Delft University of Technology
Faculty of Civil Engineering and Geosciences
Structural Mechanics Section

Exam CIEM5301 Shell Structures
Thursday 29 January 2025, 9:00 – 12:00 hours

Choose A, B, C or D.

1 A chain spans a river that is 55 m wide. The chain has a length of 86 m.
What is the deflection of the chain?

A 12 m
B 15 m
C 20 m
D 30 m

2 Which is a unit of m_{xx} ?

A N/mm^3
B kN/mm
C kNm/m
D Nmm

3 Is the following parameterisation orthogonal?
Does the *z* axis point outwards?

$$\bar{x} = u\cos v$$
$$\bar{y} = u\sin v$$
$$\bar{z} = u$$
$$0 < v < 2\pi \text{ m}$$
$$0 < u < 1 \text{ m}$$

A yes, yes
B yes, no
C no, yes
D no, no

4 k_{xx} = 1/(110 m), k_{yy} = -1/(372 m), k_{xy} = -1/(141 m)
What is the mean curvature k_m ?

A -1/(130 m)
B 1/(170 m)
C 1/(200 m)
D 1/(320 m)

5 Consider the following parameterisation.
What is the radius of curvature of this shell at the edge?

$$\bar{x} = u\cos v$$
$$\bar{y} = u\sin v$$
$$\bar{z} = u$$
$$0 < v < 2\pi \text{ m}$$
$$0 < u < 1 \text{ m}$$

A $\sqrt{2}$ m
B 1 m
C 2π m
D $2u$ m

6 Suppose we know $n_{xy} + n_{yx}$. How can we calculate n_{xy} and n_{yx}?

A $n_{xy} = n_{yx} = \frac{1}{2}(n_{xy} + n_{yx})$
B Equilibrium of a shell part in the *z* direction
C Sanders-Koiter equation 18
D We cannot, only in special cases.

7 Consider a free shell edge. There is no load on the edge. A finite element program computes a shear force on this edge. What is going on?

A The boundary condition is complicated.
B The finite elements are too large.
C Shell theory is not accurate close to an edge.
D This is caused by an edge disturbance.

8 A rocket contains liquid oxygen (49 bar) and liquid hydrogen (13 bar). The liquids are separated by a spherical bulkhead. The diameter of the rocket is 10 m. The thickness of the bulkhead is 12 mm. What is the stress in the bulkhead?

A 94 N/mm^2
B 188
C 375
D 750

9 In the finite element method for structures we specify boundary conditions. Which?

A Kinematic boundary conditions
B Dynamic boundary conditions
C Equilibrium boundary conditions
D Dirichlet boundary conditions

10 A program uses 64 bit numbers. The numbers are multiplied. How many multiplications does it take to get 1% error?

A 10^5
B 10^8
C 10^{10}
D 10^{13}

11 A cylinder is closed on both sides by diaphragms (fig. 1). Length = 0.6 m; radius = 0.3 m; thickness = 3 mm; $E = 3 \cdot 10^6$ N/mm^2; $\nu = 0.3$. Two forces of 100 kN are applied. How much will each force deflect?

A 1.82 mm
B This is not a realistic material.
C It depends on the finite element size.
D It is infinite at the singularities.

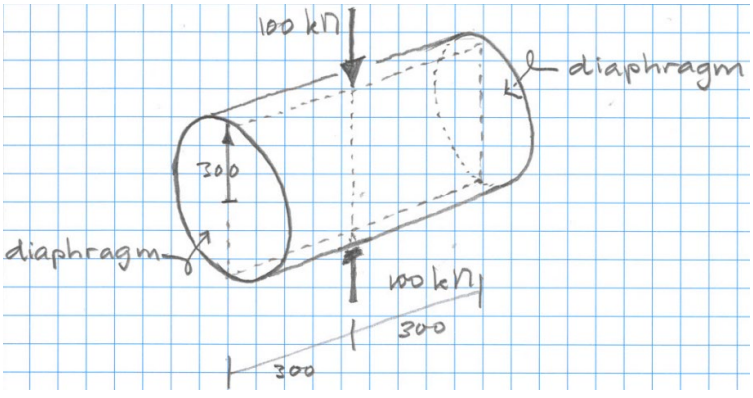


Figure 1. Pinched cylinder

12 A flat square plate has a length and width of 1 m and a thickness of 15 mm. The plate is twisted by pushing one corner out of plane. At what radius of curvature will it buckle?

A 4 m
B 8 m
C 16 m
D 32 m

13 Consider the ellipsoid on page 99 of the reader. What is parameter *a*?

A Radius of curvature
B Half the height
C Position of the first umbilic in the *u* direction
D Dimension less quantity

14 In a shell part, n_{xx} = 34 kN/m, m_{xx} = 12 kNm/m, t = 0.1 m. What is the stress?

A σ_{xx} = 4 N/mm^2
B 8
C 16
D 32

15 Reinforced concrete shells are thicker than 7 cm. Why?

A Otherwise, they would buckle.
B Only large reinforced concrete shells are economical.
C There needs to be cover on the bars.
D A thin layer of wet concrete does not stick to an inclined surface.

16 A linear finite element analysis shows a large stress at a point support. What should be done? [1]

A Choose a material that can carry this stress.
B Refine the mesh. The stress will be smaller.
C Model the point support by an area support. The stress will be smaller.
D Design the shell at the support by hand. Use the reaction force.

17 Consider the Zeckendorf hypar shell. Calculate the membrane force due to self-weight.

A 40 kN/m
B 80
C 160
D 320

18 For checking reinforcement in concrete, we rotate the local coordinate system ...

A ... in any direction.
B ... in the bar directions.
C ... in the principal directions.
D ... in the horizontal direction.

19 We design a wood grid shell with laths in the principal curvature directions. Why?

A In other directions there is torsion; the shear strength of wood is small.
B The curvature trajectory pattern is decorative.
C This provides optimum stiffness of the completed shell.
D The principal curvatures can be easily plotted and checked.

20 Consider two shells. They are identical, except for the sign of the Gaussian curvature. The shells are loaded by identical point loads perpendicular to the surface. Which deflects more?

A They have about the same deflection.
B The negatively curved shell deflects more.
C The positively curved shell deflects a bit more.
D The positively curved shell deflects about twice as much.

21 How do we call a point of a shell in which $k_1 = k_2$?

A monstar
B ridge
C principal point
D umbilic

22 Consider the parameterisation on page 128 of the reader. It is not valid for $a = b$. Which shape is this?

A hypar
B circular paraboloid
C sphere
D Ennepers surface

23 A pipe buckles at an axial force F_{cr} = …

A $\ldots \frac{4EI}{l^2}$

B $\ldots 0.6\frac{Et^2}{a}$

C $\ldots 1.2\pi Et^2$

D $\ldots \frac{\pi^2 EI}{a^2}$

24 n_{xx} = 1000, n_{yy} = -500, n_{xy} = 0 kN/m
k_{xx} = -1/10, k_{yy} = -1/20, k_{xy} = 1/(50 m)
E = 60 000 N/mm^2, t = 100 mm.
At what load factor will the shell buckle?

A 3
B 6
C 12
D 24

25 A linear buckling analysis gives us critical loads. How do we account for imperfection sensitivity?

A Select the highest consequence class.
B Specify appropriate partial load factors and partial material factors.
C Apply a knockdown factor.
D Add shape imperfections.

26 Which algorithm is used for nonlinear shell analysis?

A Kirchhoff algorithm
B Newton-Raphson algorithm
C Lanczos algorithm
D Jacobi algorithm

27 A shell will be exposed to wind and earthquakes. A modal analysis gives a smallest natural frequency of 12 Hz. Wil it resonate? [2]

A Yes, in a storm and in an earthquake.
B Yes, in a storm but not in an earthquake.
C Yes, in an earthquake but not in a storm.
D No

28 A reinforced concrete shell under service load vibrates with an amplitude of 2.5 mm. The load is removed. The damping ζ = 4%. What is the vibration amplitude after 10 cycles? [3]

A 0.011 mm
B 0.015
C 0.036
D 0.121

29 A shell structure costs $C_s = €\,4000 \ln\frac{1}{P_f}$. Note that this cost is a function of the collapse probability P_f. If the structure collapsed, the damage would be $C_f = €\ 1000\ 000$. What is the economically optimal collapse probability?

A $\frac{4}{1000\ 000}$

B $\frac{40}{1000\ 000}$

C $\frac{400}{1000\ 000}$

D $\frac{4000}{1000\ 000}$

30 Write a good shell multiple choice question for next year's exam. The question needs to be not too easy and not too difficult. The question needs to be not just copied and not copied-and-modified-a-bit. (Unless the latter modification is substantial and original.)

Answers

1 D 67% ...

2 C 100%

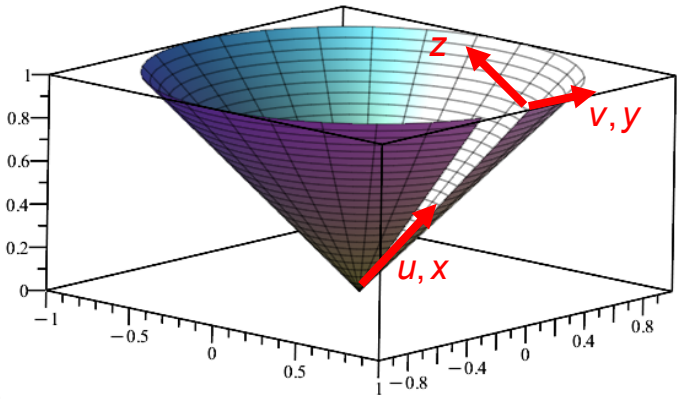
$l = 55\,m$

trial-and-error: $\frac{T}{q} = 16\,m$ $\quad L = \frac{2T}{q}\sinh\frac{ql}{2T} = 86\,m$

$x = 0 \quad y = \frac{T}{q}\left(\cosh\frac{qx}{T} - \cosh\frac{ql}{2T}\right) = -30\,m$

3 B 33% ...

```
> x := u·cos(v) :
> y := u·sin(v) :
> z := u :
> diff(x, u)·diff(x, v) + diff(y, u)·diff(y, v) + diff(z, u)·diff(z, v);
                                    0
> plot3d([x, y, z], v = 0 .. 6, u = 0 .. 1);
```

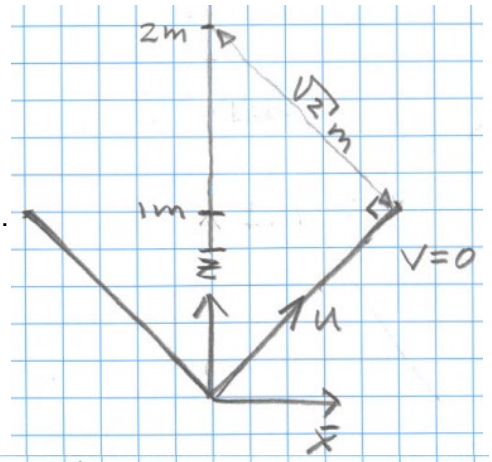


4 D 100% ... $\frac{1}{a} = \frac{k_{xx} + k_{yy}}{2} = \frac{\frac{1}{110} + \frac{-1}{342}}{2} = \frac{1}{324}$

5 A 100% .....

6 C 67%

7 A 67%



8 D 67% ... $p = 49 - 13 = 36\,bar = 3{,}6\,N/mm^2$

9 A 100%

$n = \frac{1}{2}pa = \frac{1}{2}\,3{,}6 \times 5000 = 9000\,N/mm$ (Barlow)

$\sigma = \frac{n}{t} = \frac{9000}{12} = 750\,N/mm^2$

10 D 100% ... 64 bits ⇒ double percision (p. 93)

11 A 100%

double precision ⇒ 16 digits (p. 94)

1 % error ⇒ 3 digits (p. 94)

$1.0004^{10} = 1.0040$ (try out)

⇒ 10 multiplications gives 1 less accurate digit

16 − 3 = 13

12 A 100% ...
13 B 67%

$$a = \frac{bc}{h} = \frac{1\,m \times 1\,m}{16{,}8 \times 0{,}015\,m} = 3{,}96\,m$$

$$h = 16{,}8\,t$$

14 B 67% .....
15 C 100%
16 D 67%

$$\sigma_{xx} = \frac{n_{xx}}{t} + 6\frac{m_{xy}}{t^2} = \frac{34}{0{,}1} + 6\frac{12}{0{,}01}$$

$$= 340 + 7200 = 7540\ kN/m^2 = 7{,}54\ N/mm^2$$

17 A 0% ...
18 B 100%
19 A 100%
20 B 67%
21 D 100%
22 B 33%

$$a = \frac{\frac{132'}{2}\,\frac{112'}{2}}{28'} = 132' = 40\,m$$

$$t = 3'' = 76\,mm$$

$$p_z = \rho g t = 2400\frac{kg}{m^3}\,10\frac{N}{kg}\,0{,}076\,m = 1{,}8\frac{kN}{m^2}$$

$$n_{xx} = \frac{1}{2}p_z a = \frac{1}{2}\,1{,}8 \times 40 = 36\frac{kN}{m}$$

23 C 67% ...

$$n_{cr} = -0{,}6\frac{E t^2}{a} \qquad F_{cr} = n_{cr}\,2\pi a$$

24 C 100% ...
25 C 100%
26 B 100%
27 D 100%

$$\lambda_x = -\frac{1}{n_{xx}}\frac{1}{6}\,0{,}6\,\frac{E t^2}{a_y} = -\frac{1}{1000}\frac{1}{6}\,0{,}6\,\frac{60000 \times 100^2}{20000} = -3$$

$$\lambda_y = -\frac{1}{n_{yy}}\frac{1}{6}\,0{,}6\,\frac{E t^2}{a_x} = -\frac{1}{-500}\frac{1}{6}\,0{,}6\,\frac{60000 \times 100^2}{40000} = 12$$

28 B 67% .....

trial and error

$$\delta = \frac{1}{n}\ln\frac{x_0}{x_n} = \frac{1}{10}\ln\frac{2{,}5}{0{,}015} = 0{,}511$$

$$\zeta = \frac{\delta^2}{\sqrt{4\pi^2 + \delta^2}} = \frac{0{,}511^2}{\sqrt{4\pi^2 + 0{,}511^2}} = 4\%$$

29 D 100% .....
30 100%

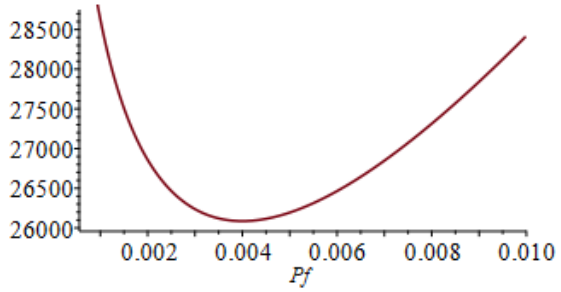
```
> Cs := 4000·euro·ln(1/Pf):
> Cf := 1000000·euro:
> Ce := Cl + Cs + Cn + Pf·Cf:
> Pfmin := solve(0 = diff(Ce, Pf), Pf);
```

$$Pfmin := \frac{1}{250}$$

```
> 4000/1000000;
```

$$\frac{1}{250}$$

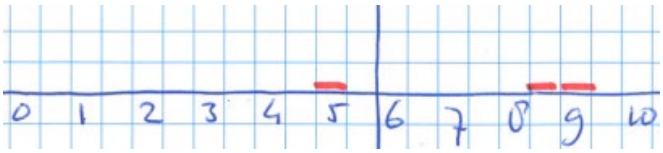
```
> euro := 1: plot(Cs + Pf·Cf, Pf = 0..0.01); euro := 'euro':
```



The grade is $(40\,s - 290) / 91$ rounded to the closest halve, where s is the number of correct answers.

$g = a + b\,s$
$0 = a + b\,29/4$
$10 = a + b\,30$

$a = -290/91$
$b = 40/91$



[1] Question by Dakka Sricharan, November 2024
[2] Question by Stijn Platzer, November 2024
[3] Question by Simon Streit, November 2024