 10^6}{450 \times 0,87 \times 505,05}$ $As = 989,6\ mm^2$ Use 4Y20 ($As = 1\ 257\ mm^2$)	(Cl 4.3.3.4.1)	
Check for the minimum main reinforcement $\frac{100\ As}{Ac} = \frac{100 \times 1\ 257}{600 \times 300}$ $0,69 > 0,45$ The reinforcement is sufficient.	Table 23 (Cl 4.11.4)	
Check the maximum reinforcement 4% *of Ac* $4\% \times 600 \times 300$ $= 7\ 200\ mm^2$ $1\ 885\ mm^2 < 7\ 200\ mm^2$	Cl 4.11.5.1	

1.2	<u>Calculate the total weight of the RC beam</u>		
	Total weight = volume × density × g.a × 10^{-3}		
	= 6,33 × 0,6 × 0,3 × 2 415 kg/m^3 × 9,81 × 10^{-3}		
	Total weight = 27 kN	6 000 + (2 × 165)	
		= 6 300 mm	
	∴ each buttress must carry 27 kN divided by 2 = 13,5 kN		

2	<u>All references taken from SANS 10100-1 (2000)</u>		
	Fcu = 25 MPa	Table 3 (4.1.5.2)	
	Span = 9,0 m	Clause 4.3.1.2	
	Density of reinforced concrete	2 425 kg/m^3	

2.1	<u>Determine the design dead loads of the beam</u>		
	Design dead load = Volume × density × 9,81 × 10^{-3} × 1,2 Gn	Cl 4.2.2.1	
	= 0,475 × 0,33 × 1 × 2 425 kg/m^3 × 9,81 × 10^{-3} × 1,2 Gn		
	Design dead load = 4,475 kN/m		
	Design imposed point load = 55 kN × 1,6Qn		
	DIL = 88,0 kN/m		
	Design imposed live load = 8 kN/m × 1,6Qn		
	DILL = 12,8 kN/m	(Cl 4.2.2.1)	

<u>Calculate reactions</u>

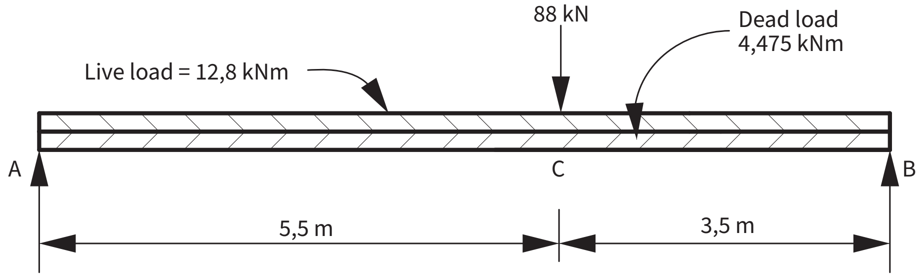


Figure 1.1

2.2 Shear force diagram

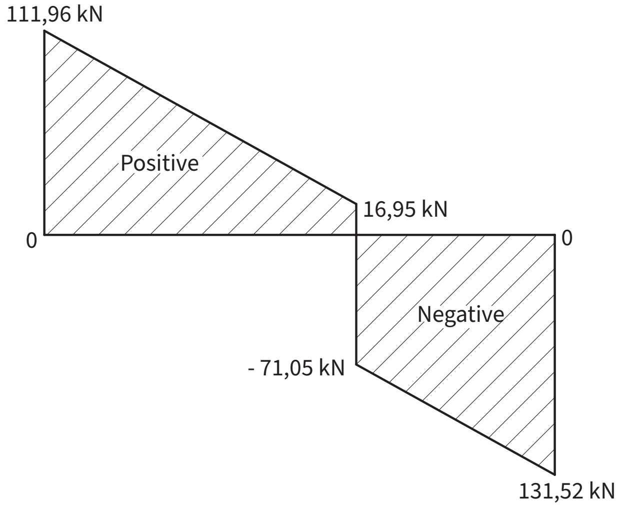


Figure 1.2

2.3	<u>Calculate the maximum bending moment</u> BM at 'C': (131,52 × 3,5) – (12,8 × 3,5 × 1,75) – (4,475 × 3,5 × 1,75) 460,32 – 78,4 – 27,41 BM at 'C' = 354,51 kNm		

2.4 <u>Bending moment diagram</u>

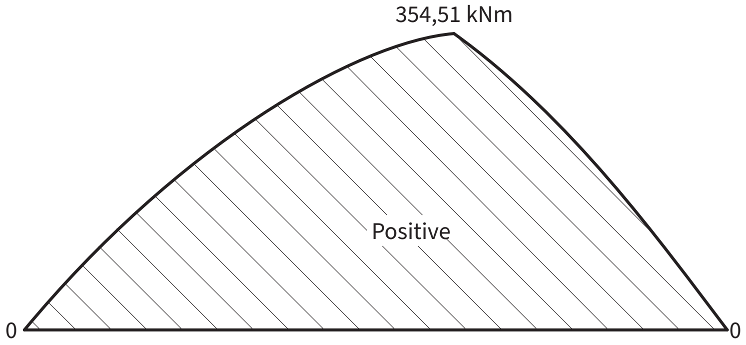


Figure 1.3

2.5

Calculate the value for 'K' $K = \frac{BM}{fcu\ b\ d^2}$ $K = \frac{354{,}51 \times 10^6}{25 \times 330 \times 425^{\ 2}}$ K = 0,238 $K < K^1 = 0{,}156$ Compression reinforcement will therefore be required.	(Cl 4.3.3.4.1) d = 475 – 50 cover = 425 mm	

Exercise 1.4

SB page 75

The following exercise focuses on slabs.

1.

All references taken from SANS 0100-1 (2000) Fcu = 25 MPa Fy = 450 MPa Span = 4,5 mm Imposed live load	 Table 2 (4.1.5.1) Table 3 (4.1.5.2) Clause 4.3.1.2 $7{,}75\ kNm^2$	
Determine the effective dead loads of the slab Effective depth = Span/16 Effective depth = 4 500 / 16 Effective depth = 281,25 mm	Table 10 Cl 4.3.6.2.1	
Determine the overall depth of the slab Assume Y16 main steel and 25 mm cover. Overall depth = 281,25 + 16/2 + 25 Overall depth = 315,25 mm (Use overall depth = 320 mm)		

Important

The main steel lies below the secondary steel. Always round off to the nearest whole number; do not use decimals.

Determine the design dead loads of the beam Design dead load = area × density × g.a × 10^{-3} × 1,2Gn = 0,320 × 1 m × 2 400 kg/m^3 × 9,81 × 10^{-3} × 1,2Gn Design dead load = 9 kNm Design imposed live load = 7,75 kNm^2 × 1 m × 1,6Qn Design imposed live load = 12,4 kNm Total design load = 9 + 12,4 = 21,4 kNm	Cl 4.2.2.1	
Calculate the maximum bending moment $BM_{max} = \frac{WL^2}{8}$ $BM_{max} = \frac{21,4x\ 4,5^2}{8}$ $BM_{max} = 54,17$ kNm		
Calculate the value for 'K' $K = \frac{M}{fcu\ b\ d^2}$ $K = \frac{54,17 \times 10^6}{25 \times 1\,000 \times 281,25^{\ 2}}$ K = 0,027 $K < K^1 = 0,156$ (only tension reinforcement required.)		
Calculate the distance of the lever arm (Z) $Z = d\left\{0,5+\sqrt{0,25-\frac{k}{0,9}}\right\} \leq 0.95\ d$ $Z = 281,25\left\{0,5+\sqrt{0,25-\frac{0,027}{0,9}}\right\} \leq 0,95 \times 281,25$ mm Z = 281,25{0,969} ≤ 272,54 mm Z = 272,54 mm > 258,92 mm Use lever arm = 258,92 mm (Lesser of the two)	(Cl 4.3.3.4.1)	
Calculate the tension reinforcement $As = \frac{M}{0,87 \times fy \times z}$ $As = \frac{54,17 \times 10^6}{0,87 \times 450 \times 258,92}$ As = 534,4 mm^2 Use Y10 at 125 centres (As = 628 mm^2)	(Cl 4.3.3.4.1)	

Note

The width of the slab is 1 000 mm or 1 m.

Check for the minimum main reinforcement $\frac{100 \times As}{Ac} = 0,13$ $\frac{100 \times 628}{1000 \times 320} = 0,22$ 0,19 > 0,13 The reinforcement is sufficient.	Table 23 (Cl 4.11.4)	
Determine the secondary reinforcement $\frac{100\ As}{Ac} = 0,24$ $As = \frac{0,24 \times 1\ 000 \times 320}{100}$ As = 768 mm^2 Use Y10 at 100 centres (As = 785 mm^2)	Cl 4.11.4.3.1 & Table 23	

2.

All references taken from SANS 0100-1 (2000) Determine the area of the main steel Y12 at 200 centres: As = 1 005 mm^2		
Calculate the distance of the lever arm (Z) $Z = d\left\{0,5+\sqrt{0,25 - \frac{K^1}{0,9}}\right\}$ $Z = 185\left\{0,5+\sqrt{0,25 - \frac{0,156}{0,9}}\right\}$ Z = 815 {0,777} Z = 143,75 mm	(Cl 4.3.3.4.1)	
Calculate the maximum moment of resistance $AS = \frac{M}{0,87 \times fy \times z}$ M = 0,87 × fy × Z × As M = 0,87 × 250 × 143,75 × 1 005 M = 31,42 kNm	(Cl 4.3.3.4.1)	

Determine the total load $BM_{max} = \frac{wl^2}{8}$ $31{,}42 = \frac{w \times 4{,}5^2}{8}$ $w = \frac{31{,}42 \times 8}{4,\ 5^2}$ $w = 12{,}41$ kNm		
Determine the dead load Dead load = Area × density × 9,81 × 10^{-3} Dead load = 0,215 × 1 × 2 400 kg/m^3 × 9,81 × 10^{-3} Dead load = 5,062 kNm		
Determine the maximum imposed load Total load = 1,2 (Gn) + 1,6 (Qn) 12,41 = 1,2 (5,062) + 1,6 (Qn) Qn = 3,959 kNm	(Cl 4.2.2.1)	

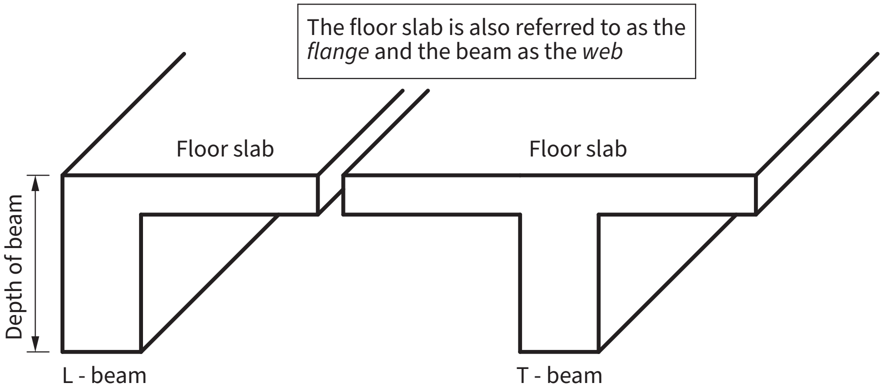
3.

All references taken from SANS 0100-1 (2000) Fcu = 25 MPa Fy = 250 MPa Span = 4,2 mm Imposed live load	Table 2 (4.1.5.1) Table 3 (4.1.5.2) Clause 4.3.1.2 6 kNm^2	
Determine the effective dead loads of the slab Effective depth = Span/16 Effective depth = 4 200/16 Effective depth = 263 mm	Table 10 Cl 4.3.6.2.1	
Determine the overall depth of the slab Assume Y16 main steel and 25 mm cover. Overall depth = 263 + 16/2 + 25 Overall depth = 291 mm (Use overall depth = 300 mm)	SANS 0144 Cl 6.1 and SANS 0100–2 Cl 8.2	

Important

The main steel lies below the secondary steel. Encourage students to round off to the nearest whole number; they must not use decimals.

Determine the design dead loads of the beam Design dead load = area × density × g.a × 10^{-3} × 1,2Gn = 0,300 × 1m × 2 400 kg/m^3 × 9,81 × 10^{-3} × 1,2Gn Design dead load = 8,48 kNm Design imposed live load = 6 kNm^2 × 1 m × 1,6Qn Design imposed live load = 9,6 kNm	Cl 4.2.2.1	
Calculate the maximum bending moment $BM_{max} = \frac{WL^2}{8} + \frac{WL^2}{8}$ $= \frac{8,48 \times 4,2^2}{8} + \frac{9,6 \times 4,2^2}{8}$ $BM_{max} = 18,7 + 21,2$ $BM_{max} = 39,87$ kNm		



The floor slab is also referred to as the *flange* and the beam as the *web*

Figure 1.4

Calculate the value for 'K' $K = \frac{M}{fcu\ b\ d^2}$ $K = \frac{39,87 \times 10^6}{25 \times 1\ 000 \times 263^2}$ K = 0,023 $K < K^1 = 0,156$ (Only tension reinforcement required.)	Cl 4.3.3.4.1	

Calculate the distance of the lever arm (Z) $Z = d\left\{ 0,5+\sqrt{0,25-\frac{k}{0,9}} \right\} \leq 0,95\ d$ $263\left\{ 0,5+\sqrt{0,25-\frac{0,023}{0,9}} \right\} \leq 0,95 \times 263\ mm$ $Z = 263\{0,97\} \leq 249,9\ mm$ $Z = 256\ mm > 249,9\ mm$ Use lever arm = 249,9 mm (Lesser of the two)	(Cl 4.3.3.4.1)	
Calculate the tension reinforcement $As = \frac{M}{0,87 \times fy \times z}$ $As = \frac{39,87 \times 10^6}{0,87 \times 250 \times 249,9}$ $As = 733,5\ mm^2$ Use R20 at 150 centres ($As = 754\ mm^2$)	(Cl 4.3.3.4.1)	
Check for the minimum main reinforcement $\frac{100 \times As}{Ac} = 0,13$ $\frac{100 \times 754}{1000 \times 300} = 0,25$ $0,25 > 0,13$ The reinforcement is sufficient.	Table 23 (Cl 4.11.4)	
Determine the secondary reinforcement $\frac{100\ As}{Ac} = 0,24$ $As = \frac{0,24 \times 1\ 000 \times 300}{100}$ $As = 720\ mm^2$ Use R12 at 150 centres ($As = 754\ mm^2$)	Cl 4.11.4.3.1 & Table 23	

Exercise 1.5

SB page 89

1.

All references taken from SANS 10100-1 (2000) Fcu = 25 MPa Fy = 450 MPa 5Y20 steel rods	 Table 2 (4.1.5.1) Table 3 (4.1.5.2) Area = 1 571 mm^2	

Calculate the lever arm distances $Z = d\left\{0{,}5+\sqrt{0{,}25-\frac{K^1}{0{,}9}}\right\} \leq 0{,}95\text{d}$ $Z = 475\left\{0{,}5+\sqrt{0{,}25-\frac{0{,}156}{0{,}9}}\right\} \leq 0{,}5 \times 475$ $Z = 475(0{,}777) \leq 0{,}95 \times 475$ $Z = 369{,}\ 08\text{ mm} \leq 451{,}25$ Use $Z = 369{,}08$ mm	(Cl 4.3.3.4.1)	
Calculate the bending moment due to the concrete $k = \frac{BM}{fcu\ b\ d^2}$ $Bm = k \times fcu \times b \times d^2$ $Bm = 0{,}156 \times 25 \times 1150 \times 475^2$ Bm = 1 011,93 kNm	(Cl 4.3.3.4.1)	
Calculate the bending moment due to the reinforcement $As = \frac{BM}{0{,}87\ fy\ z}$ $Bm = As \times 0{,}87 \times fy \times z$ $Bm = 1\ 571 \times 0{,}87 \times 450 \times 369{,}075$ Bm = 226,9 kNm		
Bending moment maximum is due to the reinforcement = 226,9 kNm		

2.

All references taken from SANS 10100-1 (2000) Fcu = 25 MPa Fy = 450 MPa	Table 2 (4.1.5.1) Table 3 (4.1.5.2)	
Calculate the value for 'K' $K = \frac{BM}{fcu\ b\ d^2}$ $K = \frac{285 \times 10^6}{25 \times 1\ 155 \times 525^2}$ $K = 0{,}036 < k^1 = 0{,}156$	(Cl 4.3.3.4.1)	

Calculate the lever arm distances $Z = d\left\{ 0,5+ \sqrt{0,25 - \frac{k}{0,9}} \right\} \le 0,95d$ $Z = 525\left\{ 0,5+ \sqrt{0,25 - \frac{0,039}{0,9}} \right\} \le 0,95 \times 525$ $Z = 525(0,955) \le 0,95 \times 525$ $Z = 501,17$ mm $\ge 498,75$ Use $Z = 498,75$ mm	(Cl 4.3.3.4.1)	
Calculate the area of reinforcement $As = \frac{BM}{fy\,0,87\,Z}$ $As = \frac{285 \times 10^6}{450 \times 0,87 \times 498,75}$ $As = 1\,459,59$ mm^2 Use 3Y25 bars ($As = 1\,473$ mm^2)	(Cl 4.3.3.4.1)	

3.

All references taken from SANS 10100-1 (2000)		
Fcu = 25 MPa	Table 2 (4.1.5.1)	
Fy = 450 MPa	Table 3 (4.1.5.2)	
Effective span =	7,5 m	
Dead load	13,5 kNm^2	
Imposed load	9 kNm^2	

3.1

Calculate the lever arm distances $Z = d\left\{ 0,5+ \sqrt{0,25 - \frac{K^1}{0,9}} \right\}$ $Z = 350\left\{ 0,5+ \sqrt{0,25 - \frac{0,156}{0,9}} \right\}$ $Z = 505\ (0,777)$ $Z = 271,95$ mm	(CL 4.3.3.4.1)	

3.2

Calculate the total design load $W = 1,2(Gn) + 1,6\ (Qn)$ $W = 1,2(\ 13,5 \times 1) + 1,6(9 \times 1)$ $W = 16,2 + 14,4$ $W = 30$ kNm	(Cl 4.3.3.4.1)	

3.3

Calculate the maximum bending moment $BM = \frac{wl^2}{8}$ $BM = \frac{30,6 \times 7^2}{8}$ BM = 81,25 kNm		

3.4

Calculate the tension reinforcement		
$A_s = \frac{M}{0,87 \times fy\,Z}$ $A_S = \frac{187,43 \times 10^6}{0,87 \times 20 \times 271,95}$	(Cl 4.3.3.4)	

4.

All references taken from SANS 10100-1 (2000)		
Fcu = 30 MPa	Table 2 (4.1.5.1)	
Fy = 450 MPa	Table 3 (4.1.5.2)	
Effective span	5,75 m	
Dead load	14 kN/m^2	
Imposed load	9,25 kN/m^2	

4.1

Calculate the effective width		
The web with + Lz/5	(Cl 4.3.1.5 (a)	
Web width = 250 + $\frac{5\ 750}{5}$		
Web width = 250 + 1 150		
Web width (X) = 1 400 mm		

4.2

Calculate the lever arm distances		
$Z = d\left\{0,5+\sqrt{0,25-\frac{K^1}{0,9}}\right\}$ $Z = 585\left\{0,5+\sqrt{0,25-\frac{0,156}{0,9}}\right\}$ $Z = 585\ (0,777)$ Z = 376,85 mm	(Cl 4.3.3.4.1)	

4.3 Calculate the total design load

W = 1,2(Gn) + 1,6 (Qn)

W = 1,2(14 × 1) + 1,6(9,5 × 1)

W = 16,8 + 15,2

W = 32 kN/m

(Cl 4.3.3.4.1)

4.4 Calculate the maximum bending moment

$$BM = \frac{wl^2}{8}$$

$$BM = \frac{32 \times 5{,}75^2}{8}$$

BM = 132,25 kNm

4.5 Calculate the tension reinforcement

$$As = \frac{m + 0{,}1\,fcu\,b_w\;d\left(0{,}45d - h_f\right)}{0{,}87\,fy\left(d - 0{,}5\,h_f\right)}$$

$$As = \frac{132{,}25 \times 10^6 + \left(0{,}1 \times 30 \times 250 \times 485\right)\left(0{,}45\text{v } 485 - 120\right)}{0{,}87 \times 450\ (485 - 0{,}5 \times 120)}$$

$$As = \frac{132{,}25 \times 10^6 + \left(363\ 750\right)\left(98{,}25\right)}{0{,}87 \times 450\ (425)}$$

$$As = \frac{132{,}25 \times 10^6 + 397\ 618{,}5}{166\ 387{,}5}$$

$$As = \frac{264\ 000\ 000}{163\ 451{,}25}$$

As = 1 586 mm^2

Use 4Y20 bars (As = 1 257 mm^2)

The neutral axis lies below the flange (Cl 4.3.3.4.2)

4.6 Check the distance between the bars

250 – 2(25 cover) – 4(20 bars) = 120.

4 bars = 3 spaces = 120/3 = 40 mm.

Spacing between bars is okay SANS 0144:2 000

Exercise 1.6

SB page 97

1.

All references taken from SANS 0100-1 (2000)		
Fcu = 30 MPa	Table 2 (4.1.5.1)	
Fy = 450 MPa	Table 3 (4.1.5.2)	
Span = 7,0 m	CL 4.3.1.5 (b)	

1.1

Loading of the beam		
Design dead load = 9 kNm^2 × 0,82 m × 1,2 Gn = 8,86 kNm	(Cl 4.2.2.1)	
Design imposed load = 6 kNm^2 × 0,82 m × 1,6 Qn = 7,87 kNm		

1.2

Calculate the maximum bending moment		
$\text{BM}_{\text{max}} = \frac{\text{WL}^2}{8} + \frac{\text{WL}^2}{8}$ $\text{BM}_{\text{max}} = \frac{8,86 \times 7,0^2}{8} + \frac{7,87 \times 7,0^2}{8}$ $\text{BM}_{\text{max}} = 54,27 + 48,2$ $\text{BM}_{\text{max}} = 102,47$ kNm		

1.3

Calculate the distance of the lever arm (Z)		
$Z = d\left\{0,5+\sqrt{0,25-\frac{K}{0,9}}\right\}$ $Z = 300\left\{0,5+\sqrt{0,25-\frac{0,156}{0,9}}\right\}$ $Z = 300\ (0,777)$ $Z = 233,1$ mm	(Cl 4.3.3.4.1)	

1.4

Calculate the tension reinforcement	(Cl 4.3.3.4.1)	
(The neutral axis lies within the flange.) $\text{As} = \frac{\text{M}}{0,87\, fy\, z}$ $\text{As} = \frac{102,47 \times 10^6}{0,87 \times 450 \times 233,1}$ As = 1 123 mm^2 Use 4Y20 bars (As = 1 257 mm^2)		

Note

Students may use any one of the two formulae. They don't need to use both.

Should the neutral axis be below the flange, do the following $Mu = 0,87 \times fy \times As \, (d - \frac{hf}{2})$ $As = \frac{M_u}{0,87 \, x \, fy \, x \left(d - \frac{hf}{2}\right)}$ $As = \frac{102,47 \times 10^6}{0,87 \times 450 \times \left(300 - \frac{120}{2}\right)}$ $As = 1\,090,6 \text{ mm}^2$ Use 3Y20 ($As = 1\,257 \text{ mm}^2$)	(Cl 4.3.3.4.3)	

1.5

The minimum distance between the bars Width of beam = 250 mm − 25 × 2 side cover = 200 mm −2 × 25 = 50 mm; 200 mm − 50 mm = 150 mm Divide by 2 spacers then the distance between the bars = 75 mm (Minimum distance = 19 mm + 5 = 25 mm)		

1.6

Check the minimum in the area of reinforcement $\frac{100 \times AS}{bw \, h} = \frac{100 \times 1\,257}{250 \times 120}$ $= 4,19 > 0,45$ (Sufficient)	Table 23	

2.

All references taken from SANS 0100-1 (2000)		
Fcu = 25 MPa	Table 2 (4.1.5.1)	
Fy = 450 MPa	Table 3 (4.1.5.2)	
Span = 6,750 m	Cl 4.3.1.5 (b)	

2.1	Calculate the effective width of the L-beam Use the lesser of: 1. Web width + $\frac{L_z}{10}$ $= 320 + \frac{6\,750}{10}$ $= 320$ mm (0,320m) OR 2. The actual width not given	(Cl 4.3.1.2)	

2.2	Calculate the design loads Design dead load = 12,5 kNm^2 × 0,995 m × 1,2 Gn = 14,93 kNm Design imposed load = 7,75 kNm^2 × 0,995 m × 1,6 Qn = 12,34 kNm	(Cl 4.2.2.1)	

2.3	Calculate the maximum bending moment $BM_{max} = \frac{WL^2}{8} + \frac{WL^2}{8}$ $BM_{max} = \frac{14{,}93 \times 6{,}75^2}{8} + \frac{12{,}34 \times 6{,}75^2}{8}$ $BM_{max} = 81{,}44 + 70{,}28$ $BM_{max} = 150{,}72$ kNm		

2.4	Calculate the distance of the lever arm (Z) $Z = d\left\{0{,}5+\sqrt{0{,}25-\frac{k^1}{0{,}9}}\right\} \le 0{,}95d$ $Z = 480\left\{0{,}5+\sqrt{0{,}25-\frac{0{,}156}{0{,}9}}\right\} \le 0{,}95 \times 480$ $Z = 480\ (0{,}777) \le 0{,}95 \times 480$ $Z = 372{,}96$ mm < 456 mm Use $Z = 372{,}96$ mm (lesser between the two)	(Cl 4.3.3.4.1)	

2.5	Calculate the area of reinforcement *Note: The neutral axis is within the flange.* $As = \frac{m}{0{,}87\,fy\,z}$ $As = \frac{150{,}72 \times 10^6}{0{,}87 \times 450 \times 372{,}96}$ $As = 1\,032{,}2\ \text{mm}^2$ Use 4Y20 bars ($As = 1\,275\ \text{mm}^2$)	(Cl 4.3.3.4.1)	

2.6	The minimum distance between the bars Width of beam = 320 mm − 25 × 2 side cover = 270 mm, −4 × 20 = 80 mm; 270 mm − 80 mm = 190 mm Divide by 3 spacers then distance between the bars = ± 60 mm. (Minimum distance = 19 mm + 5 = 25 mm)		

2.7	Check the minimum area of reinforcement $\frac{100 \times AS}{bw\,h} = \frac{100 \times 1\,257}{320 \times 180}$ = 2,18 > 0,20 (Sufficient)	Table 23	

Exercise 1.7

SB page 107

1.	All references taken from SANS 0100-1 (2000)		

1.2	Calculate the size of the pad foundation Working load = 85 kN + 870 kN + 200 kN = 1 155 kN $\text{Area} = \frac{\text{Force}}{\text{Pressure}}$ $\text{Area} = \frac{1\,155}{220}$ $\text{Area} = 5{,}25\ \text{m}^2$ For the square base $\sqrt{5{,}25}$ = 2,29 m × 2, 29 m Use a base of 2,30 m × 2,30 m		

2.

All references taken from SANS 0100-1 (2000)		

2.1

Calculate the ultimate axial load		
N = 0,4 *fcu* Ac + 0,67 *fy* Asc	(Cl 4.7.4.3)	
N = 0,4 × 30 × (330 × 220) + 0,67 × 250 × 1 885		
N = 871 200 + 315 737,5		
N = 1 186, 94 kN		

2.2

Calculate the diameter and spacing of the binders		
Binders:		
¼ of the smallest main bar	Cl 4.11.4.5.1	
¼ × 20 = 5 mm (not available)		
Use: R8 binders.		
Spacing of the binders:		
12 × diameter of smallest main bar	(Cl 4.11.4.5.1)	
12 × 20 = 240 mm (maximum)		
Use spacings of 240 mm centres.		

2.3

Calculate the minimum and maximum area of the main steel		
Minimum area of main steel: 0,4% AC	(Table 23)	
0,4% × 330 × 220		
Minimum area = 290,4 mm^2		
	(Cl 4.11.5.2)	
Maximum area of main steel: 6% AC		
6% × 330 × 220		
Minimum area = 4 356 mm^2		
Summary of round column		
RC Column 330 × 220 mm with 6Y20 Main bars R8 binders at 240 mm c/c.		

2.4–2.5 Horizontal cross-sectional view of the column with dimensions

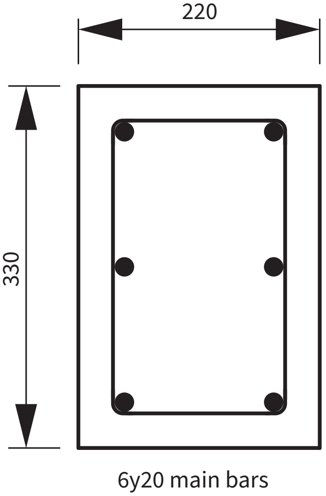


Figure 1.5

3.

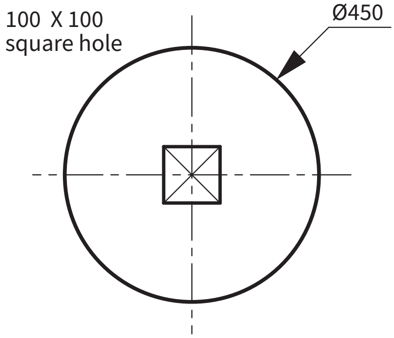
All references taken from SANS 0100-1 (2000)		

3.1

Check for the short column $= \frac{Le}{b} < 10$ $= \frac{0,9 \times 3\,000 \text{ mm}}{280 \text{ mm}} < 10$ = 9,6 < 10 okay	Cl 4.7.1.4	

3.2

Calculate the diameter and spacing of the binders. Binders: ¼ of the smallest main bar ¼ × 20 = 5 mm (not available) Use: R8 binders. Spacing of the binders: 12 × diameter of smallest main bar 12 × 20 = 240 mm (maximum) Use spacings of 240 mm centres.	Cl 4.11.4.5.1 (Cl 4.11.4.5.1)	

3.3	Calculate the area of reinforcement $N = 0,4\ fcu\ Ac + 0,67\ fy\ Asc$ $Asc = \frac{N - (0,4\ fcu\ Ac)}{0,67\ Fy}$ $Asc = \frac{1\,800\ x\ 10^3 - \left(0,4 \times 30 \times 400 \times 280\right)}{0,67 \times 450}$ $= \frac{1\,800 \times 10^3 - 1\,344\,000}{301,5}$ $Asc = 1\,512,4\ mm^2$ $Asc =$ Use 6Y20 bars ($Asc = 1\,885\ mm^2$)	(Cl 4.7.4.3)	
3.4	 *Figure 1.6* Calculate the minimum and maximum area of the main steel Minimum area of main steel: $\frac{100 \times Asc}{Ac} \geq 0,4$ $\frac{100 \times 1\,512,4}{280 \times 400} \geq 0,4$ $1,35 > 0,4$ Okay Maximum area of main steel: 6% gross cross-sectional 6% × 280 × 400 Minimum area = $6\,720\ mm^2$ Summary of rectangular column: RC Column 240 × 200 mm with 6Y20 Main bars Y8 binders at 240 mm c/c.	(Table 23) (Cl 4.11.5.2)	

4.1

Given info: RC column: Load: Fcu: Fy:	 450 mm diameter 2 200 kN 30 MPa (Table 2) 450 MPa (Table 3)	
All references taken from SANS 0100–2000 Determine the area of the concrete Net area = $\frac{\pi d^2}{4}$ – the area of the hole Net area = $\frac{\pi 450^2}{4}$ – (100 × 100) = 159 043,128 – 10 000 Net area = 149 043,13 mm^2		
Calculate the suitable reinforcement N = 0,4 fcu Ac + 0,67 fy Asc 2 350 × 10^3 = (0,4 × 30 × 149 043,13) + (0,67 × 450 × Asc) 2 350 × 10^3 = 1 788 517, 56 + 301,5 Asc Asc = $\frac{2\ 350 \times 10^3 - 1\ 788\ 517{,}56}{301{,}5}$ Asc = 1 862,97 mm^2 Use 6Y20 (Asc = 1 885 mm^2) Use minimum: Asc = 0,4% AC Asc = 0,4 %AC Asc = 0,4 × 282 743,3 mm^2 = 1 131 mm^2	 (Cl 4.7.4.3) (Table 23) (Cl 4.11.4.2.2)	
The size and spacing of the binders Binders: ¼ of the smallest main bar ¼ × 20 = 5 mm (not available) Use: R8 helical binder. Spacing of binders: 12 × diameter of smallest main bar 12 × 20 = 240 mm Use helical binder spacing of 200 mm	 (Cl 4.11.4.5.1)	

4.2 Calculate the size of the pad foundation

Working load = 2 350 kN + 250 kN

= 2 600 kN

Area = $\frac{\text{Force}}{\text{Pressure}}$

Area = $\frac{2\,600}{210}$ Area = 3,52 m^2

For the square base $\sqrt{3,52}$ = 2,29 m × 2, 29 m

Use a base of 1,9 m × 1,9 m

Exercise 1.8

SB page 115

1.	All references taken from SANS 10100-1 (2000)	
	Fcu = 25 MPa	Table 2 (4.1.5.1)
	Fy = 250 MPa	Table 3 (4.1.5.2)
	Width = 1,5 m	
	Density of reinforced concrete	2 400 kg/m^3

1.1 The slope formed by one step

$\text{Tan}\varphi = \frac{165}{225}$

$\varphi = 36,25°$

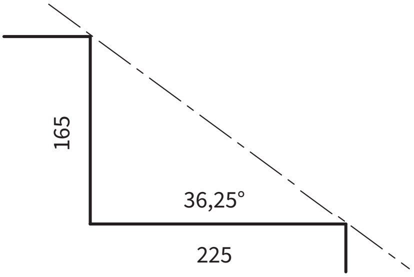


Figure 1.7

1.2 Calculate the length of the slope

Length of slope = $\sqrt{1\,950^2 + 1\,050^2}$

Length of slope = 2 215 mm

1.3	Load calculations		
	Waist:		
	W = Volume × density × g.a × 10^{-3} × 1,2Gn	(Cl 4.2.2.1)	
	W = 2,215 × 1,2 × 0,11 × 2 400 kg/m^3 × 9,81 × 10^{-3} × 1,2Gn		
	W = 8,3 kN		
	Treads or Steps:	(Cl 4.2.2.1)	
	W = Volume × density × g.a × 9,81 × 10^{-3} × 1,2Gn		
	W = ½bh × width × density × g.a × 9,81 × 10^{-3} × 1,2Gn		
	W = ½ × 0,225 × 1,05 × 1,2 × 2 400 kg/m^3 × 9,81 × 10^{-3} × 1,2Gn		
	W = 4 kN		

1.4	Design imposed load		
	1,6 Qn (3,5 kNm^2 × 1,95 m × 1,2 m) = 13,1 kN	(Cl 4.2.2.1)	

1.5	Calculate the maximum bending moment		
	$BM_{max} = \frac{WL}{10}$		
	$BM_{max} = \frac{(8,3 + 4 + 13,1) \times 1,95}{10}$		
	BM_{max} = 4,95 kNm		

2.	All references taken from SANS 10100-1 (2000).		
	Fcu = 20 MPa	Table 2 (4.1.5.1)	
	Fy = 250 MPa	Table 3 (4.1.5.2)	
	Width = 1,0 m		
	Density of reinforced concrete	2 400 kg/m^3	

2.1	Calculate the length of the slope		
	Length of slope = $\sqrt{1\,620^2 + \ 900^2}$		
	Length of slope = 1 853,2 mm		

Load calculations Waist: W = Volume × density × g.a × 10^{-3} × 1,2Gn W = 1 853,2 × 1,0 × 0,17 × 2 400 kg/m^3 × 9,81 × 10^{-3} × 1,2Gn W = 12,1 kN Treads or steps: W = Volume × density × g.a × 9,81 × 10^{-3} × 1,2Gn W = ½bh × width × density × g.a × 9,81 × 10^{-3} × 1,2Gn W = ½ × 0,25 × 0,9 × 1,0 × 2 400 kg/m^3 × 9,81 × 10^{-3} × 1,2Gn W = 3,178 kN	(Cl 4.2.2.1) (Cl 4.2.2.1)	
Design imposed load 1,6 Qn (5 kN/m^2 × 1,853 m × 1,0 m) = 14,824 kN	(Cl 4.2.2.1)	
Calculate the maximum bending moment $BM_{max} = \frac{WL}{10}$ $BM_{max} = \frac{(12{,}1+ 3{,}178 + 14{,}824) \times 2{,}62}{10}$ BM_{max} = 7,887 kNm		

2.2

Calculate the value for 'K' $K = \frac{BM}{fcu\ b\ d^2}$ $K = \frac{7{,}887 \times 10^6}{20 \times 1\,000 \times 1\,45^2}$ K = 0,018 < K1 = 0,156 Compression reinforcement is not required.	(Cl 4.3.3.4.1) Let effective depth (d) = 170 – 25 cover = 145 mm	

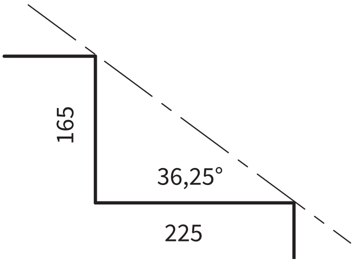
2.3

Calculate the distance of lever arm (Z) $Z = d\left\{0{,}5+ \sqrt{0{,}25 - \frac{K}{0{,}9}}\right\} \leq 0{,}95d$ $Z = 145\left\{0{,}5+ \sqrt{0{,}25 - \frac{0{,}018}{0{,}9}}\right\} \leq 0{,}95 \times 145$ Z =145(0,98) ≤ 0,95 × 145 Z = 142 mm > 137 mm Use Z = 137 mm (least)	(Cl 4.3.3.4.1)	

2.4	Calculate the tension reinforcement $As = \frac{BM}{0,87\,fy\,z}$ $As = \frac{7,887 \times 10^6}{0,87x\ 250 \times 137}$ $As = 264,69\ mm^2$ Use R12 bars @ 175 c/c ($As = 646\ mm^2$)	(Cl 4.3.3.4.1)	
	Determine the secondary reinforcement $\frac{100\ AS}{AC} = 0,24$ $As = \frac{0,24 \times AC}{100}$ $As = \frac{0,24 \times 1000 \times 175}{100}$ $As = 420\ mm^2$ Use R10 bars @ 175 c/c ($As = 449\ mm^2$)	Table 23 (Cl 4.11.4.3)	
	Fcu = 20 MPa Fy = 250 MPa Width = 1,25 m Density of reinforced concrete	Table 2 (4.1.5.1) Table 3 (4.1.5.2) 2 420 kg/m^3	
	Calculate the length of the slope Length of slope = $\sqrt{3\ 350^2 + \ 2\ 200^2}$ Length of slope = 4 007,8 mm		
	Load calculations Waist: $W = Volume \times density \times g.a \times 10^{-3}$ $W = 4\ 007,8 \times 0,12 \times 1,25 \times 2\ 420\ kg/m^3 \times 9,81 \times 10^{-3}$ $W = 14,27\ kN$ Treads or steps: $W = Volume \times density \times g.a \times 9,81 \times 10^{-3}$ $W = ½bh \times width \times density \times g.a \times 9,81 \times 10^{-3}$ $W = ½ \times 0,235 \times 2,2 \times 1,25 \times 2\ 420\ kg/m^3 \times 9,81 \times 10^{-3}$ $W = 15,34\ kN$		

	Total design dead load 1,2 Gn (14,27 kN + 15,34 kN) = 35,53 kN Design imposed load 1,6 Qn (11,5 kN/m^2 × 1,2 m × 3,35 m) = 73,97 kN		
	Calculate the maximum bending moment $BM_{max} = \frac{WL}{10} + \frac{WL}{10}$ $BM_{max} = \frac{35{,}53 \times 3{,}35}{10} + \frac{73{,}97 \times 3{,}35}{10}$ $BM_{max} = 11{,}9 + 24{,}78$ $BM_{max} = 36{,}68$ kNm		

3.	All references taken from SANS 10100-1 (2000).		
	Fcu = 25 MPa	Table 2 (4.1.5.1)	
	Fy = 250 MPa	Table 3 (4.1.5.2)	
	Width = 1,5 m		
	Density of reinforced concrete	2 400 kg/m^3	

3.1	The slope formed by one step $\tan\varphi = \frac{165}{225}$ $\varphi = 37°$  *Figure 1.8*		

3.2	Calculate the length of the slope Length of slope = $\sqrt{1\,950^2 + 1\,050^2}$ Length of slope = 2 215 mm		

3.3	Load calculations		
	Waist:		
	W = Volume × density × g.a × 10^{-3} × 1,2Gn	(Cl 4.2.2.1)	
	W = 2,215 × 1,3 × 0,11 × 2 400 kg/m^3 × 9,81 × 10^{-3} × 1,2Gn		
	W = 8,3 kN		
	Treads or steps:		
	W = Volume × density × g.a × 9,81 × 10^{-3} × 1,2Gn	(Cl 4.2.2.1)	
	W = ½bh × width × density × g.a × 9,81 × 10^{-3} × 1,2Gn		
	W = ½ × 0,225 × 1,05 × 1,2 × 2 400 kg/m^3 × 9,81 × 10^{-3} × 1,2Gn		
	W = 4 kN		
	Design imposed load		
	1,6 Qn (3,5 kN/m^2 × 1,95 m × 1,2 m) = 13,1 kN	(Cl 4.2.2.1)	
	Calculate maximum bending moment		
	$BM_{max} = \frac{WL}{10} + \frac{WL}{10}$		
	$BM_{max} = \frac{(8,3 + 4 + 13,1) \times 1,95}{10}$		
	BM_{max} = 4,95 kNm		

4.	All references taken from SANS 10100-1 (2000)		
	Fcu = 25 MPa	Table 2 (4.1.5.1)	
	Fy = 250 MPa	Table 3 (4.1.5.2)	
	Width = 1,35 m		
	Density of reinforced concrete	2 425 kg/m^3	

4.1	Calculate the length of the slope		
	Length of slope = $\sqrt{2\,250^2 + \ 1\,625^2}$		
	Length of slope = 2,775 mm (2, 775 m)		

4.2

The slope formed by one step

$$\text{Tan } \varphi = \frac{160}{220}$$

$$\varphi = 37{,}5°$$

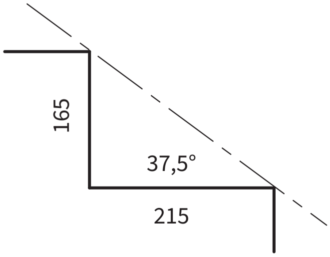


Figure 1.9

Load calculations

Waist: (Cl 4.2.2.1)

$W = \text{Volume} \times \text{density} \times \text{g.a} \times 10^{-3}$

$W = 2{,}775 \times 1{,}35 \times 0{,}12 \times 2\,425 \text{ kg/m}^3 \times 9{,}81 \times 10^{-3} \times 1{,}2\text{Gn}$

$W = 12{,}83 \text{ kN}$

Treads or Steps:

$W = \text{Volume} \times \text{density} \times \text{g.a} \times 9{,}81 \times 10^{-3}$

$W = ½\text{bh} \times \text{width} \times \text{density} \times \text{g.a} \times 9{,}81 \times 10^{-3}$

$W = ½ \times 0{,}215 \times 1{,}625 \times 1{,}35 \times 2\,425 \text{ kg/m}^3 \times 9{,}81 \times 10^{-3} \times 1{,}2\text{Gn}$ (Cl 4.2.2.1)

$W = 6{,}73 \text{ kN}$

4.3

Design imposed load

$1{,}6 \text{ Qn } (10{,}5 \text{ kNm}^2 \times 1{,}35 \text{ m} \times 2{,}25 \text{ m}) = 51 \text{ kN}$ (Cl 4.2.2.1)

4.4

Calculate the maximum bending moment

$$BM_{max} = \frac{WL}{10} + \frac{WL}{10}$$

$$BM_{max} = \frac{(12{,}83 + 6{,}73) \times 2{,}25}{10} + \frac{51 \times 2{,}25}{10}$$

$$BM_{max} = 4{,}4 + 11{,}48$$

$$BM_{max} = 15{,}88 \text{ kNm}$$

4.5	Calculate the value for 'K' $K = \frac{BM}{fcu\ b\ d^2}$ $K = \frac{15,88 \times 10^6}{25 \times 1\ 350 \times 90^2}$ $K = 0,058 < K^1 = 0,156$ Only tension reinforcement will be required.	(Cl 4.3.3.4.1) Let effective depth (d) = 120 – 30 cover = 90 mm	
	Calculate the distance of the lever arm (Z) $Z = d\left\{0,5+\sqrt{0,25-\frac{K}{0,9}}\right\} \leq 0,95d$ $Z = 90\left\{0,5+\sqrt{0,25-\frac{0,058}{0,9}}\right\} \leq 0,95 \times 90$ $Z = 90(0,93) \leq 0,95 \times 90$ Z = 83,77 mm < 85,5 mm Use Z = 83,77 mm (least)	(Cl 4.3.3.4.1)	

4.6	Calculate the tension reinforcement $As = \frac{M}{0,87\ fy\ z}$ $As = \frac{15,88 \times 10^6}{0,87 \times 250 \times 83,77}$ $As = 871,57\ mm^2$ Use R12 bars @ 125 c/c ($As = 905\ mm^2$)	(Cl 4.3.3.4.1)	

4.7	Determine the secondary reinforcement $\frac{100\ AS}{AC} = 0,24$ $As = \frac{0,24 \times\ AC}{100}$ $As = \frac{0,24 \times\ 1\ 350 \times 120}{100}$ $As = 388\ mm^2$ Use R8 bars @ 125 c/c ($As = 402\ mm^2$)	Table 23 (Cl 4.11.4.3)	

MODULE

2 The bending schedule

By the end of this module, students should be able to:

- interpret and make references to the SANS 282 summary of shape codes; and
- identify and categorise the details of a completed reinforcement bending bar schedule, with a clear understanding of the sections listed below:
  - the members (concrete staircase, concrete columns, concrete beams, concrete slabs and base foundations)
  - the bar mark
  - the type and size of reinforcement
  - the number of members
  - the number of bars in each member
  - the total number of bars
  - the length of each bar
  - the shape code
  - the columns A–E in the nearest 5-mm dimension.

The bending schedule is an itemised list of all the reinforcement required for single concrete elements. Civil engineers design the reinforcement, complete the reinforcement layout plan and section drawings as well as the bending schedule.

Exercise 2.1

SB page 137

1. 1.1

8	Number of bars
Y	Type of steel – high-yield tensile steel bars
12	Diameter of steel bars
02	Bar mark
175	Centre-to-centre spacing
abr	Alternate bars reversed

1.2

12	Number of bars
R	Type of steel – mild steel bars
08	Diameter of steel bars
04	Bar mark
T	Bars, place at the TOP.

2.

1	2	3	4	5	6	7	8	9	10	11	12
Member	**Reinforcement**					**Bending dimensions for shape codes (SANS 282)**					
Mark size and no. off	**Mark**	**Type and size**	**No. in each**	**Total no.**	**Length (mm)**	**Shape code**	**A**	**B**	**C**	**D**	**E or R**
Beam and Column (2 off)	01	Y20	03	6	6 550	35	6 350				
	02	Y16	02	4	6 350	20	6 350				
	03	Y16	03	6	6 550	35	3 350				
	04	Y10	17	34	1 700	60	500	300			
	05	Y16	04	8	1 300	37	1 000				
	06	R10	07	14	1 300	60	300	300			
	07	Y16	06	12	2 060	37	2 060	400			
	08	R08	09	18	1 460	60	240	240			

3.

1	2	3	4	5	6	7	8	9	10	11	12
Member	**Reinforcement**					**Bending dimensions for shape codes** **(SANS 282)**					
Mark size and no. off	**Mark**	**Type and size**	**No. in each**	**Total no.**	**Length (mm)**	**Shape code**	**A**	**B**	**C**	**D**	**E or R**
Composite foundation beam **(6 500 × 650)** **2 off**	01	Y 20	02	04	6 720	35	6 420				
	02	Y 20	02	04	6 720	35	6 420				
	03	Y 16	02	04	6 420	20	6 420				
	04	Y10	07	14	1 680	60	570	220			
	05	Y20	06	12	2 060	37	2 060	400			
	06	Y08	09	18	860	60	240	140			
	07	Y16	06	12	2 060	37	2 060	400			
	08	R08	09	18	1 460	60	240	240			

4.1

A	Edge beam
B	Slab
C	Stairway
D	Stub column
E	Base

Any other suitable answer(s) will be accepted.

4.2

1	**2**	**3**	**4**	**5**	**6**	**7**
Mark, size and no. of	**Mark**	**Type and size**	**No. of members**	**No. in each**	**Total number**	**Shape**
Multiple members	01	Y25	01	04	04	
	02	Y20	01	04	04	
	03	Y20	01	03	03	
	04	Y16	01	05	05	
	05	R16	01	03	03	
	06	R12	01	08	08	
	07	Y16	01	05	05	

MODULE

3 Iron and steel

By the end of this module, students should be able to:

- describe the raw materials used in the processes of producing of iron and steel by means of the following:
    - a cupula
    - an open hearth furnace
    - the Bessemer converter
    - an electric furnace;
- describe non-ferrous metals and their uses in structural work;
- determine, by means of calculation, the maximum load the connection can safely support within the thread of the shear plane using the following:
    - shearing formulae
        - shear stress
        - area
        - shear load
    - bearing formulae
        - bearing stress
        - area
        - bearing load
    - tearing formulae
        - tensile stress
        - area
        - tensile load;
- calculate the magnitude of given forces and distinguish between tension and compression on parts marked graphically or analytically;
- determine the following by means of a calculation:
    - the number of bolts required to safely secure parts to the gusset plate (the thread of the bolts will be within the shearing plane)
    - select a suitable equal-leg angle section for a part marked with a given total length;
- determine, by means of a calculation, the size and shear stress value of a bolt using the following:
    - the vertical load
    - the distance from the centroid to the furthest bolt
    - the direct load on the bolt due to an imposed load

  - the total load of each bolt
  - the size of the bolt;
- determine, by means of a calculation, the maximum tensile load of a fillet-welded joint with a given leg size and a given effective length to safely support using the following:
  - the effective length
  - the throat
  - the area of weld
  - the allowable stress
  - the maximum load;
- determine, by means of a calculation, the central point load which the compound beam must safely support given the maximum bending stress and ignoring the self-weight of the beam;
- determine, by means of calculation, the maximum point load a beam can carry at midpoint, considering the self-weight of the beam given the following:
  - the effective length of the beam
  - the maximum bending stress
  - the uniformly distributed load (UDL);
- determine, by means of calculation, the maximum effective span it can support at midspan given the following:
  - the self-weight of the beam
  - the maximum bending stress;
- determine, by means of a calculation, a suitable I-parallel flange steel beam to support the given loads using the following:
  - the included self-weight of the beam
  - the maximum bending stress;
- calculate the imposed load as well as its own self-weight;
- determine the following by means of calculation:
  - the maximum load that a beam can support at a given point using a given bending stress value
  - the magnitude of the reactions RR and RL
  - the number of bolts to safely secure the steel beam to the concrete structure;
- determine, by means of a calculation, the maximum (UDL) that each of the beams will be able to carry given a bending stress value
- explain why the loads of two beams differ
- draw two neat sketches to show how beams can be joined to form one tension member; and
- determine, by means of a calculation, the maximum UDL that the structural steel can safely support.

The bending schedule is an itemised list of all the reinforcement required for single concrete elements. Civil engineers design the reinforcement, complete the reinforcement layout plan and section drawings as well as the bending schedule.

Exercise 3.1

SB page 169

1.1 Calculate the maximum load at 'B'

$$\text{Stress} = \frac{\text{Load}}{\text{Area}}$$

$$\text{Load} = \text{stress} \times \text{area} \times 4 \times 2$$

$$\text{Load} = 110\,\frac{\text{N}}{\text{mm}^2} \times \frac{\pi\,16^2}{4} \times 4 \times 2$$

$$\text{Load} = 110\,\frac{\text{N}}{\text{mm}^2} \times 201{,}06 \times 4 \times 2$$

$$\text{Load} = 176{,}9\ \text{kN}$$

1.2 Calculate the size of the bolt at A-A

$$\text{Shear stress} = \frac{\text{Load}}{\text{Area}}$$

$$100\,\frac{\text{N}}{\text{mm}^2} = \frac{46 \times 10^3}{\frac{\pi\,d^2}{4} \times 1 \times 2}$$

$$100\,\frac{\text{N}}{\text{mm}^2} = \frac{46 \times 10^3 \times 4}{\pi d^2 \times 1 \times 2}$$

$$d = \sqrt{\frac{46 \times 10^3 \times 4}{110 \times \pi \times 1 \times 2}}$$

$$d = 16{,}3\ \text{mm}$$

Use a M16 or M18 bolt

1.3 Calculate the shear stress at 'B'

$$\text{Shear stress} = \frac{\text{Load}}{\text{Area}}$$

$$\text{Stress} = \frac{185 \times 10^3}{\frac{\pi\,12^2}{4} \times 4 \times 2}$$

$$\text{Stress} = \frac{185 \times 10^3 \times 4}{\pi \times 12^2 \times 4 \times 2}$$

$$\text{Stress} = 204{,}5\ \text{MPa}$$

2.1 Calculate the force of the bolts in shearing

The screw thread is within the shearing plane.

Load = area × stress

$F_s = A_s \times f_s \times n$

$$\text{Force in shear} = \frac{\pi\,(d - 0{,}9382\,p)^2}{4} \times f_s \times n$$

$$= \frac{\pi\,(12 - 0{,}9382 \times 1{,}75)^2}{4} \times 100 \text{ Nmm}^2 \times 6$$

Force in shear = 50,56 kN

2.2 Calculate the force of the bolts in shearing

The screw thread is outside the shearing plane.

Load = area × stress

$F_s = A_s \times f_s \times n$

$$\text{Force in shear} = \frac{\pi\,d^2}{4} \times f_s \times n$$

$$= \frac{\pi 12^2}{4} \times 100 \text{ Nmm}^2 \times 6$$

Force in shear = 67,86 kN

2.3 Calculate the force in tearing

Load = area × stress

$Ft = A_t \times f_t \times n$

$$\text{Force in tearing} = [(B \times T) - n\,(d \times t)] \times f_t$$

$$= [(56 \times 10) - 2(14 \times 10)] \times 155 \text{ Nmm}^2$$

$$= 560 - 280 \times 155 \text{ Nmm}^2$$

Force in tearing = 43,4 kN

3.1 Calculate the force of the bolts in shearing

Load = area × stress

$F_s = A_s \times f_s \times n$

$$\text{Force in shear} = \frac{\pi\,(d - 0{,}9382\,p)^2}{4} \times f_s \times n$$

$$= \frac{\pi\,(16 - 0{,}9382 \times 2)^2}{4} \times 100 \text{ Nmm}^2 \times 2$$

Force in shear = 156,67 kN

3.2 Calculate the force in tearing

Load = area × stress

$F_t = A_t \times f_t \times n$

Force in tearing = $[(B \times T) - n\,(d \times t)] \times f_t$

$= [(60 \times 6) - 2(18 \times 6)] \times 155\ \text{Nmm}^2$

$= 360 - 216 \times 155\ \text{Nmm}^2$

Force in tearing = 22,32 kN

3.3 Calculate the force in bearing

$F_b = A_t \times f_b \times n$

$Fb = (d \times t) \times 240 \times 2$

$Fb = (16 \times 6) \times 240 \times 2$

Fb = 46,1 kN

Exercise 3.2

SB page 179

1.1 Calculate the reactions of the roof truss

The truss is symmetrically loaded and therefore:

$$RL = RR = \frac{12 + 16 + 12}{2}$$

RL = RR = 20 kN

$\Sigma VC = 0$

AF Sin 30° = 20 kN

$$AF = \frac{20}{\text{Sin } 30°}$$

AF = 40 kN (Strut)

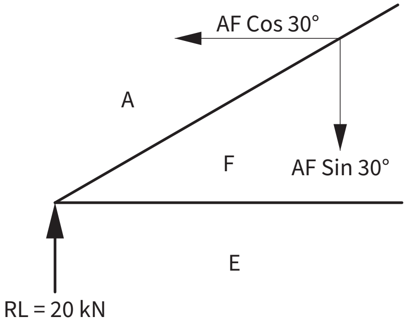


Figure 3.3: Node 1

$\Sigma HC = 0$

FE = AF Cos 30°

FE = 40 × Cos 30°

FE = 34,64 kN (Tie)

VC = 0 (Force up = Forces down)

40 Sin 30° + FG Sin 30° = 12 kN + BG Sin 30°

$20 + 0{,}5\ FG = 12 \times 0{,}5\ BG$

$20 - 12 = 0{,}5\ BG - 0{,}5\ FG$

$8 + 0{,}5\ FG = 0{,}5\ BG$

$$BG = \frac{8 + 0{,}5\ BG}{0{,}5}$$

BG = 16 + FG

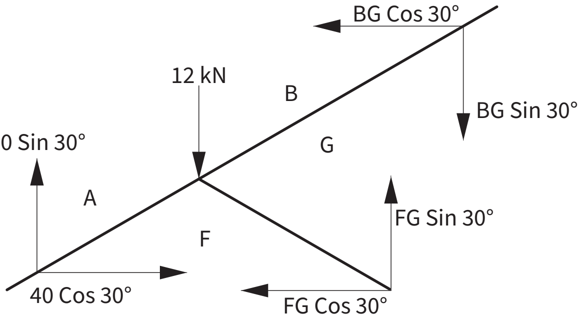


Figure 3.4: Node 2

$$\begin{aligned}
\text{HC} &= 0\\
40 \text{ Cos } 30° &= \text{BG Cos } 30° + \text{FG Cos } 30°\\
34{,}66 &= 0{,}866 \text{ BG} + 0{,}886 \text{ FG}\\
34{,}66 \text{ kN} &= 0{,}866(16 + \text{FG}) + 0{,}866 \text{ FG}\\
&= 13{,}86 + 0{,}88 \text{ FG} + 0{,}866 \text{ FG}\\
34{,}66 - 13{,}86 &= 1{,}732 \text{ FG}\\
\text{FG} &= \frac{20{,}8}{1{,}732}\\
\text{FG} &= 12 \text{ kN (Strut)}
\end{aligned}$$

$$\begin{aligned}
\text{And: BG} &= 16 + \text{FG}\\
\text{BG} &= 16 + 12\\
\text{BG} &= 28 \text{ kN (strut)}
\end{aligned}$$

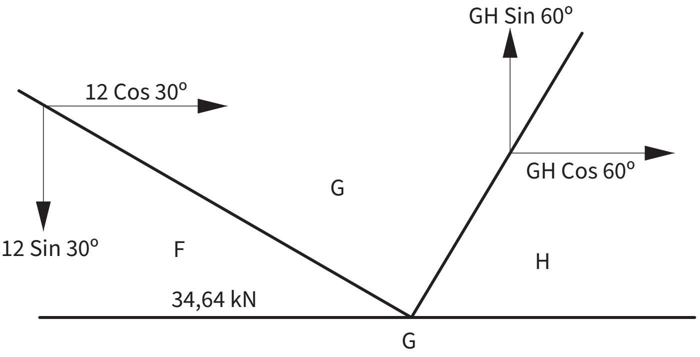


Figure 3.5: Node 3

$$\begin{aligned}
&\text{VC} = 0\\
&\text{GH Sin } 60° = 12 \text{ Sin } 30°\\
&\text{GH} = \frac{6}{0{,}866}\\
&\text{GH} = 6{,}93 \text{ (Tie)}\\
&\text{HC} = 0
\end{aligned}$$

$$34{,}64 \text{ kN} = \text{EH} + \text{GH Cos } 60° + 12 \text{ Cos } 30°$$
$$34{,}64 = \text{EH} + 6{,}93 \text{ Cos } 60° + 10{,}39$$
$$\text{HE} = 134{,}64 - 3{,}465 - 10{,}\ 39$$
$$\text{HE} = 20{,}79 \text{ kN (Tie)}$$

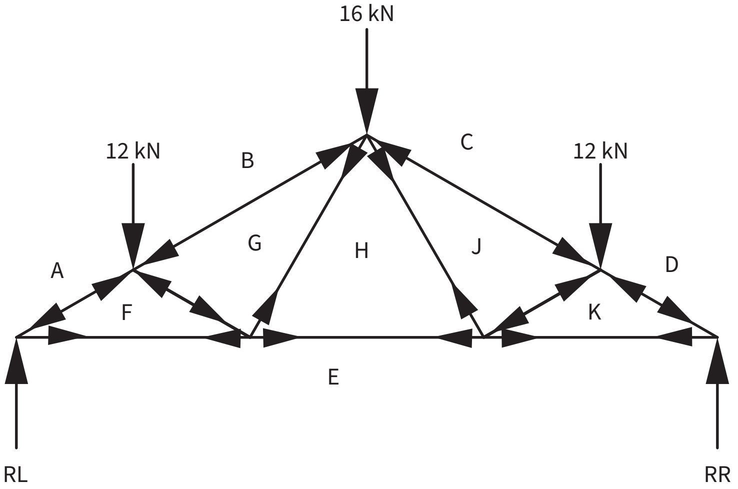


Figure 3.6:

1.2 Summary of all the forces

Member	Type	Magnitude
AF	Strut	220 kN
BG	Strut	187 kN
CJ	Strut	187 kN
DK	Strut	220 kN
FG	Tie	56,3 kN
GH	Tie	56,3 kN
HJ	Tie	56,3 kN
JK	Strut	56,3 kN
FE	Tie	190,5 kN
HE	Tie	134,2 kN
KE	Tie	190,5 kN

Exercise 3.3

SB page 192

1.1	The welded tie Calculate the effective area $A_{eff} = \frac{3A_1^2 + A_1 A_2}{3A_1 + A_2}$ The tie is welded no holes required $A_1 = A_2$ $A_1 = t(b - \frac{t}{2})$ $= 6(50 - \frac{6}{2})$ $A_1 = 282 \text{ mm}^2$ $A_2 = t(h - \frac{t}{2})$ $= 6(50 - \frac{6}{2})$ $A_2 = 282 \text{ mm}^2$ Therefore: $E_{ff} = \frac{3A_1^2 + 4A_1 A_2}{3A_1 + A_2}$ $E_{ff} = \frac{3(282^2) + 4(282)(282)}{3(282) + (282)}$ $E_{ff} = \frac{556\,668}{1\,128}$ $E_{ff} = 494 \text{ mm}^2$	(SANS 0162-Cl 9.2.1
	Calculate the force Force = stress × area $= 155 \frac{N}{mm^2} \times 494 \text{ mm}^2$ Force = 76 570 N = 76,57 kN	Table 20

1.2	The bolted tie Calculate the effective area $A_{eff} = \frac{3A_1^2 + A_1 A_2}{3A_1 + A_2}$ The tie is, bolted using M16 bolts. $A_1 = t(b - \frac{t}{2})$ – area of the hole $A_1 = 6(50 - \frac{6}{2}) - (18 \times 6)$ $A_1 = 174 \text{ mm}^2$	(SANS 0162-Cl 9.2.1

$A_2 = 282\ mm^2$ (we using the same as above) Therefore: $E_{ff} = \frac{3 A_1^2 + 4 A_1 A_2}{3 A_1 + A_2}$ $E_{ff} = \frac{3(174^2) + 4\ (174)\ (282)}{3\ (174) + (282)}$ $E_{ff} = \frac{287\ 100}{804}$ $E_{ff} = 357\ mm^2$	The hole is 2 mm larger than the bolt. M16 + 2 = 18 mm
Calculate the force Force = stress × area $= 155 \frac{N}{mm^2} \times 357\ mm^2$ Force = 55,335 N = 55,3 kN	Table 20

2.1

The welded tie Calculate the effective area $A_{eff} = \frac{3\ A_1^2 + A_1\ A_2}{3\ A_1 + A_2}$ The tie is welded no holes required $A_1 = A_2$ $A_1 = t\ (b - \frac{t}{2})$ $= 12\ (90 - \frac{12}{2})$ $A_1 = 1\ 008\ mm^2$ $A_2 = t\ (h - \frac{t}{2})$ $= 12\ (90 - \frac{12}{2})$ $A_2 = 1\ 008\ mm^2$ Therefore: $E_{ff} = \frac{3\ A_1^2 + 4\ A_1\ A_2}{3\ A_1 + A_2}$ $E_{ff} = \frac{3(1\ 008^2) + 4\ (1\ 008)\ (1\ 008)}{3\ (1\ 008) + (1\ 008)}$ $E_{ff} = \frac{7\ 112\ 448}{4\ 032}$ $E_{ff} = 1\ 764\ mm^2$	(SANS 0162-Cl 9.2.1

Calculate the force this member may be subjected to Force = stress × area $= 155 \frac{N}{mm^2} \times 1\,764\ mm^2$ Force = 273 420 N = 273,4 kN	Table 20

2.2

The bolted tie Calculate the effective area $A_{eff} = \frac{3\,A_1^2 + A_1\,A_2}{3A_1 + A_2}$ The tie is, bolted using M20 bolts. $A_1 = 12\ (b - \frac{t}{2})$ – area of the hole $A_1 = 12\ (90 - \frac{12}{2}) - (22 \times 12)$ $A_1 = 744\ mm^2$ $A_2 = 950\ mm^2$ (we using the same as above) Therefore: $E_{ff} = \frac{3A_1^2 + 4\,A_1\,A_2}{3A_1 + A_2}$ $E_{ff} = \frac{3(744^2) + 4\ (744)\ (1\,008)}{3\ (744) + (1\,008)}$ $E_{ff} = \frac{4\,660\,416}{3\,240}$ $E_{ff} = 1\,438{,}4\ mm^2$	(SANS 0162-Cl 9.2.1 The hole is 2 mm larger than the bolt. M20 + 2 = 22
Calculate the force this member may be subjected to Force = stress × area $= 155 \frac{N}{mm^2} \times 1\,438{,}5\ mm^2$ Force = 215, 85 N = 222 kN	Table 20

The chosen angle is adequate, yet a 100 × 100 × 10 member would also have been sufficient.

3.1	<u>Determine a suitable strut for part marked ‘J’ (strut)</u>	
	Required force = 56 kN	(SABS 0162 Table 19)
	Actual length = 1,55 m (discontinuous)	
	L_{eff} = 1 550 × 0,85 = 1 317,5 mm	
	Select trial section: 60 × 60 × 8 mm.	
	Area = 0,903 × 103 mm^2	
	r_{min} = 11,6 mm	
	$L/r = \frac{1\,317,5}{11,6} = 113,6$	(SABS 0162 Table 17)
	113,6 = 65,5 MPa	
	Therefore: Force = Stress × area	
	= 65,5 × 0,903 × 103 mm^2	
	Force = 59,15 kN	
	The welded strut will be able to withstand the given load of 56 kN.	

Note

Hints to find the given load

Students should note that it is not as easy to select a strut as it is with a tie. In the previous calculations in the textbook, we required a suitable strut for a load of 56 kN. They can refer to to Table 17 and observe the L/r values; as this increases as the stress values decreases.

Select a suitable rolled steel angle for marked Part 'G' (tie) Force = 65 kN Select trial section: 60 × 60 × 6 mm. Area = 0,599 × 103 mm^2 Allowable stress = 155 MPa Calculate effective area (A_{eff}) $A_{\text{eff}} = \frac{3(A_1)^2 + 4\,A_1\,A_2}{3A_1 + A_2}$ A_1 = Connected leg $A_1 = t(b - \frac{t}{2})$ – area of hole $A_1 = 6(60 - \frac{6}{2}) - (18 \times 6)$ $A_1 = 234\ \text{mm}^2$ A_2 = Unconnected leg $A_1 = t(b - \frac{t}{2})$ $A_2 = 6(60 - \frac{6}{2})$ $A_2 = 342\ \text{mm}^2$ Calculate the effective area $A_{\text{eff}} = \frac{3\,(234)^2 + 4(234)(342)}{3(234) + (342)}$ $A_{\text{eff}} = \frac{484\,389}{1\,044}$ $A_{\text{eff}} = 0,\ 464\ \text{mm}^2\ (0{,}464 \times 10^3\ \text{mm}^2)$	(SABS 0162 Table 20) (SABS 0162 Clause 9.2.1) Where A1 is the connected leg and A_2 is the unconnected leg
Therefore the tensile force: Force = $Pt \times A_{\text{eff}}$ Force = 155 N/mm^2 × 0,464 × 10^3 mm^2 Force = 71,9 kN. The bolted tie bar will be able to withstand the given load of 65 kN.	(Table 20 SANS 10162)

Select a suitable rolled steel angle for marked Part 'T' (tie) Required force = 65 kN Select trial section: 60 × 60 × 6 mm. Area = $0{,}691 \times 10^3$ mm^2 Allowable stress = 155 MPa	(SABS 0162 Table 20)
Calculate effective area (A_{eff}) $A_{eff} = \frac{3(A_1)^2 + 4\,A_1\,A_2}{3A_1 + A_2}$ A_1 = Connected leg $A_1 = t(\mathrm{b} - \frac{t}{2})$ – (area of hole) $A_1 = 6(60 - \frac{6}{2}) - (18 \times 6)$ (M16 bolts) $A_1 = 234$ mm^2	(SABS 0162 Clause 9.2.1) Where A1 is the connected leg and A2 is the unconnected leg.
A_2 (unconnected leg) $A_2 = t(\mathrm{b} - \frac{t}{2})$ $A_2 = 6(60 - \frac{6}{2})$ $A_2 = 650$ mm^2	
$A_{eff} = \frac{3(A1^2) + 4(430)(650)}{3(430) + (650)}$ $A_{eff} = \frac{1\,672\,700}{1\,940}$ $A^{eff} = 862{,}2$ mm^2 ($0{,}8622 \times 10^3$ mm^2)	

3.2

The load: Force = Pt × A_{eff} Force = 155 N/mm^2 × 0,8622 × 103 mm^2 Force = 133,6 kN The bolted tie bar will be able to withstand the given load of 128 kN	(Table 20 SANS 10162)

3.3	Calculate the minimum length of the weld Force = P × A_{eff} Calculate the throat thickness = 8 × Sin 45º = 5,66 mm Effective length: F = P × A_{eff} Where: F = P × throat thickness × length And length = $\frac{F}{P \times \text{throat thickness}}$ = $\frac{98 \times 10^3}{130 \times 5{,}66}$ Length of weld = 133,2 mm Per side = $\frac{133{,}2}{2}$ = 66,6 mm	(Cl 10.7.1.2) SANS 10162)

Exercise 3.4

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1.1	If the tie bar is welded $A_{eff} = \frac{3(A1)^2 + 4\,A1\,A2}{3A1 + A2}$ $A_1 = t(b - \frac{t}{2})$ $A_1 = 8(80 - \frac{8}{2})$ $A_1 = 608 \text{ mm}^2$ And $A_2 = 608 \text{ mm}^2$ (no holes) $A_{eff} = \frac{3(608)^2 + 4\,(608)(608)}{3(608) + (608)}$ $A_{eff} = \frac{2\,587\,648}{2\,432}$ $A_{eff} = 1\,064{,}0 \text{ m}^2$ ($1{,}064 \times 10^3 \text{ mm}^2$)	(SABS 0162 Clause 9.2.1) Where A_1 is the connected leg and A_2 is the unconnected leg.
	Therefore tensile force: Force = Pt × A_{eff} Force = 155 Nmm^2 × 1 064 mm^2 Force = 164,92 kN. The welded tie bar will be able to withstand the given load.	(Table 20 SANS 10162)

1.2

If the tie bar is bolted $A_{eff} = \frac{3(A1)^2 + 4\,A1\,A2}{3A1 + A2}$ $A_1 = t(b - \frac{t}{2}) -$ (area of the hole) $A_1 = 8(80 - \frac{8}{2}) - (22 \times 10)$ (M20 bolts) $A_1 = 608 - 220$ $A_1 = 388\ mm^2$ And $A_2 = 608\ mm^2$	(SABS 0162 Clause 9.2.1) Where A_1 is the connected leg and A_2 is the unconnected leg.
$A_{eff} = \frac{3(388)^2 + 4\,(388)(608)}{3(388)+(608)}$ $A_{eff} = \frac{1\,395\,248}{1\,772}$ $A_{eff} = 787{,}39\ mm^2\ (0{,}787 \times 10^3\ mm^2\ )$ Therefore tensile force: Force = Pt × A_{eff} Force = 155 $Nmm^2 \times 787{,}39\ mm^2$ Force = 122,05 kN. The bolted tie bar will be able to withstand the given load.	(SABS 0162 Table 20)

1.3

Number of bolts required $F = Pv \times n \times A_{eff}$ $n = \frac{F}{Pv \times Aeff}$ Where: $Aeff = \frac{(\varnothing - 0{,}9382P)^2}{4}$ $Aeff = \frac{(20 - 0{,}9382 \times 2{,}5)^2}{4}$ $A_{eff} = 244{,}\ 79\ mm^2$ $n = \frac{120 \times 10^3}{100 \times 244{,}79}$ n = 4,9 bolts Use 5M20 bolts to attach the tie bar to the gusset plate.	(Pv = 100 MPa) (SABS 0162 Table 21) (The screw thread is within the shearing plane.)

Exercise 3.5

SB page 208

1. I-Section profile parallel flange

$356 \times 171 \times 56{,}7$ kg/m:

$I_{xx} = 160{,}6 \times 10^{-6}$ m^4

$Y = \frac{h}{2} = \frac{358{,}6}{2} = 179{,}3$ mm

Bending stress = 160 MPa

Self-weight of the channel (356 × 171 × 56,7 kg/m)

Weight = 56,7 kg/m × 9,81 × 10^{-3}

Weight = 0,556 kNm

Bending moment at centre of the channel

$$M = \frac{I \times f}{y}$$

$$M = \frac{160{,}6 \times 10^{6} \times 160}{179{,}3}$$

M = 143,3 kNm

Calculate the maximum point load

$$BM = \frac{wl^2}{8} + \frac{WL}{4}$$

$$143{,}3 = \frac{0{,}556 \times 6^2}{8} + \frac{W \times 6}{4} \quad 143{,}3 = 2{,}5 + 1{,}5\ W$$

$$W = \frac{143{,}3 - 2{,}5}{1{,}5}$$

W = 93,87 kN

Calculate the maximum shear stress.

Shear force maximum = 6 (56,7 kg/m × 6 m × 9,81 × 10^{-3}) + 93,87 divide by 2

= 3,34 kN + 93,78 divide by 2

Shear stress = 48,56 kN

$$\text{Shear stress} = \frac{\text{SF max}}{d \times t_1}$$

$$= \frac{48{,}56 \times 10^3}{358{,}6 \times 8}$$

Shear stress = 17 MPa

2. I-Section profile parallel flange 356 × 171 × 56,7 kg/m:

$I_{xx} = 160{,}6 \times 10^{-6}$ m^4

$Y = \frac{h}{2} = \frac{358{,}6}{2} = 179{,}3$ mm

Bending stress = 160 MPa

Self-weight of the channel ($356 \times 171 \times 56{,}7$ kg/m)

Weight = $56{,}7 \text{ kg/m} \times 9{,}81 \times 10^{-3}$

Weight = 0,556 kNm

Calculate the bending moment

$$\frac{M}{I} = \frac{f}{y}$$

$$M = \frac{I \times f}{y}$$

$$M = \frac{160{,}6 \times 10^{6} \times 160}{179{,}3}$$

$$M = 143{,}3 \text{ kNm}$$

Equate to bending moment maximum

$$BM = \frac{w\,l^2}{8} + \frac{WL}{4}$$

$$143{,}3 = \frac{0{,}556 \times L^2}{8} + \frac{94 \times L}{4}$$

$$143{,}3 = 0{,}07\ L^2 + 23{,}5\ L$$

$$\text{Span (L)} = 0{,}07\ L^2 + 23{,}5\ L - 143$$

$$\text{Span (L)} = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

$$\text{Span (L)} = \frac{-23{,}5 \pm \sqrt{23{,}5^2 - 4 \times 0{,}07 \times -\ 143{,}3}}{2 \times 0,\ 7}$$

$$\text{Span (L)} = \frac{-23{,}5 \pm 24{,}33}{0{,}14}$$

$$\text{Span (L)} = 6 \text{ m}$$

3.1 Number of bolts required

$$F = Pv \times n \times A_{eff}$$

$$n = \frac{F}{Pv \times A_{eff}}$$

Where:

$$A_{eff} = \frac{(Ø - 0{,}9382P)^2}{4}$$

$$A_{eff} = \frac{(16 - 0{,}9382 \times 2)^2}{4}$$

$$A_{eff} = 156{,}7 \text{ mm}^2$$

$$n = \frac{143\ x10^3}{100 \times 156{,}7}$$

n = 9,13bolts

Use 9M16 bolts to attach the tie bar to the gusset plate.

3.2	Calculate the length of the weld. The shear stress is 130 MPa. Calculate the throat thickness: $T_{th} = \sin 45° \times 6$ $= 4{,}24$ mm Calculate effective length: $F = P \times A_{eff}$ $F = P \times \text{throat} \times L$ $L = \frac{143 \times 10^3}{130 \times 4{,}24}$ $L = 259{,}2$ mm Per side $= \frac{259{,}4}{2}$ 129,7 mm per side (use 130 mm)	P = 130 MPa (10.7.1.2)

Exercise 3.6

SB page 221

1.1	I-section profile parallel flange (406 × 140 × 38,6 kg/m) I_{xx} = 124,1 × 10-6 m4 $Y = \frac{h}{2} = \frac{397{,}3}{2} = 198{,}65$ mm Bending stress = 156 MPa	
	Self-weight of the beam (406 × 140 × 38,6 kg/m) Weight = 38,6 kg/m × 9,81 × 10-3 Weight = 0,379 kN/m	
	Bending moment at the centre of the channel $M = \frac{I \times f}{y}$ $M = \frac{124{,}1 \times 10^6 \times 156}{198{,}65}$ M = 97,46 kNm	

Calculate the maximum distributed load

$$= \frac{wl^2}{8} + \frac{wl^2}{8}$$

$$97{,}46 = \frac{0{,}379 \times 7{,}6^2}{8} + \frac{w \times 7{,}6^2}{8}$$

$$97{,}46 = 2{,}74 + 7{,}22\ \mathrm{W}$$

$$\mathrm{W} = \frac{97{,}46 - 2{,}74}{7{,}22}$$

$$\mathrm{W} = 13{,}12\ \mathrm{kN/m}$$

1.2 Calculate the maximum shear stress

$$\text{Shear maximum force} = (0{,}379\ \mathrm{kN/m} \times 7{,}6\ \mathrm{m} \times 9{,}81 \times 10^{-3}) + (13{,}12\ \mathrm{kN/m} \times 7{,}6\ \mathrm{m})$$

$$= 0{,}028\ \mathrm{kN} + 99{,}7\mathrm{kN}$$

$$= \frac{99{,}74}{2}$$

Shear stress = 49,87 kN

$$\text{Shear stress} = \frac{\text{SF maximum}}{d \times t_1}$$

$$= \frac{49{,}87 \times 10^3}{397{,}3 \times 6{,}3}$$

Shear stress = 19,92 MPa

2. I-Section profile parallel flange 356 × 171 × 56,7 kg/m:

$$\mathrm{I}_{xx} = 160{,}6 \times 10^{-6}\ \mathrm{m}^4$$

$$Y = \frac{h}{2} = \frac{358{,}6}{2} = 179{,}3\ \mathrm{mm}$$

Bending stress = 160 MPa

Self-weight of the channel (356 × 171 × 56,7 kg/m)

$$\text{Weight} = 56{,}7\ \mathrm{kg/m} \times 9{,}81 \times 10^{-3}$$

Weight = 0,556 kNm

Calculate the bending moment

$$\frac{\mathrm{M}}{\mathrm{I}} = \frac{\mathrm{f}}{\mathrm{y}}$$

$$\mathrm{M} = \frac{\mathrm{I} \times \mathrm{f}}{\mathrm{y}}$$

$$\mathrm{M} = \frac{160{,}6 \times 10^6 \times 160}{179{,}3}$$

M = 143,3 kNm

Equate to the maximum bending moment

$$BM = \frac{w\,l^2}{8} + \frac{WL}{4}$$

$$143{,}3 = \frac{0{,}556 \times L^2}{8} + \frac{94 \times L}{4}$$

$143{,}3 = 0{,}07\ L^2 + 23{,}5\ L$

Span $(L) = 0{,}07\ L^2 + 23{,}5\ L - 143$

$$\text{Span (L)} = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

$$\text{Span (L)} = \frac{-23{,}5 \pm \sqrt{23{,}5^2 - 4 \times 0{,}07 \times -143{,}3}}{2 \times 0,7}$$

$$\text{Span (L)} = \frac{-23{,}5 \pm 24{,}33}{0{,}14}$$

Span(L) = 6 metres

Exercise 3.7

SB page 246

1\.

Self-weight of the channel section (160 × 65 × 18,8 kg/m)

Weight $= 18{,}8\ \text{kg/m} \times 9{,}81 \times 10^{-3}$

Weight = 0,184 kN/m

Bending moment at the centre of the taper flange beam

$\frac{M}{I} = \frac{f}{y}$ Where:

$$M = \frac{I \times f}{y}$$

$$M = \frac{9{,}247 \times 10^{6}\ x\ 145}{80}$$

M = 16,76 kNm

$I_{xx} = 9{,}247 \times 10^{-6}\ m^4$

$Y = \frac{h}{2} = \frac{160}{2}$

= 80 mm

Calculate the maximum UDL

$$BM = \frac{w\,l^2}{8} + \frac{w\,l^2}{8}$$

$$16{,}76 = \frac{0{,}184 \times 5^2}{8} + \frac{w \times 5^2}{8}$$

16,76 = 0,575 + 3,125 w

3,125 w = 16,76 – 0,575

w = 16,76 – 0,575/3,125

w = 5,179 kN/m

2. *Given information:*

I-Section 305 × 165 × 46,1 kg/m: Ixx = $99{,}35 \times 10^{-6}$ m^4 Area = $5{,}878 \times 10^{-3}$ m^2 $\frac{h}{2} = \frac{307{,}1}{2} = 153{,}55$ mm	Plate: 166 mm × 12 mm $I_{xx} = \frac{BD^3}{12} = \frac{0{,}166 \times 0{,}012^3}{12}$ $= 0{,}024 \times 10^{-6}$ m^4 Area = $0{,}166 \times 0{,}012$ $= 1{,}922 \times 10^{-3}$ m^2
Total area = $5{,}878 \times 10^{-3}$ m^2 + $1{,}922 \times 10^{-3}$ m^2 Total area = $7{,}87 \times 10^{-3}$ m^2	

Calculate the neutral axis using area moments from the bottom

$7{,}87 \times 10^{-3}$ m^2 × Y1

$= (5{,}878 \times 10^{-3}\ \text{m}^2 \times 0{,}16555) + (1{,}922 \times 10^{-3}\ \text{m}^2 \times 0{,}006)$

$$Y_1 = \frac{0{,}973 \times 10^{-3}\ \text{m}^2 + 0{,}0115 \times 10^{-3}\ \text{m}^2}{7{,}87 \times 10^{-3}\ \text{m}^2}$$

$$Y_1 = \frac{0{,}985 \times 10^{-3}\ \text{m}^2}{7{,}87 \times 10^{-3}\ \text{m}^2}$$

$Y_1 = 0{,}125$ m

$Y_1 = 125$ mm

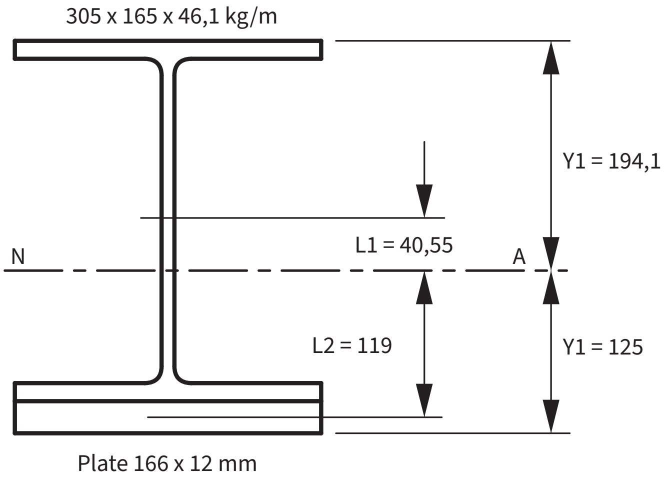


Figure 3.7

Calculate the second moment of area

$$I_{\text{xx total}} = \left(I_{\text{xx}} \text{ beam} + \text{al}^2\right) + \left(I_{\text{xx}} \text{ plate} + \text{al}^2\right)$$

$$I_{\text{xx Beam}} = \left(99,35 \times 10^{-6} + 5,878 \times 10^{-3} \times 0,04055^2\right)$$

$$= \left(99,35 \times 10^{-6} + 9,67 \times 10^{-6}\right) = 109,02 \times 10^{-6}\ \text{m}^4$$

$$I_{\text{xx Plate}} = \left(0,024 \times 10^{-6} + 1,992 \times 10^{-3} \times 0,119^2\right)$$

$$\left(0,024 \times 10^{-6} + 28,21 \times 10^{-6}\right) = 28,23 \times 10^{-6}\ \text{m}^4$$

$$I_{\text{xx total}} = 137,25 \times 10^{-6}\ \text{m}^4$$

Calculate the maximum bending moment

$$\frac{\text{M}}{\text{I}} = \frac{\text{f}}{\text{y}} \text{ where } \text{M} = \frac{\text{I} \times \text{f}}{\text{y}}$$

$$\text{BM}_{\text{max}} = \frac{137,25 \times 10^6 \times 151}{125}$$

$$\text{BM}_{\text{max}} = 165,798 \text{ kNm}$$

Calculate the central point load

The self-weight of the compound beam limited to1,5 kNm.

$$\text{BM} = \frac{\text{W l}^2}{8} + \frac{\text{Wl}}{4}$$

$$165,798 = \frac{1,5 \times 6,75^2}{8} + \frac{\text{W} \times 6,75}{4}$$

$$165,798 = 8,54 + 1,69\text{W}$$

$$\text{W} = \frac{165,798 - 8,54}{1,69}$$

$$\text{W} = 93,05 \text{ kN}$$

3. Given information

<table>
<tr>
<td><u>200 × 75 × 25,3 kg/m channel:</u>
$I_{yy} = 1,478 \times 10^{-6}\ \text{m}^4$
$\text{Area} = 3,218 \times 10^{-3}\ \text{m}^2$
$A_{\text{y}} = 20,1\ \text{m}$</td>
<td><u>365 × 171 × 56,7 kg/m I-parallel flange:</u>
$I_{xx} = 160,6 \times 10^{-6}\ \text{m}^4$
$\text{Area} = 7,225 \times 10^{-3}\ \text{m}^2$
$\frac{h}{2} = \frac{358,6}{2} = 179,3\ \text{mm}$</td>
</tr>
<tr>
<td colspan="2">Plate: 205 mm × 16 mm
$\text{I}_{xx} = \frac{bd^3}{12} = \frac{0,205 \times 0,016^3}{12} = 0,06997 \times 10^{-6}\ \text{m}^4$
$\text{Area} = 0,205 \times 0,016 = 3,28 \times 10^{-3}\ \text{m}^2$</td>
</tr>
</table>

$\text{Total area} = 3{,}218 \times 10^{-3}\ \text{m}^2 + 7{,}225 \times 10^{-3}\ \text{m}^2 + 3{,}28 \times 10^{-3}\ \text{m}^2$

$\text{Total area} = 13{,}723 \times 10^{-3}\ \text{m}^2$

Calculate the neutral axis using area moments from the bottom

$$13{,}723 \times 10^{-3}\ \text{m}^2 \times Y_1 = (3{,}218 \times 10^{-3}\ \text{m}^2 \times 0{,}0549) + (7{,}225 \times 10^{-3}\ \text{m}^2 \times 0{,}2543) + (3{,}28 \times 10^{-3}\ \text{m}^2 \times 0{,}4416)$$

$$Y_1 = \frac{0{,}17667 \times 10^{-3}\,\text{m}^2 + 1{,}837\ \text{m}^2 \times 10^{-3} + 1{,}448 \times 10^{-3}\ \text{m}^2}{13{,}723 \times 10^{-3}\ \text{m}^2}$$

$$Y_1 = \frac{3{,}462 \times 10^{-3}\ \text{m}^2}{13{,}723 \times 10^{-3}\ \text{m}^2}$$

$Y_1 = 0{,}25229\ \text{m}$

$Y_1 = 252{,}29\ \text{mm}$

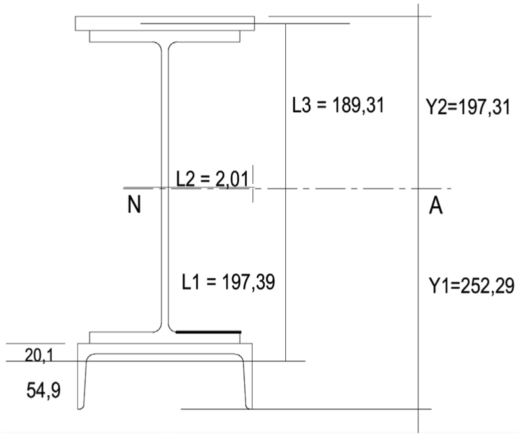


Figure 3.8

The L-distances: $L_1 = 252{,}29 - 54{,}9 = 197{,}39\ \text{mm}$

$L_2 = 252{,}29 - 75 - 358{,}6/2\ (179{,}31) = -\,2{,}01\ \text{mm}$

$L_2 = 197{,}31 - 16 - 358{,}6/2\ (179{,}31) = 2{,}01\ \text{mm}$

$L_3 = 197{,}31 - 16/2\ (8) = 189{,}31\ \text{mm}$

Calculate the second moment of area (I_{xx} total)

$$I_{xx}\text{ tot} = \left(I_{yy}\text{ Channel} + al^2\right) + \left(I_{xx}\text{ Beam} + al^2\right) + \left(I_{xx}\text{ Plate} + al^2\right)$$

$$I_{yy}\text{ Channel} = (1,478 \times 10^{-6} + 3,218 \times 10^{-3} \times 0,19739^2)$$

$$= (1,478 \times 10^{-6} + 0,1254 \times 10^{-6}) = 1,6 \times 10^{-6}\text{ m}^4$$

$$I_{xx}\text{ Beam} = (160,6 \times 10^{-6} + 7,225 \times 10^{-3} \times 2,01^2)$$

$$= (160,6 \times 10^{-6} + 29,19 \times 10^{-6}) = 189,79 \times 10^{-6}\text{ m}^4$$

$$I_{xx}\text{ Plate} = (0,06997 \times 10^{-6} + 3,28 \times 10^{-3} \times 0,18931^2)$$

$$= (0,06997 \times 10^{-6} + 0,118 \times 10^{-6}) = 0,1875 \times 10^{-6}\text{ m}^4$$

$$I_{xx}\text{ total} = 191,578 \times 10^{-6}\text{ m}^4$$

Calculate the maximum bending moment (Bending stress = 145 MPa)

$$\frac{M}{I} = \frac{f}{y}\text{ where M} = \frac{I \times f}{y}$$

$$BM_{max} = \frac{191,578 \times 10^{6}\ x\ 145}{252,29}$$

$$BM_{max} = 110,11\text{ kNm}$$

Calculate the self-weight of the compound steel beam

Channel: $25,3 \times 9,81 \times 10^{-3} = 0,248$ kN/m

I-beam: $56,7$ kg/m $\times 9,81 \times 10^{-3} = 0,556$ kN/m

Plate: $0,205 \times 0,016 \times 1 \times 1\,786$ kg/m^3 $\times 9,81 \times 10^{-3} = 0,0575$ kN/m

Self-weight = 0,862 kN/m

Calculate the UDL

Include the self-weight of the beam with an additional load of 3 kN/m.

$$BM = \frac{W\,l^2}{8} + \frac{W\,l^2}{8} + \frac{W\,l^2}{8}$$

$$110,11 = \frac{0,862 \times 9,5^2}{8} + \frac{3 \times 9,5^2}{8} + \frac{W \times 9,5^2}{8}$$

$$110,11 = 9,72 + 33,84 + 11,28\text{ W}$$

$$W = \frac{110,11 - 43,56}{11,28}$$

$$W = 5,9\text{ kN/m}^2$$

Exercise 3.8

SB page 261

Calculate the effective height of the column Effective height (l) = 1,0L Where: $L_{effective} = 1{,}0 \times 3{,}25$ m $= 3{,}25$ m (3 250 mm)	SABS 0162-1984 Table 19

Calculate the effective cross-sectional area of the column

$$Ac = \frac{\pi d^2}{4} - \frac{\pi d^2}{4}$$

$$Ac = \frac{\pi\ 76{,}2^2}{4} - \frac{\pi\ 71{,}2^2}{4}$$

Area = 4 560,4 –3 981,5 mm^2

Cross-sectional area = 578,9 mm^2

Calculate the second moment of area about the *x*-*x* axis.

$$I_{xx} = I_{yy} = \frac{\pi D^4}{64} - \frac{\pi d^4}{64}$$

$$I_{xx} = I_{yy}\ \frac{\pi\, 76{,}2^4}{64} - \frac{\pi\, 71{,}2^4}{64}$$

$I_{xx} = I_{yy}$ 1 654 968,7 mm4 –1 261 507,6 mm^4

$I_{xx} = I_{yy} = 393\ 461{,}1$ mm^4

Calculate the radius of gyration.

$$r = \sqrt{\frac{I}{Area}}$$

$$r = \sqrt{\frac{393\ 461{,}1}{578{,}9}}$$

r = 26,1 mm

Calculate the slenderness ratio $L/r = \frac{3\ 250}{26{,}1} = 124{,}5$ 124,5 = 56 MPa	From Table 17 (SANS 0162)

Calculate the maximum load

Load = Stress × Area

Load = 56 Nmm^2 × 578,9 mm^2

Load = 32,4 kN

Exercise 3.9

SB page 277

1. Calculate the direct shear on each bolt.

$$\text{Force direct} = \frac{\text{Force}}{\text{No of bolts}}$$

$$F_{\text{direct}} = \frac{16\text{ kN}}{2} = 8\text{ kN}$$

Calculate the distance from the centroid to the furthest bolt.

$$r = \frac{180}{2} = 90\text{ mm}$$

The direct load on the bolts due to the imposed load

$$\Sigma\text{cwm} = \Sigma\text{acwm}$$

$$(16 \times 190) = (F_T \times 90 \times 2)$$

$$F_T = \frac{16 \times 190}{90 \times 2}$$

$$F_T = 16{,}9\text{ kN}$$

The resultant load on each bolt

$$F_R = 16{,}9 + 8 = 24{,}9\text{ kN}$$

Calculate the size of the bolts. (Shear stress = 100 MPa)

$$F_R = \text{Shear stress} \times \text{Area of bolt}$$

$$\frac{\pi\, d^2}{4} = \frac{\text{Fr}}{\text{Shear stress}}$$

$$d = \sqrt{\frac{\text{Fr} \times 4}{\pi \times \text{stress}}}$$

$$d = \sqrt{\frac{24{,}9 \times 10^3 \text{ x } 4}{\pi \times 100}}$$

$$d = 17{,}8\text{ mm}$$

Use 2M20 bolts

2. Calculate the direct shear on each bolt.

$$\text{Force direct} = \frac{\text{Force}}{\text{No of bolts}}$$

$$F_{\text{direct}} = \frac{45\text{ kN}}{4} = 11{,}25\text{ kN}$$

Distance from the centroid to the furthest bolt.

$$r = \sqrt{160^2 + 105^2}$$

$$r = 191{,}4\text{ mm}$$

The direct load on the bolts due to the imposed load

$\Sigma cwm = \Sigma acw$

$(45 \times 450) = (F_T \times 191{,}4 \times 4)$

$20\ 250 = 765{,}6\ F_T$

$F_T = \frac{20\ 250}{765{,}6}$

$F_T = 26{,}4$ kN

$\text{Tan } \theta = \frac{160}{105}$

$\theta = 56{,}73°$

$F_{T\text{ hor.}} = F_T \times \text{Cos } \theta$

$= 26{,}4 \times \text{Cos } 56{,}73°$

$F_{T\text{ hor.}} = 14{,}48$ kN

$F_{T\text{ vert.}} = F_T \times \text{Sin } \theta$

$= 26{,}4 \times \text{Sin } 56{,}73°$

$F_{T\text{ vert.}} = 22{,}07$ kN

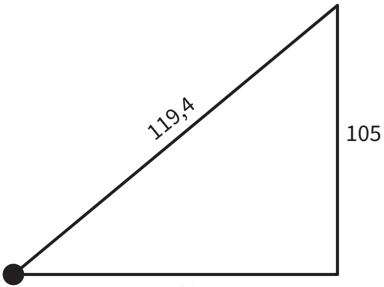


Figure 3.9

Resultant force

$F_R = \sqrt{14{,}48^2 + (22{,}07 + 11{,}25)^2}$

$F_R = 36{,}33$ kN

Calculate the size of the bolts.

$F_R = \text{Shear stress} \times \text{Area of bolt}$

$\frac{\pi d^2}{4} = \frac{Fr}{\text{Shear stress}}$

$d = \sqrt{\frac{Fr \times 4}{\pi \times \text{stress}}}$

$d = \sqrt{\frac{36{,}33 \times 10^3 \times 4}{\pi \times 115}}$

$d = 20$ mm

Use 4M20 bolts

3. Distance l_a from the centroid to the furthest bolt.

$l_a = \sqrt{100^2 + 75^2}$

$l_a = 125$ mm

Calculate Σl^2

$\Sigma l^2 = n \times l_a^{\ 2}$

$= 4 \times (125)^2$

$\Sigma l^2 = 62\ 500\ \text{mm}^2$

Calculate shearing force due to each bolt

$$\text{Force direct} = \frac{\text{Force}}{\text{No of bolts}}$$

$$F_{\text{direct}} = \frac{25\text{ kN}}{4} = 6{,}25\text{ kN}$$

The direct load on the bolts due to the imposed load

$\Sigma cwm = \Sigma acwm$

$(25 \times 450) = (F_T \times 125{,}8 \times 4)$ (4 = No of bolts)

$$11\ 250 = 500\ F_T$$

$$F_T = \frac{11\ 250}{500}$$

$$F_T = 22{,}5\text{ kN}$$

Force on any bolt $X = \frac{\Sigma\, la}{n \times e}$ $X = \frac{62\ 500}{4 \times 450}$ $X = 34{,}72\text{ mm}^2$	X = The distance between the centroid and the point through which the resultant force acts.

Load on any bolt

$$= \frac{f \times e}{\Sigma\, la^2}$$

$$= \frac{25 \times 10^3 \times 450}{62\ 500}$$

Load on any bolt = 180 kN

Load on bolts A & B

$$180 = \sqrt{(100^2 + (75 + 34{,}72)^2)}$$

$= 26{,}721$ kN

Load on bolts C & D

$$180 = (\ 100^2 + (75 - 34{,}72)^2$$

$$= 19{,}4\text{ kN}$$

4. Determine $\Sigma\, l^2$ about the edge at 'x'

$$\Sigma l_a = N(l^{21} + l^{22} + l^{23} \ldots)$$

$$= 2\,(36^2 + 106^2 + 176^2 + 246^2 + 316^2\,)$$

$$\Sigma l_a = 407\ 706 \text{ mm}^2$$

Determine the tensile load due to the moment about 'X'

$$\text{Ft moment} = \frac{P \times e \times \text{la}}{\Sigma\text{la}}$$

$$= \frac{170 \times 10^3 \times 200 \times 316}{407\ 760}$$

$$\text{Ft moment} = 26{,}35 \text{ kN}$$

<u>Load Fs due to direct shear</u>

$$\text{Force direct} = \frac{\text{Force}}{\text{No of bolts}}$$

$$F_{\text{direct}} = \frac{170 \text{ kN}}{10} = 17 \text{ kN}$$

Area of the bolt

$$\text{Effective area} = \frac{\pi d^2}{4}$$

$$= \frac{\pi 24^2}{4}$$

$$\text{Effective area} = 352{,}4 \text{ mm}^2$$

Tensile stress area Effective area $= \frac{\pi}{4}(\text{d} - 0{,}9382\ \text{P})^2$ $= \frac{\pi}{4}(24 - 0{,}9382 \times 3)^2$ Effective area $= 352{,}5 \text{ mm}^2$	SANS 0162 Cl 10.5.1

Check actual stress Tensile stress $F_t = \frac{Ft}{At}$ $= \frac{26{,}35 \times 10^3}{352{,}5}$ $F_t = 74{,}75 \text{ MPa} < 145 \text{ MPa}$	SANS 0162 Table 21

Shear stress

$$F_s = \frac{Fs}{As}$$

$$F_s = \frac{17 \times 10^3}{452{,}39}$$

$Fs = 37{,}6$ MPa < 100 MPa

Check combined stresses $\frac{Fs}{Ps} + \frac{Ft}{Pt} = 1{,}4$ $\frac{37{,}58}{100} + \frac{91{,}92}{145} = 1{,}4 =$ Sufficient. The chosen M24 bolts are satisfactory.	SANS 0162 Cl 10.5.1

Exemplar examination paper 1

The following is an example of a final question paper.

Candidates are always reminded to carefully read the instructions before answering the questions.

Duration: 4 hours **Mark allocation: 100 marks**

Instructions and information:

1. Answer ALL the questions. You may start with any question.
2. Number the answers according to the numbering system laid out in the question paper.
3. Start each question on a new page.
4. Draw a line across the page at the end of each answer.
6. All calculations must conform to the relevant SABS / SANS Codes of Practice.
7. All the applicable codes and reference clause numbers must be indicated.
8. Complement your answers with neat sketches.
9. Use the applicable required schedules at the back of your textbook.

REQUIREMENTS: BOE 8/6 Hot-rolled structural steel sections (red book)

OPEN-BOOK EXAMINATION
Candidates may use their own personal notes and textbooks. No past question papers and marking guidelines will be allowed in the examination centre.

QUESTION 1

Figure 1 shows a compound steel beam with TWO steel plates attached to the flanges of a 356 × 171 × 56,7 kg/m H-section parallel flange steel beam with a channel section to form a compound beam. The span of the beam is 6,75 m.

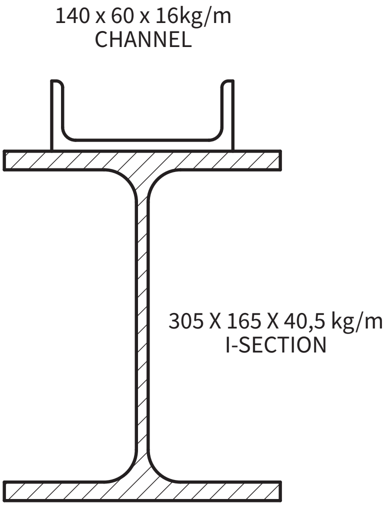


Figure 1

The steel beam must support an additional point load of 25 kN.

Include the self-weight of the compound beam and calculate the maximum uniformly distributed load that the compound beam can safely support.

Use a bending stress of 156 MPa and note that the density of structural steel is 7 860 kg/m^3. **[20]**

QUESTION 2

Figure 2 shows part of a one-directional, simply supported reinforced concrete slab with an effective span of 4,80 m. The slab will be cast over TWO 270-mm wide brick walls.

Use Grade 25 concrete with a density of 2 430 kg/m^3 then calculate the maximum uniformly distributed imposed load the slab must support.

The self-weight of the concrete slab must be included in the calculations.

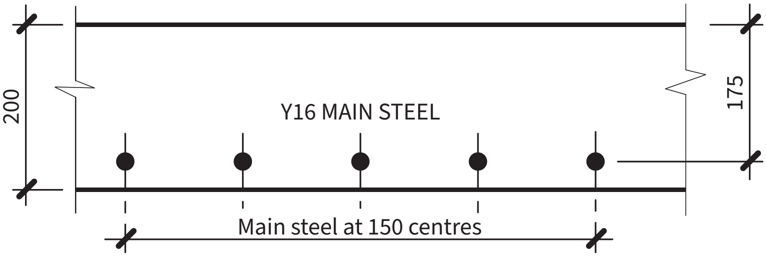


Figure 2

[12]

QUESTION 3

3.1 Figure 3 shows a rectangular reinforced concrete column. The column is reinforced with 4Y20 and 2Y16 main bars. The characteristic strength of the concrete is limited to 30 MPa.

Calculate the following:

3.1.1 The nett area of the concrete

3.1.2 The axial load the column can withstand

3.1.3 The required diameter and spacing of the binders.

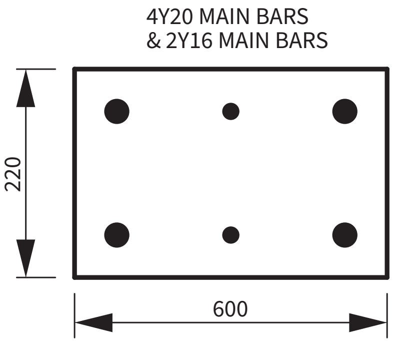


Figure 3

(9)

3.2 Calculate the minimum area of a square isolated pad foundation for the RC column mentioned in Question 3.1. The column must also resist the following loads:

Imposed load: 600 kN

Mass of foundation concrete: 85 kN

Use a safe bearing upward soil pressure of 220 kNm². (5)

[14]

QUESTION 4

4.1 Calculate the amount of cement required for a concrete mix with a water: cement ratio of 0,35 and 46 litres of water. (3)

4.2 Explain the characteristics of non-ferrous metals. (2)

4.3 State the difference between brass and bronze. (2)

[7]

QUESTION 5

A simply supported reinforced concrete beam has an effective span of 5,35 m. The beam is 230 mm wide and must support the following loads:

(a) A 12-kN point load in the centre of the beam

(b) A uniformly distributed load of 7 kNm.

The beam will be made up by using Grade 25 MPa concrete and mild steel reinforcement. The density of the concrete must be taken as 2 400 kg/m^3. The self-weight of the reinforced concrete beam must be taken into consideration.

Answer the following:

5.1 The effective depth of the reinforced concrete beam (3)

5.2 Determine the suitable tension reinforcement for the reinforced concrete beam (14)

5.3 Check for the minimum required main reinforcement. (1)

[18]

QUESTION 6

6.1 A 356 × 171 × 44,8 kg/m I-section steel column is used in a warehouse as part of the structure. The actual height of the column is 4,750 m. The column will, however, be effectively held in position at both ends, but not restrained against rotation. Calculate the maximum load that the column will be able to support. All the reference codes must be clearly indicated. (7)

6.2 State the degree of restraint of a compression member where the effective length is given as 0,70 L. State the code and reference. Also include a neat sketch to show the fixing symbol. (4)

[11]

QUESTION 7

Figure 4 shows TWO methods of using a 203 × 133 × 25,3 kg/m I-section parallel flange as a tension member to span a distance of 5,55 m.

7.1 Calculate the maximum uniformly distributed load (UDL) that each of the beams will be able to carry. Use a bending stress of 165 MPa. (10)

7.2 Explain why the loads of the two beams differ. (2)

7.3 Draw TWO neat drawings to show how the beams can be joined to form ONE compression member. (4)

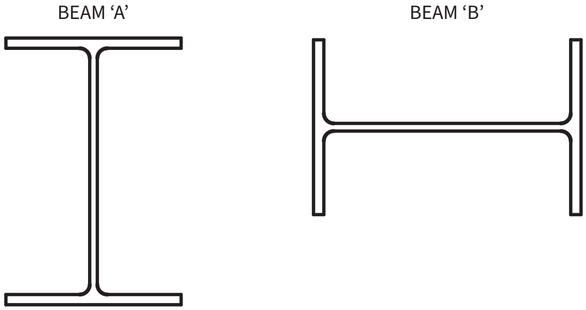


Figure 4

[16]

Total: 100 marks

Exemplar examination paper 2

The following is an example of a final question paper.

Candidates are always reminded to carefully read the instructions before answering the questions.

Duration: 4 hours **Mark allocation: 100 marks**

Instructions and information:

1. Answer ALL the questions. You may start with any question.
2. Number the answers according to the numbering system laid out in the question paper.
3. Start each question on a new page.
4. Draw a line across the page at the end of each answer.
6. All calculations must conform to the relevant SABS / SANS Codes of Practice.
7. All the applicable codes and reference clause numbers must be indicated.
8. Complement your answers with neat sketches.
9. Use the applicable required schedules at the back of your textbook.

REQUIREMENTS: BOE 8/6 Hot-rolled structural steel sections (red book)

OPEN-BOOK EXAMINATION
Candidates may use their own personal notes and textbooks. No past question papers and marking guidelines will be allowed in the examination centre.

QUESTION 1

A short, axially loaded reinforced round concrete column with a diameter of 850 mm has to support an ultimate load of 7 500 kN. Use Grade 30 concrete with high-yield tensile steel main reinforcement and a mild steel binder.

Calculate the following:

1.1 The required number and diameter of the longitudinal bars (4)

1.2 The maximum and minimum percentage of the steel reinforcement (2)

1.3 The diameter and pitch of the helical binder (4)

1.4 Draw TWO neat drawings to show the cross-sectional view and longitudinal vertical section of the column. Clearly show the positions of the main steel and THREE binders. (5)

[15]

QUESTION 2

Figure 1 shows the front view of a loaded steel roof truss.

Ignore the self-weight of the roof truss but calculate the following:

2.1 The upward forces of the reactions RR and RL (4)

2.2 The magnitude of the forces in parts 'AB', 'CD' and 'BD' (9)

2.3 Distinguish between tension and compression forces in the members.

(No marks will be awarded for the graphical solutions.) (5)

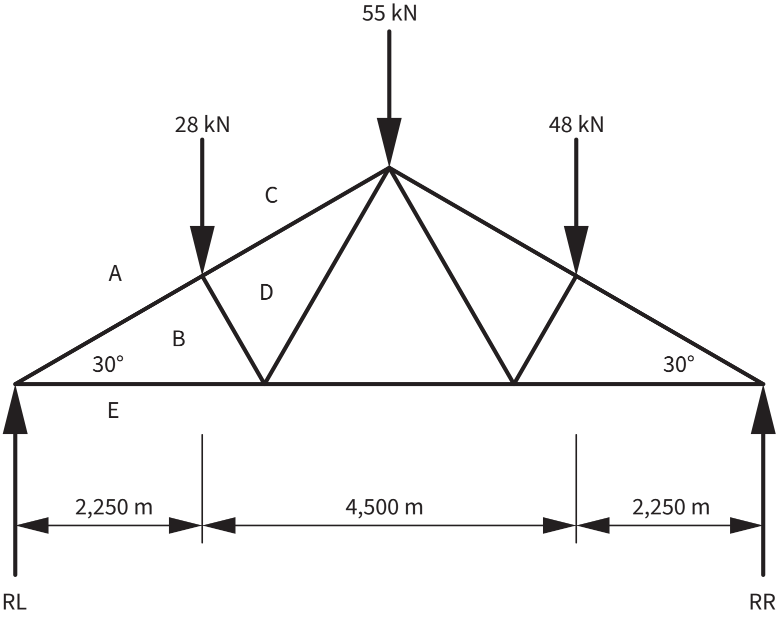


Figure 1

[18]

QUESTION 3

A simply supported reinforced concrete beam is cast over a wide opening for a roll-up metal garage door. The effective span for the opening is 9 m.

The beam supports the following loads:
(a) TWO uniformly distributed live loads of 4,475 kNm and 12,8 kNm.
(b) An 88-kN point load 3,5 m from the right-end support.

Use the following specifications:

- Grade 25 MPa concrete
- High yield tensile reinforcement

Calculate the following:
3.1. The reactions RL and RR of the beam (4)
3.2. Draw a neat sketch of the shear force diagram. (2)
3.3. Calculate and draw a neat sketch of the bending moment diagram. (4)
3.4 Calculate the value of 'K' to determine if compression reinforcement is required.

DO NOT insert any reinforcement. Ignore the self-weight of the reinforced concrete beam. (3)

[13]

QUESTION 4

A simply supported I-section steel beam supports a load of 65 kNm over an effective span of 6,35 m. The bending stress is 156 MPa.

Calculate the following:
4.1 Select a suitable parallel flange steel beam to support the given load. (5)
4..2 Add the mass of the chosen beam to the downward load and then check if the chosen steel beam is adequate to support the load as well as its own weight. (7)

[12]

QUESTION 5

A double reinforced concrete beam must be cast as a simply supported beam over a wide panoramic sliding door and window.

The following specifications are given to design the RC beam:

Width of beam:	330 mm
Effective span:	8 m
Fcu:	25 MPa
Fy:	450 MPa
Density of concrete:	2 425 kg/m^3

5.1 Calculate the following:
5.2 The effective depth of the beam (2)

5.3 The design dead load (6)
5.4 The maximum bending moment (4)
5.5 The lever arm distance (2)
5.6 The required compression reinforcement (3)
5.7 The required tension reinforcement (3)

Check for the minimum and maximum reinforcement. (2)

The self-weight of the beam must be considered in the calculations. The relevant codes and clauses must be indicated. **[22]**

QUESTION 6

1. Calculate the maximum effective span for a 457 × 191 × 89,7 kg/m structural steel beam able to carry a 375-kN point load at mid-span. The self-weight of the beam must be included in your calculations. Use a bending stress of 175 MPa. (8)
2. Figure 2 shows a tie bar (F) welded to a gusset plate by means of TWO 8-mm side fillet welds.

Use an allowable stress of 130 MPa and calculate the safe load. (5)

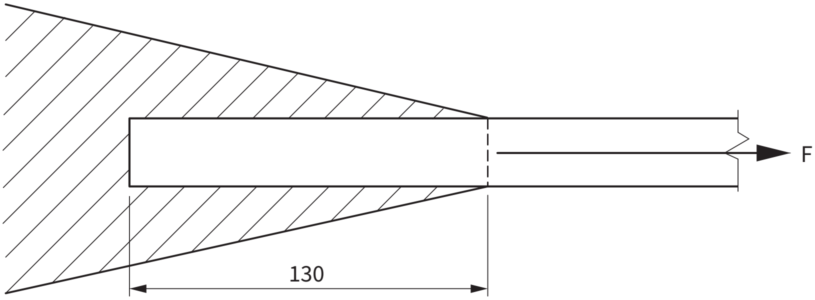


Figure 2

[13]

QUESTION 7

7.1 Name TWO of the materials used to charge up a steelmaking furnace. (2)
7.2 State the size of the concrete stone used to make concrete. (1)
7.3 Explain the effects of the water:cement ratio in a concrete mix. (2)
7.4 State the aim(s) of the water permeability test. (2)

Total: 100 marks

Exemplar examination paper 3

The following is an example of a final question paper.

Candidates are always reminded to carefully read the instructions before answering the questions.

Duration: 4 hours **Mark allocation: 100 marks**

Instructions and information:

1. Answer ALL the questions. You may start with any question.
2. Number the answers according to the numbering system laid out in the question paper.
3. Start each question on a new page.
4. Draw a line across the page at the end of each answer.
6. All calculations must conform to the relevant SABS / SANS Codes of Practice.
7. All the applicable codes and reference clause numbers must be indicated.
8. Complement your answers with neat sketches.
9. Use the applicable required schedules at the back of your textbook.

REQUIREMENTS: BOE 8/6 Hot-rolled structural steel sections (red book)

OPEN-BOOK EXAMINATION
Candidates may use their own personal notes and textbooks. No past question papers and marking guidelines will be allowed in the examination centre.

QUESTION 1

1.1 State TWO advantages of the cupola furnace. (2)

1.2 Explain how you would ensure adequate moisture content during the concrete curing process of a concrete column or wall. (2)

1 .3 Name any TWO tests that are done for concrete. (2)

[6]

QUESTION 2

Figure 1 shows a part of a strutted roof truss. The strut and tie are connected to the main rafter by means of an 8-mm thick gusset plate.

The strut and tie are single discontinuous equal-leg rolled steel angles. The Grade parts marked 'S' and 'T' are Grade 43 single discontinuous equal-leg rolled steel angles.

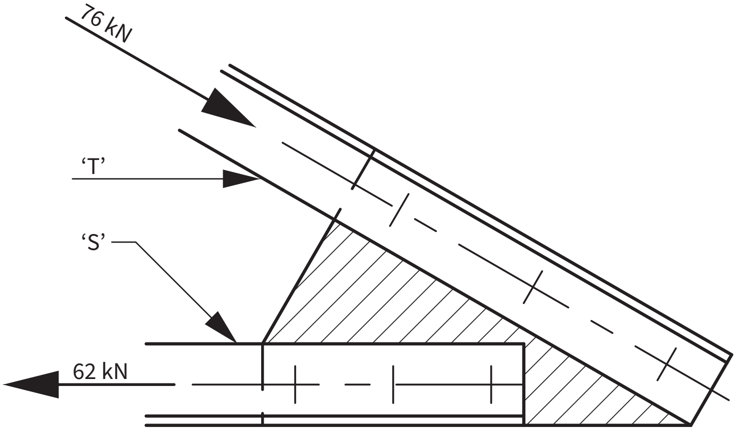


Figure 1

2.1 Select a suitable equal-leg rolled steel angle for the part marked 'T'. The tie will be bolted to the gusset plate using Grade 4,6 M16 bolts. (9)

2.2 The strut is welded to the gusset plate using an 8-mm fillet weld. Calculate the effective length for the fillet weld. The maximum shear stress 155 MPa. (5)

[14]

QUESTION 3

Figure 2 shows a fully dimensioned T-beam with a span of 5,5 m.
Use Grade 25 concrete with high-yield tensile steel reinforcement to calculate suitable tension reinforcement for the T-beam. The beam will support a dead load of 6,5 kNm^2 and an imposed load of 7,5 kNm^2.

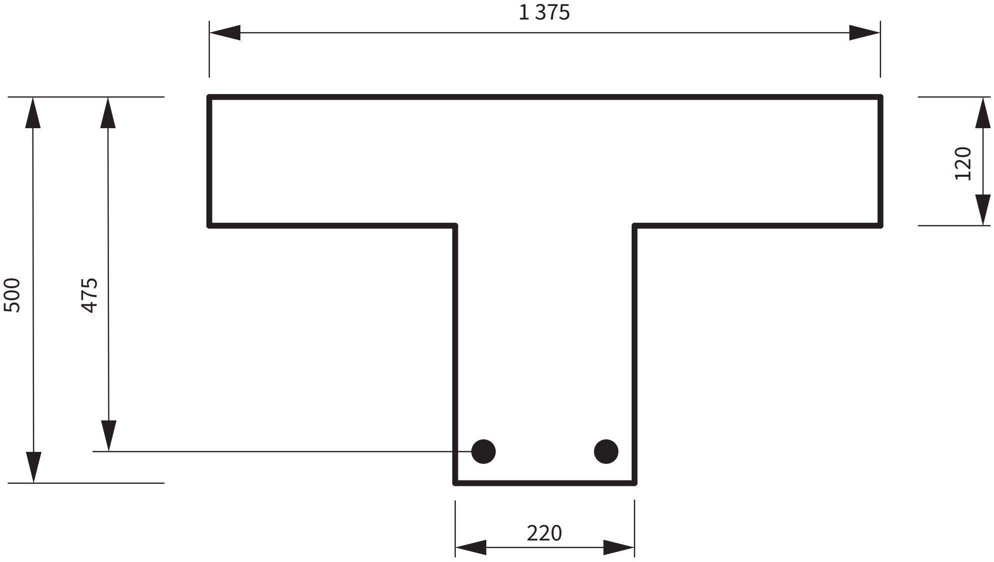


Figure 2

Your answers must include the following:

3.1 The lever arm distance (2)

3.2 The position of the neutral axis (3)

3.3 The total design load (2)

3.4 The maximum bending moment (2)

3.5 The required tension reinforcement. (4)
Use the formula: AS = m + 0,1 fcu bw d(0,45 –hf) / 0,87 fy (d-0,5hf) **[13]**

QUESTION 4

Figure 3 shows a compound steel beam with TWO steel plates attached to the flanges of a 305 × 102 × 32,8 kg/m I-parallel flanged steel beam. The steel beam will be secured over a 6,25-m wide panoramic window.

The steel beam must support an additional uniformly distributed load of 35 kNm.

Include the self-weight of the compound beam and then calculate the maximum uniformly distributed load that the steel beam can safely support.

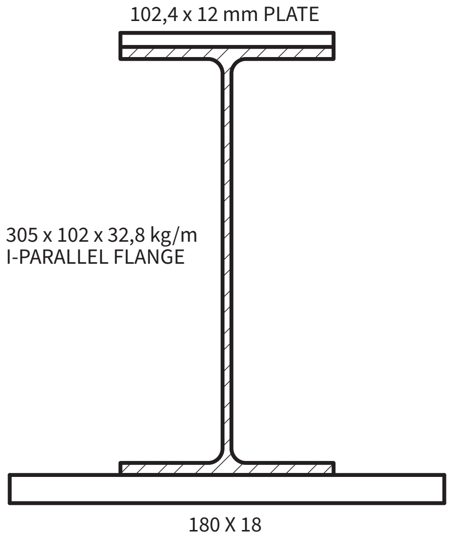


Figure 3

Use a bending stress of 165 MPa and note that the density of structural steel as 7 865kg/m^3. **[20]**

QUESTION 5

Figure 4 shows an eccentrically loaded connection. A load of 28 kN is subjected to the connection at a distance of 300 mm from the centre of the steel column.

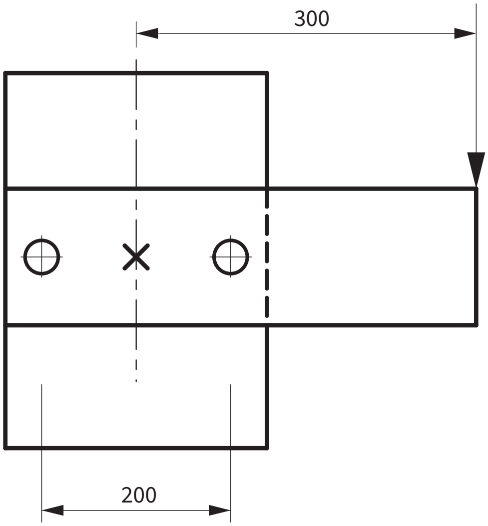


Figure 4

Calculate the diameter of the bolts required to hold the connection in place. Use a shear stress value of 105 MPa. **[11]**

QUESTION 6

A one-directional, simply supported reinforced concrete slab has an effective span of 5,25 m and supports a live load of 7,5 kNm^2. Use Grade 25 MPa concrete with mild steel reinforcement. The density of the concrete is 2 450 kg/m^3.

Calculate the suitable tension and secondary reinforcement for the given slab.

The self-weight of the slab must be, considered in the calculations. **[18]**

QUESTION 7

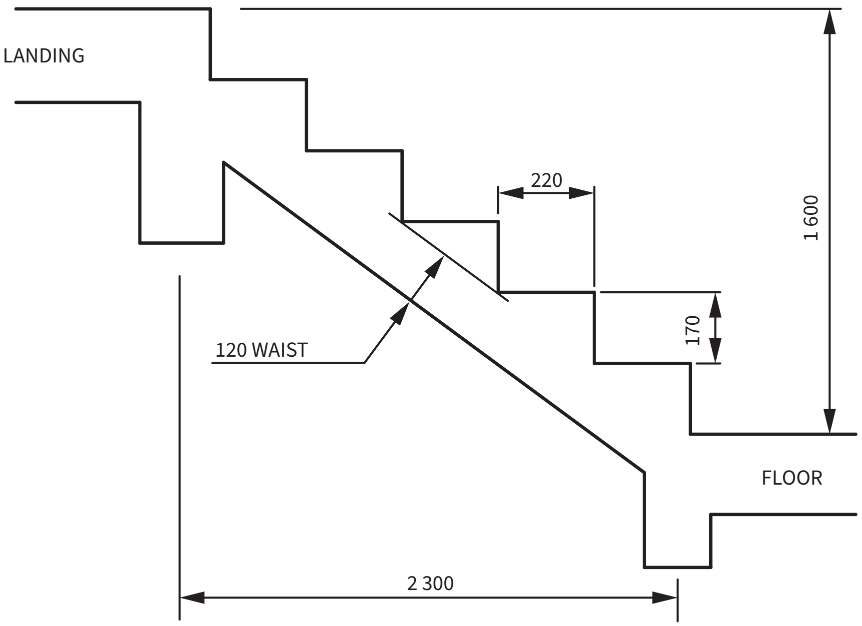


Figure 5

Calculate the suitable tension and secondary reinforcement for the reinforced concrete staircase shown in Figure 5. The staircase is supported at both ends and is subjected to a 12,5 kNm^2 imposed load. The width of the stairway is 1,15 m (1 150 mm).

The stairway is cast monolithically using Grade 20 concrete with mild steel reinforcement. The density of the concrete is 2420 kg/m^3. **[18]**

Total: 100 marks

Exemplar examination paper 1 memorandum

The following is an example of the marking guidelines for a final examination paper.

QUESTION 1

Given information:

305 × 165 × 40,5 kg/m I-section beam: $I_{xx} = 85{,}51 \times 10^{-6}\ \text{m}^4$ $\text{Area} = 5{,}165 \times 10^{-3}\ \text{m}^2$ $\frac{h}{2} = \frac{303{,}8}{2} = 151{,}9\ \text{mm}$	Channel: 140 mm × 60 × 16 kg/m $I_{yy} = 0{,}6249 \times 10^{-6}\ \text{m}^4$ $\text{Area} = 2{,}037 \times 10^{-3}\ \text{m}^2$ $Ay = 17{,}5\ \text{mm}$ $T_1 = 7\ \text{mm}$
Total area = $5{,}165 \times 10^{-3}\ \text{m}^2 + 2{,}037 \times 10^{-3}\ \text{m}^2$ Total area = $7{,}202 \times 10^{-3}\ \text{m}^2$	

Calculate neutral axis using area moments from bottom $7{,}202 \times 10^{-3}\ \text{m}^2 \times Y_1 = \text{Area beam} + \text{distance to centre}$ $(5{,}165 \times 10^{-3}\ \text{m}^2 \times 0{,}1519) = 0{,}785 \times 10^{-3}$ $+ (2{,}037 \times 10^{-3}\ \text{m}^2 \times 0{,}3213) = 0{,}654 \times 10^{-3}$ $\text{Total} = 1{,}44 \times 10^{-3}\ \text{m}^2$ $Y_1 = \frac{1{,}44 \times 10^{-3}\ \text{m}^2}{7{,}202 \times 10^{-3}\ \text{m}^2}$ $Y_1 = 0{,}19994\ \text{m}$ $Y_1 = 199{,}94\ \text{mm}$	303,8 + 17,5 = 321,3 mm	(4)

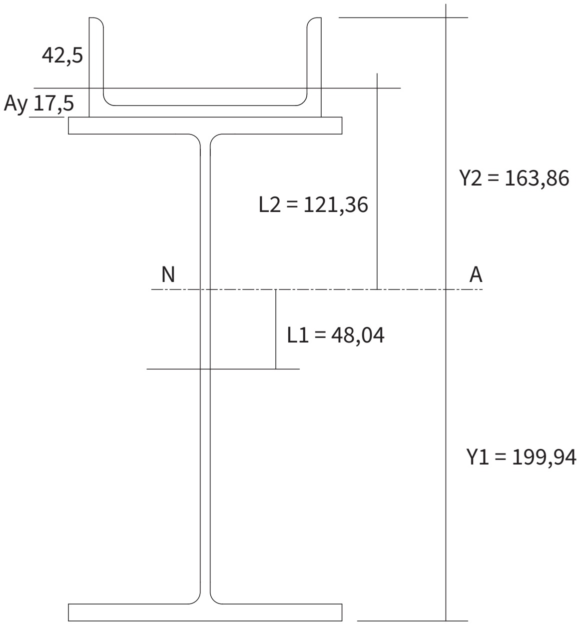


Figure A

$L_1 = 199,94 - 151,9 = 48,04$

$L_2 = 163,86 - 42,5 = 121,36$

Calculate second moment of area (I_{xx} total) $I_{xx\ tot} = \left(I_{xx}\text{ Beam} + al^2\right) + \left(I_{yy}\text{ Channel} + al^2\right)$ $I_{yy\ Beam} = (85,51 \times 10^{-6} + 5,165 \times 10^{-3} \times 0,04804^2)$ $= (85,51 \times 10^{-6} + 11,92 \times 10^{-6}) = 97,43 \times 10^{-6}\ m^4$ $I_{xx\ Channel} = (0,6249 \times 10^{-6} + 4,183 \times 10^{-3} \times 0,12136^2)$ $= (0,6249 \times 10^{-6} + 61,6 \times 10^{-6}) = 62,23 \times 10^{-6}\ m^4$ $I_{xx\ total} = 159,66 \times 10^{-6}\ m^4$		(5)
Calculate maximum bending moment (Bending stress = 158 MPa) $\frac{M}{I} = \frac{f}{y}$ where $M = \frac{f \times I}{y}$ $BM_{max} = \frac{156 \times 159,66 \times 10^{6}}{199,94}$ $BM_{max} = 124,57$ kNm		(3)

Calculate the self-weight of the beam Beam: 40,5 kg/m × 9,81 × 10^{-3} = 0,397 kNm Channel: 16 kg/m × 9,81 × 10^{-3} = 0,157 kNm Total self-weight = 0,554 kNm		(3)
Calculate the maximum point load the beam can carry Additional 35 kNm UDL beam + channel + add load + load to support $\mathrm{BM} = \frac{W\,l^2}{8} + \frac{W\,l^2}{8} + + \frac{W \times L}{4} + \frac{W\,x\,l^2}{8}$ $124{,}57 = \frac{0{,}397 \times 6{,}75^2}{8} + \frac{0{,}157 \times 6{,}75^2}{8} + \frac{25 \times 6{,}75}{4} + \frac{W \times 6{,}75^2}{8}$ 124,57 = 2,26 + 0,894 + 42,19 + 1,688 W $W = \frac{124{,}57 - (2{,}26 + 0{,}894 + 42{,}19)}{5{,}695}$ W = 15,85 kNm		(4) **[20]**

QUESTION 2

All references taken from SANS 10100-1 (2000).

Fcu = 25 MPa Fy = 450 MPa Span = 4,80 mm	Table 2 (4.1.5.1) Table 3 (4.1.5.1) Cl. 4.3.1.2	
Determine the area of the main steel Y16 at 150 centres: As = 1 340 mm^2		(1)
Calculate distance of lever arm (Z) $Z = d\left\{0{,}5 + \sqrt{0{,}25 - \frac{K^1}{0{,}9}}\right\}$ $Z = 175\left\{0{,}5 + \sqrt{0{,}25 - \frac{0{,}156}{0{,}9}}\right\}$ Z = 175{0,777} Z = 135,98 mm	(CL.4.3.3.4.1)	(2)
Calculate maximum moment of resistance $\mathrm{AS} = \frac{M}{0{,}87 \times fy \times z}$ M = 0,87 × 450 × 135,98 × 1 340 M = 71,34 kNm	(CL.4.3.3.4.1)	(2)

Determine the total load $BM_{max} = \frac{wl^2}{8} 71,34 = \frac{w \times 4,8^2}{8}$ $w = \frac{71,34 \times 8}{4, 8^2}$ w = 24,77 kNm		(2)
Determine the dead load Dead load = area × density × $9,81 \times 10^{-3}$ Dead load = $0,2 \times 1 \times 2\,430$ kg/m^3 $\times 9,81 \times 10^{-3}$ Dead load = 4,77kNm		(2)
Determine the maximum imposed load Total load = 1,2 (Gn) + 1,6 (Qn) 24,77 = 1,2 (4,77) + 1,6 (Qn) Qn = 3,86 kNm	(CL.4.2.2.1)	(2)
The maximum imposed load therefore is: Qn = 11,9 kNm^2		(1) **[12]**

QUESTION 3

All references taken from SANS 10100-1 (2000).

3.1	Fcu = 30 MPa Fy = 450 MPa	Table 2 (4.1.5.1) Table 3 (4.1.5.2)	
	Calculate the nett area of the concrete Nett area of the steel = $4(\frac{\pi d^2}{4}) + 2(\frac{\pi d^2}{4})$ $= 4(\frac{\pi 20^2}{4}) + 2(\frac{\pi 16^2}{4})$ = 1 256,76 + 402 Nett area of the steel = 1 658,76 mm^2 Nett area of concrete = (600 × 200) – 1 658,76 mm^2 = 118 341,24 mm^2		(3)
	Calculate the axial load N = 0,4 fcu Ac + 0,67 fy Asc (Cl. 4.7.4.3) N = (0,4 × 30 × 118 341,24) + (0,67 × 450 × 1 658,76) N = 1 420 094,8 + (500116,14) N = 1 920,2 kN		(4)

	Diameter and spacing of binders Binders: ¼ of the smallest compression bar ¼ × 16 = 4 mm (not available) Use: min R8 binders. (R6 discontinued) Spacing of binders 12 × diameter of smallest compression bar 12 × 12 = 144 mm Use spacing of 140 mm.	(Cl. 4.11.4.5.1)	(1) (1) (9)
3.2	Calculate area of pad foundation $\text{Area} = \frac{\Sigma \text{ of Downward loads}}{\text{Upward soil pressure}}$ $\text{Area} = \frac{3\ 400 \text{ kN} + 600 \text{ kN} + 85 \text{ kN}}{220 \text{ kNm}^2}$ Area = 18, 568 m^2 Size of foundation = $\sqrt{18{,}568 \text{ m}^2}$ 4,31 m × 4,31 m Use base size of 4,5m × 4,5m		(5) [14]

QUESTION 4

4.1	$\text{Water : cement ratio} = \frac{\text{Mass of water}}{\text{Mass of cement}}$ $\text{Mass of cement} = \frac{\text{Mass of water}}{\text{Water : cement ratio}}$ $\text{Mass of cement} = \frac{46 \text{ litres}}{0{,}35}$ Mass of cement = 128,6 litres = 128,6 kg		(3)
4.2	Non-ferrous metals **do not contain iron content**; therefore the are **resistant to rust and corrosion**. Non-ferrous metals are also **non-magnetic**.		(2)
4.3	Brass is composed of **copper and zinc** while bronze is composed of **copper and tin**.		(2) [7]

QUESTION 5

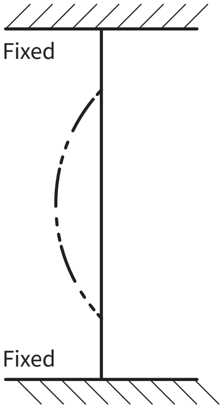
All references taken from SANS 10100-1 (2000).

	Fcu = 20 MPa Fy = 250 MPa Span = 7,00 m Density of reinforced concrete	Table 2 (4.1.5.1) Table 3 (4.1.5.2) Cl. 4.3.1.2 2 400 kg/m^3	
5.1	Determine the effective depth of the slab Effective depth = span / 16 Effective depth = 7 000 / 16 Effective depth = 437,5 mm	Table 10 (Cl.4.3.6.2.1)	(1)
	Determine the overall depth Assume R20 main steel, R8 binders and 25 mm cover. Overall depth = 437,5 + 10 + 8 + 25 Overall depth = 480,5 mm (Use overall depth = 500 mm)		(2)
5.2	Determine the design dead loads of the beam Design dead load = Volume × density × 9,81 × 10^{-3} × 1,2Gn DDL = 0,50 × 0,32 × 1 × 2 400 kg/m^3 × 9,81 × 10^{-3} × 1,2 Gn Design dead load = 4,52 kNm Design imposed UDL = 7 kNm × 1,6Qn = 11,2 kNm Design imposed point load = 12 kN × 1,6Qn = 19,2 kN	Cl.4.2.2.1 Cl.4.2.2.1	(4)
	Calculate bending moment maximum $BM_{max} = \frac{WL^2}{8} + \frac{WL^2}{8} + \frac{WL}{4}$ $BM_{max} = \frac{4,52 \times 7^2}{8} + \frac{11,2 \times 7^2}{8} + \frac{19,2 \times 7}{4}$ $= 27,69 + 68,6 + 33,6$ $BM_{max} = 129,89$ kNm		(3)
	Calculate value for ‘K’ $K = \frac{BM}{fcu\ b\ d^2}$ $K = \frac{129,89 \times 10^6}{20 \times 320 \times 437,5^{\ 2}}$ $K = 0,106 < K^1 = 0,156$ Provide tension reinforcement only.	(Cl.4.3.3.4.1)	(2)

	Calculate distance of lever arm (Z) $Z = d\left\{ 0,5+ \sqrt{0,25 - \frac{k}{0,9}} \right\} \le 0,95d$ $Z = 437,5\left\{ 0,5+ \sqrt{0,25 - \frac{0,106}{0,9}} \right\} \le 0,95 \times 437,5$ $Z = 437,5\{0,864\} \le 415,63$ $Z = 377,84 \text{ mm} < 415,63 \text{ mm}$	(Cl.4.3.3.4.1)	(2)
	Calculate tension reinforcement $As = \frac{M}{0,87 \times fy \times z}$ $As = \frac{129,89 \times 10^6}{0,87 \times 250 \times 377,84}$ $As = 1\ 518,72 \text{ mm}^2$ Use 4R25 ($As = 1\ 964 \text{ mm}^2$)	(Cl.4.3.3.4.1)	(3)
5.3	Check for minimum main reinforcement $\frac{100 \text{ As}}{\text{Ac}}$ $= \frac{100 \times 1\ 964}{500 \times 320}$ $= 0,92$ $1,23 > 0,8$ The reinforcement is sufficient.	Table 23 (Cl.4.11.4)	(2)
	Check for maximum area of reinforcement 4% of AC $4\% \times 500 \times 320$ $6\ 400 \text{ mm}^2$ $1\ 964 < 6\ 400$ The reinforcement is sufficient.	(Cl.4.11.5.1)	(1) **[20]**

QUESTION 6

6.1	Calculate the effective length Effective height (l) = $1,0 \times L$ $L_{effective} = 1 \times 4,75 \text{ m}$ $= 4\ 750 \text{ mm } (4,750 \text{ m})$	(SABS 0162-1984 Table 19)	(3)

	Calculate the slenderness ratio L/r = $\frac{4\,750}{37,7}$ = 125,99 (Use 126 MPa) From Table 17 (SABS 0162-1984) 126 = 55 MPa		(2)
	Calculate the maximum load Load = Stress × Area Load = 55 N/mm^2 × 5,702 × 10^3 mm^2 Load = 313,61 kN		(2)
6.2	SABS 0162 -1984 Table 19 states that the compression member will be, effectively held in position and restrained against rotation at both ends. The symbol:  *Figure B* Mark allocation: Code and reference stated = 1 mark Description corr. = 1mark Drawing = 2 marks		(2) (2) **[13]**

QUESTION 7

I-Parallel flange 203 × 133 × 25,3 kg/m		
Given information: Beam A: I_{xx} = 23,49 × 10^{-6} m^3 $\frac{h}{2} = \frac{203,2}{2}$ = 101,5 mm	Beam B: I_{yy} = 3,090 × 10^{-6} m^3 $\frac{b}{2} = \frac{133,4}{2}$ = 66,7 mm	

Calculate bending moment maximum

7.1	Beam A: $\frac{M}{I} = \frac{F}{Y}$ $M = \frac{f \times I}{y}$ $M = \frac{165 \times 23{,}49 \times 10^6}{101{,}5}$ $M = 38{,}186$ kN m	Beam B: $\frac{M}{I} = \frac{F}{Y}$ $M = \frac{f \times I}{y}$ $M = \frac{165 \times 3{,}090 \times 10^6}{66{,}7}$ $M = 7{,}643$ kN m	(3) + (3)

Calculate maximum point load

7.1	Beam A: $BM = \frac{W l^2}{8}$ $38{,}186 = \frac{W \times 5{,}55^2}{8}$ $W = \frac{38{,}186 \times 8}{5{,}55^2}$ W = UDL = 9,92 kNm	Beam B: $BM = \frac{W l^2}{8}$ $7{,}643 = \frac{W \times 5{,}55^2}{8}$ $W = \frac{7{,}643 \times 8}{5{,}55^2}$ W = UDL = 1,98 kNm	(2 × 4)

7.2 The loads (W) are not the same because the **second moment of area differs as the beams rotated**. This also causes the **section modulus to change**. At beam 'A', the load is, subjected vertically through the stronger centre of the beam. At beam 'B', the load is, subjected on the horizontal web. This will cause the web to bend, thus collapsing the beam. (2)

7.3

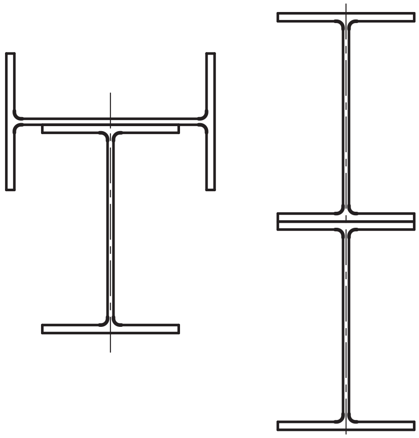


Figure C

(Also consider alternative arrangements.) (2 × 2)

[16]

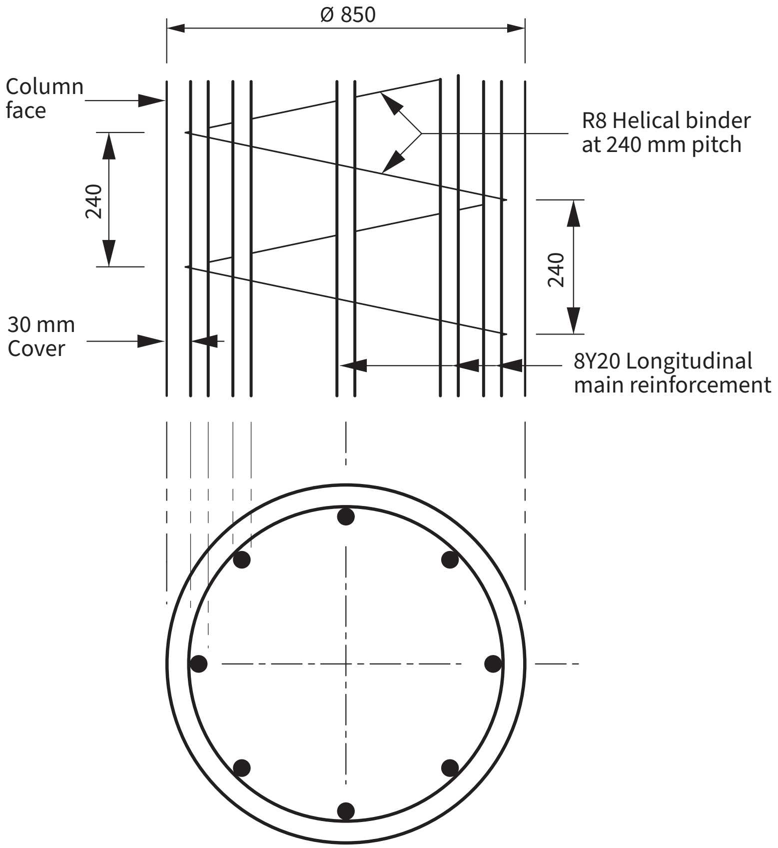
Total: 100 marks

Exemplar examination paper 2 memorandum

QUESTION 1

All references taken from SANS 10100-1 (2000).

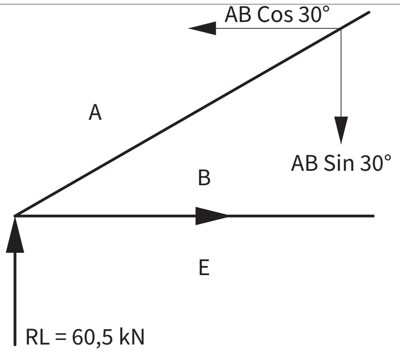
	Fcu = 30 MPa Fy = 450 MPa Axial load = 7 500 kN	Table 2 (4.1.5.1) Table 3 (4.1.5.2)	
1.1	Calculate the number of longitudinal reinforcement N = 0,4 fcu Ac + 0,67 fy Asc (Cl. 4.7.4.3) $7\,500 \times 10^3 = 0{,}4 \times 30 \times \left(\frac{\pi\, 850^2}{4}\right) + 0{,}67 \times 450 \times Asc$ $8\,500 \times 10^3 = 6\,809\,402{,}07 + 301{,}5\ Asc$ $7\,500 \times 10^3$ minus 6 809 402,07 = 301,5 Asc $Asc = \frac{690\,597{,}93}{301{,}5}$ Asc = 2 290,54 mm² Use 8Y20 (As = 2 513 mm²) (Minimum spacing between bars = height aggregate + 5 mm)		(4)
1.2	Maximum and minimum percentage of the steel reinforcement Maximum: 6% of gross sectional area (Cl. 4.11.4.5.2) $6\% \times \left(\frac{\pi\, 850^2}{4}\right) = 34\,047{,}01\ mm^2$ Minimum: 0,4% of gross sectional area (Table 23) $0{,}4\% \times \left(\frac{\pi\, 850^2}{4}\right) = 2\,269{,}8\ mm^2$		(2)
1.3	Calculate the diameter of the helical binder Binders: ¼ of the smallest main bar ¼ × 32 = 8 mm Use: R8 Helical binder.	(Cl. 4.11.4.5.1)	(2)

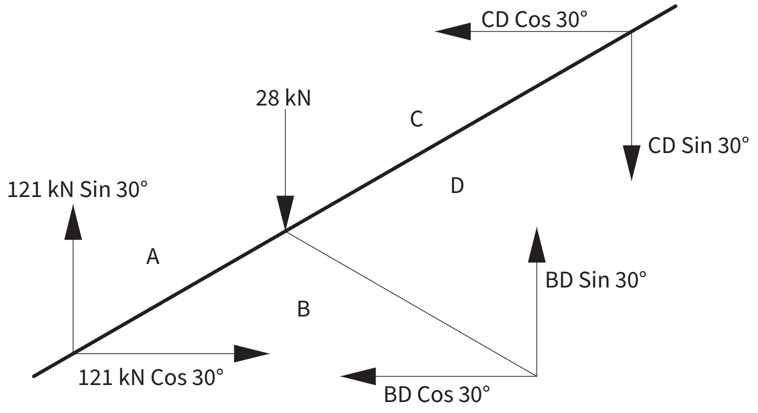
	Calculate the pitch of the binder. Spacing of binders: 12 × diameter of smallest main bar 12 × 20 = 240 mm (maximum) Use Binder pitch = 240 mm Summary: 8y20 main bars with R8 helical binders at 240 mm pitch.	(Cl. 4.11.4.5.1)	(2)
1.4	 Ø 850 Reinforced concrete column 8Y20 longitudinal main reinforcement and R8 helical binder at 240 mm pitch. 30 mm Concrete cover *Figure A* Top view correct = 1 Sectional view = 2 Reinforcement = 2 5		**[15]**

QUESTION 2

2.1	Calculate the reactions Take moments about RL: $(RR \times 9) = (48 \times 6{,}75) + (55 \times 4{,}5) + (28 \times 2{,}25)$ $RR9 = 324 + 247{,}5 + 63$ $RR = 634{,}5 / 9$ $RR = 70{,}5$ kN		(2)
	Take moments about RR: $(RL \times 9) = (28 \times 6{,}75) + (55 \times 4{,}5) + (48 \times 2{,}25)$ $RL\ 9 = 189 + 247{,}5 + 108$ $RL = 544{,}5 / 9$ $RL = 60{,}5$ kN		(2)

Determine the size and type of the members.

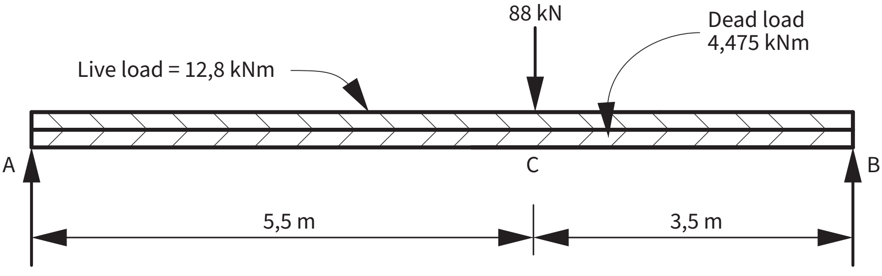
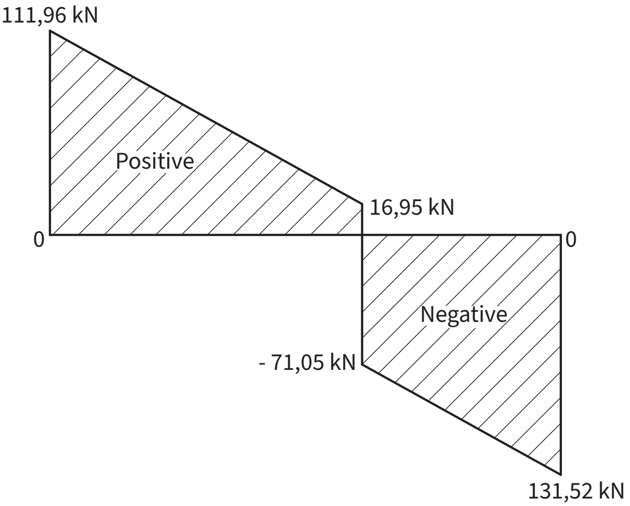
2.2	$\Sigma VC = 0$ $AB \text{ Sin } 30^o = 60{,}5$ kN $AB = 60{,}5 / \text{Sin } 30^o$ $AB = 121$ kN (Strut) $\Sigma HC = 0$ $BE = A \text{ Cos } 30^o$ $BE = 121 \times \text{Cos } 30^o$ $BE = 104{,}79$ kN (Tie)	 *Figure B*	(6)
	$\Sigma VC = 0$ $121 \text{ Sin } 30^o + BD \text{ Sin } 30^o = 28 + CD \text{ Sin } 30^o$ $60{,}5 + 0{,}5BD = 28 + 0{,}5CD$ $60{,}5 + 0{,}5BD - 28 = 0{,}5CD$ $32{,}5 + 0{,}5BD = 0{,}5CD$ $CD = \dfrac{32{,}5 + 0{,}5BD}{0{,}5}$ $CD = 65 + BD \ldots(1)$		(3)

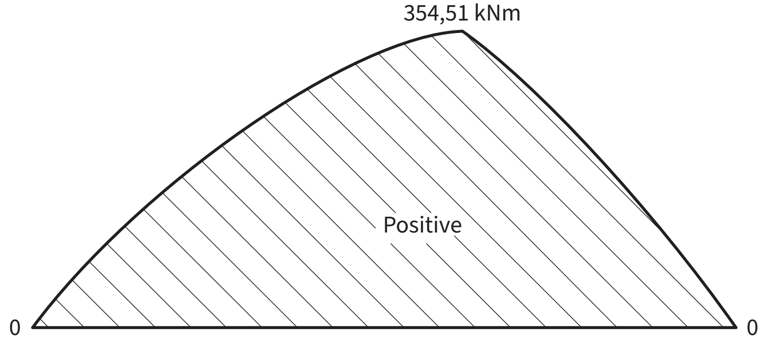
	 *Figure C*		
2.3	ΣHC = 0 121 Cos 30° = CD Cos 30° + BD Cos 30° 104,79 = 0,866 CD + 0,866 BD 104,79 = 0,866 (65 + BD) + 0,866 BD 104,54 = 56,29 + 0,866 BD + 0,866 BD BD = $\frac{164,54 - 56,29}{1,732}$ BD = 62,5 kN (Strut) Therefore CD = 65 + BD CD = 65 + 62,5 = 127,50 kN (Strut)		(5) **[18]**

QUESTION 3

Calculate reactions

3.1	<u>Take moments about RL:</u> (RR × 9) = (12,8 × 9 × 4,5) + (4,475 × 9 × 4,5) + (88 × 5,5) RR = 518,4 + 181,24 + 484 / 9 (1 183,64 / 9) RR = 131,52 kN <u>Take moments about RR:</u> (RL × 9) = (12,8 × 9 × 4,5) + (4,475 × 9 × 4,5) + (88 × 3,5) RL = 518,4 + 181,24 + 308 / 9 (1 007,64 / 9) RL = 111,96 kN	(2)

	 *Figure D*	
3.2	**Shear force diagram**  *Figure E*	(2)
3.3	Calculate bending moment Max BM at 'C': (131,52 × 3,5) – (12,8 × 3,5 × 1,75) – (4,475 × 3,5 × 1,75) 460,32 – 78,4 – 27,41 BM at 'C' = 354,51 kNm	(2)

	Bending moment diagram  ***Figure F***		(2)
3.4	Calculate value for 'K' $K = \frac{BM}{fcu\ b\ d^2}$ $K = \frac{354,51 \times 10^6}{25 \times 330 \times 425^{\ 2}}$ K = 0,238 $K < K^1 = 0,156$ Compression reinforcement will therefore be required.	(Cl.4.3.3.4.1) d = 475 −50 cover = 425 mm	(3) **[13]**

QUESTION 4

4.1	Select a suitable I-section steel beam $\frac{M}{I} = \frac{f}{y}$ Bending moment max = $\frac{w \times l^2}{8}$ $= \frac{65 \times 6,35^2}{8}$ BM max = 327,62 kNm Then: $z = \frac{M}{f}$ $z = \frac{327,62 \times 10^6}{156}$ $z = 2\ 100\ 128,2\ mm^3$ $z = 2\ 100,\ 13 \times 10^{-6}\ m^3$ Select 533 × 210 × 101 kg/m (Z_e value = $2\ 297 \times 10^{-6}\ m^3$)		(5)

4.2	Check if the beam is adequate Determine the self-weight of the beam Dead load = 101 kg/m × 9,81 × 10^{-3} Dead load = 0,991 kNm Total load = 65 kNm + 0,991 kNm = 65,991 kNm Revised bending moment max = $\frac{w \times l^2}{8}$ $= \frac{65,991 \times 6,35^2}{8}$ BM max = 332,62 kNm Maximum bending moment Then: $z = \frac{M}{f}$ $z = \frac{332,62 \times 10^6}{156}$ z = 2 132 187,5 mm^3 z = 2 132, 9 × 10^{-6} m^3 The selected steel beam is 533 × 210 × 101 kg/m (Z_e value = 2 297 × 10^{-6} m^3) is adequate the support its own weight as well as the imposed load.		(7) **[12]**

QUESTION 5

All references taken from SANS 10100-1 (2000).

	Fcu = 25 MPa Fy = 450 MPa Span = 8 metres Density of reinforced concrete	Table 2 (4.1.5.1) Table 3 (4.1.5.2) Cl. 4.3.1.2 2 425 kg/m^3	(5)
5.1	Determine the effective depth of the beam Effective depth = span / 16 Effective depth = 8 000 / 16 Effective depth = 500 mm	Table 10 (4.3.6.2.1)	(1)

5.2	Determine the overall depth Assume Y25 main steel and Y10 binders Assume Cover of 25 mm. Overall depth = $500 + \frac{25}{2} + 10 + 25$ Overall depth = 547,5 mm (Use overall depth = 550 mm)		(2)
	Determine the design dead loads of the beam Design dead load = Volume × density × $9{,}81 \times 10^{-3} \times 1{,}2$Gn DDL = $0{,}55 \times 0{,}33 \times 1 \times 2\,425$ kg/m^3 $\times 9{,}81 \times 10^{-3} \times 1{,}2$ Gn Design dead load = 5,18 kNm Design imposed load = 36 kNm × 1,6Qn Design imposed load = 57,6 kNm Total design load = 5,18 + 57,6 = 62,78 kNm	(Cl.4.2.2.1) (Cl.4.2.2.1)	 (2) (2)
5.3	Calculate bending moment maximum $BM_{max} = \frac{WL^2}{8}$ $BM_{max} = \frac{62{,}78 \times 8{,}0^2}{8}$ $BM_{max} = 502{,}25$ kNm		(2)
	Calculate value for 'K' $k = \frac{BM}{fcu\ b\ d^2}$ $k = \frac{502{,}25 \times 10^6}{25 \times 330 \times 500^{\ 2}}$ $k = 0{,}244 > K^1 = 0{,}156$ Tension and compression reinforcement required.	(Cl.4.3.3.4.1)	(2)
5.4	Calculate distance of lever arm (Z) $Z = d\left\{0{,}5 + \sqrt{0{,}25 - \frac{k^1}{0{,}9}}\right\}$ $Z = 500\left\{0{,}5 + \sqrt{0{,}25 - \frac{0{,}156}{0{,}9}}\right\}$ Z = 500{0,777} Z = 388,50 mm	(Cl.4.3.3.4.1)	(2)

5.5	Determine compression reinforcement $A's = \frac{(k - k^1)\ Fcu\ b\ d^2}{Fyc\ (d - d^1)}$ (Use d^1 = 50 mm) Where: $Fyc = \frac{Fy}{1{,}15 + \frac{Fy}{2\ 000}}$ $Fyc = \frac{450}{1{,}15 + \frac{450}{2\ 000}}$ Fyc = 327 MPa $A's = \frac{(0{,}244 - 0{,}156)\ 25 \times 330 \times 500^2}{327\ (500 - 50)}$ A's = 1 233,44 mm^2 Use 4Y20 (As = 1 257 mm^2)	(Cl.4.3.3.4.1) Figure 2 $\gamma m = 1{,}15$ (Cl.3.3.3.2)	(2)
	Check for minimum compression reinforcement $\frac{100\ As}{Ac} = \frac{100 \times 1\ 257}{550 \times 330}$ $= 1{,}06$ 0,69 > 0,24 The reinforcement is sufficient.	Table 23 (Cl.4.11.4)	(1)
5.6	Determine tension reinforcement $As = \frac{k^1\ Fcu\ b\ d^2}{0{,}87 \times fy \times z} + \frac{A's\ Fyc}{0{,}87 \times fy}$ $As = \frac{0{,}156 \times 25 \times 330 \times 500^2}{0{,}87 \times 450 \times 388{,}5} + \frac{1\ 257 \times 327}{0{,}87 \times 450}$ As = 2 115,42 + 1 049,91 As = 3 165,33 mm^2 Use 4y32 (As = 3 217 mm^2)	(Cl.4.3.3.4.2)	
5.7	Check for minimum main reinforcement $\frac{100\ As}{Ac} = \frac{100 \times 3\ 217}{550 \times 330}$ $= 1{,}77$ 1,77 > 0,45 The reinforcement is sufficient	Table 23 (Cl.4.11.4)	

	Check for maximum area of reinforcement 4% of AC 4% × 550 × 330 $5\ 940\ mm^2$ $(3\ 217 + 1\ 257) < 7\ 260$ The reinforcement is sufficient	(Cl.4.11.5.1)	(1) **[22]**

QUESTION 6

6.1	I-Section parallel flange (457 × 191 × 89,7 kg/m) $I_{xx} = 411,4 \times 10^{-6}\ m^4$ $Y = 463,6/2 = 231,8$ mm Bending stress = 175 MPa		
	Self-weight of the steel beam Weight = 89,7 kg/m × 9,81 × 10^{-3} Weight = 0,88 kNm		(1)
	Calculate the bending moment maximum $BM_{max} = \frac{w L}{4} + \frac{W L^2}{8}$ $BM_{max} = \frac{375 \times L}{4} + \frac{0,88 \times L^2}{8}$ $BM_{max} = (93,75 L + 0,11 L^2)$		(2)
	Equate to maximum bending moment $\frac{M}{I} = \frac{f}{y}$ $\frac{(93,73 L + 0,11 L^2) \times 10^6}{411,4 \times 10^6} = \frac{175}{231,8}$ $231,8\ (93,73\ L + 0,11\ L^2) = 175 \times 411,4$ $21\ 726,614\ L + 25,\ 498\ L^2 = 71\ 995$ Span: $25,\ 489\ L^2 + 21\ 726,614\ L = 71\ 995$ (divide by 25,489) Span: $L^2 + 852,09\ L - 2\ 823,55$ Span $= \frac{-b \pm \sqrt{b^2 - 4\ ac}}{2\ a}$ Span (L) $= \frac{-\ 852,09 \pm \sqrt{852,09^{\ 2} - 4 \times 1 \times -2\ 823,55}}{2 \times 1}$ Span (L) $= \frac{-\ 852,09 \pm 858,69}{2}$ Span(L) = 3,3 m		(5) **[8]**

6.2	Effective length on each side: 130 – (2 × 8) = 114 mm Total effective length: 2 × 114 = 228 mm Throat thickness: Sin 45° × 8 = 5,66 mm Throat area: 5,66 mm × 228 mm = 1 290,5 mm^2 Safe load: Stress × area $130\frac{\text{N}}{\text{mm}^2} \times 1\,290{,}5\ \text{mm}^2$ = 167,765 kN		(5) **[13]**

QUESTION 7

7.1 Any TWO of the following:
Iron ore, coal, limestone and recycled steel. (2)

7.2 19 mm. (Also accept 13 mm). (1)

7.3 Any TWO of the following:
The water:cement ratio determines the potential **strength**, **permeability** and **durability** of the hardened concrete. (2)

7.4 The aim of the water permeability test is to determine how **durable and resistant the concrete is in extreme weather conditions** and **exposure to its environment**. (2)

[7]

Total: 100 marks

Exemplar examination paper 3 memorandum

QUESTION 1

1.1	Any TWO of the following: • It has simple construction design. • The cupola requires less floor space. • A can melt a wide range of materials. • The construction and maintenance of the cupola is cost effective. • It does not require highly skilled operators.		(2)
1.2	Any TWO of the following: • Leaving the formwork in place, • Covering the concrete with a material that would shelter it from direct sunlight by keeping the concrete moist. • Applying a membrane-forming compound.		(2)
1.3	Any TWO of the following: • The bending test • The slump test. • The water permeability test • The cube test. • The concrete abrasion test.		(2) **[6]**

QUESTION 2

2.1	Select a suitable rolled steel angle for marked part 'S' (Tie) Force = 62 kN Select trial section: 70 × 70 × 6 mm. Area = $0{,}813 \times 10^3$ mm^2 Allowable stress = 155 MPa Calculate effective area (Aeff) $A_{eff} = \frac{3(A1)^2 + 4\,A1\,A2}{3A1 + A2}$ A_1 = Connected leg $A_1 = t(b - \frac{t}{2}) - (\text{area of hole})$ $A_1 = 6(70 - \frac{6}{2}) - (22 \times 10)$ (M18 bolts) $A_1 = 294$ mm^2 A_2 (unconnected leg) 90 $A_2 = t(b - \frac{t}{2})$ $A_2 = 6(70 - \frac{6}{2})$ $A_2 = 402$ mm^2 $\text{Aeff} = \frac{3\,(294)^2 + 4(294)(402)}{3(294) + (402)}$ $A_{eff} = \frac{732\,060}{1\,284}$ $A_{eff} = 570{,}14$ mm^2 ($0{,}57014 \times 10^3$ mm^2)	(SABS 0162 Table 20) (SABS 0162 Cl. 9.2.1) Where A_1 is the connected leg and A_2 is the unconnected leg	(2) (3)
	Therefore Load: Force = Pt × A_{eff} Force = 155 Nmm^2 × 570,14 mm^2 Force = 88,4 kN The bolted tie bar will be able to withstand the given load of 62 kN	(Table 20 SANS 10162)	(3)

2.2	Select a suitable rolled steel angle for marked Part ‘T’ (Strut) Force = 76 kN The angle is discontinuous. Actual length = 0,9 m Effective length = 0,9 × 0,85 L_{eff} = 0,765 (765 mm) Select trial section: 70 × 70 × 6 mm. Area = $0,813 \times 10^3$ mm^2 R_{min} = 13,7 mm Calculate slenderness ratio $L/r = \frac{765}{13,7}$ = 55,83 55,83 = 129,15 MPa (Table 17)	(SABS 0162 Table 20)	(3)
2.3	Therefore load: Calculate the load Load = stress × area = 107,25 × 0,183 × 10^3 Load = 87,2 kN The 70 × 70 × 6 will be suitable.	(Table 20 SANS 10162)	(2) **[13]**

QUESTION 3

All references taken from SANS 10100-1 (2000).

	Fcu = 25 MPa Fy = 450 MPa Efective span Dead load Imposed load	Table 2 (4.1.5.1) Table 3 (4.1.5.2) 5,5 m 6,5 kNm^2 7,5 kNm^2	
3.1	Calculate the lever arm distances $Z = d\left\{0,5+\sqrt{0,25-\frac{K^1}{0,9}}\right\} \leq 0,95d$ $Z = 475\left\{0,5+\sqrt{0,25-\frac{0,156}{0,9}}\right\}$ Z = 475(0,777) Z = 369, 1 mm	(Cl.4.3.3.4.1)	(2)

3.2	Determine the position of the neutral axis $X = \frac{d - z}{0,45}$ $X = \frac{475 - 369,1}{0,45}$ X = 235,33 mm > 150 mm Therefore, the N A lies below the flange.	(Cl.4.3.3.4.1)	(3)
3.3	Calculate the total design load W = 1,2(Gn) + 1,6 (Qn) W = 1,2(6,5 × 1) + 1,6(7,5 × 1) W = 7,80 + 12,0 W = 19,8 kNm	(Cl.4.3.3.4.1)	(2)
3.4	Calculate bending moment due to the concrete $BM = \frac{wl^2}{8}$ $BM = \frac{19,8 \times 5,5^2}{8}$ BM = 74,87 kNm	(Cl.4.3.3.4.1)	(2)
3.5	Calculate tension reinforcement $As = \frac{m + 0,1\, fcu\, b_w\, d \left(0,45d - h_f\right)}{0,87\, fy \left(d - 0,5\, h_f\right)}$ As $= \frac{74,87 \times 10^6 + (0,1 \times 25 \times 220 \times 475)\,(0,45 \times 475 - 120)}{0,87 \times 450\,(475 - 0,5 \times 120)}$ $As = \frac{74,87 \times 10^6 + (261\ 250)\,(93,75)}{0,87 \times 450\,(415)}$ $As = \frac{74,87 \times 10^6 + 24\ 492\ 187,5}{162\ 472,5}$ $As = \frac{99\ 362\ 187,5}{162\ 472,5}$ $As = 611,55\ mm^2$ Use 2R20 bars ($As = 628\ mm^2$)	(Cl.4.3.3.4.2)	(1) (1) (2) **[13]**

QUESTION 4

Given information:

3.2	Plate: 180 mm × 18 mm $I_{xx} = \frac{b\,d^3}{12} = \frac{0{,}180 \times 0{,}018^3}{12} = 0{,}0875 \times 10^{-6}\ \text{m}^4$ Area = $0{,}180 \times 0{,}018 = 3{,}24 \times 10^{-3}\ \text{m}^2$ 305 × 102 × 32,6 kg/m I-Parallel flange: $I_{xx} = 65{,}01 \times 10^{-6}\ \text{m}^4$ Area = $4{,}183 \times 10^{-3}\ \text{m}^2$ $\frac{h}{2} = \frac{312{,}7}{2} = 156{,}35\ \text{mm}$ Plate: 102,4 mm × 12 mm $I_{xx} = \frac{b\,d^3}{12} = \frac{0{,}1024 \times 0{,}012^3}{12} = 0{,}01475 \times 10^{-6}\ \text{m}^4$ Area = $0{,}1024 \times 0{,}012 = 1{,}229 \times 10^{-3}\ \text{m}^2$ Total area = $3{,}24 \times 10^{-3}\ \text{m}^2 + 4{,}183 \times 10^{-3}\ \text{m}^2 + 1{,}229 \times 10^{-3}\ \text{m}^2$ Total Area = $8{,}652 \times 10^{-3}\ \text{m}^2$ (1)	
4.	Calculate neutral axis using area moments from bottom $8{,}652 \times 10^{-3}\ \text{m}^2 \times Y_1 =$ $(3{,}24 \times 10^{-3}\ \text{m}^2 \times 0{,}009) = 0{,}0292 \times 10^{-3}$ $+ (4{,}183 \times 10^{-3}\ \text{m}^2 \times 0{,}1895) = 0{,}7921 \times 10^{-3}$ $+ (1{,}229 \times 10^{-3}\ \text{m}^2 \times 0{,}3367) = 0{,}4138\ 10^{-3}$ Total = $1{,}2351 \times 10^{-3}\ \text{m}^2$ $Y_1 = \frac{1{,}2351 \times 10^{-3}\ \text{m}^2}{8{,}652 \times 10^{-3}\ \text{m}^2}$ $Y_1 = 0{,}14275\ \text{m}$ $Y_1 = 142{,}75\ \text{mm}$	(4)

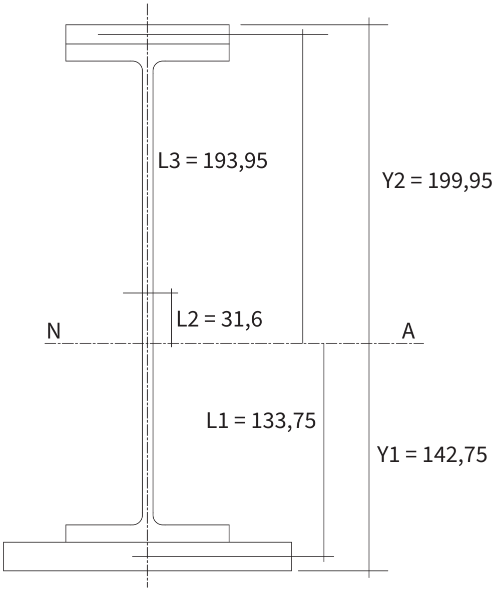


Figure A

4.	<u>Calculate second moment of area (Ixx total)</u> $I_{xx\ tot} = \left(I_{xx}\text{ Plate}+ al^2\right)_{+}\left(I_{xx}\text{ Beam} + al^2\right)_{+}\left(I_{xx}\text{ Plate} + al^2\right)$ $I_{yy\ Plate} = \left(0{,}0875 \times 10^{-6} + 3{,}24 \times 10^{-3} \times 0{,}13375^2\right)$ $= \left(0{,}0875 \times 10^{-6} + 57{,}96 \times 10^{-6}\right) = \underline{58{,}05 \times 10^{-6}\ \text{m}^4}$ $I_{xx\ Beam} = \left(65{,}01 \times 10^{-6} + 4{,}183 \times 10^{-3} \times 0{,}0316^2\right)$ $= \left(65{,}01 \times 10^{-6} + 4{,}177 \times 10^{-6}\right) = \underline{69{,}87 \times 10^{-6}\ \text{m}^4}$ $I_{xx\ Plate} = \left(0{,}01475 \times 10^{-6} + 1{,}229 \times 10^{-3} \times 0{,}19395^2\right)$ $= \left(0{,}01475 \times 10^{-6} + 46{,}23 \times 10^{-6}\right) = \underline{46{,}25 \times 10^{-6}\ \text{m}^4}$ $I_{xx\ total} = \underline{174{,}17 \times 10^{-6}\ \text{m}^4}$	(7)
	<u>Calculate maximum bending moment (Bending stress = 158 MPa)</u> $\frac{M}{I} = \frac{f}{y}$ where $M = \frac{f \times I}{y}$ $BM_{max} = \frac{165 \times 174{,}17\ \times 10^6}{142{,}75}$ $BM_{max} = 201{,}32$ kNm	(3)

	Calculate the self-weight of the beam Plate: 7 865 kg/m^3 × 0,180 × 0,018 × 9,81 × 10^{-3} = 0,25 kNm Beam: 65,1 kg/m × 9,81 × 10^{-3} = 0,638 kNm Plate: 7 865 kg/m^3 × 0,1024 × 0,012 × 9,81 × 10^{-3} = 0,095 kNm Total self-weight = 0,983 kNm	(2)
	Calculate the maximum point load the beam can carry Additional 15 kNm UDL $BM = \frac{W\,l^2}{8} + \frac{W\,l^2}{8} + \frac{W\,l^2}{8}$ $201{,}32 = \frac{0{,}983 \times 6{,}25^2}{8} + \frac{35 \times 6{,}25^2}{8} + \frac{W \times 6{,}25^2}{8}$ 201,32 = 4,8 + 170,9 + 4,88 W $W = \frac{201{,}32 - 170{,}9}{4{,}88}$ W = 6,23 kN	(3) [20]

QUESTION 5

5.	Calculate the direct shear on each bolt Force direct = Force / No of bolts F_{direct} = 28 kN / 2 = 14 kN	(1)
	Calculate the distance from the centroid to the furthest bolt r = 200 / 2 = 100 mm	(1)
	The direct load on the bolts due to the imposed load Σcwm = Σacwm $(28 \times 300) = (F_T \times 100 \times 2)$ $F_T = \frac{28 \times 300}{100 \times 2}$ F_T = 42 kN	(3)
	The resultant load on each bolt F_R = 14 + 42 = 56 kN	(2)

	Calculate the size of the bolts. (Shear stress = 105 MPa) F_R = Shear stress × Area of bolt $\frac{\pi d^2}{4} = \frac{Fr}{\text{Shear stress}}$ $d = \sqrt{\frac{Fr \times 4}{\pi \times stress}}$ $d = \sqrt{\frac{56 \times 10^3 \; x \; 4}{\pi \times 125}}$ d = 23,88 mm Use 2M24 bolts	(4) **[11]**

QUESTION 6

All references taken from SANS 10100-1 (2000).

	Fcu = 25 MPa Fy = 250 MPa Span = 5,25 m Density of reinforced concrete	Table 2 (4.1.5.1) Table 3 (4.1.5.2) Cl. 4.3.1.2 2 450 kg/m^3	
6.	Determine the effective depth of the slab Effective depth = span / 16 Effective depth = 5 250 / 16 Effective depth = 328,13 mm	Table 10 (4.3.6.2.1)	(1)
	Determine the overall depth *Assume R16 main steel and cover of 25 mm.* Overall depth = 328,13 + 16/2 + 25 cover Overall depth = 361,13 mm (Use overall depth = 370 mm)		(2)
	Determine the design dead loads of the slab Design dead load = Volume × density × 9,81 × 10^{-3} × 1,2Gn = 0,37 × 1 × 1 × 2 450 kg/m^3 × 9,81 × 10^{-3} × 1,2 Gn Design dead load = 10,67 kNm Design imposed load = 7,5 kNm^2 × 1 × 1,6Qn Design imposed load = 12,0 kNm Total design load = 10,67 + 12,0 = 22,38 kNm	Cl.4.2.2.1 (Cl.4.2.2.1)	(3)

	Calculate bending moment maximum $BM_{max} = \frac{WL^2}{8}$ $BM_{max} = \frac{22,67 \times 5,25^2}{8}$ $BM_{max} = 78,11$ kNm		(2)
	Calculate value for 'K' $K = \frac{BM}{fcu\ b\ d^2}$ $K = \frac{78,11 \times 10^6}{25 \times 1\ 000 \times 328,13^{\ 2}}$ $K = 0,029$ $K < K^1 = 0,156$ therefore only tension reinforcement required.	4.3.3.4.1	(2)
	Calculate distance of lever arm (Z) $Z = d\left\{0,5+\sqrt{0,25-\frac{k}{0,9}}\right\} \leq 0,95d$ $Z = 328,13\left\{0,5+\sqrt{0,25-\frac{0,029}{0,9}}\right\} \leq 0,95d$ $Z = 328,13\{0,97\} \leq 0,95 \times 328,13$ $Z = 317,19 \text{ mm} \leq 311,72 \text{ mm} \leq 0,95d$	(Cl.4.3.3.4.1)	(2)
	Calculate tension reinforcement $As = \frac{M}{0,87 \times fy \times z}$ $As = \frac{77,11 \times 10^6}{0,87 \times 250 \times 317,19}$ $As = 1\ 117,72 \text{ mm}^2$ Use R16 at 175 centres (As = 1 149 mm^2)	(Cl.4.3.3.4.1)	(2)
	Check for minimum main reinforcement $\frac{100\ As}{Ac} = \frac{100 \times 1\ 149}{1000 \times 360}$ $= 0,32$ $0,24 = 0,32$ The reinforcement is sufficient.	Table 23 (Cl.4.11.4)	(2)

	Determine secondary reinforcement $\frac{100\ As}{Ac} = 0,24$ $As = \frac{0,24 \times 1\ 000 \times 360}{100}$ $As = 864\ mm^2$ Use R12 at 125 centres ($As = 905\ mm^2$)	Cl.4.11.4.3.1 & Table 23	(2) [18]

Total: 100 marks

Glossary

A

Additives – a substance which can be added to something to enhance or alter its properties

Admixtures – cement mixtures comprising natural or manufactured chemicals or additives

Alloying elements – elements which are used to change the properties of other metals

B

Bleed water – the excess water in a concrete mix which pushes up to the surface and is part of a process called *bleeding*

Bod – clay lining

C

Cast iron – an alloy of iron and carbon produced from pig iron in a furnace

Charge – the furnace charge of iron-bearing materials, coke and flux

Coke – a solid fuel made by heating coal in the absence of air so that the volatile components are driven off

Cupola furnace – a cylindrical or shaft-like furnace for melting metals

Curing compound – a liquid substance applied as a surface coating on freshly cast concrete to prevent loss of water and heat

D

Decarburises – related to *decarburisation*, which is the process of decreasing carbon content in metalworking

Drying shrinkage – the change in volume of concrete when water leaves the concrete during the curing process

Ductility – the ability of a material to be drawn or plastically deformed without fracture

E

Efflorescence – a white, powdery deposit of salts which forms on the surface of concrete

Electric arc – an electrical discharge between two electrodes or points

Electrodes – conductors used to make contact with the parts of a circuit which are not metallic

F

Falsework – temporary structures (the props, beams and plates etc.) which support the formwork

Ferromanganese – an alloy of iron and manganese which usually contains about 80% manganese and is used in the manufacture of steel

Ferrous – containing iron

Friable –a substance that crumbles easily

Frustum – the opening of the cone

G

Galena – the principal ore and the most important compound of lead

Gypsum – a cement retarding agent

H

Hearth – the base or floor of a furnace or fireplace

Hessian – a woven fabric made from the jute plant or sisal fibres

Hydration – the chemical reaction between the cement and water that allows the cement to set.

Hydraulic – a material (in this case, cement) that reacts with water by hardening and setting

I

Ingots – a block of relatively pure metal, like a gold bar, which is so shaped to make it easier to process further

Interpolation – a method of calculating values using given data points

Intumescent paint – considered to be the lightest form of passive fire protection; the paint swells as a result of heat exposure and causes an increase in volume and a decrease in density

Ironmongery – the manufacturing of iron goods

M

Mill scale – a black scale of magnetic oxide of iron formed on iron and steel when heated for rolling, forging or other processing; unlike rust, which forms over a long period due to exposure to oxygen and moisture, scale forms on all steel and iron products that are hot-rolled

Mineral spirits – a petroleum-derived chemical compound

Molybdenum – a chemical element used to produce alloys

O

Oxidation – a chemical reaction involving the loss of electrons when a substance comes into contact with oxygen or another oxidising substance

Oxide film – a thin, protective deposit on the surface of a metal which has undergone oxidation

Oxidised roasting – thermal gas- and solid reactions involved in the process of converting metallic compounds into oxides

P

Pig iron – crude iron ore smelted in a blasted furnace

Plastic shrinkage cracking – when the rate of evaporation of moisture from the surface *exceeds* the rate at which moisture is being supplied

R

Refractory – a substance that is resistant to heat

Residuals – metal elements which are present but aren't purposefully included when working with a particular metal

Retarding agent – a chemical agent which slows down a chemical reaction

Rust-inhibitive primer – an anti-rust treatment which prevents the rusting and corrosion of metals

S

Sea coal –a mineral coal that is distinct from other types of coal and charcoal; used as a constituent of foundry sand constituent of foundry sand

Slag – a by-product of smelting ores and other metals

Solder – a low-melting alloy or the act of joining with a solder, as in *soldering*

Spiegeleisen – a type of pig iron that is rich in manganese and carbon

Superplasticisers – additives used to produce high-strength concrete; also known as high-range water reducers

T

Truncated – shortened or cut off

Trunnion – a pin or pivot allowing a turning bucket to turn from one side to the other

Tuyeres – a nozzle through which air is forced into a smelter, furnace or forge

W

Welding – the art of joining metals by pressure after heating it to a plastic or semi-molten state, or by fusion of the metals alone.

Workability – in metalworking processes, the extent to which a material can be deformed without cracking; or the measure of ease with which concrete can be placed, compacted and finished without the segregation of the aggregate