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

Exam CIEM5301 Shell Structures
Thursday 1 February 2024, 9:00 – 12:00 hours

Choose A, B, C or D.

1 Is a chicken egg thin from a shell structure point of view?

A Yes, 20 / 0.3 > 30
B Yes, 40 mm is thinner than most shell structures.
C No, there is almost no shear deformation in egg shells.
D No, it is just right for protecting a baby chick.

2 Who discovered that arches are like hanging cables?

A Antoni Gaudi
B Heinz Isler
C Robert Hooke
D Jakob Bernoulli

3 Consider the arch of the Van Brienenoordbrug. Should it be higher?

A Yes, its sagitta should be 40% of the span.
B No, a higher arch may buckle.
C No, the bridge deck acts as a tension cord.
D No, the arch load is not evenly distributed.



4 A spherical kettle has a diameter of 3 m. The kettle wall is made of 4 mm steel. The kettle contains an over pressure of 1 N/mm^2. Could it fail?

A No, kettles are designed and tested for resisting high pressures.
B No, construction steel can easily resist 1 N/mm^2 compression.
C Yes, the kettle could buckle.
D Yes, the stress is too high for normal construction steel.

5 What is a zebra analysis?

A Inspection of a surface for jumps in curvature
B Projection of a neon light ceiling onto a car body
C Computation of stress concentrations in internal shell edges
D Detection of in-extensional deformation of shell structures

6 In some programs the global $\bar{z}$ axis points up, in others it points down.
What is a consequence for the moments?

A The moments are positive if the load is in the positive $\bar{z}$ direction.
B The definitions of the positive moment directions are different.
C The computed value of the torsion moment is different in sign.
D It does not matter, finite elements have their own coordinate systems.

7 An optimal dome has a span of 1000 m. It is made of glass E = 85 000 N/mm^2, ρ = 2500 kg/m^3. What is its a/t ratio? [1]

A 0.9
B 9
C 90
D 900

8 What is a property of Gaussian curvature?

A It correlates with the buckling membrane force.
B It does not depend on the coordinate system.
C When zero the shell suffers from edge disturbances.
D It can be plotted with Mohr's circle.

9 Consider a simply supported tube loaded by gravity with a length l and a diameter d.
At what length is shear deformation important for the stresses?
At what length is shear deformation important for the deflection?
For most applications an error of 5% is acceptable.

A $l < 2\,d$, $l < 5\,d$
B $l < 3\,d$, $l < 10\,d$
C $l > 4\,d$, $l > 14\,d$
D $l > 6\,d$, $l > 20\,d$

10 The Sanders-Koiter equations are not used often. Why not?

A They are only valid for small translations.
B They do not include out of plane shear deformation.
C They are not accurate for many shell shapes.
D Finite element analysis is faster.

11 Is it possible to make cylindrical boiler drums without edge disturbance?

A Yes, a thick flat cap prevents any edge disturbance.
B Yes, a spherical cap of half thickness has the same hoop strain as the cylinder.
C No, a change in curvature is inevitable and this will cause an edge disturbance.
D No, a thicker cylinder will not reduce the stress concentration value.

12 In the finite difference method, several φ_x grid points are outside the shell. Why?

A To apply the boundary condition $\varphi_x = 0$.
B For a faster computation of the u_z boundary values .
C To have no exception in the discretised κ_{xx} equation.
D To facilitate plotting of the independent variables.

13 Every node in a shell finite element model has dofs. How many?

A 3
B 4
C 5
D 6

14 Finite element programs sometimes use an eigenvalue algorithm. In which analysis?

A linear elastic analysis
B linear buckling analysis
C nonlinear analysis
D transient analysis

15 An hourglass mode is caused by …

A … in-extensional deformation.
B … spurious energy.
C … reduced integration.
D … an irregular mesh.

16 How do we check the arithmetic accuracy of linear elastic analyses?

A Redo the computation on another computer.
B Redo the computation with another finite element program.
C Calculate equilibrium of load and support reactions.
D Do an extra analysis with half size finite elements.

17 In a shell location m_{xx} = 32 kNm/m. The shell thickness t = 24 mm. What is the stress?

A 0.33 N/mm^2
B 5.55
C 333
D 800

18 The formula for ring buckling is $n_{cr} = -0.6\frac{Et^2}{a}$. What is the formula for chess bord buckling?

A the same
B $n_{cr} = -\pi E t$
C $n_{cr} = -0.1Ea$
D $n_{cr} = -0.1\frac{Et^2}{a}$

19 A cylinder has the dimensions, length = 0.5 m, diameter = 0.3 m, thickness is 4 mm. What is its buckling length?

A 42 mm
B 59 mm
C 83 mm
D 500 mm

20 Why do engineers design stiffeners in thin shell structures? [2]

A To prevent buckling
B To reduce membrane forces
C To reduce deflection
D To increase the material strength

21 Consider a reinforced concrete shell roof with a positive Gaussian curvature. The roof length and width are 42 m. The radius of curvature is 50 m. The thickness is 150 mm. What imperfection amplitude should we use in a nonlinear analyses?

A 73 mm
B 99 mm
C 162 mm
D 227 mm

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 Consider a steel shell in an area where earthquakes occur. The shell has natural frequencies of 4 Hz and higher. What can we do to improve the design? [3]

A reduce the thickness
B reduce the bending moments
C reduce the stiffener spacing
D reduce the curvature

24 Consider two shells of the same material with the same supports and the same distributed load. Self-weight is small compared to the distributed load and neglected. The second shell has twice the diameter and twice the thickness. What is its natural frequency? [4]

A half that of the first shell
B the same
C twice
D four times

25 A shell structure has an unexpectedly small natural frequency.
What could be the going on? [5]

A middle third rule
B edge disturbances
C inextensional deformation
D imperfection sensitivity

26 For which shell load is a transient analysis not suitable? [6]

A earthquake
B explosion
C storm
D local support collapse

27 For computing failure probability, we need two wind load distributions: the *everyday* and the *design live largest*. What for?

A Turkstra's rule
B Personal safety check and the economic safety check
C New structures and existing structures
D Including human error and excluding human error

28 According to Turkstra's rule we compute the failure probability for each variable load being extreme. What do we do with these probabilities?

A pick the largest
B add
C multiply
D average

29 A new concert hall in Scheveningen has a large shell roof. The structure is economically designed to last for 100 years. It storms often in Scheveningen. If the roof collapses, 60% of the visitors die. Erik goes there for a three hour concert once every 4 weeks. What is the probability that Erik dies in a Scheveningen concert hall collapse this year? [7]

A $1.3\ 10^{-8}$
B $1.3\ 10^{-7}$
C $1.3\ 10^{-6}$
D $1.3\ 10^{-5}$

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 100% of the answers were correct.
2 C 100%
3 B 14% … A 29% is wrong because the derivation does not cover this situation.
C 29% is wrong because the tension cord does not matter.
D 29% is wrong because the load is evenly distributed.

4 A 14% …

$n = \frac{1}{2} p a$ (Barlow's formula, p. 8)

$\sigma = \frac{n}{t} = \frac{pa}{2t} = \frac{1\ N/mm^2 \times 1500\ mm}{2 \times 4\ mm} = 188 < 340\ N/mm^2$ O.K.

B 29% is wrong: the material is mostly loaded in tension.
C 14% is wrong: the kettle is loaded in tension.
D 43% is wrong: the stress is much smaller than 340 N/mm^2.

5 A 43% … B 57% is wrong: the engineer does the analysis, not the software.
However, many people call drawing the stripes – what the software does – also analysis. Nowadays, stress analysis is done by software too.
So, answer B was accepted as correct too.

6 D 100%
7 D 100% …

$s = 0{,}3\ l = 0{,}3 \times 1000 = 300\ m$

$a = \frac{1}{2} s + \frac{1}{8} \frac{l^2}{s} = \frac{300}{2} + \frac{1000^2}{8 \times 300} = 567\ m$

$t = \frac{20}{9} \frac{p g l^2}{E} = \frac{20}{9} \frac{2500 \times 10 \times 1000^2}{85000 \cdot 10^6} = 0{,}653\ m$

$\frac{a}{t} = \frac{567}{0{,}653} = 868$

8 B 100%
9 B 57% … D 29% is wrong: diameter *d* is in the equation, not radius *a*. Moreover, shear is important in short tubes, not in long tubes.
10 D 14% … B 71% is wrong: most shells are so thin that shear is negligible.
11 B 0% … C 86% is wrong: there is no edge disturbance, if cylinder and cap expand the same, despite a difference in curvature.
12 C 29% … A 75% is wrong: the boundary condition $\varphi_x = 0$ can also be applied if the grid point is in the edge.
13 D 100%
14 B 100%
15 C 100%
16 C 100%
17 C 86% …

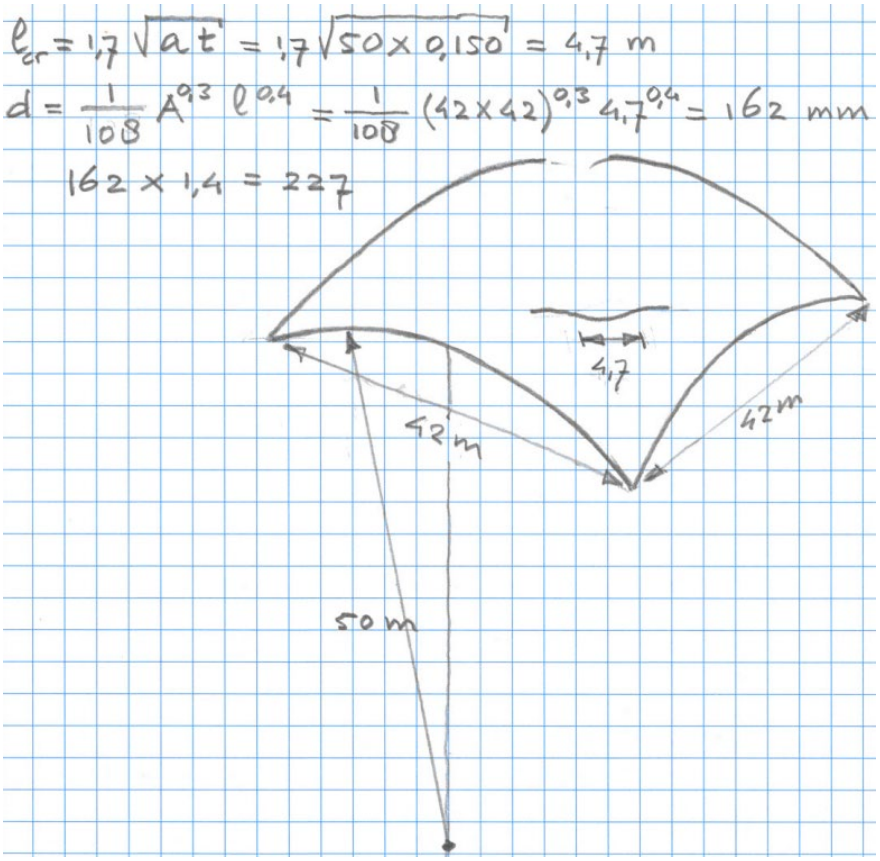
$\sigma_{xx} = \frac{32000}{\frac{1}{6} 24^2} = 333\ N/mm^2$

18 A 100%
19 A 100% …

$l_{cr} = 1{,}7 \sqrt{at} = 1{,}7 \sqrt{150 \times 4} = 42\ mm$

20 A 100%

21 D 29% … C 71% is wrong … please include the 1.4 safety factor.



22 71% … For glass, the material strength is difficult because it depends on invisible 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 C 86%

24 A 86%

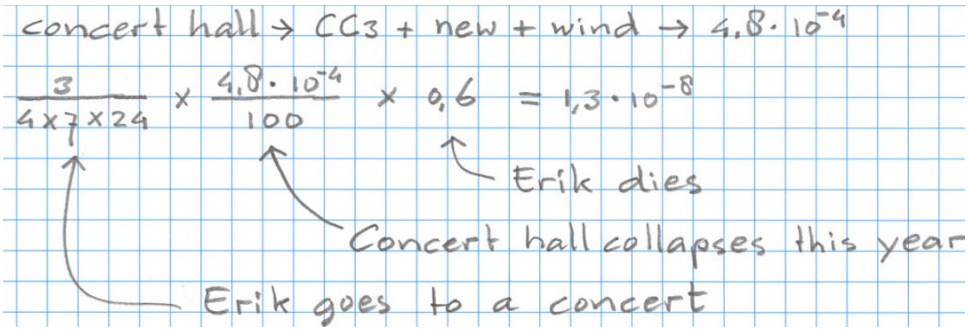
25 C 100%

26 C 86%

27 A 71%

28 B 0% … A 86% is wrong
Example: One calculation represents 50 years. We do 1000 of these and check wind loads. This gives 3 failures. We do *the same* 1000 x 50 years and now check snow loads. This gives 2 failures. The failure probability is (3+2)/1000 = 3/1000 + 2/1000, so add.

29 A 29% …

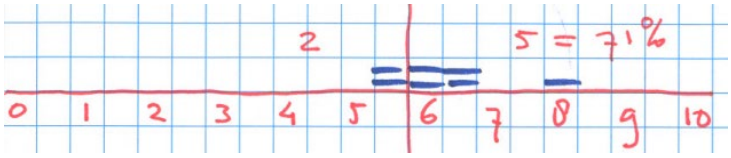


30 71%

The grade is $\frac{10s-70}{23}$ rounded to the closest halve, where *s* is the number of correct answers.

g = a + b s
0 = a + b 28/4
10 = a + b 30

a = -70/23
b = 10/23



[1] Question by Kenneth Brouwer, November 2023
[2] Question by Ruben van Gils, November 2023
[3] Question by Danny Bond, November 2023
[4] Question by Mariana Fuente Zazueta, November 2023
[5] Question by Wail Abdellaoui, November 2023
[6] Question by Stijn Platzer, November 2023
[7] Question by Ilse van der Zwet, November 2023