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

Exam CIEM5301 Shell Structures
Thursday 9 November 2023, 9:00 – 12:00 hours

Choose A, B, C or D.

1 What is a corbel?

A Stone that sticks out of a wall
B Primitive stone arch
C Type of dome built in ancient Greece
D Construction method for stone structures

2 What is the difference between a pressure line and a meridional force?

A N/mm^2 …….. kN/m
B vertical direction ……. horizontal direction
C should be in the middle third …… always in the middle
D in equilibrium …….. not in equilibrium

3 When inspecting a shell, we pay extra attention to fixed edges. Why?

A inextensional deformation
B concentrated shear force
C stress concentration
D singularities

4 A stone dome has the shape of half a sphere. The radius of curvature is 12 m. The dome thickness is 300 mm. The bottom edge is reinforced by a hoop made of a steel rod. The rod diameter is 20 mm. Is this sufficient?

A No, the rod diameter is too small.
B Yes, the rod diameter is just sufficient.
C No, the rod diameter is much too large.
D Yes, but there is no need for reinforcement.

5 A shell is modelled with the shell membrane equations. We formulate boundary conditions. How many can be included in solving the equations?

A 1 per edge.
B 2 per edge.
C 3 per edge.
D 4 per edge.

6 When we know the displacement functions u_x, u_y, u_z, we can use the Sanders-Koiter equations to calculate all other dependent variables easily. This is demonstrated in the ping pong ball example (reader p. 56). From this point of view we need to solve only 3 dependent variables: u_x, u_y and u_z. When we have solved these, we know all. Nonetheless, in the finite difference method we solve 21 dependent variables. Why is this? In other words, what is so special about a ping pong ball, that it is an exception?

A The ping pong ball is spherical.
B The ping pong ball has no boundary conditions.
C The ping pong ball has a large *a*/*t* ratio.
D The ping pong ball is filled with compressed air.

7 How many stresses act on a small cube?

A 3
B 6
C 9
D 18

8 Linear buckling modes go inward or outward. What is the difference?

A Inward modes are often due to gravity and outward modes are due to wind suction.
B Inward modes are unstable and outward modes are stable.
C Inward modes are due to inextensional deformation and outward modes are not.
D The difference has no meaning. It is random.

9 n_{xx} = 3.17 kN/m
n_{yy} = -2.41
n_{xy} = 4.60
n_{yx} = 4.55
Which forces does the reinforcement need to carry?

A n_{sx} = 3.17 kN/m n_{sy} = 0 kN/m
B n_{sx} = 0 n_{sy} = 9.01
C n_{sx} = 7.74 n_{sy} = 2.26
D n_{sx} = 11.85 n_{sy} = 0

10 What is inextensional deformation?

A Deformation with moments and without membrane forces
B Deformation without strains anywhere in the shell material
C Strain-less body motion for any rigid foundation settlement
D Shell-like deformation of trusses, frames and plates

11 The total Gaussian curvature of a brick is 4π. Which parts contribute most to the 4π ?

A the volume
B the 6 faces
C the 12 edges
D the 8 corners

12 A steel shell has a Gaussian curvature $k_G = 1/(9\ m^2)$. The shell thickness is 3 mm. A point load $P = 12$ kN is placed far from the edges and perpendicular to the surface pointing outwards. What is the membrane force under the point load?

A 270 kN/m
B 811 kN/m
C 933 kN/m
D 1200 kN/m

13 A square plate, which is twisted, develops a compression membrane force n in the middle (second order effect). At what force does this plate buckle?

A $n = -4.41\dfrac{E\,t^3}{b^2}$

B $n = -4.41\dfrac{E\,t^2}{b}$

C $n = -4.41\dfrac{E\,b^3}{t^2}$

D $n = -4.41\,E\,t\sqrt{1-\nu^2}$

14 Umbilics are used for …

A … checking stresses in a shell.
B … tracking singularities.
C … spotting inextensional deformation.
D … nothing.

15 Which algorithm is **not** used in finite element programs?

A LU decomposition
B Lanczos algorithm
C Newton-Raphson method
D Bubble sort

16 Which buckling occurs in a thick elastic cylinder?

A Chessboard pattern
B Yoshimura pattern
C Elephant foot
D Ring pattern

17 A cylinder has the dimensions, length = 1 m, diameter = 0.4 m, thickness is 5 mm. What is its buckling length?

A 53 mm
B 76 mm
C 107 mm
D 161 mm

18 FEM software performs a linear analysis before a linear buckling analysis. Why?

A The membrane forces are input for a linear buckling analysis.
B The unity checks need to be satisfied on deformation and stresses.
C To determine the load combinations.
D To check if there is a need for linear buckling analyses (compression).

19 A thin sphere has the following buckling load factors.
3.4, 3.4, 3.4, 3.6, 3.6, 3.7, 4.0, 4.1, …
What shall we do?

A Nothing. The load factors are fine.
B Improve the design. The factors need to be larger than 6.
C Reduce the load. The factors are too large.
D Add shape imperfections. Factors should not occur twice.

20 Consider a reinforced concrete shell roof with a positive Gaussian curvature. The roof length and width are 21 m. The radius of curvature is 140 m. The thickness is 250 mm. What imperfection amplitude should we use in a nonlinear analyses?

A 25 mm
B 101 mm
C 166 mm
D 203 mm

21 FEM software performs a linear buckling analysis before a nonlinear analysis. Why?

A The nonlinear deformation is a summation of linear buckling modes.
B The buckling load factor is used to determine the load increments.
C The buckling mode is used for checking the magnitude of the nonlinear deformation.
D The buckling mode is a shape imperfection added before a nonlinear analysis.

22 Consider the calculation and test of your shell object. Which parameters (thickness, radius, yield strength, …) were difficult to determine and had a large influence on the ultimate load? Explain your answer.

23 In which direction does gravity act?

A We can choose; *x*, *y*, or *z* direction.
B Any direction in the global coordinate system
C In the *u* or in the *v* direction but not in both directions (paper space)
D Usually in the local *z* direction pointing down

24 A circular steel pipe has the following dimensions: length = 16 m, diameter = 1 m, thickness = 12 mm. Both ends are open. What is its smallest natural frequency?

A 8 Hz
B 25 Hz
C 33 Hz
D 51 Hz

25 Consider a square curved panel with edge stiffeners (diaphragm boundary conditions). What is the influence of a shear force n_{xy} on the smallest natural frequency?

A No influence
B f_n becomes larger.
C f_n becomes smaller.
D If n_{xy} is positive, f_n becomes larger and if n_{xy} is negative, f_n becomes smaller.

26 What is a limit state function?

A Function that puts a limit on the state something is in
B Equation that checks if collapse occurs or another failure
C Software that performs unity checks of structural failure
D Yield contour

27 Henk's school (reader p. 177) is renovated. Does it need to be strengthened too?

A Yes because extra safety is always welcome.
B Yes because it is an existing school dominantly loaded by wind and needs to have a collapse probability of 0.011 in 50 years.
C No because Henk will graduate before it is finished.
D No because the chance of Henk or any student dying has not changed and is acceptable.

28 We can compute the 1 year collapse probability (P_{f1}) and the design live collapse probability (P_{f50}) of a large thin shell roof. What do we do with these numbers?

A P_{f1} < economical safety target
P_{f50} < personal safety requirement

B Chance that a person who uses this structure is there × P_{f1} < personal safety requirement
P_{f50} ≈ economical safety target

C P_{f1} < personal safety requirement
P_{f50} × chance that a person dies < economical safety target

D P_{f1} ≈ personal safety target
P_{f50} < economical safety requirement

29 We compute the collapse probability of a shell design. This probability appears to be too large. What can we do?

A Reduce the number of Monte Carlo Simulations.
B Increase the personal safety requirement.
C Reduce the shell thickness.
D Increase the factors in the load combinations.

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 A 58% of the answers were correct.
2 C 89% … A 11% is wrong because a pressure line shows the location of a force [kN]
3 C 89%
4 A 32% …

```
> a := 12·m : t := 300·mm : d := 20·mm :
> rho := 3000·kg/m^3 : g := 9.8·m/s^2 : fy := 400·N/mm^2 :
> m := 1000·mm : kg := N·s^2/m : N := kN/1000 :
> p := rho·g·t :
> n := p·a :
> F := n·a/4; # estimated width over which tension acts (meewerkende breedte)
                                F := 317.5200000 kN
> F := 1/4·3.1415·d^2·fy;
                                F := 125.6600000 kN
```

5 B 79% … D 21% is wrong. The Sanders-Koiter equations have 4 b.c. per edge.
6 B 63% … A 32% is wrong. A torus does not need edge molecules either.
7 B 68% … D 21% is wrong. It is a small cube. The stress on the back is the same as the stress on the front.
8 D 95%
9 C 84% …

```
> nxx := 3.17 : nyy := -2.41 : nxy := 4.60 : nyx := 4.55 :
> nsx := nxx + sqrt(nxy·nyx);
                                nsx := 7.744931693
> nsy := nyy + sqrt(nxy·nyx);
                                nsy := 2.164931693
```

10 A 79% … D 21% is wrong because only the middle surface is not strained.
11 D 47% … B 37% is wrong because the faces are flat: zero Gaussian curvature.
C 16% is wrong. The edges are cylindrical: zero Gaussian curvature.
12 B 100% …

```
> a := 3·m : t := 3·mm : P := -12·kN : nu := 0.35 : m := 1000·mm : kN := 1000·N :
> n := -sqrt(3.)/8·P/t·sqrt(1 - nu^2);
                                n := 811.2490374 N/mm
```

13 A 74% …

```
> u := 16.8·t :
> kG := -u^2/b^4 :
> n := 1/64·E·t·b^2·kG;
                                n := -4.410000000 E t^3/b^2
```

14 D 79%
15 D 100%
16 D 58% … C 21% is wrong because it is elastic buckling.
17 A 79% ….

```
> l := 1·m : d := 0.4·m : t := 5·mm : m := 1000·mm : assume(mm > 0) :
> a := d/2 - t/2 :
> lcr := 1.7·sqrt(a·t);
                                lcr := 53.42167162 mm~
```

18 A 89%

19 B 47% … A 47% is wrong because we need to apply a knockdown factor of 1/6.

20 D 42% …

> $l := 21 \cdot m : a := 140 \cdot m : t := 250. \cdot mm : m := 1000 \cdot mm :$

> $lcr := 1.7 \cdot \mathrm{sqrt}(a \cdot t);$

$$lcr := 10057.33563 \sqrt{mm^2}$$

> $d := \frac{1}{108} \cdot (l \cdot l)^{0.3} \cdot lcr^{0.4};$

$$d := 144.8441631 \sqrt{mm^2}$$

> $d \cdot 1.4;$

$$202.7818283 \sqrt{mm^2}$$

21 D 68% … B 16% is wrong. The engineer enters the load increments (or the number of steps in which each load combination is applied). (The engineer can use a linear buckling analysis to decide on the load increments.)

C 16% is wrong because a buckling mode has no magnitude.

22 78% … For glass, the material strength is difficult because it depends on scratches in the surface. Thickness can be difficult to measure before the experiment without a specialised tool and it is squared in the formula. Young's modulus of plastic can be difficult, if we do not know the type of plastic. The shape of an object may allow multiple places for crushing or buckling and finding the right one can be important.

23 B 42% … D 47% is wrong. The local *z* direction is perpendicular to the surface.

24 B 63% …

> $l := 16 \cdot m : d := 1 \cdot m : t := 12 \cdot mm : E := 2.1e5 \cdot \frac{N}{mm^2} : \mathrm{nu} := 0.35 : \mathrm{rho} := 7900 \cdot \frac{kg}{m^3} :$

> $m := 1000 \cdot mm : N := kg \cdot \frac{m}{s^2} : assume(mm > 0) : assume(s > 0) :$

> $a := \frac{d}{2} - \frac{t}{2} :$

> $fne := \frac{16}{2 \cdot 3.1415} \cdot \frac{a}{l^2} \mathrm{sqrt}\left(\frac{E}{\mathrm{rho}}\right);$

$$fne := \frac{25.33588086}{s\sim}$$

> $fnj := \frac{1}{2 \cdot 3.1415} \cdot \mathrm{sqrt}\left(\frac{3}{5.}\right) \cdot \frac{t}{a^2 \cdot \mathrm{sqrt}\left(1 - \nu^2\right)} \cdot \mathrm{sqrt}\left(\frac{E}{\mathrm{rho}}\right);$

$$fnj := \frac{33.36633094}{s\sim}$$

25 C 89%

26 B 58% … D 25% is wrong; a synonym does not explain much.

27 D Cancelled because it was incomplete at the time of the exam.

28 B 74%

29 D 42% … B 32% is wrong. We should not change a safety requirement. We must make the structure safer.

30 88%

The grade is $\frac{40s - 270}{89}$ rounded to the closest halve, where *s* is the number of correct answers.

